IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF COLUMBIA

SAFE SKIES CLEAN WATER WISCONSIN, INC., Plaintiff,	)	
v.	)	No. 1:21-cv-00634-CKK
UNITED STATES AIR FORCE, et al., Defendants.	)	

PLAINTIFF'S MOTION TO SUPPLEMENT THE ADMINISTRATIVE RECORD

Comes now Plaintiff, and pursuant to Fed.R.Civ.P. 7 and 56(e), requests that the Court allow it to supplement the record. In support of its motion, Plaintiff files the accompanying Memorandum of Points and Authorities.

Dated: August 20, 2021.

/s/ Kathleen Henry
Kathleen Henry (Bar No. MO0001)
Dairyland Public Interest Law
PO Box 352
Madison, WI 53701
(608) 213-6857
khenry@dairylandpublicinterestlaw.com
Attorneys for Plaintiff

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF COLUMBIA

SAFE SKIES CLEAN WATER WISCONSIN, INC.,	)	
Plaintiff,	)	
v.	)	No. 1:21-cv-00634-CKK
	)	
UNITED STATES AIR FORCE, et al.,	)	
Defendants.	)	

PLAINTIFF'S MEMORANDUM OF POINTS AND AUTHORITIES IN SUPPORT OF MOTION TO SUPPLEMENT THE ADMINISTRATIVE RECORD

Dated: August 20, 2021.

/s/ Kathleen Henry
Kathleen Henry (Bar No. MO0001)
Dairyland Public Interest Law
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(608) 213-6857
khenry@dairylandpublicinterestlaw.com
Attorneys for Plaintiff

TA LE OF CONTENTS

TA LE OF AUTHORITIES

Plaintiff files this Memorandum of Points and Authorities in Support of Plaintiff s Motion to Supplement the Record.

INTRODUCTION

Plaintiff, Safe Skies Clean Water Wisconsin, Inc., (Safe Skies), challenges a decision by the Air Force to bring F-35A fighter ets to Truax Field in Madison, Wisconsin. Plaintiff argues the defendants violated NEPA in preparing the Environmental Impact Statement in numerous ways, including by failing to take a hard look at noise and environmental pollution. Plaintiff also argues defendants should prepare a Supplemental Impact Statement accounting for information released after the ROD was issued that provides further information about noise pollution and climate change-causing pollutants, and that sheds light on the already existing PFAS pollution that the National uard Bureau and Air Force have still not cleaned up, and that will be increased with the F-35As.

AC ROUND

Defendants filed a 71,8 7-page record in this case. Plaintiff seeks additional documents that were relied on in defendants decision but not included. Plaintiff also seeks additional documents relating to the issues that were released after the ROD was issued. Plaintiff and defendants engaged in consultation and defendants provided many more documents. The parties were unable to reach an agreement on the documents named in this Memorandum.

AR UMENT

I D d S d S R rd D R d r D

Federal courts hold that, A complete administrative record should include all materials that might have influenced the agency s decision. *A fa esorts e t of t e nterior*, 143 F. Supp. 2d 7, 12 (D.D.C. 2001).

Plaintiff seeks specifically materials actually considered by the agency but omitted from the record. These include: documents that led to the decision in 2016 to select Truax the full document of AR0068766, the unredacted version of AR0068772, and the FAA s comments stating its reasons for disapproval of the pro ect. The documents omitted are materials that might have influenced the agency s decision, *A fa esorts* 143 F. Supp. 2d at 12, and so should be included in the Record. These documents would support Count I of the Complaint.

A D d d Tr

The Air Force announced in 2017 it had selected Madison, but very few pages of the entire 71,8 7 pages are dated before 2017. Plaintiff seeks documents that would show the reasons the Air Force selected Madison.

T F D AR

AR0068766 is one of very few documents that are dated before 2017. It is attached to this document as Exhibit 1, pp. 1-6. It appears to be an email from System to the Pentagon, and has a header of Simmons Deametreyess D MSgt USAF AF-CC (US). It discusses, Basing criteria for the fifth and sixth F-35A operational locations (AN) / basing candidates for the seventh F-35A operational location (AFRC), yet is heavily redacted. (Ex. 1, p. 1.) Pages 2, 4 and 5 are redacted in their entirety. Page 3 is mostly redacted, but leaves in a sentence making it clear that this document is an approval of the basing decision of the F-35 at Truax: Approve Basing Criteria/Candidates - F-35A fifth and sixth operational locations. Page 6 is mostly redacted, but shows that on May , 2016, the Secretary of the Air Force ordered, Implement my approval actions as indicated above. (Ex. 1, p. 6.)

Citi ens deserve to know why their community was selected to receive the F-35. This decision was made in 2016 but this supporting document is heavily redacted.

C T U r d d V r D AR

AR0068772 is attached to this document as Exhibit 1, p. 7. This document is another one of the very few documents out of the thousands filed in the Record that is dated before 2017. This document is prepared by the Air Force and lists 18 Air Force bases in the United States and ranks them for their suitability to, Obtain SecAF approval of way ahead for F-35A Ops 5 6 candidate installations. Page 2 (Ex. 1, p. 8) is heavily redacted. Citi ens cannot learn why Truax is ranked number 1. This Court should require defendants to provide the unredacted document.

D T FAA' C S R r D r Pr

In document AR0004270, the Air Force requested the FAA to be a cooperating agency. (Ex. 1, p. .) In document AR0004461, the FAA says it will be a cooperating agency. (Ex. 1, p. 10.) In document AR0004434, FAA says its comments were not resolved and it could not comply with its own NEPA. (Ex. 1, p. 12.) There are no further documents from the FAA and its comments are not included in the record. In consultation, defendants claimed the comments are inter-agency deliberative materials. However, plaintiff believes the comments are like other agency comments, such as those filed by the EPA, and must be released. Furthermore, if a lead agency leaves out or ignores a cooperating agency, an EIS may later be found to be inadequate. Plaintiff has a right to see what the FAA believes violates NEPA.

II T C r S d P S R rd M r r N C d r d D d r N r r C r C d A r r I r

Plaintiff files with this Motion and Memorandum a Supplemental Record of 612 pages of documents that show that the Air Force did not take a hard look at the environmental impacts of basing the F-35s in Madison, and that the Air Force needs to conduct a Supplemental Environmental Impact Statement because of new evidence of environmental harms.

Federal courts hold that:

It may sometimes be appropriate to resort to extra-record information to enable udicial review to become effective . C ourts have developed a number of exceptions countenancing use of extra-record evidence to that end. As recently summari ed by two commentators, exceptions to the general rule have been recogni ed: (1) when agency action is not adequately explained in the record before the court (2) when the agency failed to consider factors which are relevant to its final decision (3) when an agency considered evidence which it failed to include in the record (4) when a case is so complex that a court needs more evidence to enable it to understand the issues clearly (5) in cases where evidence arising after the agency action shows whether the decision was correct or not (6) in cases where agencies are sued for a failure to take action (7) in cases arising under the National Environmental Policy Act and (8) in cases where relief is at issue, especially at the preliminary in unction stage.

s e tter, 876 F.2d 76, 1 (D.C. Cir. 1 8).

In addition:

Preparation of an EIS does not alone complete an agency s NEPA duties NEPA requires agencies to review the environmental consequences of their pro ects after preparation of an EIS and to: (1) ... prepare supplements to either draft or final environmental impact statements if: (i) The agency makes substantial changes in the proposed action that are relevant to environmental concerns or (ii) There are significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts. 40 C.F.R. 1502. (c)(1).

> Supplemental EIS reports may be required, moreover, if the new information shows that remaining government action will affec t the quality of the human environment in a significant manner or to a significant extent not already considered in the original EIS. *Mars re on at ral es o n il*, 4 0 U.S. 360, 374, 10 S.Ct. 1851, 104 L.Ed.2d 377 (1 8).

e i al ea ons or in ro e t of ef, 655 F.Supp.2d 18, 23 (D.D.C. 200).

In this case, exceptions 1, 2, 3, 5 and 7 as explained in the *s* case apply: (1) when agency action is not adequately explained in the record before the court (2) when the agency failed to consider factors which are relevant to its final decision (3) when an agency considered evidence which it failed to include in the record (5) in cases where evidence arising after the agency action shows whether the decision was correct or not and (7) in cases arising under the National Environmental Policy Act.

In addition, under the *e i al ea ons or in ro* case test, There are significant new circumstances or information relevant to environmental concerns and bearing on the proposed action or its impacts and T he new information shows that remaining government action will affec t the quality of the human environment in a significant manner or to a significant extent not already considered in the original EIS. *e i al ea ons or in ro* , 655 F.Supp.2d at 23.

The following is a list of documents plaintiff seeks to be admitted, as stated in the Table of Contents of the Supplemental Record.

TABLE OF CONTENTS

SR Page No.

A D R C III d I C

Documents numbered 1, 5-15, 17-25, 27 and 28 are necessary to add to the Record because they show that PFAS cause more harm to human health than the Air Force has acknowledged, and that the N B has not completed the clean-up of PFAS as ordered by the Wisconsin Department of Natural Resources. These are relevant to Counts III and I of plaintiff s complaint. More and more evidence of PFAS contamination has been found since the ROD was completed and ust because the ROD was issued in 2020 does not meant the Air Force has to stop looking at the environmental impacts of the pro ect supported by the EIS.

Document 1 is issued by the Air Force and spells out the dangers of PFAS to human health, but says the Air Force will continue to emit them with the fire-fighting foam it uses. The Air Force did not take a hard look at the health impacts of PFAS.

Documents 5-12 are from the Wisconsin Department of Natural Resources to the Air National uard telling the AN to clean up the PFAS, and telling it the AN has repeatedly failed to clean up the water and soil. By omitting them from their review, the Air Force paints an incomplete picture of the environmental impacts of its actions.

Documents 14 and 15 are EPA documents that provide basic information about the harms PFAS cause to human health. The Air Force does not take a hard look at the health impacts of the pollutants it is emitting and that will be increased with the F-35s.

Documents 17-20 show the extent of the PFAS contamination in Madison s drinking wells. This is a serious problem as one well has already been closed. The Air Force glosses over the harmful impacts of its pollutants.

Documents 21-24 are articles from the Wisconsin State ournal showing that the Air National uard is not cleaning up the PFAS, and that the AN is ignoring calls from the City and State to do so. Document 25 shows that in August, 2021, the EPA added Lake Monona to the list of Impaired Waters due to the PFAS contamination. The PFAS pollution is increasing in water bodies off of Truax and the Air Force needs to account for this.

Document 26 is a newspaper article showing the City of Madison denied a permit to a developer proposing to build a housing development near the airport. The City denied it because of PFAS pollution. This denial harms the City s revenue. The Air Force did not take a hard look at impacts on the City.

Documents 27 and 28 are newspaper articles from anuary and une, 2021, well after the ROD was released, showing that the PFAS are still spreading from the airport into the public waters and wells, and that the Air Force is not adequately addressing the contamination.

Plaintiff argues the N B and Air Force should not be allowed to increase the amount of PFAS-containing chemicals they disperse into the air, soil and groundwater until they have complied with WI DNR orders to clean up Truax. The foregoing documents show that the decision was not correct (*s* 876 F.2d at 1), and that, the government action will affec t the quality of the human environment in a significant manner or to a significant extent not already considered in the original EIS (*e i al ea ons ro* , 655 F.Supp.2d at 23).

D R C V C

Documents numbered 2-4 should be added because they relate to plaintiff s Count and show defendants did not take a hard look at the air pollutants emitted by F-35s and the harm the pollutants cause to human health. These meet the *s* and *e i al ea ons or in ro* standards. The record contains documents that show the amount of ha ardous air pollutants emitted, but not documents showing the health effects of the pollutants. These are reputable studies that the Air Force should examine.

C D R C VI

Document number 2 should be allowed into the Record because it proves plaintiff s Count I: defendants did not adequately consider climate change impacts. The Report issued on August , 2021, by the Intergovernmental Panel on Climate Change (IPCC) shows that we have almost no time to act before it is too late for the planet: it is no longer acceptable for agencies to claim their climate-change causing pollutants are insignificant. The IPCC Summary Report proves that, the decision was not correct

(*s* 876 F.2d at 1), and, the government action will affec t the quality of the human environment in a significant manner or to a significant extent not already considered in the original EIS. (*e i al ea ons ro* , 655 F.Supp.2d at 23.)

D D R C II

Documents 16, 30 and 31 relate to plaintiff s Count II: defendants failed to take a hard look at the detrimental noise impacts the F-35As will have on the quality of life for people in Madison, WI. Document 16, the World Health Organi ation uidelines for Noise Pollution, prove that defendants used an outdated standard for decibel levels. Documents 30 and 31 show exactly how the F-35s affect people living in ermont. Defendants refused to fly an F-35 over Madison during the Comment period these documents foretell the affects the F-35s will have on the people in Madison. They prove the decision was not correct and that the government action will affect the quality of the human environment in a significantly detrimental manner. (*s* 876 F.2d at 1, *e i al ea ons or in ro* , 655 F.Supp.2d at 23.)

III C

WHEREFORE, for the foregoing reasons, plaintiff requests this Court to order defendants to supplement the Administrative Record with the requested documents and to allow plaintiff to file the Supplemental Record.

Dated: August 20, 2021.

/s/ Kathleen Henry
Kathleen Henry (Bar No. MO0001)
Dairyland Public Interest Law
PO Box 352
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(608) 213-6857
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Attorneys for Plaintiff

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SAFE SKIES CLEAN WATER WISCONSIN, INC., Plaintiff,	)	
v.	)	No. 1:21-cv-00634-CKK
UNITED STATES AIR FORCE, et al., Defendants.	)	

ORDER RANTIN PLAINTIFF'S MOTION
TO SUPPLEMENT THE RECORD

The Court, having considered Plaintiff s Motion to Supplement the Record and the arguments in opposition, hereby ORDERS that the Motion is RANTED. The Court orders defendants to supplement the Record with the omitted documents, and the Court admits into the Record the documents labeled by Plaintiff as Supplemental Record 1 through 31.

Dated:

COLLEEN KOLLAR KOTELL
U.S. DISTRICT UD E

Copies to:
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(202) 532-54 2 (phone)
ashley.carter@usdo .gov
gregory.cumming@usdo .gov
o nsel for efendants

Exhibit 1
1:21cv634CKK

Simmons, Deametreyess D MSgt USAF AF-CC (US)

From: System, TMT <WTM_TMTDoNotReply@afncr.af.mil>
Sent: Monday, April 25, 2016 4:42 PM
To: USAF Pentagon AF-CC Mailbox AF-CC Workflow
Subject: COORD: HAF1609801991 | Mar 16 Strategic Basing Monthly Update | SUSP 29 Apr 2016 16:00 | Release COORD from SAF/US\SIMMONS, COREY

Classification: UNCLASSIFIED

To access this Tasker, click the following link - HAF1609801991

Final Coord Forward Summary -
This Tasker was forwarded from SAF/US to AF/CC on 25 Apr 2016 16:42.

--------------------------------COORD
AF/CVAT Coord - Nye, Maj, 18 Apr 16
AF/CVA Coord - Mancuso, Maj Gen, 18 Apr 16
AF/CV Coord - Goldfein, GEN, 24 Apr 16
SAF/US Coord - Disbrow, Lisa EX-III 25 Apr16
AF/CC Coord - Info provided, 4-star COORD provided by VCSAF//h/p/27 Apr 16
SAF/OS Sig - 9 MAY 2016
--------------------------------STAFF SUMMARY
AO: Mr. Teran Judd, SAF/IEIB, DSN 222-1472
SSS DATE: 5 Apr 16
SUSPENSE: 29 Apr 16
OUTSIDE AGENCY SUSPENSE: N/A

SUBJECT: March 2016 Strategic Basing Monthly Update

1. PURPOSE: Obtain SecAF approval/disapproval of nine basing decisions by signing the March 2016 Strategic Basing Monthly Update (tab 1).

Redacted

Redacted

Redacted

b. Basing criteria for the fifth and sixth F-35A operational locations (ANG) / basing candidates for the seventh F-35A operational location (AFRC).

Redacted

Redacted

DEPARTMENT OF THE AIR FORCE
WASHINGTON, DC

OFFICE OF THE ASSISTANT SECRETARY

14 Apr 16

MEMORANDUM FOR THE SECRETARY OF THE AIR FORCE

FROM: SAF/IE

SUBJECT: Strategic Basing Monthly Update – March 2016

Redacted

APPROVED/DISAPPROVED

2. Approve Basing Criteria/Candidates - F-35A fifth and sixth operational locations (F-35A Ops 5-6) basing criteria and F-35A Ops 7 basing candidates

- Ops 5-6 are ANG locations; Ops 7 is an AFRC location
- Ops 5-6 enterprise includes CONUS ANG installations with a fourth generation fighter mission and a runway ≥ 8,000 ft
  - Criteria consists of Mission (55 points; weather 5 points, training infrastructure 50 points), Capacity (25 points; logistics facilities 12 points, ops facilities 9 points, ramp & parking 4 points), Environmental (10 points), and Cost (10 points)
  - ACC and the ANG support the criteria
- Ops 7 criteria not required due to the small AFRC enterprise

- Candidates include Davis-Monthan AFB, Homestead ARB, NAS JRB Ft. Worth, and Whiteman AFB

Briefing date: Briefed to the SecAF/CSAF on 24 Mar 16

Redacted

Redacted

Redacted

POC for this memo is Ms. Carol Ann Beda, 703-692-7477, carolann.y.beda.civ@mail.mil.

BALLENTINE.MIRANDA.ALICE ANDERSON.1473586467

Digitally signed by BALLENTINE.MIRANDA.ALICE ANDERSON.1473586467
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USAF, cn=BALLENTINE.MIRANDA.ALICE ANDERSON.1473586467
Date: 2016.04.14 15:03:58 -04'00'

MIRANDA A. A. BALLENTINE
Assistant Secretary of the Air Force
(Installations, Environment and Energy)

1st Ind to SAF/IE, 14 Apr 16, Strategic Basing Monthly Update – March 2016

SAF/OS

-9 MAY 2016

MEMORANDUM FOR SAF/IE

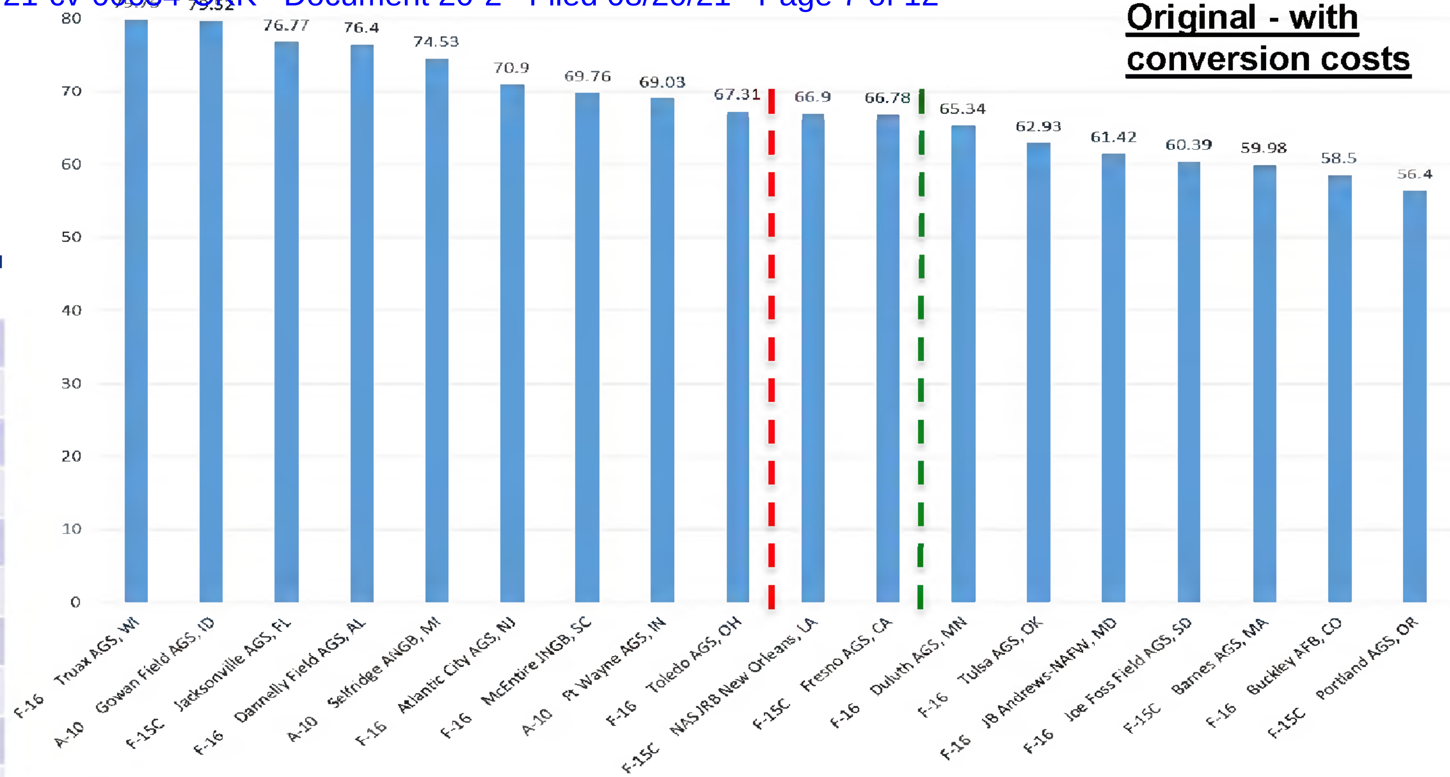
Implement my approval actions as indicated above.

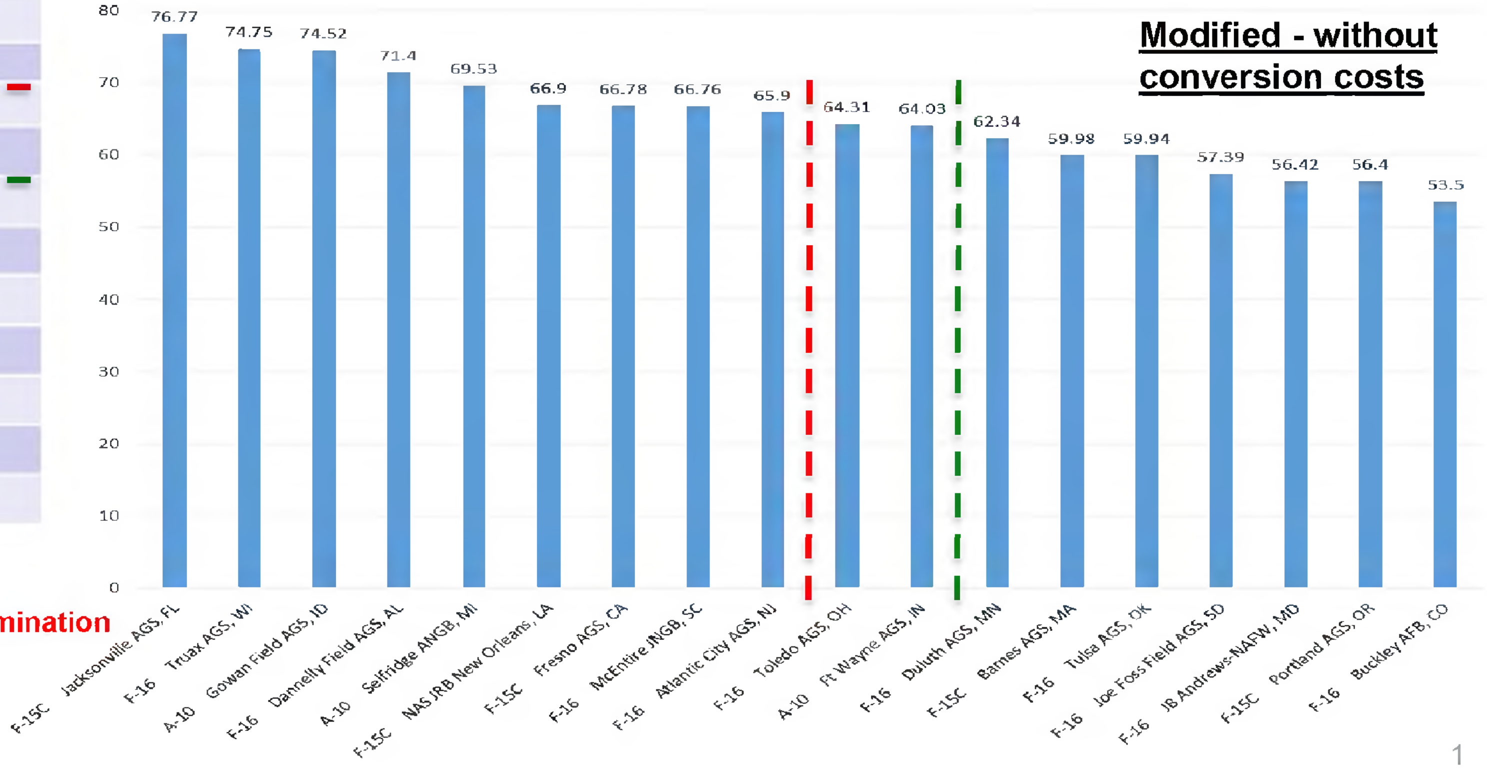
Deborah Lee James
Deborah Lee James
Secretary of the Air Force

Facer Slide

U.S. AIR FORCE

		Rank	
MDS	Installation	Original	Modified
F-16	Truax AGS	1	2
A-10	Gowan Field AGS	2	3
F-15C	Jacksonville AGS	3	1
F-16	Dannelly Field AGS	4	4
A-10	Selfridge ANGB	5	5
F-16	Atlantic City AGS	6	9
F-16	McEntire JNGB	7	8
A-10	Ft Wayne AGS	8	11
F-16	Toledo AGS	9	10
F-15C	NAS JRB New Orleans	10	6
F-15C	Fresno AGS	11	7
F-16	Duluth AGS	12	12
F-16	Tulsa AGS	13	14
F-16	JB Andrews-NAFW	14	16
F-16	Joe Foss Field AGS	15	15
F-15C	Barnes AGS	16	13
F-16	Buckley AFB	17	18
F-15C	Portland AGS	18	17





FOUO Pre-decisional Not for Public Dissemination

U.S. AIR FORCE

F-35-A Ops 5&6 (ANG) EWL Results Review

Purpose: Obtain SecAF approval of way ahead for F-35A Ops 5&6 candidate installations

Strategic Narrative:

Redacted

Enterprise: CONUS ANG (Ops 5&6) installations with a 4th Generation fighter mission and a runway ≥ 8,000' (18 Installations)

Criteria: SecAF approved Feb 16; Announced to Congress Mar 16

- Mission (55 pts): Optimized for fighter Aircraft F-35A Ready Aircrew Program (RAP)
- Capacity (25 pts): Ability to accept 18-24 PAA squadron w/max utilization of existing facilities
- Environmental (10 pts): Air Quality and Encroachment
- Cost (10 pts): Area Construction Cost Factors, Area Locality Costs, Conversion Costs
  - Conversion Costs assessed up to 5 points for a/c anticipated to retire (e.g. A-10 and F-16 B30)

Redacted

- Nov 2016: Announce candidate installations
- Summer 2017: SecAF selects preferred and reasonable alternatives
- Summer 2019: EIAP complete; SecAF final basing decision
- May 2023: Ops 5 FAA
- October 2023: Ops 6 FAA

Redacted

DEPARTMENT OF THE AIR FORCE
WASHINGTON DC

OFFICE OF THE ASSISTANT SECRETARY

SEP 2 2 2017

SAF/IEI
1665 Air Force Pentagon
Washington, DC 20330-1665

Mr. Elliott Black
Director, Office of Airport Planning and Programming (APP-1)
Federal Aviation Administration National Headquarters
800 Independence Ave SW
Orville Wright Bldg (FOB10A)
Washington, DC 20591

Dear Mr. Black,

The Air Force requests the Federal Aviation Administration's participation as a cooperating agency in preparation of an environmental impact statement (EIS) for the F-35A Operations 5 and 6 basing alternative locations. The alternative locations are Boise Municipal Airport, Boise, ID; Montgomery Regional Airport, Montgomery, AL; Jacksonville International Airport, Jacksonville, FL; Dane County Regional Airport, Madison, WI; and Selfridge ANGB, Harrison Charter Township, MI.

This participation arrangement is described in the Council on Environmental Quality National Environmental Policy Act Regulations, 40 CFR § 1501.6, *Cooperating Agencies*. As a cooperating agency, the Air Force requests the Federal Aviation Administration participate in various portions of the EIS development. Specifically, the Air Force asks for your support as a cooperating agency by:

- Participating in the scoping process
- Assuming responsibility, upon request by the Air Force, for developing information and preparing analyses on issues for which the Federal Aviation Administration has special expertise
- Making staff support available to enhance interdisciplinary review capability and provide specific comments (40 CFR §1503.3)
- Provide review and comments within the timelines prescribed in the program milestone schedule
- Responding, in writing, to this request

Our points of contact for this matter are Mr. Jack Bush at (703) 614-0237 (jack.bush@us.af.mil) and Ms. Christel Johnson at (240) 612-8508 (christel.johnson@us.af.mil).

Sincerely,

Jennifer L Miller

JENNIFER L. MILLER
Deputy Assistant Secretary of the Air Force
(Installations)

BREAKING BARRIERS...SINCE 1947

U.S. Department
of Transportation
**Federal Aviation
Administration**

Office of Airport Planning
and Programming

800 Independence Ave., SW.
Washington, DC 20591

NOV 1 7 2017

Ms. Jennifer Miller
Deputy Assistant Secretary of the Air Force (Installations)
SAF/IEI
1665 Air Force Pentagon
Washington, DC 20330

Dear Ms. Miller:

Thank you for your September 22 letter requesting Federal Aviation Administration (FAA) participation as a cooperating agency in preparation of an Environmental Impact Statement (EIS) for F-35A operations and basing alternatives.

The FAA supports the Air Force decision to prepare an EIS for this proposal and agrees to be a cooperating agency. The FAA will participate in accordance with 40 CFR § 1501.6, *Cooperating Agencies*, from the Council on Environmental Quality's Regulations on the National Environmental Policy Act (NEPA) and FAA's NEPA Procedures (FAA Orders 1050.1F, *Environmental Impacts: Policies and Procedures* and FAA Order 5050.4B, *NEPA Implementing Instructions for Airport Actions*).

The airports being considered in this EIS include:

- Boise Air Terminal/Gowen Field Airport, Boise ID;
- Montgomery Regional Airport, Montgomery AL;
- Jacksonville International Airport, Jacksonville FL;
- Dane County Regional-Truax Field Airport, Madison, WI; and
- Selfridge Air National Guard Base[1], Harrison Charter Township, MI.

These locations span multiple FAA Regional Airports Divisions and Airports District Offices (ADOs). Therefore, we ask the Air Force direct all communications on the EIS to FAA Headquarters' Airport Planning and Environmental Division (APP-400). The APP-400 point of contact will coordinate with our Regions/ADOs and consolidate FAA input on the EIS.

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[1] Please note that this location is not a civil airport, and therefore, the FAA does not normally have jurisdiction over airport issues.

The FAA point of contact for this EIS is Ms. Jean Wolfers-Lawrence, Environmental Specialist, APP-400, at (202) 267-9749 or jean.wolfers-lawrence@faa.gov.

Sincerely,

Elliott Black
Director, Office of Airport Planning
and Programming

U.S. Department
of Transportation
**Federal Aviation
Administration**

Office of Airport Planning and Programming

800 Independence Ave, SW.
Washington, DC 20591

October 25, 2019

Ramon Oritz
National Guard Bureau
NGB/A4AM. Shepperd Hall
3501 Fetchet Avenue
Joint Base Andrews, Maryland 20762-5157

Re: Draft Environmental Impact Statement for F-35A Aircraft Beddown

Dear Mr, Oritz:

As you know, the Federal Aviation Administration (FAA) agreed to participate as a cooperating agency for the F-35A Operational Beddown Environmental Impact Statement (EIS). The draft EIS has been developed in accordance with United States Air Force (USAF) National Environmental Policy Act (NEPA) implementing regulations which differ from FAA's NEPA policies and procedures[1].

During development of the Draft EIS, the FAA provided input in coordination with the National Guard Bureau (NGB) and USAF. This included reviewing relevant information and analyses, providing comments, and participating in meetings and information sessions. Not all of FAA's comments were resolved during this process. As a result the, FAA would not be able to rely on the information and analysis in the Draft EIS to comply fully with its NEPA policies and procedures.

Should the NGB and USAF select one or more alternatives that would involve FAA action(s) subject to NEPA (e.g., construction that would require FAA approval of changes to an Airport Layout Plan), FAA would need to conduct additional analyses and prepare separate documentation to support FAA's decision.

The FAA is available to discuss the contents of this letter at your convenience. Our point of contact is Ms. Jean Wolfers-Lawrence, Environmental Specialist, FAA Airport Planning and Environmental Division, at (202) 267-9749 or jean.wolfers-lawrence@faa.gov.

Sincerely,

Michael S. Hines

Michael S. Hines
Manager, Airport Planning and Environmental Division

CC: Lt. Col. Joseph Sundy - National Guard Bureau

---

[1] See FAA Order 1050.1F, *Environmental Impacts: Policies and Procedures*, and FAA Order 5050.4B, *National Environmental Policy Act (NEPA) Implementing Instructions for Airport Actions.*

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v.	)	No. 1:21-cv-00634-CKK
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PLAINTIFF'S SUPPLEMENTAL RECORD

/s/ Kathleen Henry
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TA LE OF CONTENTS

SR P N

Air Force Public Affairs

FREQUENTLY ASKED QUESTIONS

As of Nov. 20, 2017

General PFOS/PFOA

Q. What are Perfluorooctanesulfonic acid (PFOS) and Perfluorooctanoic acid (PFOA)?

A. PFOS and PFOA are synthetic fluorinated organic chemicals used in many industrial and consumer products such as nonstick cookware, stain-resistant fabric and carpet, some food packaging and specialized foam, including Aqueous Film Forming Foam. AFFF is highly effective for controlling petroleum-based fires, and is used by the military services, commercial aviation and industry.

Q. Why is PFOS/PFOA being discovered on closed and active installations?

A. Since the 1970s, the Air Force used Aqueous Film Forming Foam - a firefighting foam containing PFOS/PFOA - at crash sites, in fire training areas and some maintenance hangers at active, Reserve, Air National Guard installations. In the U.S., the Air Force is systematically testing for potential PFOS/PFOA contamination in soil, surface water and groundwater where AFFF may have been released.

Q. How many Air Force locations have had PFOS/PFOA releases?

A. The Air Force identified approximately 200 installations in the U.S. (active, Reserve, Air National Guard and closed) where AFFF may have been released and is conducting site inspections to confirm if releases occurred. The Air Force is prioritizing sampling based on factors, such as; potential pathways to drinking water, depth to groundwater and potential for contaminate to migrate off base.

PFCs

Q. Is it true the Air Force has known for decades that PFCs are dangerous to humans?

A. The Air Force depends on the EPA and the Department of Health and Humans Services Agency for Toxic Substances and Disease Registry to determine potential danger to human health and the environment. In 1999, the EPA began investigating PFOS and did the same for PFOA in 2000. It wasn't until 2009 however, that EPA accumulated sufficient information to issue its first provisional lifetime drinking water health advisory. Between 2009 and 2016, the Air Force issued initial policy to address sampling and response actions for PFOS and PFOA, conducted Preliminary Assessments at nearly all our installations and began providing alternative drinking water at certain sites that tested above the EPA's lifetime HA. The EPA issued its Lifetime Health Advisory in 2016 at the current level and the Air Force has adjusted its response to meet that new level.

Q. Did the Air Force conduct studies on PFCs in the 1970s and 1980s?

A. The Air Force has the ability to conduct risk assessments associated with how Airmen should safely handle materials in their work. The AF does not have the capability to address risk associated with drinking water, food safety etc. Between 1979 and 1995, the Air Force conducted a small number of studies (10-15), which included PFOA and PFOS, most of which were intended to address occupational exposure risk. The Air Force relies on the EPA to address and set environmental regulatory limits for human health. The EPA conducts rigorous peer-reviewed processes to establish risk levels for chemicals and used several hundred studies that resulted in the drinking water health advisory we have today.

Air Force Response to PFOS/PFOA in drinking water

Q. How is the Air Force addressing PFOS/PFOA on closed and active installations?

A. The Air Force's investigation work and mitigation actions are guided by the Comprehensive Environmental Response, Compensation and Liability Act, or CERCLA, applicable state laws and the EPA's lifetime drinking water health advisory of 70 parts per trillion.

The Air Force is using a comprehensive approach – identify, respond, prevent – to address the potential for PFOS/PFOA contamination of drinking water, and respond appropriately. When drinking water sample results indicate PFOS/PFOA concentrations exceed 70 ppt, and there is evidence the Air Force is likely a primary source of the contamination, the Air Force determines an appropriate mitigation action, such as providing an alternate drinking water source, filtration system, and/or providing bottled water if needed. When PFOS/PFOA are detectable but below the lifetime HA level in drinking water, the Air Force may conduct well monitoring as needed to track level changes and determine if further action is needed.

Q. What is the Air Force's comprehensive approach to PFOS/PFOA?

A. The Air Force is focused on three lines of effort to address PFOS/PFOA contamination of drinking water supplies:

- *Identify:* The Air Force is conducting sampling and analysis of drinking water systems enterprise-wide. Additionally, in the U.S. the Air Force is identifying potential AFFF release sites; conducting site inspections to confirm releases; and using groundwater, surface water, soil and sediment sampling to map potential plume migration pathways.
- *Respond:* Where PFOS/PFOA levels exceed the lifetime health advisory levels in drinking water supplies, and there is indication the AF is likely a primary source of the contamination, the Air Force will immediately provide alternate drinking water sources if needed. If necessary, the Air Force will then identify and initiate a long-term solution to provide drinking water that does not exceed the HA, which may include alternate water supply sources or filtration systems.
- *Prevent:* The Air Force replaced legacy AFFF in emergency response vehicles with more environmentally responsible AFFF, and will replace AFFF in all hangar fire prevention systems. Additionally, the Air Force is evaluating approaches to reduce the risk of inadvertent discharges and ensure containment of both the legacy and replacement foam.

Q. What is the difference between groundwater and surface water?

A. The water on the Earth's surface—surface water—occurs as streams, lakes, and wetlands, as well as bays and oceans. Surface water also includes the solid forms of water— snow and ice.

The water below the surface of the Earth is ground water. The vast majority of underground water occupies the spaces between soil and rock particles. At a certain depth below the land surface, the spaces between the soil and rock particles can be totally filled with water, resulting in an aquifer. (Source: USGS)

Q. What is the Air Force doing when it finds groundwater or surface water contaminated with PFOS/PFOA?

The Air Force is using groundwater, surface water, soil and sediment sampling to map potential migration pathways to drinking water. Where PFOS/PFOA levels exceed the lifetime health advisory (LHA) levels in drinking water supplies, and there is evidence the AF is likely a potential source of the contamination, the Air Force will immediately provide alternate drinking water sources if needed. If necessary, the Air Force will then identify and initiate a long-term solution to provide drinking water that does not exceed the LHA, which may include alternate water supply sources or filtration systems.

Q. How is the Air Force responding to regulator requests for PFOS/PFOA sampling at former and active installations?

A. Requests for environmental sampling for PFOS/PFOA by regulatory agency officials are addressed on a case-by-case basis. In cases where a specific local, state or federal regulation or agreement is driving the request, the installation must have reason to believe an Air Force release of PFOS/PFOA is probable (based on past installation activities), and be able to determine if there is a likelihood for the contamination to reach a drinking water source. For overseas installations, the AF is conducting sampling and analysis of Air Force drinking water sources.

Q. How does the Air Force respond if they are the water purveyor?

A. The Air Force is testing all drinking water supplies where it is the purveyor. If sample results exceed the EPA's lifetime health advisory of 70 parts per trillion, the Air Force will immediately provide a safe drinking water source and follow the EPA-recommended actions, which include retesting, communicating with local regulators and drinking water officials, proper consumer notification and evaluation of options to reduce PFOS/PFOA concentrations below the lifetime HA.

Investigation/Mitigation Cost

Q. In the fall of 2016, the Air Force said it plans to spend $2 billion to clean up PFC-contaminated water. Is that still an accurate estimate?

A. The estimate was a projection of the potential cost across the entire Department of Defense, and is only an anecdotal estimate. Please contact the public affairs team at the Office of the Secretary of Defense for information on the total cost of PFOS/PFOA activities.

Q. How much money is set aside by the Air Force for PFOS/PFOA investigations and mitigations?

A. For fiscal year 2018, the Air Force is projecting approximately $293 million for all environmental restoration program activities, including actions related to PFOA/PFOS response.

Q. Does the Air Force cover the cost of maintaining water filters overtime?

A. PFCs are found widely in the environment today, and there are likely other contributors to the contamination. However, where drinking water is above the lifetime health advisory and the Air Force could be a contributor, we will work with local authorities to provide alternative drinking water if needed and identify interim mitigation options. Following installation and initial monitoring, the Air Force will maintain filters on private wells until a long-term alternative can be implemented. If the Air Force installs filters on public wells, public water systems will assume ownership, operation and maintenance of the filters after a period of Air Force maintenance to ensure proper operation.

Testing Method

Q. How does the Air Force test for PFOS/PFOA in drinking water?

A. The Air Force employs EPA Method 537 to test samples for drinking water contaminants. Information about EPA Method 537 can be found on the EPA website.

Well Sampling/Results

Q. What will happen if my private well is found to have levels of PFOS/PFOA above the lifetime drinking water health advisory levels due to PFOS/PFOA that have migrated off the installation?

A. The Air Force's priority is protecting human health and drinking water sources. If the Air Force samples your well and determines the PFOS/PFOA level is above the EPA's lifetime drinking water HA, the Air Force will provide alternate drinking water supplies or implement mitigation approaches. This may include supplying your household with bottled drinking water, connecting your home to a public drinking water supply, or installing a treatment/filtration system on your private well.

Q. My well sampling yielded results below the HA—how can the Air Force know that won't change? Will they continue sampling?

A. When PFOS/PFOA are detectable but below the lifetime HA level in drinking water, the Air Force may conduct well monitoring as needed to track level changes and determine if further action is needed.

Q. Will the Air Force test my well?

A. The Air Force is taking a proactive, measured approach to sampling off-base wells. During the site inspection phase, the Air Force will identify wells to sample based on probability of contamination, proximity to contaminant areas and possible pathways from the site of contamination to the drinking water wells. If the site inspection indicates your well might be impacted, we could then sample the well.

Q. I live near an installation; why won't the Air Force sample my well?

A. Air Force sampling actions are data driven. We use data and site information to map contaminant migration and potential pathways to drinking water so we can continue to protect human health by focusing sampling efforts in the locations potentially impacted. The Air Force evaluates site-specific factors to assess if there is a potential for contamination to reach drinking water supplies.

Q. Can you provide the results of samples taken off base?

A. We can't release results for specific wells – that information belongs to the well owner – but we can provide a range of PFOS/PFOA levels.

General Water Use

Q. Can I cook, bathe and brush my teeth with water tested above HA?

A. The EPA health advisory is specific to the human consumption of water. According to the EPA, water is safe for activities that do not include consumption, such as bathing, doing laundry and washing dishes. For more information, contact the EPA or your local and state health department.

Q. Will my pets be contaminated if they drink water tested above HA?

A. The EPA health advisory is specific to the human consumption of water. For more information, please refer to the EPA.

Q. Can I breathe in PFOS/PFOA or absorb through my skin through the dirt and/or wind?

A. These health advisories only apply to exposure scenarios involving drinking water. For additional health specific information, please refer to the EPA, your medical provider or your local and state health department.

Agricultural/Food Concerns

Q. Will eggs, milk, fruits, vegetables and meat from farms using water above HA contain a significant amount of PFOS/PFOA to be concerned?

A. These health advisories only apply to exposure scenarios involving drinking water. They are not appropriate for use in identifying risk levels for ingestion of food sources, including fish, meat produced from livestock that consumes contaminated water, or crops irrigated with contaminated water. For more information, contact the EPA or your local and state health department.

Q. Will livestock, fruits and vegetables still be considered organic?

A. Please contact the U.S. Department of Agriculture for questions about organic certification.

Q. What about surface water? How does this impact fishing and crabbing?

A. These health advisories only apply to exposure scenarios involving drinking water. They are not appropriate for use in identifying risk levels for ingestion of food sources, including: fish, meat produced from livestock that consumes contaminated water, or crops irrigated with contaminated water. For more information, contact the EPA or your local and state health department.

Regulations/State Laws

Q. Why is the Air Force focusing its efforts on temporary solutions? Why not just start cleanup and fix the root of the problem?

A. PFOS/PFOA is an emerging contaminant; regulations are few and evolving. Protecting human health is an Air Force priority and we are aggressively responding to potential drinking water contamination when there is evidence the Air Force is likely a primary source of that contamination. Additionally, the Air Force is moving forward in accordance with the CERCLA process to identify, define and mitigate potential contamination. The CERCLA process is federal law; makes certain thorough investigation work is done, and promotes accountability, community involvement and long-term protectiveness.

Q. What is the Air Force doing about potential food contamination?

A. The Department of Defense does not have the expertise nor authority to conduct a food safety investigation, or to develop a food-specific interim health-based guideline. The U.S. Food and Drug Administration (FDA) oversees the safety of foods through the assessment of potential exposure and risk.

Q. Will the Air Force follow lower health advisory levels passed by states?

A. The Air Force complies with state environmental cleanup laws to the extent authorized and required by Federal law.

Q. Will the Air Force fund a study on the health effects of people exposed to PFCs in drinking water?

The Air Force relies on the Agency for Toxic Substances and Disease Registry (ATSDR), under the Department of Health and Human Services (DHHS), for guidance on health based actions. To date, ATSDR has not conducted a nationwide health study to determine what, if any, health effects from PFOS/PFOS exposure can be substantiated and what actions should be taken.

Q. Will the Air Force pay for blood testing for individuals who live in areas impacted by PFOS/PFOA that have migrated off base?

A. The Air Force does not have authority to pay for blood tests. The Air Force relies on the Agency for Toxic Substances and Disease Registry (ATSDR), under the Department of Health and Human Services (DHHS), for guidance on health based actions. To date, ATSDR does not recommend blood tests. They assert the ubiquitous nature of PFAS over the decades assures virtually everyone on the planet has some level in their blood stream. PFOS/PFOA levels in blood gradually diminish over an extended period of time and nothing can be done to address or speed up that process.

Reimbursements/Claims

Q. Will the Air Force pay for my drop in property value?

A. Residents who believe they have incurred damages may submit a claim to the base's legal office using the Air Force claims process.

Q. Why have some claims been denied?

A. We can't speak to specific details of denied claims.

Generally speaking, however, the Air Force may only pay claims when there is a legal obligation to do so. Under the Federal Tort Claims Act the claimant must demonstrate that their injury was caused by a negligent act(s) of the Air Force or one of its employees. In addition, the alleged negligent act must fall outside of the "discretionary function exception," which essentially means the negligent act must also violate a law, regulation, or practice of the applicable agency.

Q. Will the Air Force reimburse communities for costs incurred in dealing with contamination issues?

A. The Air Force does not have the legal authority to retroactively reimburse communities for costs incurred in dealing with environmental contamination issues. However, we continue to work with affected communities to identify proactive strategies to address this issue. Where we have factual data acknowledging we are a contributor to the contamination, the Air Force has the authority, under the Defense Environmental Restoration Program, to enter into prospective agreements with a state/local government entity to obtain its services to assist the Air Force in meeting its obligations. The Air Force may also contract a third party to address clean-up mitigation. These agreements must be signed prior to expending funds.

Aqueous Film Forming Foam (AFFF)

Q. What is AFFF?

A. Aqueous Film Forming Foam, or AFFF, is a firefighting agent used commercially and by the Department of Defense, including the Air Force. Most commonly used to combat petroleum fires in aircraft accidents, hangars and during live-fire training exercises, this formulation of AFFF contains perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) - two perfluorinated compounds that persist in the environment and are not known to degrade by any natural process. The EPA has classified these compounds as emerging contaminants due to inconclusive human health risks and evolving regulatory standards.

Q. Why didn't the Air Force immediately stop using AFFF after the health concerns regarding PFOS/PFOA came to light?

A. It was not until November 2015 that there was a more environmentally responsible option available on the DOD's qualified products list for firefighting agents. With the identification of this effective substitute, the AF has replaced its entire inventory of legacy AFFF to this more responsible and environmentally safer version.

Q. Why doesn't the Air Force just use PFOS/PFOA free foam?

A. AFFF agents that contain some form of PFOS/PFOA or related flurosurfactants are the most effective foams currently available to fight flammable liquid fires in military, industrial, aviation and municipal arenas. They provide rapid extinguishment, burn-back resistance and protection against vapor release.

Foam manufacturers are transitioning to the use of more environmentally responsible formulas that do not contain long-chain perfluorinated compounds. These short-chain formulas are low in toxicity and not considered bio- accumulative or bio-persistent.

AFFF Replacement Program

Q. When did the Air Force begin eliminating PFOS-based AFFF?

A. In 2007, U.S. Air Force locations in Europe began replacing PFOS-based AFFF in both mobile and fixed systems with European-Union-approved AFFF after the European Parliament and the council of the European Union issued a directive restricting the use of PFOS-containing substances.

In March 2011, the Air Force Civil Engineer Center initiated an informal plan for Air Force fire chiefs to dispose of "excess" PFOS-based AFFF Air Force-wide over a 10-year period. In November 2015, more environmentally responsible formulas were added to the DOD's qualified products list for firefighting agents. The Air Force began replacing both PFOS-based and other legacy AFFF products with a new, environmentally responsible formula in August 2016. The Air Force completed new foam delivery in August 2017.

Q. What type of replacement foam will be used and how effective is it?

A. The Air Force awarded a $6.2 million contract to ICL Performance Products for 418,000 gallons of Phos-Chek 3 percent, six carbon chain AFFF. Delivery began in August 2016 and was completed in May 2017. The new formula meets both MILSPEC requirements for firefighting, and the goals of the U.S. EPA 2010/15 PFOA Stewardship Program.

Q. How is the new aqueous film forming foam (AFFF) different from the legacy AFFF?

A. The legacy AFFF formula contains long-chain fluorosurfactants while the new formula contains shorter chain molecules. Data reviewed by the EPA in 2009 suggests these shorter-chain formulas are less toxic because the chemicals are cleared from the body faster and are not considered bio-accumulative or bio-persistent. The new formula meets both military specifications for firefighting, and the goals of the EPA's 2010/15 PFOA Stewardship Program.

Q. When will legacy AFFF be out of the Air Force's inventory?

A. The Air Force began replacing legacy AFFF in fire trucks and stockpiles in August 2016. AFCEC completed delivery of 418,000 gallons of replacement foam to all locations in August 2017. AFFF contained in some fire protection systems in hangars will be replaced in conjunction with hangar renovations. Unlike mobile fire trucks, AFFF in hangars are contained to a stationary location — a more controlled environment.

Q. Is the Air Force replacing AFFF anywhere other than hangars and fire trucks?

A. Some installations may have put the new AFFF bench stock in trailers or overhead storage tanks but the Air Force has reduced the backup requirement. All legacy AFFF (C8) has been removed from vehicles and bench stock to include any fire department storage containers.

Q. How is the AF disposing of AFFF?

A. The process for AFFF disposal is to drain and collect the legacy AFFF from fire vehicles then triple rinse the vehicle foam tanks and collect the effluent. The legacy AFFF and effluent will then be sent to an authorized disposal facility for incineration. The incineration disposal method is currently the most environmentally safe way to eliminate the health and environmental risks associated with AFFF.

Q. Has the Air Force considered using fire-fighting foam made with non-fluorinated chemicals? If so, which ones?

A. To date, no non-fluorinated AFFF formulation has met the MILSPEC performance criteria necessary to safeguard our Airmen from real time fire emergency responses.

AFFF agents that contain some form of PFOS/PFOA are the most effective foams currently available to fight flammable liquid fires in military, industrial, aviation and municipal arenas. They provide rapid extinguishment, burn-back resistance and protection against vapor release. Foam manufacturers are transitioning to the use of more environmentally-responsible formulas that do not contain long-chain PFOS/PFOA. These short-chain formulas are low in toxicity and not considered bio-accumulative or bio-persistent.

AFFF Replacement in Hangars

Q. How many hangars require new foam?

A. According to base-report counts, there are approximately 386 facilities with AFFF systems on active duty Air Force installations, to include Air Force Reserve and Air Guard tenant facilities.

Q. When will hangar foam replacement be complete?

A. The Air Force expects to complete the project to replace hangar foam in FY18.

AFFF Containment

Q. What are holding ponds and tanks in fire training areas used for? What's the difference?

A. Fire training area tanks and ponds collect burn pit effluent (foam, fuel, etc.) so it doesn't get in storm water drains. For example, retention ponds are placed at the bottom of a slope from a burn pit to catch runoff. Ponds are equipped with a double, high-density Polyethylene liner and designed for the required operating volume, plus rainfall from a 10-year-rain event. Ponds also have leak-monitoring stations.

Q. How does the Air Force empty/dispose of AFFF-containing runoff in holding ponds, tanks and other containment methods in training areas?

A. The Air Force negotiates with the local waste water treatment plant to determine what they will receive from burn pits.

Q. What protocols does the Air Force follow for uncontained AFFF releases?

A. Even though PFOS and PFOA are not designated as hazardous, the Air Force treats AFFF releases as a hazardous material release, which requires immediate action. Installations are required to establish response procedures in accordance with National Fire Protection Standard 472. This standard defines hazardous material response requirements.

Q. What about risks of trucks leaking AFFF?

A. The Air Force's vehicular maintenance program ensures truck systems operate properly and malfunctions are quickly identified and fixed. Due to proactive maintenance, foam line leaks seldom occur, and even those rare occurrences have a second line of protection from drip pans under the vehicles to prevent ground contamination.

Future AFFF use

Q. When will the new AFFF be ready to use?

A. Except for four overseas locations awaiting shipping lanes to reopen, the new foam is already in use across the service.

Q. How will the Air Force respond to AFFF releases once trucks are equipped with the new AFFF?

A. The Air Force will continue to treat all AFFF release as a hazardous material release. Although environmentally preferable, six-carbon chain foams like Phos-Chek 3 percent still contain trace amounts of PFOA.

The Air Force discontinued regular fire truck system tests in July 2015 and will not resume foam-discharge tests, even with the new foam product, unless the installation has an environmentally approved containment system. The Air Force is retrofitting all fire trucks with a system that supports fire protection training needs and is environmentally friendly. The new system bypasses the tank containing AFFF and, instead, flows water through the extinguishing system and the cart, gathering data readings and discharging water from the vehicle's turret. Retrofitting approximately 850 fire trucks will take 15 months and be complete by December 2018.

Q. At one time, there was no reason to believe that legacy PFOS-based firefighting foam was not safe. What is the Air Force doing to ensure history isn't repeated?

A. The Air Force is taking steps to guard against future contamination by replacing legacy AFFF stockpiles with a foam that reduces PFOS/PFOA exposure, Phos-Chek 3 percent, six carbon chain AFFF. The Air Force is taking additional steps to reduce or eliminate unnecessary foam releases by:

- Retrofitting all fire vehicles with a switch mechanism to test functionality without discharging AFFF into the environment.
- Standardizing hangar systems and replacing systems containing the old formulation in conjunction with building renovations.
- Conducting fire training exercises in double-lined pits to prevent soil and groundwater contamination.
- Treating any uncontained releases of AFFF as if it were a hazardous-material spill and requiring immediate cleanup.

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Impacts of Aviation Emissions on Near-Airport Residential Air Quality

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ABSTRACT: Impacts of aviation emissions on air quality in and around residences near airports remain underexamined. We measured gases (CO, CO_2, NO, and NO_2) and particles (black carbon, particle-bound aromatic hydrocarbons, fine particulate matter ($PM_{2.5}$), and ultrafine particles (reported using particle number concentrations (PNC) as a proxy)) continuously for 1 month at a residence near the Logan International Airport, Boston. The residence was located under a flight trajectory of the most utilized runway configuration. We found that when the residence was downwind of the airport, the concentrations of all gaseous and particulate pollutants (except $PM_{2.5}$) were 1.1- to 4.8-fold higher than when the residence was not downwind of the airport. Controlling for runway usage and meteorology, the impacts were highest during overhead landing operations: average PNC was 7.5-fold higher from overhead landings versus takeoffs on the closest runway. Infiltration of aviation-origin emissions resulted in indoor PNC that were comparable to ambient concentrations measured locally on roadways and near highways. In addition, ambient NO_2 concentrations at the residence exceeded those measured at regulatory monitoring sites in the area including near-road monitors. Our results highlight the need for further characterization of outdoor and indoor impacts of aviation emissions at the neighborhood scale to more accurately estimate residential exposures.

■ INTRODUCTION

In 2018, 10 million flights carrying one billion passengers flew into or out of airports in the United States (US).[1] Over the next 25 years, flight operations and enplanements in the US are projected to grow annually at the rate of 1 and 2%,[2] respectively, and a similar outlook is expected worldwide.[3] To meet this growing flight demand, in the last two decades over half of the 35 busiest airports in the US have undergone airfield expansions to increase their capacity.[4] These trends are of significance to the health of millions of people who live or work near airports and are thereby regularly exposed to noise and air pollution originating from aviation activity. For example, increased rates of adverse health outcomes ranging from hypertension,[5−13] cardiovascular disorders,[6,14−16] birth outcomes,[17,18] respiratory diseases,[19] and learning deficit in children[20−22] have been observed near airports. Furthermore, implementation of the Next Generation Air Transportation System,[23] which guides airplanes on precise paths via satellites, has narrowed the flight paths and lowered landing altitudes, concentrating the impacts further in certain communities.

Recently, the impacts of aviation emissions on ground-level ambient ultrafine particle (UFP; aerodynamic diameter < 100 nm) concentrations were found to extend over unexpectedly large areas near airports and in particular along flight paths.[24] For example, elevated particle number concentrations (PNC) were reported downwind of major international airports as far as 7 km near Amsterdam, 7.3 km in Boston, 18 km in Los Angeles, and 22 km in London.[25−29] UFPs are emitted at high rates by jet aircraft[30] and linked to increased rates of hypertension and cardiovascular morbidities.[31,32] However, UFPs do not contribute significantly to mass in the fine particle range and are not routinely monitored, in part due to a lack of ambient air quality standards. Therefore, they present the possibility of being an additional important confounder for near-airport epidemiological investigations.[33,34] For example, Wing et al.[35] found that UFP exposure was. independently associated with adverse birth outcomes in the vicinity of Los Angeles International Airport. Similarly, black carbon (BC) and oxides of nitrogen, which are also emitted at high rates by aircraft[30,36−38] and have recognized adverse cardiovascular effects,[39] are also elevated near airports.[24,25] Some near-airport epidemiological studies have accounted for confounding pollutants, like fine ($PM_{2.5}$[16]) and coarse particulate matter (PM_{10}[15,40,41]), ozone,[16] and NO_2,[41] but by using regional-scale central monitor data or predictive models that only account for larger-scale spatial patterns and ground-transportation emissions. Confounding co-exposure to aviation-origin emissions

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themselves remains unaccounted for, limiting the causal interpretation of the epidemiological results.

Moreover, research on near-airport air quality has been limited to ambient (outdoor) observations to date.[24] The extent and conditions under which aviation emissions infiltrate residences and impact indoor air quality remain largely unaddressed. We found only one study that reported on residential infiltration of aviation emissions.[42] In that study, 16 homes in Boston (MA), which were selected primarily for assessment of highway impacts on indoor air quality, were found to contain higher PNC indoors when the residences were downwind of the Logan International Airport. This study did not quantify infiltration rates due to the lack of concurrent outdoor and indoor measurements. Further, no studies have investigated the influence of meteorology and aviation activity on infiltration or quantified impacts of aviation emissions on indoor air quality.

In this study, we concurrently monitored outdoor and indoor air pollutant concentrations in a near-airport residence to assess the influence of temporal factors including time of day, meteorology and aviation activity intensity, and operation type (landings and takeoffs). We studied a residence of a common architectural style and vintage in Winthrop, MA, a community that is significantly impacted by the Logan International Airport. About a third of the Winthrop's population of 17 500 lives within the 60 dB noise impact zone (an annual average of cumulative 24 h day and night noise exposures with a 10 dB night-time penalty).Ours is the first study to detail the disproportionate impact of overhead landing jets on residential outdoor and indoor air quality.

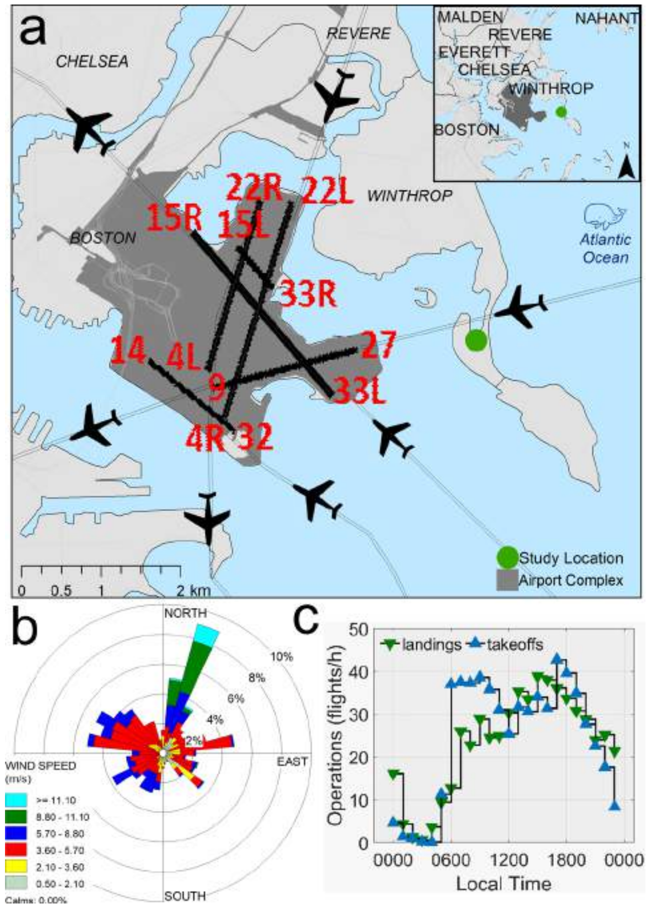

Figure 1. (a) Monitoring the site location and flight trajectories for preferred runway configurations for jets during SW and NW winds at the Logan Airport. (b) Windrose and (c) diurnal flight activity for the study period.

METHODS

Airport Description. The General Edward Lawrence Logan International Airport is located 1.6 km east of downtown Boston (Figure 1). It has six runways and supports ~1000 operations per day (combined landings and takeoffs [LTO]). For each wind-direction quadrant, the airport has a '*preferred runway configuration*' consisting of a subset of runways (three out of the six runways), as shown in the Supporting Information (SI), Figure S1, to which operations are preferentially directed. In the US, the naming convention on runways is such that they represent the numerical heading in tens of degrees of the planes using the runways. For example, planes taking off or landing on runway 27 at the Logan airport head ~270° true north, while planes taking off or landing on runway 4 head ~40° true north.

Residential Air Quality Monitoring and Instruments. Monitoring was conducted from August 23 to September 23, 2017, at a residence in Shirley Point, Winthrop located 1.3 km from the eastern end of runway 9/27 (Figure 1). Jets descend overhead of the residence at an elevation of ~75−100 m. The residence is located in a suburban neighborhood with only one major collector/arterial road within a 1 km radius, and the road leads to a dead end and thus has very limited vehicular traffic (Figure S2a). Outdoor monitoring was performed using the Tufts Air Pollution Monitoring Laboratory (described in detail elsewhere[43]), which was parked in the driveway on the northern side of the property. Outdoors, a suite of gaseous and particulate pollutants were measured including particle number concentrations (PNC, measured at 1 s resolution using a TSI (MN) Condensation Particle Counter 3783 [CPC, d_{50} = 7 nm]), black carbon (BC), fine particulate matter ($PM_{2.5}$), particle-bound polycyclic aromatic hydrocarbons (PBPAH) for PAH-containing particles ≤1.0 μm), carbon monoxide (CO), and oxides of nitrogen (NO, NO_2, and NO_X) (see Table S1 for details of the instruments used). To limit disturbance to the residents (i.e., due to noise from the monitoring equipment), indoor measurements were restricted to PNC using the same make and model CPC as outside. It was placed in the first-floor living room. Weekly maintenance of the instruments included flow checks, clock resets, and data download.

Residence Characteristics and Ventilation Practices. The residence, built in 1920, is a two-story, two-bedroom, 1700 ft^2 colonial wood-frame house that is typical of the architectural style of the neighborhood. It does not have a centralized ventilation system (neither AC nor fans) and neither the kitchen nor the single bathroom is equipped with exhaust fans. It has eight double-hung windows, four picture windows, two inoperable windows, a front door, a back door, and a sliding glass door. In the early 1990s, all of the windows, the front door, and the sliding glass door were replaced with new, tighter versions as part of Massport's Residential Sound Insulation Program.[44] This is a voluntary program where owners of residences located within the 65 dB DNL threshold area can apply for noise reduction measures. Therefore, this residence may have lower air exchange rates under closed window conditions than residences without soundproofing. New storm windows and storm doors were also added at this time.

Prior to the start of monitoring, we deliberately did not discuss ventilation practices (or instruct residents to modify or not modify current practices) so as not to influence their behavior during the month of monitoring. Following the monitoring period, the residents were surveyed *post hoc*[45] on cooking practices, fan and air conditioner use, and window openings during the month-long study. On the survey, the residents indicated that on weekdays windows were opened minimally during the day (~2 h) and in the evening (~1 h), while on weekends, 3−5 windows were typically opened for 2−5 h during the day and 1−2 h in the evening (1800−2300 h). At night (after 2300 h) on both weekdays and weekends, all windows were closed and as many as three window-mounted AC units were operated to provide cooling. Also, the residents (two full-time working adults) indicated that they cooked infrequently.

Regulatory Monitoring Sites and Other Sites. To provide perspective on near-airport observations, we also compare concentrations of pollutants measured near the airport with those measured at regulatory monitoring sites and in near-highway neighborhoods in the Boston area. Data from five proximal regulatory monitoring sites operated by the Massachusetts Department of Environmental Protection[46] in Suffolk and Essex counties were obtained. For ease of interpretation, we refer to these sites by their distinguishing features. The sites are as follows: (a) a site on the shoulder of Interstate I-93N and 6 km SW of the airport (referred to as *adjacent-highway*); (b) a near-roadway site at the intersection of five streets and 100 m N from Interstate I-90 and ~6 km W of the airport (*near-roadway*); (c) a site in downtown Boston 3.5 km W of the airport (*downtown*); (d) a site located 7.5 km WSW of the airport that is considered indicative of the neighborhood scale (*urban-background*); and (e) a site 13 km NNE of the airport in Lynn, MA, that is considered indicative of regional-scale air quality (*regional-background*). Traffic volumes (annual average daily traffic estimated from the regional planning commission[47]) in the 1 km area around these sites are shown in Figure S2b−f in Table S2.

The air quality monitoring instruments used at regulatory sites are listed in Table S2. We used federal equivalent method instruments to measure CO and oxides of nitrogen at the near-airport site. For $PM_{2.5}$, we used an optical sensor instead of federal reference/equivalent methods; this nephelometer tends to read higher than federal reference/equivalent methods, is sensitive to relative humidity, which we do not correct for, and requires gravimetric calibration to local aerosol for data to be comparable to regulatory data.[48] Thus, we do not discuss absolute $PM_{2.5}$ concentration differences between the near-airport residence and the regulatory sites and limit interpretation to broad trends.

Because ultrafine particles are not a regulated air pollutant in the US, PNC is not routinely monitored at the regulatory sites by state or federal agencies. Comparable PNC data were available from the Tufts UFP Monitoring Network (TUMN), which uses the same CPCs as we used at the near-airport residence (TSI model 3783). Data were available from two locations: first, the roof of a three-story building in Chelsea, 4.0 km northwest from the airport, for the entire study duration (August 23−September 23, 2017) and second, from a station collocated at the urban-background regulatory site for August 23−September 09, 2017.

Data Acquisition and Statistical Analysis. Meteorological data collected at the airport (KBOS) were obtained from the National Centers for Environmental Information[49] and aggregated to hourly resolution. Regulatory monitoring site data was obtained from EPA's AirData websites https://www.epa.gov/airdata and https://aqs.epa.gov/api at hourly average resolution. Measured pollutant data were aggregated to hourly resolution and aligned with the meteorological and regulatory data.

Data on flight activity at the airport were web-scraped from https://secure.symphonycdm.com, a public portal for tracking flight activity at the airport. A coordinate grid was established for each runway, and when a plane entered or exited, a grid, it was counted as having landed or taken off, respectively. Data was extracted at 30 s intervals and aggregated to the hour. To check for errors in the automated methodology, flight activity was also replayed and tracked manually for 5 h (three busy hours with >2 operations/minute and two more hours with <0.5 operations/minute) (Table S3); scraping/automated extraction underestimated operations by 0−3% in busy hours and 0% in other hours. Detailed flight activity logs including idling and taxiing times for airplanes on the tarmac were unavailable to us.

Statistical analysis was conducted in MATLAB 2018. Nonparametric statistics were used because the pollutant data were non-normally distributed; differences were tested using the Wilcoxon rank-sum test (significance threshold $p < 0.05$), and the Spearman's rank correlation coefficients (r_s) are reported. Extreme outliers were defined using Tukey's fences,[50] i.e., three times the interquartile range, and excluded from indoor-to-outdoor (I/O) ratio analysis (amounting to 0.007% of data during impact sector and 4.9% of the data during other winds). As a check, all extreme outliers were found to exceed unity, indicating that indoor concentrations exceeded outdoor concentrations likely due to indoor sources.

RESULTS AND DISCUSSION

Flight Activity Patterns. SW-NNW winds orient the residence downwind of the airport. During these winds, landings occurred mostly over the water and takeoffs occurred mostly over the land (Figure 1a shows flight trajectories). For example, when winds are from the S-W (180−270°), the predominant wind direction (WD) in the Boston area during summer, jets are preferentially directed to land on 22L (heading 214.6°) and 27 (heading 271.5°) and takeoffs are directed to occur on 22L and 22R (heading 214.6°). When winds are from the W-N (270−360°), flights are preferentially directed to land on runways 27, 32 (heading 320.6°) and 33L (heading 330.1°) and takeoff from 27 and 33L. During the study, 100% landings and 100% takeoffs occurred on preferred runways for 62 and 48% of the hours, respectively, and >50% of the operations occurred on preferred runways 70% of the hours. Takeoffs were far more frequently directed to nonpreferred runways than landings (e.g., during SW and NW winds, ~15% of takeoffs occurred on nonpreferred runways compared to <5% of landings). The windrose and flight activity for the study duration are shown in Figure 1b,c. Overall, we observed 1.2 times as many flights during evening peak rush hour (1700−1800) than during morning peak rush hour (0900−1000). The hours of 0100−0600 were the least busy due to night-time flight restrictions (Figure 1c).

Wind Direction and Pollutant Patterns. The WSW-N sector (247.5−360°) stands out in the bivariate polar plots as the sector associated with the highest PNC (Figure 2a,b), a trend also reflected by most of the other pollutants (Figure

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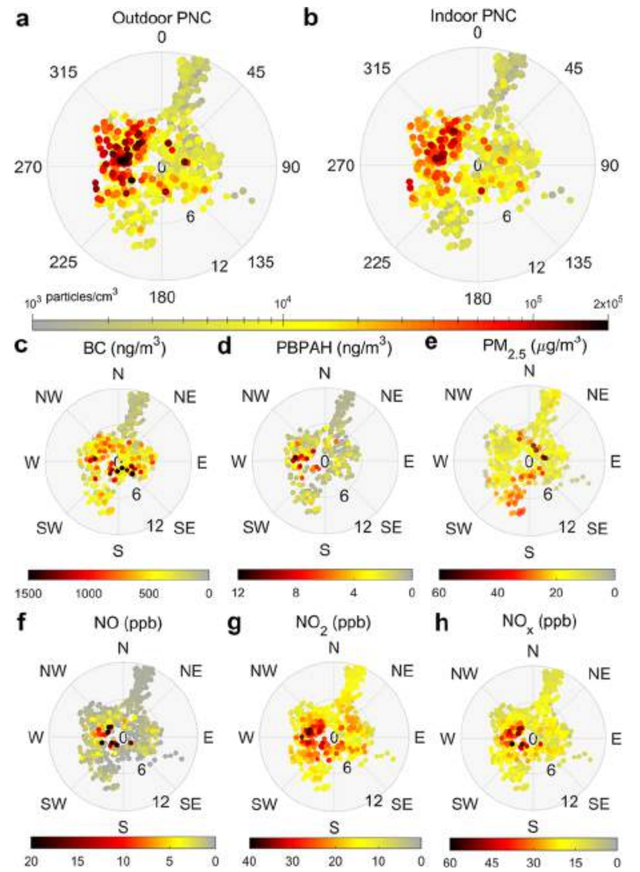

Figure 2. Polar plots of hourly average pollutant concentrations versus wind direction and speed. (a) Outdoor and (b) indoor particle number concentrations (particles/cm^3) and (c–h) hourly average outdoor concentrations of other pollutants. Radial axis labels placed along 135°show wind speed in m/s.

2c–h). During these winds, the residence was downwind of the airport complex as well as flight trajectories for the runways preferred during westerly winds. We identified this sector as the impact sector (247–360°), similar to other works.[27,42,51,52]

Non-impact-sector winds (i.e., winds from 0 to 246.9°) oriented the monitoring site upwind of the airport and were further subdivided into winds from over-the-ocean (0–112.5°) and over-the-land (112.6–246.9°).

Significantly higher concentrations of PNC, oxides of nitrogen (NO, NO_2, and NO_X), CO, BC, and PBPAH were observed during impact-sector winds compared to non-impact-sector winds (Table 1). Fold elevation, or the ratio of mean concentration for all hours of impact-sector winds to the mean concentration for all hours of non-impact-sector winds, was highest for PNC (Table 1): PNC were 4.8-fold elevated outside and 4.2-fold elevated inside the residence. Fold elevation was lower for other pollutants. BC was 1.3-fold elevated and PBPAH was 1.8-fold elevated. NO, NO_2, and NO_X were 1.9, 1.2, and 1.2-fold elevated, respectively (n.b., the difference between means was much greater for NO_2 (2.7 ppb) than for NO (0.8 ppb)). Fold elevation was lowest for CO, 1.1-fold. Only $PM_{2.5}$ concentrations were not elevated during impact-sector winds relative to non-impact-sector winds. Higher $PM_{2.5}$ concentrations were observed when winds were from the S–SW, a pattern consistent with that observed at vicinal regulatory monitoring sites (Figure S3a) and associated with long-range transport of aerosols from regional sources upwind.

Generally, when winds were from over-the-ocean, pollutant concentrations were lower; the lowest levels occurred during a 3.5-day-long storm event (mid-day 19 September–23 September, 2017), during which winds were high and from the NNE (see Figures 1c and 2). Table S4 summarizes concentrations for non-impact-sector winds further split into over-the-ocean and over-the-land winds.

Diurnal Patterns. PNC diurnal patterns during impact-sector winds were very distinct from those for other pollutants and distinct from PNC diurnal patterns during non-impact-sector winds. As shown in Figure 3, PNC increased steadily from 1600 to 2300 h to levels that were far higher than those at any other time of the day and decreased precipitously with a drop in flight activity, in particular, after 0100 h. The late-evening (2000–2300 h) average exceeded the morning (0600–1100 h) average by a factor of three (80 000 ±

Table 1. Statistics for Hourly Averaged Pollutant Concentrations during Monitoring (23 August–23 September, 2017)

pollutant	n (hours of data): impact sector	n (hours of data): non-impact sector	mean (± st. dev.): impact sector	mean (± st. dev.): non-impact sector	mean (± st. dev.): fold elevation	median (IQR): impact sector	median (IQR): non-impact sector	Wilcoxon rank-sum test statistics[a]: p-value	Wilcoxon rank-sum test statistics[a]: z-value
PNC indoors (number/cm^3)	261	469	25000 ± 27000	6000 ± 8000	4.2	13 000 (6000–32 000)	4000 (2000–7000)	<0.05	14.1
PNC outdoors (number/cm^3)	255	484	38000 ± 42000	8000 ± 15000	4.8	17 000 (7000–55 000)	4000 (3000–7000)	<0.05	15.0
PNC I/O ratio	255	469	0.77 ± 0.27	0.83 ± 0.23		0.78 (0.60–0.91)	0.81 (0.69–0.95)	<0.05	−3.7[b]
BC (ng/m^3)	141	370	390 ± 230	300 ± 250	1.3	330 (230–530)	250 (130–390)	<0.05	5.0
PBPAH (ng/m^3)	159	229	1.8 ± 1.9	1 ± 1.1	1.8	1.1 (0.7–2)	0.6 (0.4–1.2)	<0.05	6.9
$PM_{2.5}$ (μg/m^3)[c]	251	419	11 ± 4	15 ± 7		11 (8–13)	13 (11–17)	1	−7.1
NO (ppb)	252	419	2 ± 3	1 ± 2	1.9	1 (0–2)	0 (0–1)	<0.05	7.3
NO_2 (ppb)	252	419	17 ± 7	14 ± 5	1.2	15 (12–21)	13 (11–16)	<0.05	5.2
NO_X (ppb)	252	419	18 ± 8	15 ± 6	1.2	16 (13–22)	14 (11–17)	<0.05	5.6
CO (ppb)	196	401	220 ± 50	200 ± 60	1.1	210 (180–240)	180 (150–230)	<0.05	5.3

[a]One-sided hypothesis test, where the alternative hypothesis states that the median of the impact sector is greater than the median of other winds. [b]One-sided hypothesis test, where the alternative hypothesis states that the median of other winds is greater than the median of the impact sector. [c]Factory calibration based.

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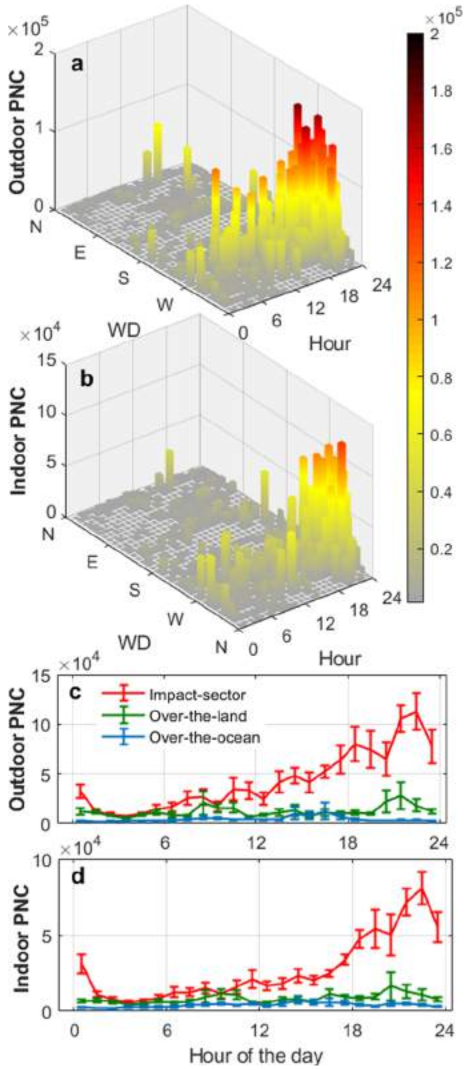

Figure 3. Outdoor (a) and indoor (b) PNC patterns with respect to wind direction (WD) and hour of the day; data were binned into 36 10°-wide WD and 24 hourly bins, resulting in an unequal distribution of data per bin but reflecting the natural frequency of WD during the monitoring period. Diurnal trends of outdoor (c) and indoor (d) PNC for impact-sector and other winds. Error bars show the standard error. Note the difference in the y-axis scale for outdoor versus indoor PNC.

51 000 versus 25 000 ± 26 000 particles/cm^3) even though total flight operations were only 15% higher in the evening relative to the morning. This indicates that the late-evening PNC increase was promoted by factors other than a proportional increase in flight activity. We also observed a pronounced late-evening PBPAH peak during impact-sector winds. PBPAH are emitted directly in aircraft exhaust, but they can also form due to condensation of semivolatile PAH on particles in the atmosphere.[37] The highest ratio of PBPAH concentration to BC concentration (BC is also emitted directly in aircraft exhaust and is a relatively inert pollutant) also occurred in the late evening hours during impact-sector winds (Figure S5). Lack of detailed tarmac-level activity data (idling and taxiing times) and chemical composition precludes an explanation for the late-evening PNC increase we observed. For example, the increase could have derived from greater airplane idling and other low-thrust operations during evening hours; low-thrust operations like idling have a higher PNC emission index (number of particles/kg fuel burnt) than high-thrust operations.[53] Greater knowledge of how plumes chemically evolve as they are transported from airplanes to downwind receptor areas near airports could help to better explain our findings.

Other than PNC, all of the pollutants had bimodal diurnal concentration profiles during impact-sector winds and the magnitude of morning and evening peaks were comparable except for NO, where the morning peak concentration was about 3-fold higher than the evening peak concentration, and NO_2, where the average concentration in late-evening exceeded the morning average by 1.3-fold (Figure 4).

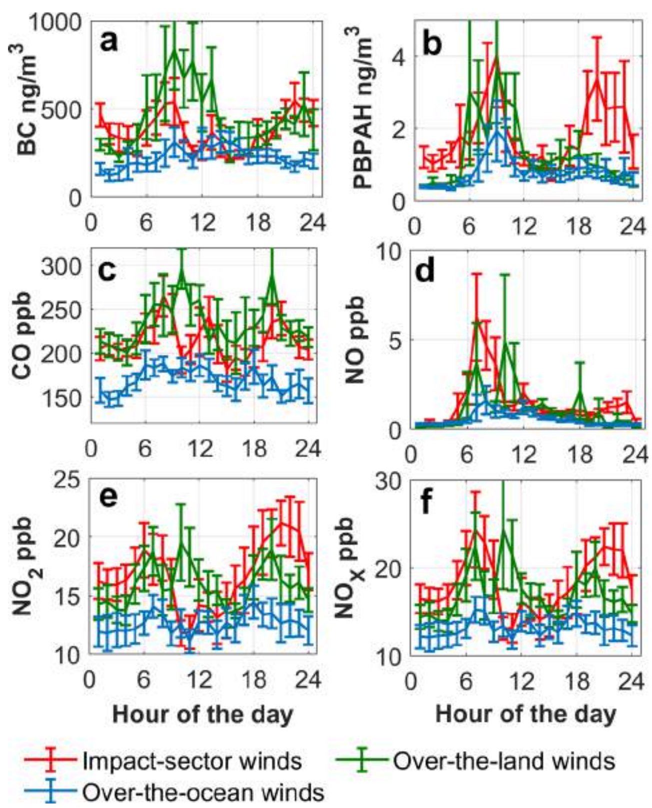

Figure 4. Diurnal trends of hourly averages of outdoor pollutant concentrations for the monitoring period during impact-sector and other winds. Error bars show the standard error. See Figure S3b for $PM_{2.5}$ and Figure S6 for CO_2.

In comparing non-impact-sector/over-the-land winds, non-impact-sector/over-the-ocean winds, and impact-sector winds, several key observations emerge. First, during over-the-ocean winds, the concentrations of pollutants were consistently and expectedly the lowest compared to other wind sectors. Also, upon examination of over-the-ocean diurnal patterns, there were small coincident peaks of PBPAH, BC, NO, and NO_2 in the morning. The few upwind air pollution sources in this sector include marine vessels, activities at Deer Island where the Deer Island Wastewater Treatment Plant is located, and traffic on roadways near the monitoring site; it is possible that these sources were responsible. Second, during over-the-land winds, the concentrations of pollutants were lower than impact-sector winds, except BC and CO. During morning to mid-day hours (0500−1300), BC concentrations during over-the-land winds were substantially higher than during impact-sector winds (650 ± 120 versus 390 ± 110 ng/m^3). The diurnal profiles for CO during over-the-land and impact-sector winds were similar and concentrations were only moderately different (230 ± 60 versus 220 ± 50 ppb); the evening peak coincided with the ground-traffic rush-hour period (1700−2000 h), indicating the influence of primary vehicular emissions from the Boston area at this monitoring site. Third, no distinct diurnal pattern was observed for $PM_{2.5}$ (Figures S3b and S7). Fourth, the diurnal pattern for CO_2 was similar for all three wind sectors (Figure S6). Finally, during both impact-sector and non-impact-sector winds, the lowest concentrations of pollutants were observed during 0200−0500 h when flight activity was minimal (Figure 1c) and during the warm afternoon hours when convective mixing was greatest. Correlations between pollutants at hourly time resolution are discussed in the SI (Figure S7).

Particle Infiltration. Indoor diurnal PNC patterns were nearly identical to outdoor PNC patterns (Figure 3), indicating that there was substantial infiltration of outdoor particles into the residence. Time-series plots based on 1 s measurements indicate that infiltration occurred rapidly, on the order of minutes (Figure S8). Overall, indoor PNC during both impact-sector and non-impact-sector winds were only ∼25% lower than outdoor PNC but there were modest wind-sector differences in the I/O ratios. I/O ratios were significantly ($p < 0.001$) lower during impact-sector winds compared to other winds: 0.77 ± 0.27 during impact-sector winds compared to 0.82 ± 0.23 during other winds (Figure S9a). In addition, the I/O ratios were generally negatively correlated with outdoor concentrations (Figure S9e), but more strongly so for impact-sector winds ($r_s = -0.49$, $p < 0.0001$) than non-impact-sector winds ($r_s = -0.32$, $p < 0.001$). These results are consistent with the expectation that the I/O ratios should be lower for particle mixtures dominated by smaller particles (like aircraft emissions[26,54]) because they have lower penetration rates or higher diffusional losses through cracks.[55] But the differences are modest, and coincidental influence of unquantified factors, like irregular window opening, cannot be ruled out.

Flight Activity on Preferred Runways and Pollutant Patterns during Impact-Sector Winds. Pollutant concentrations and correlations with flight activity strongly depended on the operational runway configuration. The highest correlations between ambient pollutant concentrations and total flight activity (combined landings and takeoffs per hour; LTO/h) occurred when the preferred runway configuration for impact-sector winds was used. For these conditions, all pollutants except $PM_{2.5}$ were positively correlated with total flight activity (r_s ranged from 0.31 to 0.57 for landings and 0.28−0.54 for takeoffs (Figure S12)). In contrast, flight activity on nonpreferred runways, even during impact-sector winds, was negatively correlated with pollutant concentrations although the monitored residence was still downwind of the airport (r_s ranged from −0.48 to −0.17 for landings and −0.45 to −0.22 for takeoffs). Correlation coefficients for all pollutants are shown in Figure S12.

Further, whether jets were landing or taking off at a particular runway made a remarkable difference on the downwind impacts. This point is illustrated in Figure 5a, which shows outdoor and indoor PNC (1 s resolution data) and the fraction of hourly flight activity on runways 27 and 33L. These are the two closest runways to our monitoring site. They are also preferred for operations during impact-sector winds (Figure 1a) and the majority of flight operations were

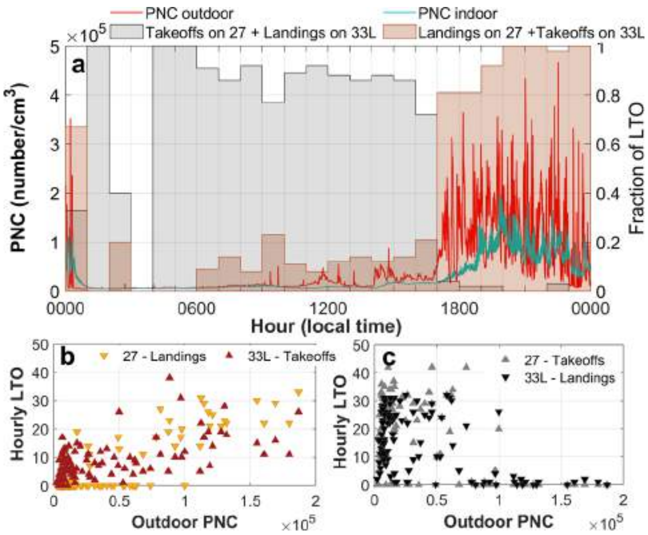

Figure 5. (a) 24-h time series of PNC and fraction of flight activity on runways 27 and 33L for a day of sustained impact-sector winds. (b, c) Scatter plots of hourly operations exclusively on runways 27 and 33L and outdoor PNC during impact-sector winds over the entire study period (n = 103 h). Figures S13−S16

conducted on these two runways during the 24-h period shown in Figure 5a. One key difference over the course of this day was that between 0400 and 1700 h, 70−100% of operations/hour occurred such that landings were on 33L and takeoffs on 27, but between 1700 and 0000 h the runway configuration switched and 80−100% of operations/hour occurred such that landings were on 27 (i.e., overhead of our monitoring site) and takeoffs on 33L. Concurrent with this switch at 1700 h, we observed recurrent PNC spikes that exceeded 100 000 particles/cm^3 and an overall increase in both outdoor and indoor PNC. Average outdoor PNC were 7.5-fold higher (121 000 ± 74 000 versus 16 000 ± 10 000 particles/cm^3) during 1700−0000 h than during 0400−1700 h. Likewise, average indoor PNC were similarly 7.7-fold higher (73 000 ± 31 000 versus 9 500 ± 3 400 particles/cm^3) during 1700−0000 h than during 0400−1700 h. Time series for other pollutants from the same 24-h period Figure 5 are shown in Figures S13−S16. Our results are consistent with reported observations of ground-level PNC spikes from descending plumes of landing jets under the landing trajectory up to 2.75 km from the runway.[26] It is noteworthy that pollutants are known to be entrained in the descending vortices from the jet wingtips[56] and the altitude of descending overhead jets at this residence (75−100 m) is below the expected planetary boundary layer height in summer. Examination of the hours in which flight activity occurred exclusively on runways 27 and 33L, i.e., n = 103 h, 40% of the impact-sector data set yielded similar results; data is shown in Figure 5b,c and statistics are discussed in the SI.

Comparison with Regulatory and Other Data sets. We compared our measurements from the near-airport residence to measurements collected during the month-long study period at five regulatory monitoring and two UFP monitoring locations in the Boston area. Locations for all sites are shown in Figure S17a, diurnal trends are shown in Figure S17b−h, and concentrations are summarized in Table S8.

The most interesting intercomparison was observed for oxides of nitrogen. Jet-engine exhaust emissions are highly

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enriched in NO_2[38] relative to NO, while exhaust emissions from ground-transportation gasoline engines are primarily in the form of NO. NO can be oxidized within minutes to NO_2 in the presence of high ozone concentrations.[57] NO_2 concentrations at the near-airport residence were higher than those recorded at all of the regulatory monitoring sites including the ones adjacent to highways and busy roadways. Study-duration ambient average NO_2 at the residence was 15 ± 6 ppb (17 ± 7 ppb during impact-sector winds). This is ∼40% higher than at the adjacent-highway (11 ± 7 ppb) and near-roadway (12 ± 8 ppb) sites, which are purposefully monitored to account for the highest exposures as part of EPA's and MassDEP's near-roadway network.[58] It was also nearly 2-fold higher than at the urban-background site (8 ± 7 ppb) and 7.5-fold higher than at the regional-background site (2 ± 3 ppb). In contrast, NO concentrations at the near-airport residence were lower than those at all regulatory sites except the regional-background site. Expectedly, the highest NO concentrations were observed at sites in close proximity to traffic emissions, i.e., the adjacent-highway (8 ± 10 ppb) and near-roadway (5 ± 6 ppb) sites. The study-duration average NO concentration at the near-airport residence (1 ± 2 ppb overall and 2 ± 3 ppb during impact-sector winds) was 5-fold higher than at the regional-background site (0.2 ± 1 ppb), comparable to the urban-background site (2 ± 4 ppb), and many-fold lower than at the adjacent-highway and near-roadway sites. It is noteworthy that our study site is also farther downwind of the airport than the near-roadway regulatory sites are to traffic emission sources; thus, we likely measured a more aged plume with greater NO_2 relative to NO. See discussion in SI (Section S2.7) for other pollutants.

The study-duration average outdoor PNC as well as indoor PNC at the near-airport residence exceeded the outdoor PNC at the two UFP monitoring sites for all hours of the day (Figure 5h). The near-airport residence study-duration average concentrations were 18 000 ± 31 000 particles/cm^3 outdoors and 13 000 ± 20 000 particles/cm^3 indoors with the impact-sector averages being 38 000 ± 42 000 and 25 000 ± 27 000 particles/cm^3, respectively. In comparison, the ambient average PNC at the Chelsea site was 11 000 ± 9700 particles/cm^3 and 12 000 ± 5900 particles/cm^3 at the urban-background site. Near-airport indoor averages were comparable to the median 8000−27 000 particles/cm^3 concentrations measured on-road with a mobile lab in Boston and Chelsea[59] and to the 25 000 particles/cm^3 median concentration reported within 0−50 m of I-93 during summer; all-season median was 37 000 particles/cm^3, which was comparable to the outdoor median concentration during impact-sector winds at the near-airport residence.[43]

IMPLICATIONS

Our results show that when jet airplanes used preferred runways during impact-sector winds, particularly when such a configuration included overhead descents, outdoor and indoor PNC were remarkably elevated at our residential monitoring site ∼1 km from the Logan Airport. Temporally, the highest PNC coincided with the periods of highest noise co-exposures (i.e., overhead landing flight hours). This finding is consistent with previous studies that have investigated the spatial patterns of pollutants around airports and have shown that PNC is significantly elevated downwind,[24] but especially under landing jet trajectories coinciding with the highest noise impact contours.[25] Our work underscores the need to account for both aviation-origin air pollution and noise co-exposures to avoid potential confounding of health risk associations to airport proximity.

Further, by clearly demonstrating the relationships between meteorological forcings (e.g., wind direction and wind speed) and aviation activity on UFP infiltration, our results add to the nascent body of knowledge of airport impacts on surrounding neighborhoods. These findings have implications for exposure assessment: exposure monitoring campaigns should be designed to include adequate coverage of the times of day (and times of high flight activity) with specific meteorological conditions of concern, especially wind direction. Our results also show that in the vicinity of airports, exposure to pollutants, particularly UFP and NO_2, is as significant in magnitude as that observed in the vicinity of highways. Also, we observed that indoor PNC were comparable to on- and near-highway PNC and that ambient NO_2 concentrations exceeded those observed at regulatory monitoring sites near an interstate highway and major arterial roadways. It is noteworthy that at this residence (and nearby areas),[60] PNC were highest during the evening and night-time hours (1700−2300 h), the times that people spend most of their time at home. In contrast, the lowest PNC in near-highway homes and on-road in the Boston metropolitan area occur during the late evening to overnight hours.[59,61] Compared to investigations of near-highway exposures to UFP and other traffic-related air pollutants, near-airport exposures remain essentially unaddressed in the literature.[16]

While our results provide a basis for better characterizing exposures to air pollutants of aviation origin at near-airport residences, additional work is needed to assess generalizability. For example, further work is needed to quantify the impact of housing stock characteristics (age, architectural style, and degree of sound insulation) on infiltration. Likewise, studying a greater range of behaviors that impact infiltration and indoor air quality (e.g., air conditioner use, in-home filtration, and ceiling fans) could help to identify practices that reduce indoor exposures. In addition, because we conducted our study in summer, it would be informative to repeat it in winter to quantify seasonal differences in both outdoor air quality and indoor infiltration; both are expected to differ seasonally. Similarly, because we only measured PNC infiltration, it would be useful to measure additional pollutants indoors (e.g., NO_2 and BC) to determine whether other pollutants infiltrate to the same extent as PNC. Finally, the chemical composition of aviation-related particulate air pollution at the neighborhood or community scale (i.e., few to tens of kilometers from the airport) remains unaddressed in the literature. Studies of the chemical composition of particles may shed light on the relative contributions from landings, takeoffs, idling, and taxiing at this scale and may also provide insights into mitigating these impacts (e.g., benefits derived from reducing idling times).

ASSOCIATED CONTENT

SI Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.0c01859.

Maps showing preferred runway configurations, traffic around the near-airport site and regulatory sites, details of instruments, summary of concentrations, diurnal trends for pollutants and meteorological parameters, correlations between pollutants and between pollutants

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and flight activity, illustration of particle infiltration and trends of the I/O ratios with respect to the temporal and meteorological parameters, and comparison of near-airport concentrations to those at regulatory sites including the diurnal patterns and their discussion and a concentration summary table (PDF)

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) Bureau of Transportation Statistics. *2018 Traffic Data for U.S Airlines and Foreign Airlines U.S. Flights*; BTS, 2018.

(2) Federal Aviation Administration. *Terminal Area Forecast Summary Fiscal Years 2018-2045*; FAA, 2018.

(3) ICAO. *Global Air Transport Outlook to 2030 and Trends to 2040*; International Civil Aviation Organization, 2013.

(4) Ryerson, M. S.; Woodburn, A. Build Airport Capacity or Manage Flight Demand? How Regional Planners Can Lead American Aviation Into a New Frontier of Demand Management. *J. Am. Plan. Assoc.* **2014**, *80*, 138−152.

(5) Jarup, L.; Babisch, W.; Houthuijs, D.; Pershagen, G.; Katsouyanni, K.; Cadum, E.; Dudley, M.-L.; Savigny, P.; Seiffert, I.; Swart, W.; Breugelmans, O.; Bluhm, G.; Selander, J.; Haralabidis, A.; Dimakopoulou, K.; Sourtzi, P.; Velonakis, M.; Vigna-Taglianti, F. HYENA study team. Hypertension and Exposure to Noise Near Airports: The HYENA Study. *Environ. Health Perspect.* **2008**, *116*, 329.

(6) Dimakopoulou, K.; Koutentakis, K.; Papageorgiou, I.; Kasdagli, M.-I.; Haralabidis, A. S.; Sourtzi, P.; Samoli, E.; Houthuijs, D.; Swart, W.; Hansell, A. L.; Katsouyanni, K. Is Aircraft Noise Exposure Associated with Cardiovascular Disease and Hypertension? Results from a Cohort Study in Athens, Greece. *Occup. Environ. Med.* **2017**, *74*, 830−837.

(7) Knipschild, P. Medical Effects of Aircraft Noise: General Practice Survey. *Int. Arch. Occup. Environ. Health* **1977**, *40*, 191−196.

(8) Eriksson, C.; Rosenlund, M.; Pershagen, G.; Hilding, A.; Östenson, C.-G.; Bluhm, G. Aircraft Noise and Incidence of Hypertension. *Epidemiology* **2007**, *18*, 716−721.

(9) Rosenlund, M.; Berglind, N.; Pershagen, G.; Järup, L.; Bluhm, G. Increased Prevalence of Hypertension in a Population Exposed to Aircraft Noise. *Occup. Environ. Med.* **2001**, *58*, 769−773.

(10) Babisch, W.; Kamp, I. Exposure-Response Relationship of the Association between Aircraft Noise and the Risk of Hypertension. *Noise Health* **2009**, *11*, 161.

(11) Yang, K.; Cui, Q.; Huang, D.; Song, X.; Tian, J.; Wang, Q. Is There an Association between Aircraft Noise Exposure and the Incidence of Hypertension? A Meta-Analysis of 16784 Participants. *Noise Health* **2015**, *17*, 93.

(12) Franssen, E. A. M.; van Wiechen, C. M. A. G.; Nagelkerke, N. J. D.; Lebret, E. Aircraft Noise around a Large International Airport and Its Impact on General Health and Medication Use. *Occup. Environ. Med.* **2004**, *61*, 405−413.

(13) Floud, S.; Vigna-Taglianti, F.; Hansell, A.; Blangiardo, M.; Houthuijs, D.; Breugelmans, O.; Cadum, E.; Babisch, W.; Selander, J.; Pershagen, G.; Antoniotti, M. C.; Pisani, S.; Dimakopoulou, K.; Haralabidis, A. S.; Velonakis, V.; Jarup, L. HYENA Study Team. Medication Use in Relation to Noise from Aircraft and Road Traffic in Six European Countries: Results of the HYENA Study. *Occup. Environ. Med.* **2011**, *68*, 518−524.

(14) Floud, S.; Blangiardo, M.; Clark, C.; de Hoogh, K.; Babisch, W.; Houthuijs, D.; Swart, W.; Pershagen, G.; Katsouyanni, K.; Velonakis, M.; Vigna-Taglianti, F.; Cadum, E.; Hansell, A. L. Exposure to Aircraft and Road Traffic Noise and Associations with Heart Disease and Stroke in Six European Countries: A Cross-Sectional Study. *Environ. Health* **2013**, *12*, 89.

(15) Hansell, A. L.; Blangiardo, M.; Fortunato, L.; Floud, S.; de Hoogh, K.; Fecht, D.; Ghosh, R. E.; Laszlo, H. E.; Pearson, C.; Beale, L.; Beevers, S.; Gulliver, J.; Best, N.; Richardson, S.; Elliott, P. Aircraft Noise and Cardiovascular Disease near Heathrow Airport in London: Small Area Study. *BMJ* **2013**, *347*, No. f5432.

(16) Correia, A. W.; Peters, J. L.; Levy, J. I.; Melly, S.; Dominici, F. Residential Exposure to Aircraft Noise and Hospital Admissions for Cardiovascular Diseases: Multi-Airport Retrospective Study. *BMJ* **2013**, *347*, No. f5561.

(17) Matsui, T.; Matsuno, T.; Ashimine, K.; Miyakita, T.; Hiramatsu, K.; Yamamotc, T. Association between the Rates of Low Birth-Weight and/or Preterm Infants and Aircraft Noise Exposure. *Jpn. J. Hyg.* **2003**, *58*, 385−394.

(18) Argys, L. M.; Averett, S. L.; Yang, M. *Residential Noise Exposure and Health: Evidence from Aviation Noise and Birth Outcomes*; Institute of Labor Economics, 2019.

(19) Lin, S.; Munsie, J. P.; Herdt-Losavio, M.; Hwang, S. A.; Civerolo, K.; McGarry, K.; Gentile, T. Residential Proximity to Large Airports and Potential Health Impacts in New York State. *Int. Arch. Occup. Environ. Health* **2008**, *81*, 797−804.

(20) Stansfeld, S.; Berglund, B.; Clark, C.; Lopez-Barrio, I.; Fischer, P.; Öhrström, E.; Haines, M.; Head, J.; Hygge, S.; van Kamp, I.; Berry, B. RANCH study team. Aircraft and Road Traffic Noise and Children's Cognition and Health: A Cross-National Study. *Lancet* **2005**, *365*, 1942−1949.

(21) Hygge, S.; Evans, G. W.; Bullinger, M. A Prospective Study of Some Effects of Aircraft Noise on Cognitive Performance in Schoolchildren. *Psychol. Sci.* **2002**, *13*, 469−474.

(22) Eagan, M. E.; Nicholas, B.; McIntosh, S.; Clark, C.; Evans, G. Assessing Aircraft Noise Conditions Affecting Student Learning−Case Studies, ACRP Web-Only Doc, 2017. https://trid.trb.org/view/1497747.

(23) Modernization of U.S. Airspace, FAA. https://www.faa.gov/nextgen/ (accessed Mar 10, 2020).

(24) Stacey, B. Measurement of Ultrafine Particles at Airports: A Review. *Atmos. Environ.* **2019**, *198*, 463−477.

(25) Hudda, N.; Gould, T.; Hartin, K.; Larson, T. V.; Fruin, S. A. Emissions from an International Airport Increase Particle Number

Concentrations 4-Fold at 10 Km Downwind. *Environ. Sci. Technol.* **2014**, *48*, 6628−6635.
(26) Hudda, N.; Fruin, S. A. International Airport Impacts to Air Quality: Size and Related Properties of Large Increases in Ultrafine Particle Number Concentrations. *Environ. Sci. Technol.* **2016**, *50*, 3362−3370.
(27) Hudda, N.; Simon, M. C. C.; Zamore, W.; Brugge, D.; Durant, J. L. Aviation Emissions Impact Ambient Ultrafine Particle Concentrations in the Greater Boston Area. *Environ. Sci. Technol.* **2016**, *50*, 8514−8521.
(28) Keuken, M. P.; Moerman, M.; Zandveld, P.; Henzing, J. S.; Hoek, G. Total and Size-Resolved Particle Number and Black Carbon Concentrations in Urban Areas near Schiphol Airport (the Netherlands). *Atmos. Environ.* **2015**, *104*, 132−142.
(29) Harrison, R. M.; Beddows, D. C. S.; Alam, M. S.; Singh, A.; Brean, J.; Xu, R.; Kotthaus, S.; Grimmond, S. Interpretation of Particle Number Size Distributions Measured across an Urban Area during the FASTER Campaign. *Atmos. Chem. Phys.* **2019**, *19*, 39−55.
(30) Kinsey, J. *Characterization of Emissions from Commercial Aircraft Engines during the Aircraft Particle Emissions EXperiment (APEX) 1 to 3 to U.S*; EPA/600/R-09/130; Environmental Protection Agency: Washington, DC, 2009.
(31) HEI Review Panel on Ultrafine Particles. *Understanding the Health Effects of Ambient Ultrafine Particles*; HEI, 2013.
(32) Downward, G. S.; van Nunen, E. J. H. M.; Kerckhoffs, J.; Vineis, P.; Brunekreef, B.; Boer, J. M. A.; Messier, K. P.; Roy, A.; Verschuren, W. M. M.; van der Schouw, Y. T.; Sluijs, I.; Gulliver, J.; Hoek, G.; Vermeulen, R. Long-Term Exposure to Ultrafine Particles and Incidence of Cardiovascular and Cerebrovascular Disease in a Prospective Study of a Dutch Cohort. *Environ. Health Perspect.* **2018**, *126*, No. 127007.
(33) Hansell, A. L.; Gulliver, J.; Beevers, S.; Elliott, P. Authors' Reply to Corbin, Moore, and Coebergh. *BMJ* **2013**, *347*, No. f6795.
(34) Corbin, J. C. PM0.1 Particles from Aircraft May Increase Risk of Vascular Disease. *BMJ* **2013**, *347*, No. f6783.
(35) Wing, S. E.; Larson, T. V.; Hudda, N.; Boonyarattaphan, S.; Fruin, S. A.; Ritz, B. Preterm Birth among Infants Exposed to In Utero Ultrafine Particles from Aircraft Emissions. *Environ. Health Perspect.* **2020**, *128*, No. EHP5732.
(36) Wood, E. C.; Herndon, S. C.; Timko, M. T.; Yelvington, P. E.; Miake-Lye, R. C. Speciation and Chemical Evolution of Nitrogen Oxides in Aircraft Exhaust near Airports. *Environ. Sci. Technol.* **2008**, *42*, 1884−1891.
(37) Herndon, S. C.; Jayne, J. T.; Lobo, P.; Onasch, T. B.; Fleming, G.; Hagen, D. E.; Whitefield, P. D.; Miake-Lye, R. C. Commercial Aircraft Engine Emissions Characterization of In-Use Aircraft at Hartsfield-Jackson Atlanta International Airport. *Environ. Sci. Technol.* **2008**, *42*, 1877−1883.
(38) Herndon, S. C.; Shorter, J. H.; Zahniser, M. S.; Nelson, D. D.; Jayne, J.; Brown, R. C.; Miake-Lye, R. C.; Waitz, I.; Silva, P.; Lanni, T.; Demerjian, K.; Kolb, C. E. NO and NO2 Emission Ratios Measured from In-Use Commercial Aircraft during Taxi and Takeoff. *Environ. Sci. Technol.* **2004**, *38*, 6078−6084.
(39) Janssen, N. *Health Effects of Black Carbon*; Weltgesundheitsorganisation; World Health Organization: Regional Office for Europe: Copenhagen, 2012.
(40) Huss, A.; Spoerri, A.; Egger, M.; Röösli, M. Swiss National Cohort Study Group. Aircraft Noise, Air Pollution, and Mortality From Myocardial Infarction. *Epidemiology* **2010**, *21*, 829−836.
(41) Evrard, A.-S.; Bouaoun, L.; Champelovier, P.; Lambert, J.; Laumon, B. Does Exposure to Aircraft Noise Increase the Mortality from Cardiovascular Disease in the Population Living in the Vicinity of Airports? Results of an Ecological Study in France. *Noise Health* **2015**, *17*, 328−336.
(42) Hudda, N.; Simon, M. C.; Zamore, W.; Durant, J. L. Aviation-Related Impacts on Ultrafine Particle Number Concentrations Outside and Inside Residences near an Airport. *Environ. Sci. Technol.* **2018**, *52*, 1765−1772.
(43) Padró-Martínez, L. T.; Patton, A. P.; Trull, J. B.; Zamore, W.; Brugge, D.; Durant, J. L. Mobile Monitoring of Particle Number Concentration and Other Traffic-Related Air Pollutants in a near-Highway Neighborhood over the Course of a Year. *Atmos. Chem. Phys.* **2012**, *61*, 253−264.
(44) Noise Reduction at Boston Logan International Airport, Massport, 2019. http://www.massport.com/logan-airport/about-logan/noise-abatement/.
(45) Piazza, T. *Study of Ventilation Practices and Household Characteristics in New California Homes*; Environmental Protection Agency, Air Resources Board, Research Division: California, 2007.
(46) MassDEP Ambient Air Quality Monitoring Network & Annual Plan, MassDEP, 2019. Mass.Gov.
(47) MassGIS Data: Massachusetts Department of Transportation (MassDOT) Roads, MassGIS, 2011. https://docs.digital.mass.gov/dataset/massgis-data-massachusetts-department-transportation-massdot-roads#Attributes.
(48) Wang, Z.; Wang, D.; Peng, Z. R.; Cai, M.; Fu, Q.; Wang, D. Performance Assessment of a Portable Nephelometer for Outdoor Particle Mass Measurement. *Environ. Sci.: Processes Impacts* **2018**, *20*, 370−383.
(49) Automated Surface Observing System (ASOS), NOAA NCEI. https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/automated-surface-observing-system-asos (accessed Sep 30, 2019).
(50) Hoaglin, D. C.; John, W. Tukey and Data Analysis. *Stat. Sci.* **2003**, *18*, 311−318.
(51) Carslaw, D. C.; Beevers, S. D.; Ropkins, K.; Bell, M. C. Detecting and Quantifying Aircraft and Other On-Airport Contributions to Ambient Nitrogen Oxides in the Vicinity of a Large International Airport. *Atmos. Environ.* **2006**, *40*, 5424−5434.
(52) Grange, S. K.; Lewis, A. C.; Carslaw, D. C. Source Apportionment Advances Using Polar Plots of Bivariate Correlation and Regression Statistics. *Atmos. Environ.* **2016**, *145*, 128−134.
(53) Wey, C. C.; Anderson, B. A.; Wey, C.; Miake-Lye, R. C.; Whitefield, P.; Howard, R. Overview on the Aircraft Particle Emissions Experiment (APEX). *J. Propul. Power* **2007**, *23*, 898−905.
(54) Riley, E. A.; Gould, T.; Hartin, K.; Fruin, S. A.; Simpson, C. D.; Yost, M. G.; Larson, T. Ultrafine Particle Size as a Tracer for Aircraft Turbine Emissions. *Atmos. Environ.* **2016**, *139*, 20−29.
(55) Liu, D.-L.; Nazaroff, W. W. Particle Penetration Through Building Cracks. *Aerosol Sci. Technol.* **2003**, *37*, 565−573.
(56) Graham, A.; Raper, D. W. Transport to Ground of Emissions in Aircraft Wakes. Part II: Effect on NOx Concentrations in Airport Approaches. *Atmos. Environ.* **2006**, *40*, 5824−5836.
(57) Seinfeld, J. H.; Pandis, S. N. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*; John Wiley & Sons, 2006.
(58) Near-Road NO_2 Monitoring, Ambient Monitoring Technology Information Center. https://www3.epa.gov/ttnamti1/nearroad.html (accessed Nov 5, 2019).
(59) Simon, M. C.; Hudda, N.; Naumova, E. N.; Levy, J. I.; Brugge, D.; Durant, J. L. Comparisons of Traffic-Related Ultrafine Particle Number Concentrations Measured in Two Urban Areas by Central, Residential, and Mobile Monitoring. *Atmos. Environ.* **2017**, *169*, No. 113.
(60) Li, H. Z.; Gu, P.; Ye, Q.; Zimmerman, N.; Robinson, E. S.; Subramanian, R.; Apte, J. S.; Robinson, A. L.; Presto, A. A. Spatially Dense Air Pollutant Sampling: Implications of Spatial Variability on the Representativeness of Stationary Air Pollutant Monitors. *Atmos. Environ. X* **2019**, *2*, No. 100012.
(61) Fuller, C. H.; Brugge, D.; Williams, P. L.; Mittleman, M. A.; Lane, K.; Durant, J. L.; Spengler, J. D. Indoor and Outdoor Measurements of Particle Number Concentration in Near-Highway Homes. *J. Exposure Sci. Environ. Epidemiol.* **2013**, *23*, 506−512.

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Emissions from an International Airport Increase Particle Number Concentrations 4-fold at 10 km Downwind

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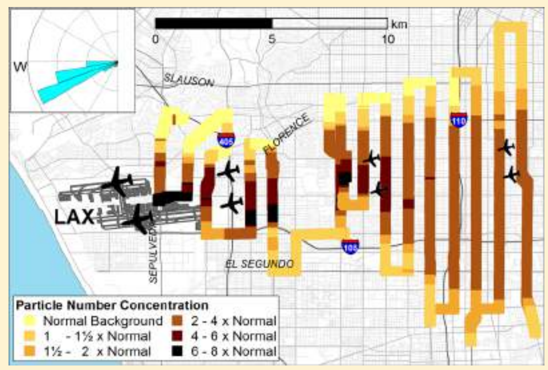
Supporting Information

ABSTRACT: We measured the spatial pattern of particle number (PN) concentrations downwind from the Los Angeles International Airport (LAX) with an instrumented vehicle that enabled us to cover larger areas than allowed by traditional stationary measurements. LAX emissions adversely impacted air quality much farther than reported in previous airport studies. We measured at least a 2-fold increase in PN concentrations over unimpacted baseline PN concentrations during most hours of the day in an area of about 60 km^2 that extended to 16 km (10 miles) downwind and a 4- to 5-fold increase to 8–10 km (5–6 miles) downwind. Locations of maximum PN concentrations were aligned to eastern, downwind jet trajectories during prevailing westerly winds and to 8 km downwind concentrations exceeded 75 000 particles/cm^3, more than the average freeway PN concentration in Los Angeles. During infrequent northerly winds, the impact area remained large but shifted to south of the airport. The freeway length that would cause an impact equivalent to that measured in this study (i.e., PN concentration increases weighted by the area impacted) was estimated to be 280–790 km. The total freeway length in Los Angeles is 1500 km. These results suggest that airport emissions are a major source of PN in Los Angeles that are of the same general magnitude as the entire urban freeway network. They also indicate that the air quality impact areas of major airports may have been seriously underestimated.



INTRODUCTION

Previous studies that directly measured the impact of aviation activity on air quality have mostly conducted measurements in close proximity of airports. Few studies have reported significant air quality impacts extending beyond a kilometer.[1−4] Carslaw et al. 2006[1] analyzed differences in pollutant concentrations by wind speed and direction along with differences in aircraft and ground traffic activity at Heathrow Airport in London. They found airport contributions of up to 15% of total oxides of nitrogen (NO_x) at a site 1.5 km downwind of the nearest runway. At Hong Kong International Airport, Yu et al. 2004[2] used nonparametric regression analysis on pollutant concentrations by wind speed and direction. They calculated that aircraft nearly doubled sulfur dioxide concentrations 3 km away and also increased concentrations of carbon monoxide and respirable suspended particles under similar wind speeds and directions. Fanning et al. 2007[3] measured particle numbers concentrations in the 10–100 nm range and found significant increases above background at 1.9, 2.7, and 3.3 km downwind of the Los Angeles International Airport (LAX) blast fence. Although measurements were stationary and not concurrent, they also noted that takeoffs produced high concentrations and downwind gradients within 600 m of the blast fence. Dodson et al. 2009[4] found that aircraft activity at a regional airport in Warwick, RI contributed 24–28% of the total black carbon (BC) measured at five sites 0.16–3.7 km from the airport.

Several other airport and aviation emissions studies focused on quantifying the air quality impacts from jet takeoffs[5,6] and measured air pollutant concentrations very close to runways. Of particular relevance to this study, Hsu et al. 2013[7] linked flight activity at LAX with 1 min average PN concentrations. Their models suggested that aircraft produced a median PN concentration of nearly 150 000 particles/cm^3 at the end of the departure runway. PN concentrations decreased rapidly with distance to 19 000 particles/cm^3 at a location 250 m downwind and to 17 000 particles/cm^3 at a location 500 m further downwind. The rapid drop-off in concentration, however, may have reflected an increasing offset from the centerline of impacts with greater downwind measurement distance. Similar magnitude PN concentrations and correlations

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with departures were reported by Westerdahl et al. 2008[8] and Zhu et al. 2011[9] at sites located within 100−200 m of the Hsu et al. 2013[7] measurements.

Our study was motivated by mobile monitoring platform (MMP) based observations of large but gradual increases in PN concentrations as we approached locations under LAX jet landing trajectories on multiple transects up to 10 km downwind of LAX. We hypothesized that emissions from LAX activities were increasing PN concentrations over much larger areas and longer downwind distances than previously observed in studies that focused on near freeway and jet takeoff impacts to air quality. An extensive monitoring campaign confirmed that LAX-related emissions increased PN concentrations downwind at least 2-fold to 16 km. This large, previously undiscovered spatial extent of the air quality impacts downwind of major airports may mean a significant fraction of urban dwellers living near airports likely receive most of their outdoor PN exposure from airports rather than roadway traffic.

■ MATERIALS AND METHODS

Monitoring Area. LAX is the sixth busiest airport in the world and third busiest in the United States. About 95% of flights take off and land into the prevailing westerly/west-southwesterly (W/WSW) onshore winds[10] (i.e., 263 degrees, the direction of runway alignment[2]) using two sets of parallel runways separated by about 1.5 km. In the busiest hours, 40−60 jets per hour arrive during hours 0700−1900 and depart during hours 0800−2100. Reduced activity is typical for the early morning and late evening hours. 20−40 jets per hour arrive during hours 0600 and 1000−0100 and depart during hours 0700 and 2200−2300. During other hours typically fewer than five jets per hour arrive or depart.[10]

The airport complex is about 4.5 km east to west (E-W) and about 2.5 km north to south (N−S) and is surrounded by major roadways and freeways, as highlighted in Figure 1 (Figure S.1 in Supporting Information (SI) shows a map of this area with street name labels). The Federal Aviation Administration noise contours of the modeled annual 65 dB A-weighted equivalent (L_{Aeq}) noise threshold are shown[11] extending eastward along the predominant downwind direction and reflect the jet trajectories used for landing. They also extend west of the airport over the Pacific Ocean (not shown).

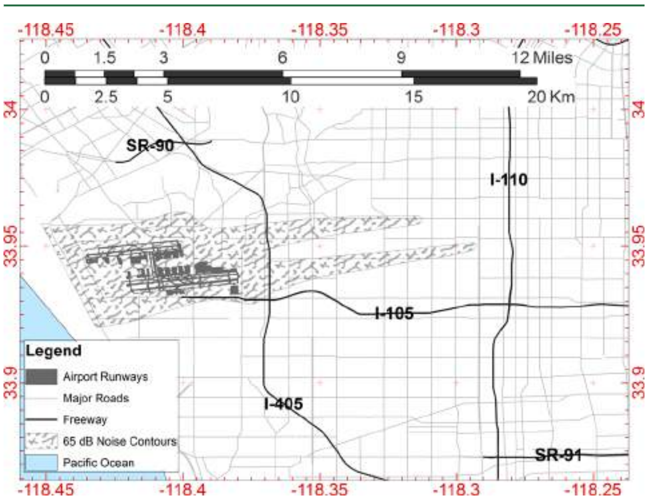

Figure 1. Los Angeles International Airport and 65 dB noise contours indicating eastern jet trajectories.

Mobile Monitoring. Monitoring consisted of transects 4−16 km in length, nearly perpendicular (i.e., N−S) to the direction of the prevailing winds, at varying downwind distances. Different monitoring routes were required to fully capture the changes in impact locations due to shifts in wind direction. A general downwind direction was chosen based on meteorological predictions but transect lengths and locations were determined during the monitoring run based on observations of the rate of change of PN concentrations. For each transect, monitoring was extended several hundred meters beyond the location where baseline PN concentrations appeared stable.

Measurements were conducted over 29 days with the University of Southern California (USC) MMP, a gasoline-powered hybrid vehicle. A second MMP, the University of Washington (UW) MMP, a gasoline-powered minivan, joined the monitoring on 3 days (June 22, 27 and July 1, 2013). Table 1 gives monitoring dates and times.

Most measurements were conducted during times of onshore westerly winds, typically strongest during 1100−1600, but we also conducted measurements during early morning and late night hours when air traffic was low and onshore winds were reduced (August 13, 16, 23, 24 and 25, December 03, 09, 15 and 16, 2013). Monitoring focused on the area east of LAX (i.e., the predominant downwind direction) but included several runs along the boundary of the airport in the upwind direction and south of the airport complex during occasions of northerly winds in winter months.

Instrumentation. Concentration measurements included PN, BC, NO, NO_2, NO_x, and particle surface UV-photo-ionization potential (measured using Ecochem Photoelectric Aerosol Sensor [PAS] that responds to elemental carbon and particle-bound polycyclic aromatic hydrocarbons [PB−PAH]). Instrument details are provided in SI (Table S.1 and S.2). Instruments were powered by two deep-cycle marine batteries via DC-to-AC inverter. Our power arrangement allowed for 5 h of run time if all instruments were running. For sampling runs that were anticipated to exceed 5 h, several instruments were shut down to extend battery life and the Condensation Particle Counter (CPC) was run on the vehicle's 12 V cell phone power outlet. If other instruments were turned on later, the required warm-up time was 25 min.

Instrument clock times were regularly synchronized to be within 1 s of the global positioning system device time, which also recorded speed and location. Measurements from instruments with a delayed response time were advanced to match the instantaneous instruments and the GPS time and location recorded at 1 s intervals. For pollutant measurements recorded at 10 s intervals, all locations within the recording interval were assigned the pollutant value reported for that interval.

Meteorological Data. Minute and hourly wind speed and wind direction data were obtained from the Automated Surface Observing Systems monitor at LAX airport (latitude 33.943 and longitude −118.407). Due to the 16 km distance between eastern edge of the study area and the meteorological station located at LAX, we could not assume that wind speed and direction were identical to those measured at LAX, but wind direction in this region of Los Angeles tends to be similar over large areas during daytime.[12]

The average wind direction at LAX is WSW (252°).[12] Daytime southwesterly sea breezes typically occur 16 h per day in the summer (0900−0100 for June−August), decreasing to 6

Table 1. Sampling Days, Time Periods and Meteorological Conditions during Sampling

date[a]	time	sampling distance from LAX (km)	WD[b]	WS (m/s)	urban background PN[c]	ratio of impacted to unimpacted baseline PN, 10 km downwind
4/6/2011	14:30−16:45	8−12	WSW, **W**	5.0 ± 1.8	15 000	2.0
4/10/2011	15:00−17:30	8−12	**W**	6.9 ± 1.2	10 000	4.5
5/24/2011	09:00−11:00	8−12	**Calm**, W	1.0 ± 2.5	10 000	3.0
5/27/2011	12:15−14:45	8−12	WSW, **W**	6.3 ± 1.3	10 000	4.7
1/26/2012	17:28−20:22	8−12	WSW, **W**	2.9 ± 2.1	20 000	6.0
9/29/2012	13:30−17:30	0−8	**W**	6.1 ± 1.1	10 000	3.7
9/30/2012	15:45−18:30	0−8	**W**	6.1 ± 0.4	5000	5.2
6/11/2013	14:14−15:14	2.5−8.5	**WSW**, W	6.7 ± 0.0	15 000	5.0
6/12/2013	13:30−16:30	2.5−10.5	**W**	4.0 ± 0.4	15 000	4.0
6/22/2013	11:47−18:50[d]	0−8	WSW, **W**	5.7 ± 0.4	10 000	4.4
6/27/2013	11:49−18:00[d]	0−8	WSW, **W**	5.3 ± 0.7	10 000	4.0
7/01/2013	10:30−18:30[d]	0−8	**W**, ESE	3.8 ± 1.0	15 000	3.8[e]
8/6,7/2013	23:56−02:45	0−8	WSW, W, S	3.3 ± 0.7	10 000	3.3
8/13/2013	06:30−15:00	0−8	Calm, WSW, **W**, NNE, NE, ENE, E, ESE[f]	3.0 ± 2.0	10 000	4.0
8/15/2013	08:30−15:30	0−16	Calm, WSW,**W**	2.5 ± 2.1	20 000	3.8
8/16/2013	09:45−20:50	0−16	SW, WSW,**W**, WNW	4.4 ± 1.3	10 000	3.0
8/23,24/2013	12:00−01:30	0−16	SSW, WSW,**W**	4.4 ± 2.2	20 000	4.0, 5.0
8/24,25/2013[g]	17:30−01:00	0−16	Calm, SSW, SW, WSW,**W**, ESE	3.1 ± 2.1	15 000	6.0
11/1/2013	16:00−19:50	0−12	SSE, W, **WSW**	3.7 ± 0.7	10 000	3.8[e]
12/3/2013	19:45−00:20	0−12	**WSW, W, WNW**	8.8 ± 1.4	5000	6.0
12/5/2013	13:00−18:30	0−12	WSW, **W**, WNW	5.5 ± 0.6	10 000	2.8
12/9/2013	16:00−00:00	0−10	**N**, NNE	2.7 ± 0.6	20 000	n/a
12/10/2013	15:30−21:30	0−10	**WNW,N**, NW	3.1 ± 1.1	20 000	5.0
12/14/2013	17:00−20:30	0−10	W, Calm	2.1 ± 0.5	20 000	data lost
12/15,16/2013	22:00−02:00	0−10	N, **NE**, ESE	2.9 ± 1.0	17 500	n/a
12/16/2013	10:00−16:00	0−12	**N, W**	2.8 ± 1.6	10 000	4.5
12/18/2013	17:30−20:30	0−10	**WSW**, SSW, SSE	3.3 ± 1.3	10 000	6.0
12/20/2013	16:30−20:00	0−10	**WSW, Calm**, E	2.6 ± 1.3	15 000	4.0
12/23/2013	15:15−19:00	0−12	**W**, Calm, E	2.8 ± 1.3	10 000	11.0

[a]The runs for which maps are presented are formatted in bold. [b]Predominant wind direction is formatted as bold. [c]Urban background value concentrations are reported to nearest 2500 particles/cm^3 and are the average baseline values in the unimpacted areas away from local traffic sources [d]Concurrent MMP sampling times: June 22:1320−1720, June 27:1325−1510, July 1:1240−1640. [e]Monitoring route did not cover the full N−S extent of the impact on Western Av (10 km downwind) on these days, values have been reported for Crenshaw Blvd. (8 km downwind). [f]Easterly flow was recorded in morning hours (until 1000) and westerly later morning to afternoon [g]08/25/2013 was not counted as an additional monitoring day because only 1 h of monitoring (0000−0100) was conducted on this date

h in the winter (1200−1800 in December). Only during the winter months (November−February, 0000−0900) are light easterly off-shore winds common.[12] Wind speed and direction during the monitoring periods are summarized in Table 1. Wind roses based on 1 min data are shown in Figure S.2 and S.3 of the SI.

Data Processing. MMP measurements included a localized traffic emissions signal representing microscale and middle scale variations (10−100 m and 100−500 m, respectively) and an underlying "baseline" pollutant concentration that varied gradually over the neighborhood scale (500 m−4 km).[13] Watson et al. 1997[13] derived these categories by considering the spatial scales of impact of various types of air pollution sources. We adopted a smoothing methodology to estimate baseline PN concentrations that excluded the microscale and middle scale impacts due to local sources, usually specific vehicles.

Baseline PN concentrations were derived from our mobile measurements by taking a rolling 30-s fifth percentile value of the 1-s concentration time series, and assigning that value to the measured location. This removed the microscale and middle scale impacts from traffic sources such as specific vehicle plumes. Baseline concentrations for a run were relatively spatially uniform outside of the LAX impact areas, with coefficients of variation (CV) of less than 5%. In comparison, the raw PN concentrations on roadways outside the LAX impact areas had CVs on the order of 40%. On rare occasions, the MMP was behind a high emitter for longer than 30 s. Such events, only if verifiable by video and field notes, were censored. However, less than 0.5% of data were censored in this manner, generated from about a dozen instances of prolonged influence from high emitting vehicles. An illustration of both raw and smoothed concentration time series is presented in the SI (Figures S.4−S.7). The figures in this text are based on smoothed data.

RESULTS AND DISCUSSION

Spatial Pattern and Extent of Elevated PN Concentrations. Downwind of LAX we observed gradual but large increases in baseline PN concentrations occurring over transect distances of multiple kilometers. PN concentrations were elevated 4-fold or more above nearby unimpacted baseline concentrations up to 10 km in the downwind direction from

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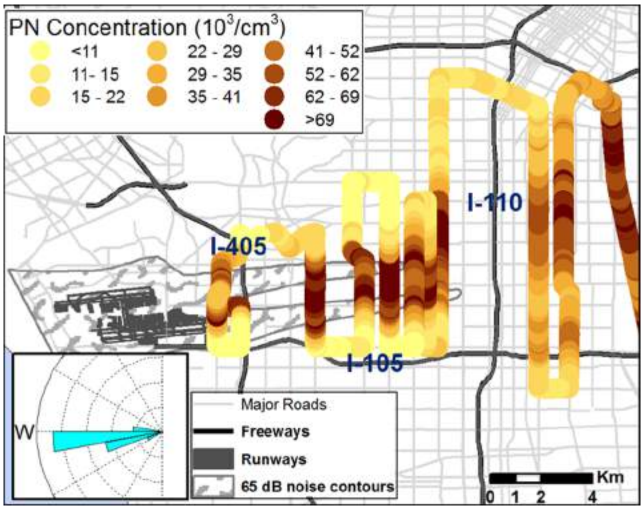

Figure 2. Spatial pattern of PN concentration (colored by deciles) for the afternoon and evening hours of August 23, 2013.

LAX. Figure 2 shows an example of the spatial pattern of the elevated PN concentrations.

The size of the impacted areas with high PN concentration increases was remarkable. At 16 km downwind, a 2-fold increase in PN concentration over baseline concentrations was measured across 6.5 km. Assuming a trapezoidal shaped plume with parallel edges of length 1.5 and 6.5 km, PN concentrations were at least doubled over an area of 60 km^2. Eight km downwind, a 5-fold increase in PN concentrations over baseline concentrations extended across 3 km and covered a total area of 24 km^2. (Concentrations in this large area exceeded 71 000 particles/cm^3, the average concentration on Los Angeles freeways.[14]) Within 3 km of the airport boundary, concentrations were elevated nearly 10-fold, exceeding 100 000 particles/cm^3, with concentrations of 150 000 particles/cm^3 occurring over a several km^2 area.

This pattern of elevated PN concentrations over large areas east of LAX was consistently observed during periods when there were both westerly winds and high air traffic volumes, typically all daylight hours and well into the night. Figure 3

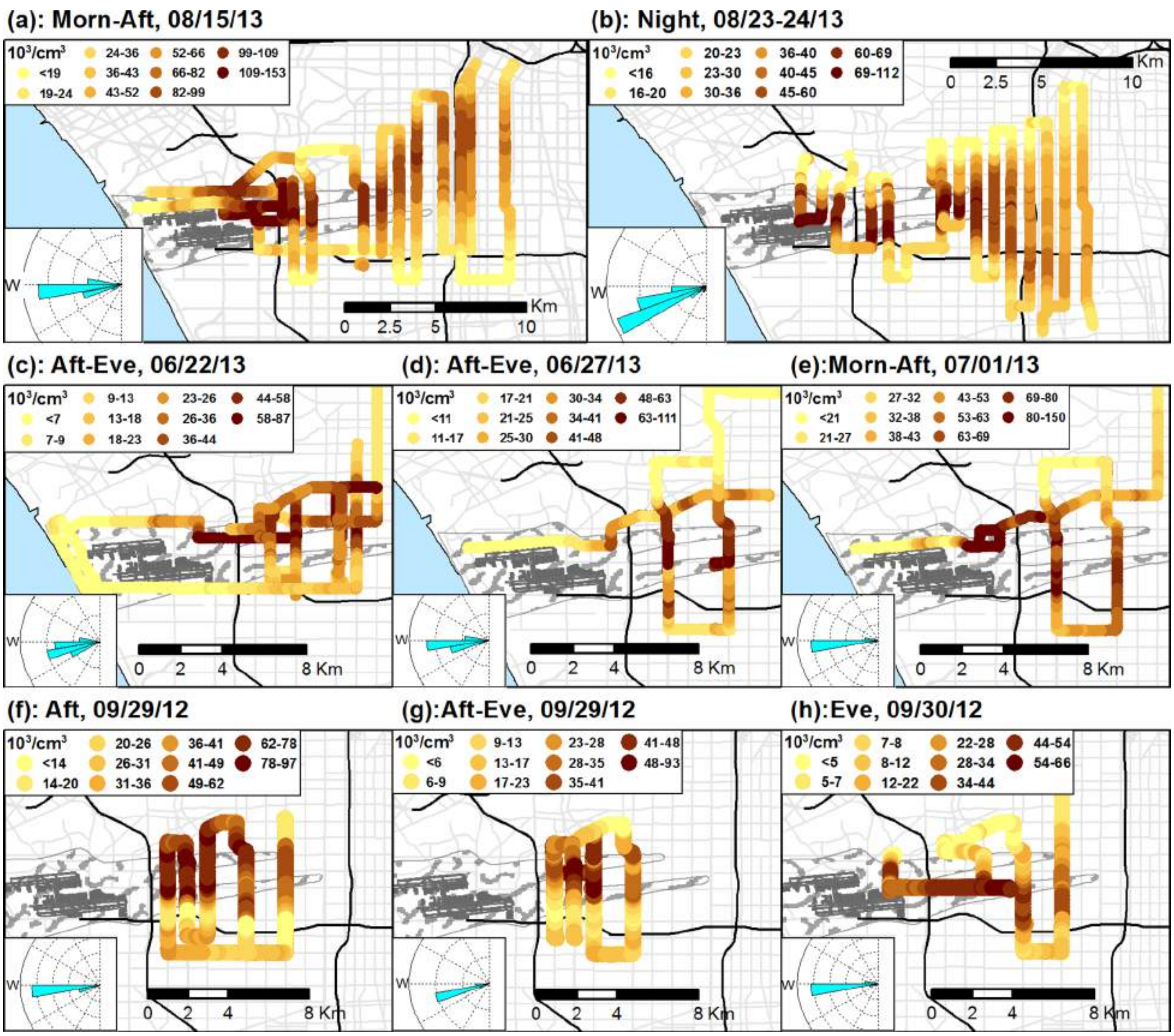

Figure 3. Spatial pattern of impact during different monitoring events. Wind direction during monitoring is shown in insets on bottom left. PN concentrations are classified and colored by deciles.

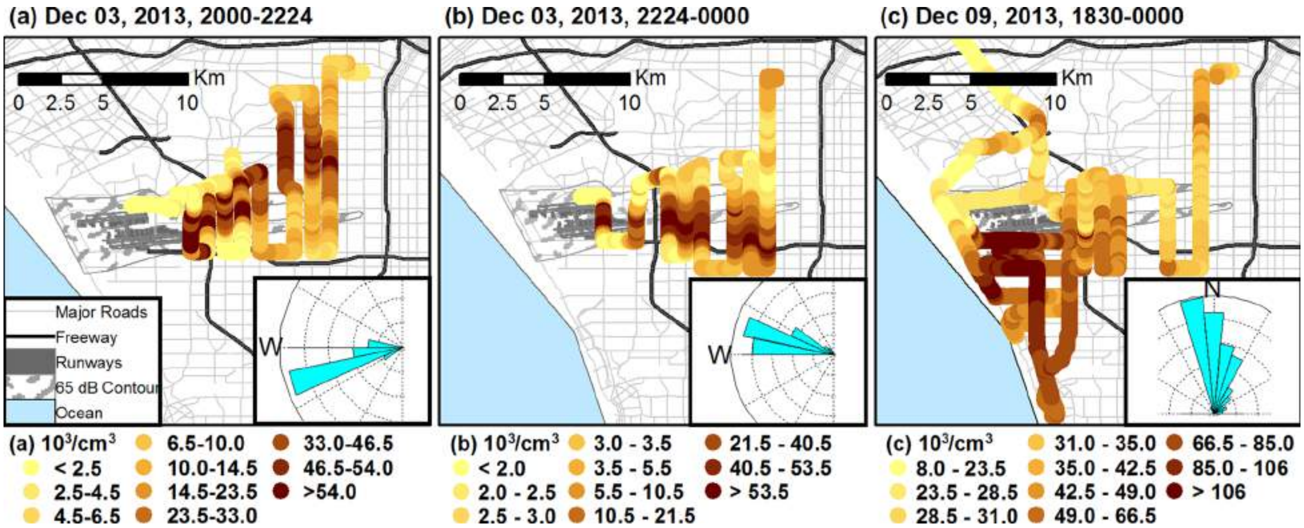

Figure 4. Change in location of impact due to shift in wind direction. Wind direction during monitoring is shown in insets on bottom left. PN concentrations are classified and colored by deciles.

shows the consistency of the patterns over eight monitoring runs at various times of day, displayed in each row by similarity of spatial scale.

In directions other than the downwind direction, no large areas of elevated PN concentrations were observed. Figures 3(c)−(e) include concentrations measured upwind of the LAX boundary (these are indicated by faint yellow lines within the noise contour); the concentrations recorded were typical of the coastal baseline concentrations, less than 10 000 particles per cm^3 (also see Figure S.8 in SI). Of possible other PN sources, a large refinery is located south of the airport but we did not observe elevated PN or other pollutant concentrations directly downwind of this source. In general, industrial point sources of pollution in the Los Angeles Air Basin are very tightly regulated by the South Coast Air Quality Management District.

We did not observe distinct day versus night differences, as might be expected based on the large change in meteorologically driven dilution between day and night for ground level sources. It appeared that the distant impacts we observed downwind of LAX required sufficient wind speeds for the jet climbing and landing emissions to reach the ground, as observed in Yu et al., 2004[2] at LAX and Hong Kong International Airports and Carslaw et al. 2006[1] at Heathrow Airport. At LAX, this probably corresponded to the development of the on-shore sea breezes that typically started 4−6 h after sunrise and lasted until 3−6 h after sunset.[12]

We also did not see the impacts of individual jets at the distances monitored, but the merging of individual jet impacts is not unexpected at distances of multiple km. Considering the frequency of landings and takeoffs (>90 per hour from 0900−2100[10]), at an average wind speed of 4 m/s, for example, an incoming parcel of air will travel only about 160 m before another jet landing or takeoff occurs. Under normal daytime air turbulence and the enhanced turbulence produced by jets,[15,16] significant mixing is expected over a 5−10 km distance (20−40 min). The generally smooth increases and decreases observed across the length of transects at such distances are additional evidence that mixing of plumes occurs. Examples of these smooth concentration increases for individual transects are shown in Figures S.6 and S.7 in the SI.

The consistent and distinctive spatial pattern of elevated concentrations was aligned to prevailing westerly winds and landing jet trajectories, and roughly followed the shape of the contours of noise from landing jets, indicating that landing jets probably are an important contributor to the large downwind spatial extent of elevated PN concentrations. As defined by the International Civil Aviation Organization, typical engine thrust during landing is 30%, as compared to 100% for takeoff and 85% for the climbing phase.[6] Stettler et al. 2011[6] calculated 18% of total NO_x emissions from landings, with 12% from taxiing and holding, 18% from takeoff, and 52% from the climb and climb out phases, respectively. When the extra upwind distance of the climb and climb out phases are taken into account, the landing approach emissions likely produce a significant fraction of the increased PN concentrations observed downwind.

Influence of Wind Direction on Location of Impact. The downwind location of the impact changed with shifts in the prevailing wind direction, although significant shifts in wind direction during the daytime are not typical of this area of Los Angeles.[12] Figure 4(a) and (b) illustrate one such change in impacted locations due to a shift in wind direction on a gusty day with frontal weather that also resulted in cleaner upwind baseline PN concentrations of less than 5000 particles/cm^3. The impacted locations were aligned along the NE direction during 2000−2220 h when winds were from W to WSW (250−280°). The impact then moved southwards between 2220−0000 h as winds turned more W to WNW (280−330°). During this shift, the impact centerline moved by 5.5 km on transects 8−10 km east of LAX.

Monitoring was also conducted during N to NE prevailing winds that tend to occur late at night in November and December (2100−2300).[12] This N to NE wind direction resulted in impacts that were centered south of the airport (Figure 4(c)). The PN concentrations in this southerly impact were roughly twice as high as on other days, in part because the baseline PN concentrations reflected urban air from northerly winds instead of marine air from westerly winds.

Diurnal wind patterns change little by season in Los Angeles basin.[12] Onshore westerly winds are common during midday hours, even in winter. As a result, areas of elevated PN

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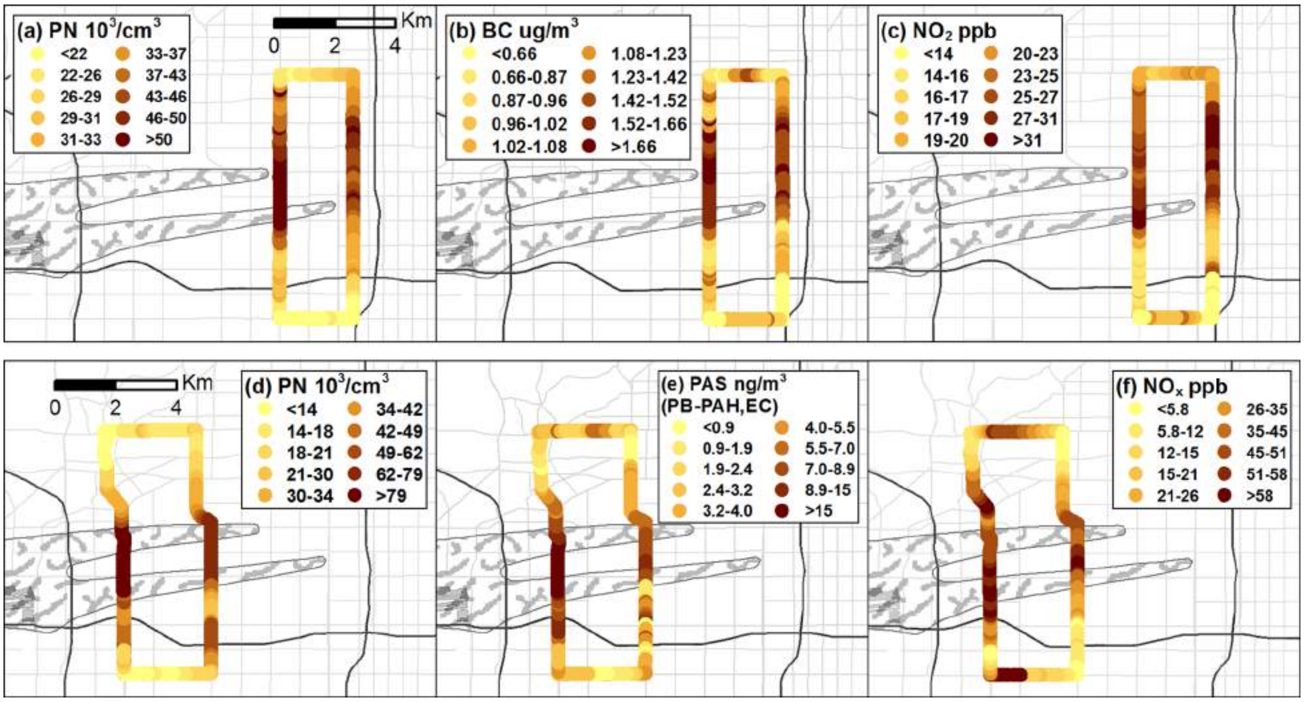

Figure 5. Spatial pattern of simultaneously measured pollutants during 1400−1530 on June 27, 2013. Concentrations are classified and colored by deciles. Panels (a)−(c) show data measured by the UW MMP and (d)−(f) show data measured by the USC MMP.

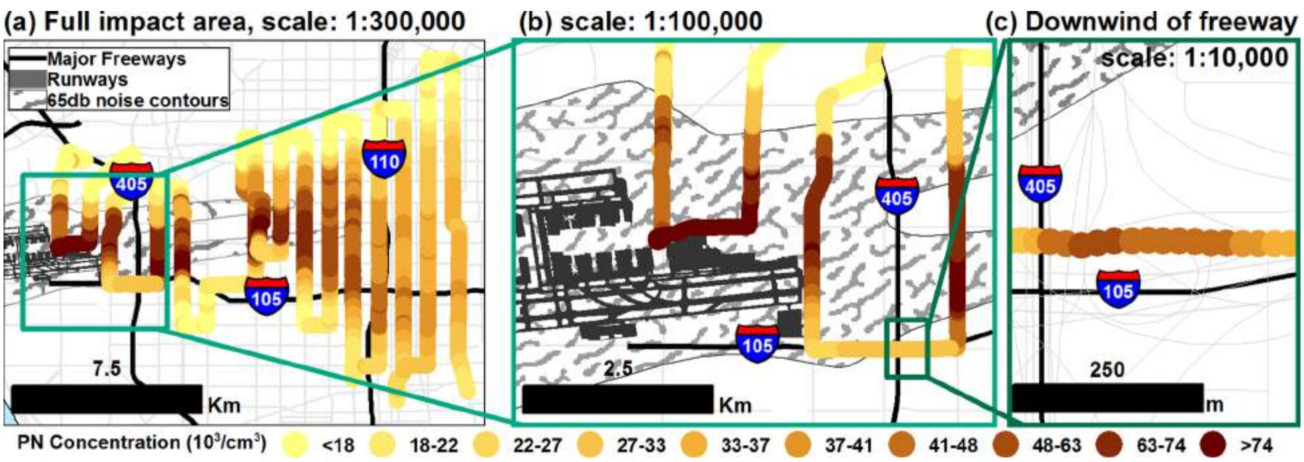

Figure 6. Comparison of the spatial scale of freeway impacts compared to airport impacts for monitoring during nighttime on August 23−24, 2013.

concentrations downwind and east of LAX likely occur in all seasons. Monitoring in different seasons demonstrated the consistent year round presence of this impact. Examples of similarly extensive impacts in non-summer months are shown in the SI (Figures S.8 and S.9).

Other Pollutants. Over large areas downwind of LAX, concentrations of pollutants other than PN were also elevated. Figure 5(a)−(c) show nearly indistinguishable spatial patterns for PN, BC, and NO_2 concentration measured simultaneously at distances of 9.5−12 km from LAX. This suggests a common source for these pollutants, although the BC concentration increases were not large when compared to PN and NO_x, about 0.5−1 $\mu g/m^3$ at 8−10 km downwind. While jet aircraft are not known to produce large amounts of BC, two studies found elevated BC from plane takeoffs at LAX. Zhu et al. 2011[9] measured an increase of about 1 $\mu g/m^3$ of BC due to plane activity 140 m downwind of the runway. Westerdahl et al. 2008[8] measured increases in BC concentration of several $\mu g/m^3$ during takeoff events near the eastern LAX boundary, but also observed elevated BC concentrations at all times. At a smaller airport, Dodson et al. 2009[4] found median contributions of about 0.1 $\mu g/m^3$, about one-quarter of total BC measured at five sites ranging in downwind distance from 0.3−3.7 km, and also observed departures producing about twice the impact as arrivals. Therefore, it appears some jets at LAX are capable of producing measurable increases in BC, particularly at takeoffs.

Spatial patterns of simultaneously measured PN and PAS response (PB−PAH and EC) were also similar on transects 4.5−7.5 km from LAX (Figure 5(d)−(e)). The NO_X elevation pattern was less regular (Figure 5(f)). This was likely due to smaller LAX related contributions compared to baseline concentrations, thus reducing the signal-to-noise ratio.

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Overall, the top quartile concentrations (highly impacted) of all pollutants were about three times higher than the lowest quartile within 7.5 km from LAX and two times higher at 12 km distance. In addition, concurrent sampling with the two mobile platforms demonstrated high temporal (SI Figure S.10) and spatial consistency (SI Figure S.11) for PN measurements.

Comparison of LAX and Freeway PN Impacts. PN concentration increases from ground level line sources such as freeways, under conditions of daytime crosswind dilution, decrease exponentially with increasing downwind distance and return to baseline concentrations within 200−300 m.[17] The two N−S freeways (I-405 and I-110 that run perpendicular to the prevailing winds) did not contribute appreciably to elevated PN concentrations in areas where we observed large impacts from LAX on PN concentrations. This is illustrated in Figure 6, which contains two enlargements to show the increase in PN number concentrations over approximately 250 m distance downwind of I-405, a distance and an increase in PN concentration that is not discernible at the scale of Figures 2 and 3. The panel in Figure 6(c) at 1:10 000 scale shows the PN concentration increase of about 24 000/cm^3. The maximum PN concentration was not immediately downwind of the freeway because at this location there is an elevated overpass and some distance is needed for emissions to reach the ground.

To put into further perspective the extent of the elevated PN concentrations observed downwind of LAX, we estimated the freeway length necessary to produce an equivalent impact in terms of PN concentration-weighted area of impact assuming typical daytime dilution conditions for freeways.

For the days we captured the fullest downwind extent of the impact under typical daytime wind conditions (August 15, 23, and 24), we calculated an integrated PN impact above baseline PN concentrations of 2.3, 1.6, and 1.1 × 10^6 (particles/cm^3) × km^2, respectively. See Table S.3(a)−(c) of SI for calculations. Impacted areas were calculated using ArcGIS spatial analysis tools and were conservatively defined as areas where increased PN concentration were at least double the baseline concentrations measured north and south of the impact zone. The resulting impact areas were 30−65 km^2. For comparison, a less conservative criterion for defining the impact area such as a 50% or 33% increase over baseline PN concentrations increased the impacted area by 40% and 80%, respectively.

To calculate PN impacts downwind of freeways, we combined the exponential regression fit of near-freeway measurements made downwind of I-405 by Zhu et al. 2002a[18] with updated average daytime on-freeway PN concentrations taken from Li et al. 2013[14] (71 000 particles/cm^3). PN concentrations were at least double the baseline PN concentrations of 15 000−20 000 particles/cm^3 for 90−130 m downwind.[3] This resulted in a concentration-weighted impact area of 2930−3930 (particles/cm^3) × km^2 per km of freeway length.

Based on these concentration-weighted impact areas, 280−790 km of freeway are needed to produce the equivalent PN-concentration-weighted impact area of LAX. (The less conservative criteria resulted in ranges of freeway length of 340−1000 km and 430−1100 km for thresholds of 50% and 33%, respectively.) There are only about 1500 km of freeways and highways in Los Angeles County.[19] Therefore, LAX should be considered one of the most important sources of PN in Los Angeles. For comparison, within the 60 km^2 area of elevated PN concentrations downwind and east of LAX, the 15−25 km of freeways contributed less than 5% of the PN concentration increase.

Recommendations for Other Studies. LAX is in a region of Los Angeles with highly consistent wind direction. This provided the several hours necessary for a single mobile platform to monitor a sufficient number of transects to cover the large area impacted by LAX emissions. At airport locations where the prevailing wind direction frequently shifts during the day, multiple platforms would be necessary to quickly capture the full spatial extent of emissions impacts to surrounding air quality.

The emissions from LAX are likely not unique on a per-activity basis. The large area of impact from LAX suggests that air pollution studies involving PN, localized roadway impacts, or other sources whose impacts are in the influence zone of a large airport should carefully consider wind conditions and whether measurements are influenced by airport emissions.

Source apportionment of specific airport sources or activities was beyond the scope of our study but would be necessary to evaluate the effectiveness of possible mitigation options. Differing NO_2 to NO_x ratios at different levels of engine thrust[20] might be used to distinguish the contributions of jet landing, idling or takeoff activities. Takeoff and idling emission also differ in surface properties (i.e., the ratio of active surface area to surface bound photoionizable species)[21] and particle size distributions differ between aircraft and ground support equipment emissions.[21]

■ ASSOCIATED CONTENT

Supporting Information

Map of monitoring area (Figure S.1), the instruments used (Tables S.1−S.2), wind roses (Figures S.2 and S.3), illustration of data processing (Figures S.4−S.7), additional maps illustrating the spatial pattern (Figures S.8 and S.9), concurrent sampling with two mobile measurement platforms (Figures S.10 and S.11) and calculations for comparing freeway impact (Table S.3 (a)−(c)) are presented in the Supporting Information. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) Carslaw, D. C.; Beevers, S. D.; Ropkins, K.; Bell, M. C. Detecting and quantifying aircraft and other on-airport contributions to ambient nitrogen oxides in the vicinity of a large international airport. *Atmos. Environ.* **2006**, *40* (28), 5424−5434.

(2) Yu, K. N.; Cheung, Y. P.; Cheung, T.; Henry, R. C. Identifying the impact of large urban airports on local air quality by nonparametric regression. *Atmos. Environ.* **2004**, *38* (27), 4501−4507.

(3) Fanning, E., Yu, R. C., Lu, R., Froines, J. *Monitoring and Modeling of Ultrafine Particles and Black Carbon at the Los Angeles International Airport*; California Air Resources Board, 2007.

(4) Dodson, R. E.; Houseman, E. A.; Morin, B.; Levy, J. I. An analysis of continuous black carbon concentrations in proximity to an airport and major roadways. *Atmos. Environ.* **2009**, *43* (24), 3764−3773.

(5) Klapmeyer, M. E.; Marr, L. C. CO_2, NO_x and particle emissions from aircraft and support activities at a regional airport. *Environ. Sci. Technol.* **2012**, *46*, 10974−110981.

(6) Stettler, M. E. J.; Eastham, S.; Barrett, S. R. H. Air quality and public health impacts of UK airports. Part I: Emissions. *Atmos. Environ.* **2011**, *45*, 5415−5424.

(7) Hsu, H. H.; Adamkiewicz, G.; Houseman, E. A.; Zarubiak, D.; Spengler, J. D.; Levy, J. I. Contributions of aircraft arrivals and departures to ultrafine particle counts near Los Angeles International Airport. *Sci. Total Environ.* **2013**, *444*, 347−355.

(8) Westerdahl, D.; Fruin, S. A.; Fine, P. M.; Sioutas, C. The Los Angeles International Airport as a source of ultrafine particles and other pollutants to nearby communities. *Atmos. Environ.* **2008**, *42*, 3143−55.

(9) Zhu, Y.; Fanning, E.; Yu, R. C.; Zhang, Q.; Froines, J. R. Aircraft emissions and local air quality impacts from takeoff activities at a large international airport. *Atmos. Environ.* **2011**, *45*, 6526−33.

(10) California State Airport Noise Standards Quarterly Report, First Quarter, Los Angeles World Airports, September 18, 2013. http://www.lawa.org/welcome_lax.aspx?id=1090 (accessed December 03, 2013).

(11) Los Angeles County Regional Planning Department, Airport Land Use Commission, DRP_Airport_Influence_Areas. http://egis3.lacounty.gov/dataportal/2011/02/09/airport-influence-areas/ (accessed April 19, 2014).

(12) Fisk, C. J. *Diurnal and Seasonal Wind Variability for Selected Stations in Southern California Climate Regions*, 20th Conference on Climate Variability and Change; American Meteorological Society: New Orleans, January 20−24, 2008; http://ams.confex.com/ams/pdfpapers/135164.pdf (accessed November 11, 2013).

(13) Watson, J. G.; Chow, J. C.; DuBois, D. W.; Green, M. C.; Frank, N. H.; Pitchford, M. L. *Guidance for Network Design and Optimal Site Exposure for $PM_{2.5}$ and PM_{10}*, Report No. EPA-454/R-99-022; *U.S. Environmental Protection Agency*, Research Triangle Park, NC. **1997**.

(14) Li, L.; Wu, J.; Hudda, N.; Sioutas, C.; Fruin, S. A.; Delfino, R. J. Modeling the concentrations of on-road air pollutants in southern California. *Environ. Sci. Technol.* **2013**, *47* (16), 9291−9299.

(15) Graham, A.; Raper, D. W. Transport to ground of emissions in aircraft wakes. Part I: Processes. *Atmos. Environ.* **2006**, *40*, 5874−85.

(16) Graham, A.; Raper, D. W. Transport to ground of emissions in aircraft wakes. Part II: Effect on NO_x concentrations in airport approaches. *Atmos. Environ.* **2006**, *40*, 5824−36.

(17) Karner, A.; Eisinger, A.; Niemeier, D. Near-roadway air quality: Synthesizing the findings from real-world data. *Environ. Sci. Technol.* **2010**, *44*, 5334−5344.

(18) Zhu, Y.; Hinds, W. C.; Kim, S.; Shen, S.; Sioutas, C. Concentration and size distribution of ultrafine particles near a major highway. *J. Air Waste Manage. Assoc.* **2002a**, *36* (27), 4323−4335.

(19) California Department of Transportation. http://www.dot.ca.gov/dist07/aboutus/profile/d7p_print.html (accessed November 11, 2013).

(20) Herndon, S. C.; Shorter, J. H.; Zahniser, M. S.; Nelson, D. D. J.; Jayne, J. T.; Brown, R. C.; Miake-Lye, R. C.; Waitz, I. A.; Silva, P.; Lanni, T.; Demerjian, K. L.; Kolb, C. E. NO and NO_2 emissions ratios measured from in use commercial aircraft during taxi and take-off. *Environ. Sci. Technol.* **2004**, *38*, 6078−84.

(21) Herndon, S. C.; Onasch, T. B.; Frank, B. P.; Marr, L. C.; Jayne, J. T.; Canagaratna, M. R.; Grygas, J.; Lanni, T.; Anderson, B. E.; Worsnop, D.; Miake-Lye, R. C. Particulate emissions from in-use commercial aircraft. *Aerosol Sci. Technol.* **2005**, *39* (8), 799−809, DOI: 10.1080/02786820500247363.

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Aviation-Related Impacts on Ultrafine Particle Number Concentrations Outside and Inside Residences near an Airport

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Supporting Information

ABSTRACT: Jet engine exhaust is a significant source of ultrafine particles and aviation-related emissions can adversely impact air quality over large areas surrounding airports. We investigated outdoor and indoor ultrafine particle number concentrations (PNC) from 16 residences located in two study areas in the greater Boston metropolitan area (MA, USA) for evidence of aviation-related impacts. During winds from the direction of Logan International Airport, that is, impact-sector winds, an increase in outdoor and indoor PNC was clearly evident at all seven residences in the Chelsea study area (~4−5 km from the airport) and three out of nine residences in the Boston study area (~5−6 km from the airport); the median increase during impact-sector winds compared to other winds was 1.7-fold for both outdoor and indoor PNC. Across all residences during impact-sector and other winds, median outdoor PNC were 19 000 and 10 000 particles/cm^3, respectively, and median indoor PNC were 7000 and 4000 particles/cm^3, respectively. Overall, our results indicate that aviation-related outdoor PNC infiltrate indoors and result in significantly higher indoor PNC. Our study provides compelling evidence for the impact of aviation-related emissions on residential exposures. Further investigation is warranted because these impacts are not expected to be unique to Logan airport.

■ INTRODUCTION

Aircraft engine exhaust emissions are a significant source of ultrafine particles (UFP; aerodynamic diameter <100 nm) and can cause several-fold increases in ground-level particle number concentrations (PNC) over large areas downwind of airports.[1−4] The spatial extent and magnitude of the impact varies depending on factors including wind direction and speed, runway use pattern, and flight activity but encompasses large populations in cities where airports are located close to the urban residential areas. For example, in Amsterdam, PNC (a proxy for UFP) were found to be elevated 7 km downwind of Schiphol Airport[2] while in Los Angeles, PNC were reported to be elevated 18 km downwind of Los Angeles International Airport.[1,3] Thus, it is important to characterize aviation-related UFP.

Previous studies have shown that UFP can cross biological boundaries (entering the circulatory system) due to their extremely small size.[5−7] Exposure to UFP is of particular concern because it is associated with inflammation biomarkers, oxidative stress and cardiovascular disease.[6] Recent exposure assessment studies have started testing airport variables in UFP predictive models,[8−12] but epidemiological studies that incorporate airports in the exposure assessment are lacking; currently, they primarily focus on traffic-related UFP. To better inform UFP exposure assessment efforts, it is also important to distinguish aviation-related contributions from other urban sources and to characterize them independently. This is particularly challenging in urban areas with pervasive and dense road networks. Furthermore, studies have shown that residing in the vicinity of airports is significantly associated with hospitalization for cardiovascular disease;[13,14] however, there the focus has been on association between cardiovascular health effects and increased noise around airports, which can be confounded by UFP. To date, no studies described in the literature investigate the health effects of UFP, or of noise controlling for UFP, around airports.

In a previous study, we found that during winds from the direction of the Logan International Airport (Boston, MA) PNC at two long-term, central monitoring stations located 4 km and 7.5 km downwind of the airport were 2-fold and 1.33-fold higher, respectively, compared to average for all other winds.[4] In the current study, we investigated residential data sets from wider areas surrounding those two central sites. Our primary objectives were (1) to investigate short-term residential PNC monitoring data for evidence of aviation-related impacts that could be identified despite the influence of other urban sources of UFP, and (2) to analyze the data for evidence of indoor infiltration of aviation-related PNC. To our knowledge,

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this is the first study to report the impact of aviation-related emissions inside residences.

MATERIALS AND METHODS

Logan International Airport and Central and Residential Monitoring Sites. The General Edward Lawrence Logan International Airport is located 1.6 km east of downtown Boston (Figure 1(a)). It has six runways and supports about 1000 flights per day. Flight statistics are shown in the Supporting Information (SI) Figure S1. Prevailing winds in the Boston region are westerly (northwest in winter and southwest in summer, combined annual frequency 56%, see Figure 1(b)). The downwind advection of airport-related emissions occurs largely over urban areas located east and northeast of the airport as well as over the ocean during prevailing winds. During easterly winds, several other urban areas are downwind of the airport. We studied two of these areas: Chelsea and Boston.

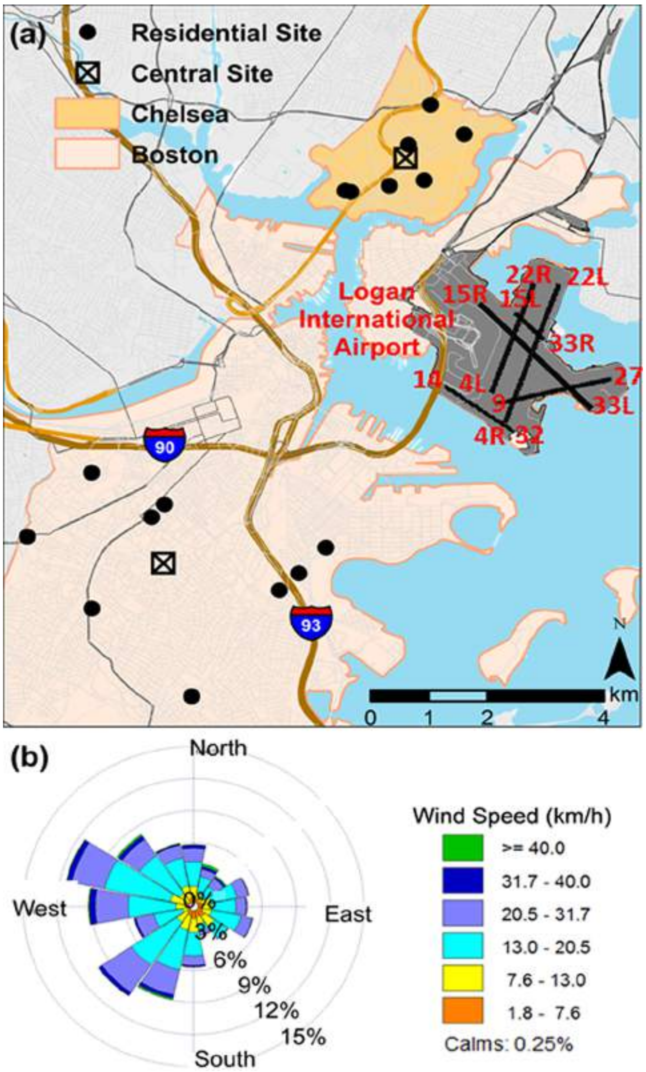

Figure 1. (a) Map of the runways at Logan International Airport and the locations of the central and residential monitoring sites in Chelsea and Boston. Base layers were obtained from mass.gov. (b) Windrose is based on 1 min data for 2014 reported by National Weather Service Automated Surface Station located at the airport.

In Chelsea, outdoor (i.e., ambient) and indoor monitoring was conducted at seven residences that were located 3.7—4.9 km downwind from the airport along 133°—165° azimuth angles measured to the geographic center of the airport (Figure 1(a)). Each residence was monitored for six consecutive weeks between February — December 2014. Ambient monitoring was also conducted continuously at a central site in Chelsea (located on top of a three-story building) during the entire 11-month period (Figure 1(a)). In Boston, monitoring was conducted at nine residences between May 2012 and October 2013. The residences were located 5.0—10.0 km downwind from the airport along 43°—74° azimuth angles measured to the geographic center of the airport. Monitoring was also conducted continuously during this 18-month period at a central site in Boston—the U.S. Environmental Protection Agency Speciation Trends Network site (ID: 25−025−0042). Central sites were selected based on their proximity to the geographic center and representativeness for the study area. Residential sites were selected based on their proximity to highways and major roads (the latter defined as annual average daily traffic >20 000): four sites were <100 m, seven between 100 and 200 m, and five >200 m from highways or major roads. Monitoring schedule, meteorological parameter summary, residence characteristics, and distance to major roadways are shown in SI Tables S1−S6.

During the six-weeks of monitoring at each residence, a HEPA filter (HEPAirX, Air Innovations, Inc., North Syracuse, NY) was operated in the room where the condensation particle counter (CPC) was located for three consecutive weeks followed by three consecutive weeks of sham filtration or vice versa. Only nonsmoking residences were recruited and we found no evidence of smoking in residences. Residences were monitored one or two at a time with limited overlap between monitoring periods. For further details of residential monitoring and filtration, see Simon et al.[15] and Brugge et al.,[16] respectively.

Instruments and Data Acquisition. PNC were monitored using four identical water-based CPCs (model 3783, TSI Inc., Shoreview MN), which recorded 30 s or 1 min average concentrations. The CPCs were annually calibrated at TSI and measured to within ±10% of one another, consistent with manufacturer-stated error. Ambient PNC were monitored continuously at the central-sites. At residences, a solenoid valve connected to the inlet switched the air flow between outdoor and indoor air every 15 min. Thus, residential outdoor and indoor PNC were monitored for 30 min per hour. To ensure that the sampling lines (1-m-long conductive silicon tubing for both indoor and outdoor carrying transport flow of 3 L per minute) were fully flushed, the first and last data points per switch were discarded (7−13% of the total). Any data that were flagged by the instruments (<1% of the total) and hours with <50% data recovery were not included in the analysis.

Flight records for individual aircraft were obtained from the Massachusetts Port Authority (East Boston, MA) and counted to obtain hourly totals for landings, takeoffs and the sum of the two (LTO). Meteorological data (a 2 min running average at 1 min resolution for wind direction and speed) were obtained from the National Weather Service station at the airport and processed through AERMINUTE[17] (a meteorological processor developed by EPA for use in AERMET and AERMOD) to obtain hourly values.

Data and Statistical Analysis. Each PNC data set (residential indoor, residential outdoor, and central-site) was

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Table 1. Impact Sector Definitions and Summary of Particle Number Concentration Statistics for Residential Sites

				impact-sector winds hourly PNC statistics			other winds hourly PNC statistics		
ID	distance to airport (km)	impact sector definition (WD°)	impact sector winds frequency, hours	outdoor median	indoor median	indoor minimum	outdoor median	indoor median	indoor minimum
			Chelsea Residences						
D1	4.3	111−155	4.7%, 47	36 000	11 100	7600	13 200	4400	3700
D2	4.4	111−154	5%, 50	37 100	14 600	7500	16 200	5100	3500
U1	4.9	142−176	5.3%, 53	14 900	2300	1400	7800	1900	1600
U2	4.0	117−164	11.8%, 119	18 600	2500	1800	10 700	2400	1800
C1	4.2	145−182	5.2%, 50	12 800	3500	2800	8100	2500	1900
C2	4.4	130−171	5.4%, 54	19 700	1900	1300	9700	2200	1700
C3	3.7	124−173	10.8%, 111	26 600	6400	4700	8900	2800	2200
			Boston Residences						
D1	6.1	31−59	6.9%, 63	27 800	8400	4300	10 700	5300	4000
U1	5.0	28−61	8.4%, 79	25 100	22 700	17 500	14 700	7400	6100
U2	5.6	30−59	8.2%, 70	19 700	10 900	6900	9700	6100	3700
C1	6.8	53−79	9.6%, 97	9400	3700	2600	8000	2300	1800
C2	7.1	53−78	3%, 30	11 900	7900	6400	10 000	4100	2800
C3	7.8	62−86	9.6%, 94	21 000	7700	5800	14 300	3900	3300
B1	10.0	33−53	3.4%, 34	13 500	4900	4200	10 100	4500	3400
B2	8.8	48−67	6%, 65	8200	4900	3200	7200	4500	3000
B3	9.2	60−78	4%, 39	12 900	15 400	11 600	8100	6300	5100

aggregated separately to calculate hourly medians. Hourly medians were further aggregated by 10°-wide wind-direction sectors, and medians were calculated for each sector. Wind-direction sectors were centered on even 10° and spanned ±5°. Data were also classified as impact-sector versus other based on the wind direction. Winds that positioned monitoring sites downwind of the airport were called *impact-sector* winds. Impact-sector boundaries (Table 1) correspond to the azimuth angles measured from a monitoring site to the widest distance across the airport complex (SI Figure S2).

For indoor data we also calculated the hourly minimum in addition to hourly medians. Indoor data were also classified by filtration scenario (HEPA or sham). Indoor measurements reflect contributions from both particles generated indoors and particles of outdoor origin that infiltrate indoors. We did not quantify fraction of indoor- versus outdoor-origin particles. Instead, we compared hourly indoor minimums (less likely to be influenced by indoor-generated PNC spikes) with outdoor PNC to determine if higher indoor PNC occurred during impact-sector winds. During periods of elevated outdoor concentrations, indoor concentrations are also expected to be elevated due to air exchange between residences and their surroundings.

Spearman's rank correlation (coefficients reported as r_S) was calculated between PNC and wind speed and PNC and LTO. Inferences based on Spearman's rank correlation were limited to ordinal associations. Correlations were considered significant if p-values were <0.05. Bootstrapped 95% confidence intervals for the correlation coefficients were also calculated. Further, impact-sector wind data sets at residences were relatively small; they ranged from 30 to 119 h or 3.0−11.8% of the total data. To take the resulting uncertainty into account, we compared distributions of correlation coefficient estimates − generated using bootstrap resampling methods (1×10^4 random samples with replacement) − for impact-sector winds to other winds. Subsamples (1×10^4 random samples without replacement) from other-wind data sets but of size comparable to impact-sector-winds were also compared where appropriate.

RESULTS AND DISCUSSION

We found strong evidence of aviation-related particle infiltration. Outdoor and indoor PNC were statistically significantly higher during impact-sector winds compared to other winds. Wilcoxon rank sum tests indicated that the median of 10°-wide-sector medians from all residences for impact sector winds was higher than other winds for outdoor concentrations (p-value <0.0001, z-value = −8.1) as well as for indoor concentrations during both sham filtration (p-value <0.0001, z-value = −5.1) and HEPA filtration (p-value = 0.0037, z-value = −2.7). Table 1 summarizes indoor and outdoor concentrations.

We present detailed results in the following sections where we have organized our lines of reasoning as follows: first, we demonstrate elevated outdoor PNC during different impact-sector winds in the two study areas (each showing an impact when it was oriented downwind of the airport) including sites upwind and downwind of a highway; second, we discuss correlation of outdoor PNC with wind speed and flight activity, which indicated the aviation-related origin of elevated PNC during impact-sector winds; and third, we report indoor trends at all residences and discuss indoor infiltration of aviation-related, elevated, outdoor PNC for two residences in detail.

Wind Direction and Ambient PNC Patterns at Residences. Higher ambient PNC were observed during winds that positioned the sites downwind of the airport (i.e., impact-sector winds). Impact sector differed by study area and from residence to residence within the study areas. In Chelsea (located NW of the airport) PNC were elevated during SE winds and in Boston (located SW of the airport) PNC were elevated during NE winds (Figure 1). This impact is thus spatially widely distributed in the Boston area.

Chelsea. During impact-sector winds in the Chelsea study area (ESE-S, 111°−182°), PNC were elevated at the central site and all seven residences. Residences that were upwind of the highway during impact-sector winds are denoted with a U, residences that were downwind of the highway during impact-sector winds are denoted as D, and community sites that are

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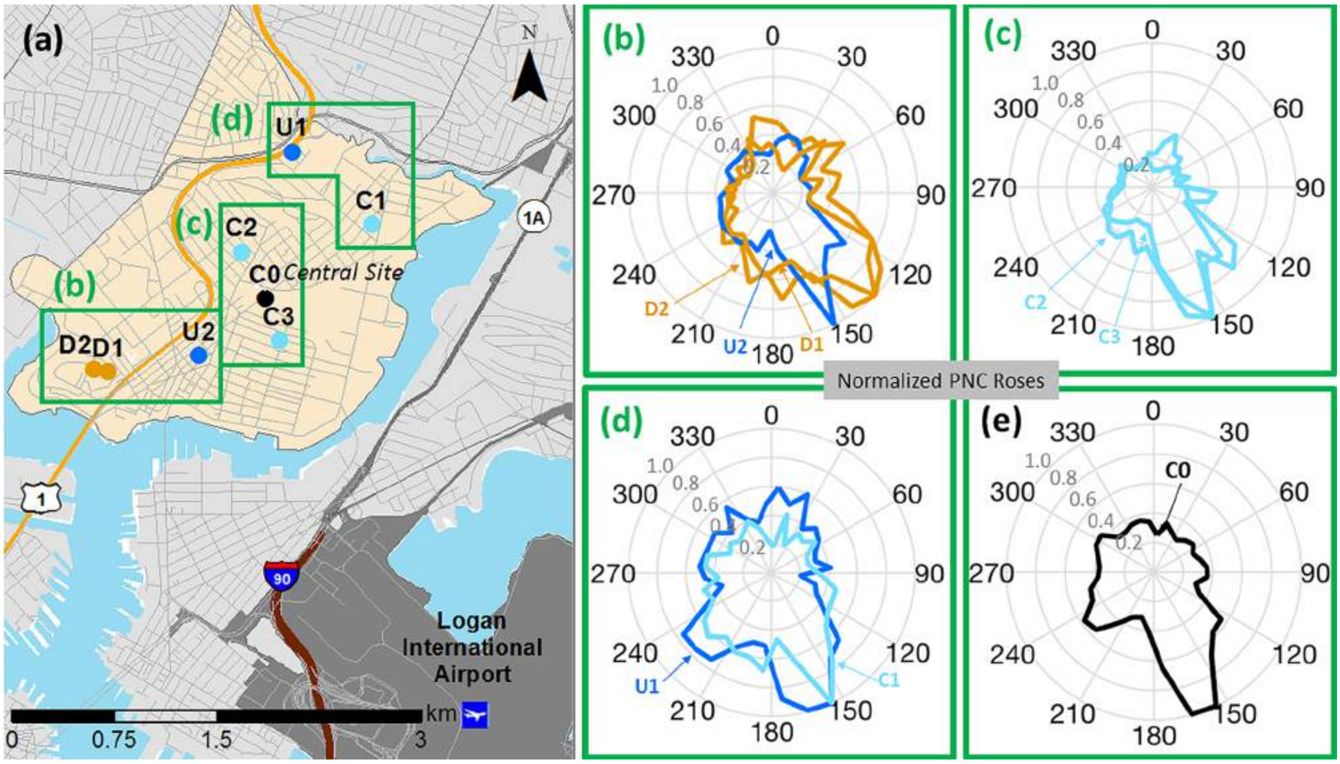

Figure 2. (a) Locations of the central site (C0, black) and seven residences monitored in Chelsea. Residences were classified as upwind (U, dark blue) of the highway during impact-sector winds, downwind of the highway (D, orange) during impact-sector winds and community sites that were not in proximity of the highway (C, light blue). (b)−(e) Normalized (by the maximum) PNC roses are based on hourly medians; concentric circles are increments of 0.2 on a 0−1 scale.

not in proximity of a highway are denoted as C (Figure 2). Median PNC during impact-sector winds were 1.6- to 3.0-fold higher than the medians for all other winds (Table 1). Highest and lowest residential impact-sector medians were 37 000 and 13 000 particles/cm^3, respectively, as compared to 16 000 and 8000 particles/cm^3 during all other winds.

Impact-sector winds occurred for 4.7−11.8% of the time (annually, ∼ 7% in 2014) during the residential monitoring, but their weighted contributions to the monitoring averages were 8−26%. It should be noted that these contributions likely include some input from other sources in impact sectors, such as, traffic. Heatmaps of PNC by wind direction and hour of the day for the central site and all seven residences studied in Chelsea (SI Figure S3 (a) and (c)) indicate PNC peaks coincided with morning and evening vehicular and aviation traffic rush-hours. However, these peaks were highly elevated during impact-sector winds even though traffic impacts are not particularly concentrated in the impact sector; only two of the seven residences (D1 and D2) were downwind of major roadways and highways during impact-sector winds.

Boston. In the Boston study area, a pronounced increase in PNC during impact-sector winds was evident at three sites 5.0−6.1 km downwind of the airport (Figure 3). At residences U1 and U2 (NNE-ENE, 28°−61°), which were both also upwind of Interstate 93 (I-93) (Figure 3(b)), median PNC during impact-sector winds were 25 000 and 20 000 particles/cm^3, respectively, as compared to 15 000 and 10 000 particles/cm^3 during all other winds. At site D1, which was 6.1 km downwind of the airport and 200 m downwind of I-93 during impact-sector (NE) winds, but impacted by the highway during both NE (31°−59°) and SE (115°−145°) winds, median PNC were greater during NE winds than during SE winds (29 000 vs 19 000 particles/cm^3, respectively; means were 29 000 ± 46% vs 21 000 ± 70% particles/cm^3, respectively) for similar I-93 traffic volume (hourly traffic flow was 7000 ± 47% during times of NE vs 8000 ± 39% during SE winds).

At the other six sites in Boston, which were 6.8−10.0 km from the airport, increases in PNC during impact-sector winds were not as distinct (Figure 3(c)). Ambient median PNC during impact-sector winds, which likely included considerable contributions from upwind sources including busy roadways and highways in Boston, were 1.1- to 1.6-fold higher at these six residences than the medians for all other winds (Table 1). Heatmaps for PNC by wind direction and time of day for the central site and all residences (SI Figure S3 (b) and (d)) indicate PNC peaks coincided with morning and evening vehicular and aviation traffic rush-hours. The impact-sector PNC were lower in Boston compared to Chelsea.[15]

Correlations between PNC and Wind Speed. Because higher wind speeds generally promote greater dispersion and mixing, PNC and wind speed are typically negatively correlated. However, for buoyant aviation emissions plumes, higher wind speeds promote faster ground arrival counterbalancing the increased dilution.[18] Thus, a distinct feature of aviation emissions impacts (unlike road traffic emissions impacts) is a lack of negative correlation between PNC and wind speed.[4,19,20] We too observed this phenomenon. During impact-sector winds at Chelsea and Boston central-sites, the negative correlation between PNC and wind speed was lacking; correlation coefficients were r_S = 0.17 and 0.19, n = 435 and 408 h, respectively, and p-value < 0.001. In contrast, during other winds, the expected negative correlation between PNC and wind speed was observed (r_S = −0.24 and −0.05, n = 7552 and 10 537 h, respectively, and p-value < 0.001). Similar trends

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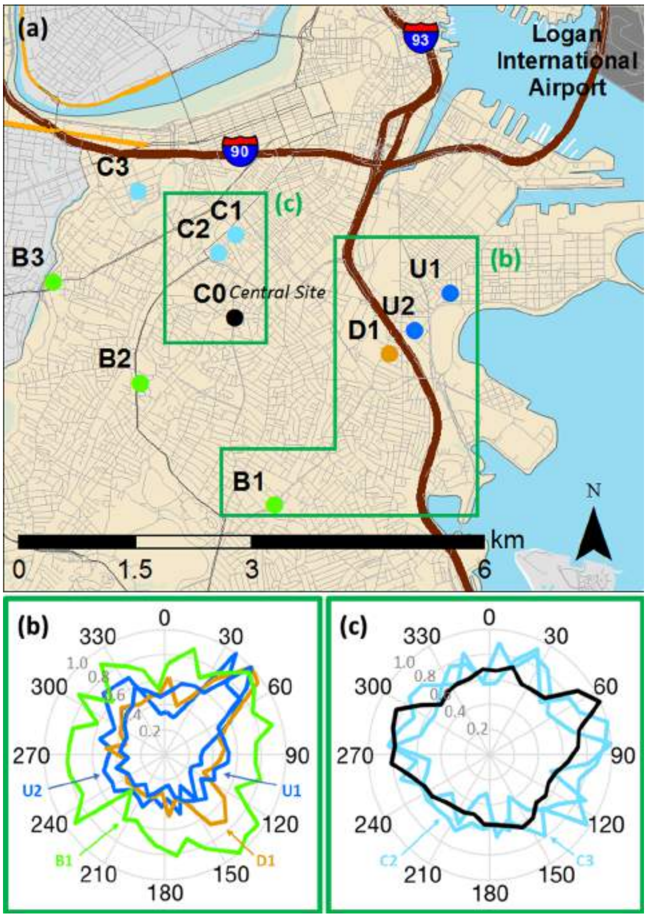

Figure 3. (a) Locations of the central site (C0, black) and nine residences monitored in Boston. Residences were classified as upwind (U, dark blue) of the highway during impact-sector winds, downwind of the highway (D, orange) during impact-sector winds, community sites (C, light blue) and background sites (B, green). (b)−(c) Normalized (by the maximum) PNC roses are based on hourly medians; concentric circles are increments of 0.2 on a 0−1 scale.

were found at the residences in both study areas: correlation between PNC and wind speed was either lacking or even positive during impact-sector winds but it was negative during other winds. Correlation coefficients for residences are shown in Figure 4 where points have been jittered along the categorical *x*-axis to reduce overlap.

Because impact-sector winds were a small fraction of all winds (3−12% of the total data set) we conducted bootstrap resampling of correlation estimates (r_S) and bootstrap subsampling of a similarly small data set from other wind conditions to ensure that the lack of negative correlation was not by chance. The correlation estimates during impact-sector winds were different from the negative estimates obtained for other winds; results are shown in SI Figure S4−S19. The contrast in correlation was most evident in Chelsea and sites upwind of I-93 in Boston. Notable exceptions were sites downwind of both a highway and the airport during impact-sector winds likely because they were dominantly impacted by highway emissions given their proximity to the highways. For example, at site D1 in Boston, we observed no difference in correlation estimates between impact-sector and other winds (SI Figure S11). In comparison, at sites U1 and U2 in Boston, which were upwind of the highway during impact-sector winds but still downwind of the airport, correlation estimates were

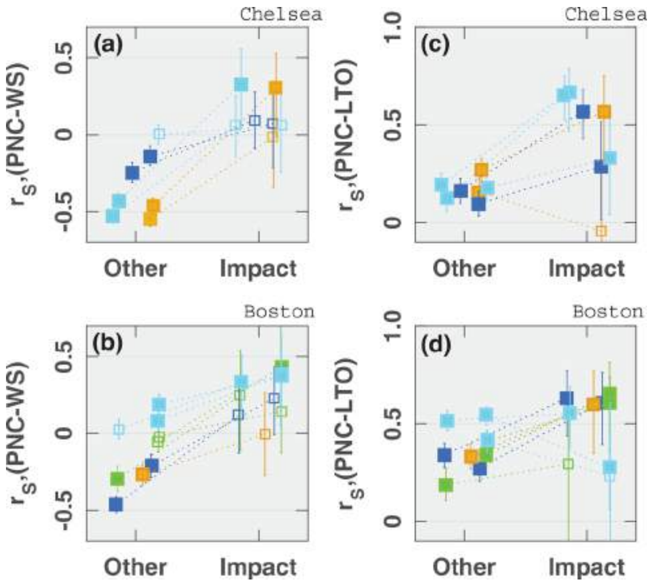

Figure 4. Correlation coefficients between outdoor PNC and wind speed (a, b) and LTO (c, d) for seven Chelsea and nine Boston residences during impact-sector and other winds. Filled squares represent significant correlation (p-value <0.05) and unfilled squares represent insignificant correlations. *X*-axis is categorical but points have been jittered to enhance visual clarity by reducing overlap. For description of colors, see captions for Figures 2 and 3.

positive during impact-sector winds and negative during other winds (SI Figure S12−S13).

Correlations between PNC and Flight Activity. PNC at both central sites were previously reported to be positively correlated with aviation activity (measured as LTO, the hourly total landings and takeoffs) after controlling for traffic volume, time of day and week, and meteorological factors (wind speed, temperature, and solar radiation).[4] Because the central sites both had relatively large data sets (several years of monitoring), we were able to control for these factors; however, the relatively small PNC data sets for residences and the lack of local traffic volume information limited meaningful controls in the current analysis. Also, because the temporal patterns of flight activity and vehicle traffic are similar, some confounding was observed between PNC and LTO irrespective of the wind direction. For example, Pearson's correlation coefficient for hourly LTO and traffic volume on I-93 in 2012 was 0.85. Nonetheless, Spearman's correlations and the bootstrap analysis (SI Figure S20−S35) indicate that PNC versus LTO correlation estimates during impact-sector winds were generally higher than during other winds; that is, r_s ranged from 0.29 to 0.67 during impact-sector winds compared to 0.10−0.54 during other winds, but there were exceptions (see discussion in SI).

Indoor Infiltration of PNC during Impact-Sector Winds. *Overall Trend at Residences.* Infiltration of aviation-related outdoor PNC was evident in the data as higher indoor concentrations during impact-sector winds compared to other winds. The median increase in indoor concentrations during impact-sector winds compared to other winds was 1.7-fold (range: 0.9−3.1-fold). PNC measurements (median and minimums) are summarized in Table 1 for all residences. For trends with respect to wind direction for individual residences see SI Figures S36−S51, which show an increase in indoor medians coincident with impact-sector winds is more apparent for residences in Chelsea and Boston closer to the airport, while

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some residences located farthest away (like B1 and B2) showed no trend with respect to wind direction for either outdoor or indoor PNC.

HEPA filtration lowered the indoor concentrations; indoor-to-outdoor PNC ratios were 0.33 ± 0.17 lower during HEPA filtration as compared to sham filtration (see Brugge et al.[16]). Figure 5 compares 10°-wide-sector PNC medians for impact-sector and other winds separately for sham and HEPA filtration scenarios in all 16 homes. Because filtration efficiency is not preferential to ambient wind direction, higher concentrations (despite lower indoor-to-outdoor ratios) were still observed during impact-sector winds. Further, this trend was apparent in both the hourly medians and hourly minimums (range: 0.8–2.9-fold) of indoor PNC even though hourly medians are more likely to be skewed by contributions from indoor sources than the hourly minimums (SI Figure S52).

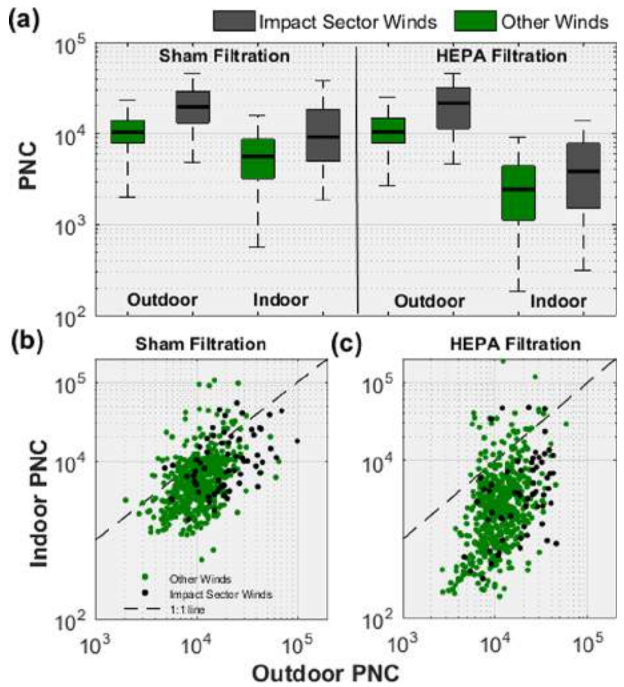

Figure 5. (a) Tukey's boxplots of indoor and outdoor PNC data during sham and HEPA filtration from all 16 homes. The horizontal line inside each box is the median; the boxes extend from the 25th to the 75th percentile and the whiskers extend to 1.5*interquartile range. In (b) and (c) each point in the scatterplots represents the median of hourly medians classified into 10-degree-wide wind sectors.

Previous studies have shown that ambient PNC infiltrate indoors via multiple pathways such as forced air ventilation systems, open windows, or cracks in the building envelope.[21] Infiltration factors vary from 0.03 to 1.0[21,22] in the ultrafine range, the size range for the majority of the aviation-related particulate emissions.[3] Infiltration of aviation-related PNC and, resultantly, an increase in indoor PNC and residential exposures can thus be expected in near-airport residences. Our results clearly indicate that to be the case; particles of aviation-related origin infiltrate residences. Two cases are illustrated in detail in the following section.

Illustration of Infiltration at Select Residences. Infiltration of PNC is illustrated for residence C3 in Chelsea in Figure 6 (a). Time series of indoor PNC closely followed the same pattern as outdoor PNC during an 18-h period of consistent impact-sector winds (from 1900 h on Oct 6 to 1200 h on Oct 7, 2014). During hours of minimal flight activity (0100–0500 h; LTO = 1.5 h^{-1}), PNC indoors and outdoors at C3 and the central site were all low but increased as flight activity resumed after ~0500 h. Residential outdoor PNC was also remarkably highly correlated (Pearson's r = 0.96) with the central site located 1 km away indicating the spatial homogeneity of the aviation-related impact over a large area. Further, even though it was past the evening traffic rush-hour period (and thus traffic would have contributed minimally to the observations or for that matter particle formation) when the winds shifted (at ~1900 h) to the impact sector, outdoor and central-site concentrations increased to high levels (1 min averages were between 50 000 and 100 000 particles/cm^3), which underscores the magnitude of this impact. In comparison, Simon et al.[15] reported mean 1 min on-road PNC from 180 h of mobile monitoring across Chelsea including traffic rush-hours was 32 000 particles/cm^3 which was about one third to one half of the observed PNC at C3 during impact-sector winds. Overall, at C3, the median indoor PNC was nearly 3-fold higher for impact-sector winds compared to other winds (8900 versus 2800 particle/cm^3) (Figure 6(c), SI Figure S42).

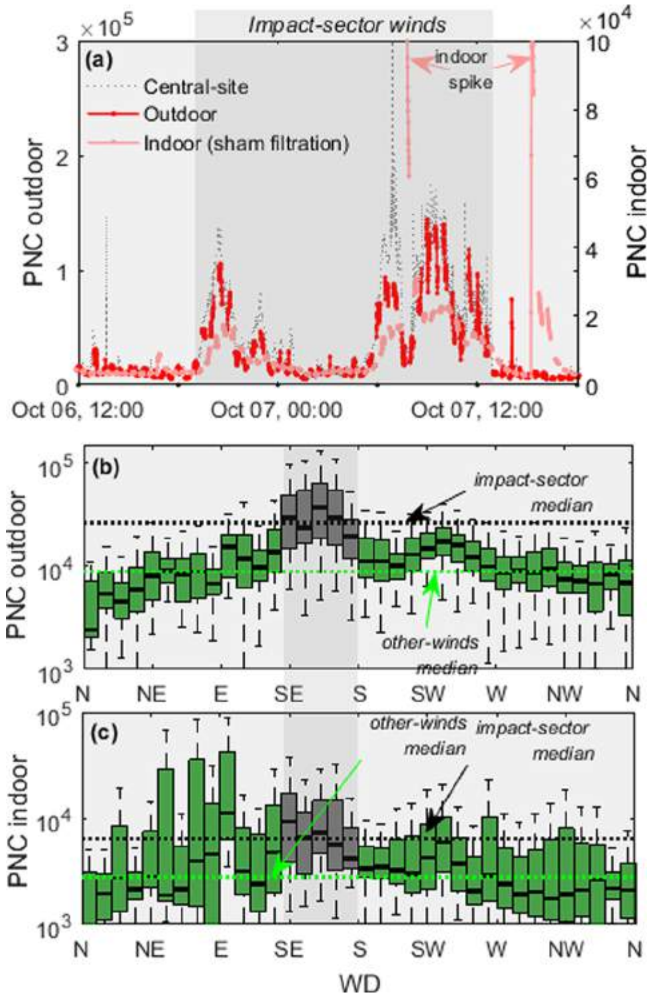

Figure 6. PNC time series for October 6–7, 2014 for site C3 in Chelsea is shown in (a). Impact-sector winds are highlighted in gray. Tukey's boxplots in (b) and (c) show outdoor and indoor PNC. The horizontal line inside each box is the median, the boxes extend from the 25th to the 75th percentile and the whiskers extend to 1.5*interquartile range.

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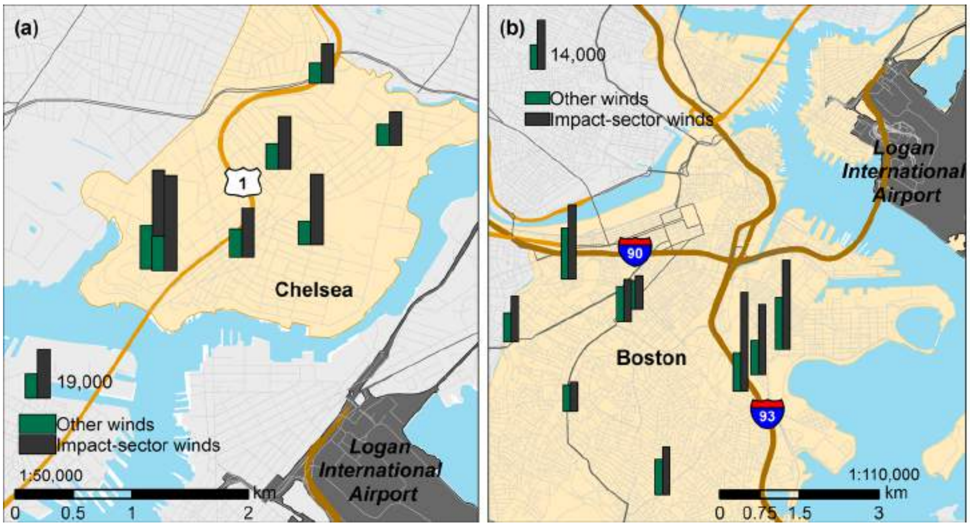

Figure 7. Outdoor PNC at residences during six-week monitoring periods in Chelsea (a) and Boston (b). Median of hourly medians classified as impact-sector and other winds are shown.

Another example of infiltration is shown in Figure S53(a) where a 22-h period of generally consistent impact-sector winds is highlighted (from 1900 h on Nov 6 to 1700 h on Nov 7, 2012) for residence U1 from the Boston study area. U1 is relatively close to I-93 but it is upwind of the highway during impact-sector winds. Outdoor concentrations during impact-sector winds from 1900 h to as late as midnight on Nov 6−7, 2012 were ∼40 000 particles/cm^3 but then decreased to as low as 2000 particles/cm^3 during the hours of low flight activity at the airport (LTO decreased from 32 h^{-1} to 2.8 h^{-1} during 1900−0000 h to 0000−0500 h). The indoor PNC time series was consistent with the outdoor concentration during these hours. Both outdoor and indoor concentration started increasing again around 0500 h when flight activity resumed at the airport; however, around 0800 h indoor PNC spiked, likely from an indoor particle-generation event that dominated indoor PNC during the following hours despite impact-sector winds. Overall, the median indoor PNC was 2-fold higher for impact-sector winds compared to other winds (15 000 versus 7400 particles/cm^3) (Figure S53(c) and Figure S44).

Strength and Limitations. To our knowledge this is the first investigation of the impacts of aviation-related emissions at residences around airports. Our results show an increase in outdoor as well as indoor PNC. These findings point to the need for studies to provide further characterization of these impacts (e.g., measure additional pollutants in a greater number and variety of residences both near and far from airports and under a greater diversity of meteorological conditions and indoor activities).

Our study also had limitations. The foremost is that monitoring was not specifically designed for quantifying the impacts of aviation-related emissions on indoor and outdoor PNC. Data were collected as part of the Boston Puerto Rican Health Study (a study of exposure to urban air pollution and cardiovascular health effects in a Puerto Rican cohort[23]), but it allowed for the reported analysis because of the residences' proximity to and distribution around the airport. Ideally, for quantifying the aviation-related impacts and distinguishing them from other outdoor sources (such as traffic) and indoor sources (such as cooking), continuous indoor and outdoor monitoring at several locations in carefully characterized residences with indoor time-activity records would be necessary. In addition, the study was not designed to characterize the air exchange rates or infiltration factors for ambient particles. As a result, we could not quantify the contribution of indoor- versus outdoor-origin PNC to total indoor observations, or more pertinently the contribution from aviation-related outdoor PNC to indoor observations. Further, the lack of concurrent data from all or even multiple residences precluded spatial analysis. Residence-to-residence differences in outdoor and indoor PNC (Figure 7 and Table 1) were observed. For example, at sites closer to the airport PNC were generally higher than farther away, but at sites immediately downwind of highways, even though they were farther downwind of the airport, PNC were even higher, likely due to impacts from both aviation-related and traffic emissions. Such spatial differences were not investigated. Observed outdoor concentration differences were likely not solely due to the differences in spatial location with respect to the airport or other sources; temporal differences (e.g., meteorological and seasonal factors) likely also contributed significantly, but they could not be controlled for due to lack of concurrent data.

Significance of the Results. Altogether, our results make a compelling case for further investigation of aviation-related air pollution impacts and resulting exposures because these impacts are not expected to be unique to Logan airport. Extrapolating from Correia et al.[13], we estimate that in the United States ∼40 million people live near 89 major airports (i.e., within areas with ≥45 dB noise levels near airports). Inclusion of aviation-related impacts may also improve predictive models for exposure assessments. Future studies of this impact with concurrently located sites that allow analysis of the spatial gradient and comparison with traffic impacts could be very informative for ultrafine particle epidemiology.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.est.7b05593.

Information related to flight activity at Logan International Airport (Figure S1), details of monitoring schedule residence characteristics, and summary statistics of the

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data (Table S1–S6, Figure S2), heatmaps of PNC by wind direction and time of the day (Figure S3), correlation coefficient estimates from bootstrap subsampling and resampling (Figure S4–S35), additional graphics related to particle number concentration trends with respect to wind direction at monitoring sites (Figure S36–S52) and an example of infiltration (Figure S53) (PDF)

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) Hudda, N.; Gould, T.; Hartin, K.; Larson, T. V.; Fruin, S. A. Emissions from an international airport increase particle number concentrations 4-fold at 10 km downwind. *Environ. Sci. Technol.* **2014**, *48* (12), 6628–6635.

(2) Keuken, M. P.; Moerman, M.; Zandveld, P.; Henzing, J. S.; Hoek, G. Total and size-resolved particle number and black carbon concentrations in urban areas near Schiphol airport (the Netherlands). *Atmos. Environ.* **2015**, *104*, 132–142.

(3) Hudda, N.; Fruin, S. A. International Airport Impacts to Air Quality: Size and Related Properties of Large Increases in Ultrafine Particle Number Concentrations. *Environ. Sci. Technol.* **2016**, *50* (7), 3362–3370.

(4) Hudda, N.; Simon, M. C.; Zamore, W.; Brugge, D.; Durant, J. L. Aviation Emissions Impact Ambient Ultrafine Particle Concentrations in the Greater Boston Area. *Environ. Sci. Technol.* **2016**, *50* (16), 8514–8521.

(5) Geiser, M.; Rothen-Rutishauser, B.; Kapp, N.; Schürch, S.; Kreyling, W.; Schulz, H.; Semmler, M.; Im Hof, V.; Heyder, J.; Gehr, P. Ultrafine particles cross cellular membranes by nonphagocytic mechanisms in lungs and in cultured cells. *Environ. Health Perspect.* **2005**, *113* (11), 1555–1560.

(6) HEI Review Panel. *Understanding the Health Effects of Ambient Ultrafine Particles*; Health Effects. Institute, January, **2013**, 122.

(7) Oberdorster, G.; Oberdorster, E.; Oberdorster, J. Nanotoxicology: An emerging discipline evolving from studies of ultrafine particles. *Environ. Health Perspect.* **2005**, *113* (7), 823–839.

(8) van Nunen, E.; Vermeulen, R.; Tsai, M.-Y.; Probst-Hensch, N.; Ineichen, A.; Davey, M.; Imboden, M.; Ducret-Stich, R.; Naccarati, A.; Raffaele, D.; et al. Land Use Regression Models for Ultrafine Particles in Six European Areas. *Environ. Sci. Technol.* **2017**, *51* (6), 3336–3345.

(9) Hatzopoulou, M.; Valois, M. F.; Levy, I.; Mihele, C.; Lu, G.; Bagg, S.; Minet, L.; Brook, J. Robustness of Land-Use Regression Models Developed from Mobile Air Pollutant Measurements. *Environ. Sci. Technol.* **2017**, *51* (7), 3938–3947.

(10) Weichenthal, S.; Ryswyk, K. V; Goldstein, A.; Bagg, S.; Shekkarizfard, M.; Hatzopoulou, M. A land use regression model for ambient ultrafine particles in Montreal, Canada: A comparison of linear regression and a machine learning approach. *Environ. Res.* **2016**, *146*, 65–72.

(11) Kerckhoffs, J.; Hoek, G.; Messier, K. P.; Brunekreef, B.; Meliefste, K.; Klompmaker, J. O.; Vermeulen, R. Comparison of Ultrafine Particle and Black Carbon Concentration Predictions from a Mobile and Short-Term Stationary Land-Use Regression Model. *Environ. Sci. Technol.* **2016**, *50* (23), 12894–12902.

(12) Eeftens, M.; Phuleria, H. C.; Meier, R.; Aguilera, I.; Corradi, E.; Davey, M.; Ducret-Stich, R.; Fierz, M.; Gehrig, R.; Ineichen, A.; et al. Spatial and temporal variability of ultrafine particles, NO2, PM2.5, PM2.5 absorbance, PM10 and PMcoarse in Swiss study areas. *Atmos. Environ.* **2015**, *111* (2), 60–70.

(13) Correia, A. W.; Peters, J. L.; Levy, J. I.; Melly, S.; Dominici, F. Residential exposure to aircraft noise and hospital admissions for cardiovascular diseases: multi-airport retrospective study. *BMJ.* **2013**, *347* (oct08_3), f5561.

(14) Hansell, A. L.; Blangiardo, M.; Fortunato, L.; Floud, S.; de Hoogh, K.; Fecht, D.; Ghosh, R. E.; Laszlo, H. E.; Pearson, C.; Beale, L.; et al. Aircraft noise and cardiovascular disease near Heathrow airport in London: small area study. *BMJ.* **2013**, *347* (oct08_3), f5432.

(15) Simon, M. C.; Hudda, N.; Naumova, E. N.; Levy, J. I.; Brugge, D.; Durant, J. L. Comparisons of traffic-related ultrafine particle number concentrations measured in two urban areas by central, residential, and mobile monitoring. *Atmos. Environ.* **2017**, *169*, 113–127.

(16) Brugge, D.; Simon, M. C.; Hudda, N.; Zellmer, M.; Corlin, L.; Cleland, S.; Lu, E. Y.; Rivera, S.; Byrne, M.; Chung, M.; et al. Lessons from in-home air filtration intervention trials to reduce urban ultrafine particle number concentrations. *Build. Environ.* **2017**, *126*, 266–275.

(17) Environmental Protection Agency. AERMINUTE User's Instructions; 2011.

(18) Seinfeld, J. H.; Pandis, S. N. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*, 2006.

(19) Carslaw, D. C.; Beevers, S. D.; Ropkins, K.; Bell, M. C. Detecting and quantifying aircraft and other on-airport contributions to ambient nitrogen oxides in the vicinity of a large international airport. *Atmos. Environ.* **2006**, *40* (28), 5424–5434.

(20) Barrett, S. R. H.; Britter, R. E.; Waitz, I. A. Impact of aircraft plume dynamics on airport local air quality. *Atmos. Environ.* **2013**, *74* (2), 247–258.

(21) Rim, D.; Wallace, L.; Persily, A. Infiltration of Outdoor Ultrafine Particles into a Test House. *Environ. Sci. Technol.* **2010**, *44* (15), 5908–5913.

(22) Long, C. M.; Suh, H. H.; Catalano, P. J. A.; Koutrakis, P. Using Time- and Size-Resolved Particulate Data To Quantify Indoor Penetration and Deposition Behavior. *Environ. Sci. Technol.* **2001**, *35* (10), 2089–2099.

(23) Tucker, K. L.; Mattei, J.; Noel, S. E.; Collado, B. M.; Mendez, J.; Nelson, J.; Griffith, J.; Ordovas, J. M.; Falcon, L. M. The Boston Puerto Rican Health Study, a longitudinal cohort study on health disparities in Puerto Rican adults: challenges and opportunities. *BMC Public Health* **2010**, *10* (1), 107.

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Environ. Sci. Technol. 20[illegible] [illegible]65–1772

State of Wisconsin
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Fitchburg, WI 53711-5397

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Preston D. Cole, Secretary
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WISCONSIN
DEPT. OF NATURAL RESOURCES

Hand Delivered

October 31, 2019

Major General Donald Dunbar
Wisconsin Air National Guard
2400 Wright Street
Madison, WI 53708

BRRTS Activity # 02-13-581254

Subject: **NOTICE OF VIOLATION/REQUEST FOR ENFORCEMENT CONFERENCE**

Dear Major General Dunbar:

The Department of Natural Resources (department) believes Wisconsin Air National Guard (WI ANG) is in violation of the Spill Law and environmental remediation laws under Wis. Stats. ch. 292 for failing to take the actions necessary to restore the environment to the extent practicable and minimize the harmful effects from the discharge at the property located at Truax Field, 3110 Mitchell Street, Madison in Dane County, Wisconsin. In 2018, the department received a notification of a hazardous substance discharge on the property, as reported by WI ANG. The department believes WI ANG is a responsible party as the possessor and controller of the hazardous substances discharged onto the property.

The department alleges the following violation:

> **Section 292.11(3), Wis. Stats. states a person who possesses or controls a hazardous substance which is discharged or who causes the discharge of a hazardous substance is required to take the actions necessary to restore the environment to the extent practicable and minimize the harmful effects from the discharge to the air, lands, or waters of this state.**

On April 26, 2018, the department issued a responsible party letter to WI ANG outlining the requirements for a site investigation (including an assessment of the vapor intrusion pathway) and cleanup of contamination at the property. To date, WI ANG has not submitted a work plan for completing the investigation.

We have scheduled the following Enforcement Conference to discuss this matter in more detail:

Conference Date:	Monday November 18, 2019
Conference Time:	1:30 pm
Location:	Fitchburg Service Center 3911 Fish Hatchery Road, Fitchburg

We request you attend the Enforcement Conference as it is an important opportunity to discuss the circumstances surrounding the alleged violations and to learn your perspective on this matter. Please note that in an effort to encourage a candid and productive conversation, attendance is limited to you, your legal counsel and others with the technical expertise necessary to understand, evaluate and correct the violation.

The department's enforcement decision will be based upon available information if you do not attend the Enforcement Conference.

This Notice of Violation constitutes a Notice of Claim and fulfills the requirements of s. 893.80 and 893.82, Wis. Stats., which requires written notice of the circumstances of a claim be served upon the state agency, employee or officer, and the attorney general within 120 days after the happening of the event which gave rise to the claim.

Please be advised that violations of ch. 292, Wis. Stats., may be referred to the Department of Justice to obtain court ordered compliance and penalties up to $5,000 per day of violation with each day of continued violation a separate offense.

If you have questions or need to reschedule the conference, please contact me at 608-279-5219.

Sincerely,

Pam Buss

Pamela Buss
Environmental Enforcement Specialist

Enclosure – What is an enforcement conference information sheet

cc: Mike Schmoller
Steve Martin
Mark Aquino
Deputy Secretary Beth Bier
Attorney General Josh Kaul

Notice of Claim certification to follow on next page.

I, Pamela Buss, first being duly sworn on oath, state that I have read the foregoing Notice of Claim and that the facts or statements contained therein are true and correct to the best of my knowledge and belief.

Pamela Buss

Pamela Buss
Environmental Enforcement Specialist
South Central Region

Subscribed and sworn to before me this 31st day of Oct., 2019

Notary Public, State of Wisconsin Cheryl B. Housley
My commission is permanent.
My commission expires on. 1/27/2020

WISCONSIN
DEPT. OF NATURAL RESOURCES

Environmental Enforcement Conference

An Enforcement Conference (EC) is a meeting between Department of Natural Resources (Department) staff and representatives of a person or business that the Department believes has violated an environmental law. The Department issues a Notice of Violation (NOV) when it has reason to believe that a violation of a permit condition, administrative rule or statutory requirement has occurred. The NOV either offers or schedules an EC.

Why Should I Attend?
The EC is an important opportunity to discuss the Department's basis for the alleged violation(s) and learn more about what happened, why it may have happened, and any factors you believe the Department should consider, such as steps that have been or will be taken to stop the violation, correct any effects of the violation, and prevent violations from occurring in the future. It is also your opportunity to explain why you might disagree with the factual and legal conclusions underlying the NOV.

Historic data shows that most violations are resolved at the EC level, without the need for court ordered compliance and/or penalties. In situations where the significance of the violation warrants further enforcement action, your cooperative efforts to resolve the violation and prevent future violations will help minimize your legal and financial liability.

Who Should Attend the EC?
Department staff involved in the EC typically consists of an Environmental Enforcement Specialist and regulatory staff that are familiar with the issues identified in the NOV.

While not required, you may seek representation by legal counsel or the assistance of an environmental consultant to prepare for and/or attend the EC. The EC is most productive when all involved are well-prepared to discuss the allegations and any corrective actions that may be necessary.

To ensure a productive candid discussion, participation in the EC is limited to the person or business involved and others with the legal or technical expertise necessary to understand, evaluate, mitigate and correct the violation. The EC is not an open meeting under state law and the Department will limit participation to those directly involved in the resolution of the matter.

What Happens if I don't Attend the EC?
If a party is unable to attend the EC, they should immediately contact the Environmental Enforcement Specialist at the phone number in the NOV to reschedule. When a party refuses to attend the EC and provides no further information to the Department, the Department's enforcement decision will be based upon available information.

What Happens Following the EC?
The EC is part of the Department's stepped enforcement process. At the EC, Department staff will explain the process and options available to address the alleged violation. Generally, the options range from closing the matter with no further action to referral to the Wisconsin Department of Justice (DOJ) or to U.S. EPA, for further enforcement action. In limited circumstances, the Department can issue citations, which are handled in local court similar to traffic offenses. If a case is referred to DOJ, the DOJ may initiate an action in court on behalf of the State. The State typically asks the Court to impose financial penalties and order completion of any necessary corrective actions. In most of the Department's cases, a cooperative return to compliance with any necessary restoration results in close out of the case. At close out, the Department will send a letter advising of no further enforcement action.

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WISCONSIN
DEPT. OF NATURAL RESOURCES

March 13, 2020

Col. Kevin Philpot
Vice Wing Commander
Wisconsin Air National Guard
2400 Wright Street
Madison, WI 53708

Subject: Response Action Requirements – Wisconsin Air National Guard-Truax Field, BRRTs #02-13-581254

Dear Col. Philpot:

On February 3, 2020, the Wisconsin Department of Natural Resources (DNR) met with representatives from the Wisconsin Air National Guard (WANG), Dane County, Dane County Airport and the City of Madison to discuss the results of investigation into PFAS contamination at Truax Field (Truax) and Starkweather Creek and the status of additional required work. **The following information is being provided per your request at the February 3, 2020 meeting.** At this meeting, you requested clarification regarding requirements for environmental investigation and remediation for the per and polyfluoralalkyl substances (PFAS) contamination at Truax.

Data collected by WANG and submitted to the DNR shows there have been discharges of PFAS to the environment at the WANG base located at Truax Field. Due to the discharges of a hazardous substance and the presence of environmental pollution, WANG is required under Wis. Stat. ch. 292 to conduct a site investigation, and as needed, implement interim and remedial actions to minimize the effects to the environment. On November 18, 2019, DNR staff met with representatives of WANG regarding WANG's responsibility under Wis. Stat. ch. 292. During that meeting, DNR staff explained the need for WANG to take immediate actions to address the environmental impacts from the PFAS discharge and resultant environmental pollution. At that meeting WANG agreed:

> "that within 60 days, WANG would retain a consultant to prepare a workplan. The workplan should include soil, sediment, surface water and groundwater investigations as well as incorporate immediate actions to address PFAS impacted groundwater leaving the site to the west and southeast."

A full summary of the meeting and actions to be taken by WANG was sent to Major General Dunbar on December 2, 2019.

DNR has not received notification from WANG that it has retained a qualified environmental consultant, nor has DNR received a workplan. Due to the ongoing discharges and impacts from environmental pollution from the WANG facility, WANG is out of compliance with state law and the DNR expects the following:

- By May 4, 2020 WANG will submit a site investigation workplan to the DNR for determining the degree and extent of PFAS contamination from WANG.
- By August 17, 2020, WANG will submit to the DNR the results of the site investigation and plan for proposed interim remedial actions to stop the ongoing contaminant discharge of PFAS contamination from the WANG facility.
- By November 30, 2020, WANG will have in place and operating the DNR-approved response actions to eliminate the discharge of PFAS contaminants and environmental pollution to the Starkweather Creek watershed from the contaminated groundwater known to exist beneath Truax. This includes mitigating and treating stormwater runoff and groundwater migration into surface waters and off-site of the Truax property.

These actions shall comply with the requirements of Wis. Stat. ch. 292 and shall be conducted in accordance with the provisions of Wis. Admin. Code chs. NR 700-754. This work shall be completed by a Wis. Admin. Code ch. NR 712 qualified environmental consultant.

I hope this clarifies WANG responsibilities in this matter. If you have further questions, please contact DNR project manager Michael Schmoller at 608-275-3303.

Sincerely,

Christine Haag
Director, Remediation & Redevelopment Program

Cc: Beth Bier – AD/8
Darsi Foss – AD/8
Mike Schmoller – SCR
Steve Martin – SCR
Phil Bower – LS/8

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April 9, 2020

Col. Kevin Philpot
Wisconsin National Guard
2400 Wright Street
PO Box 8111
Madison, WI 53708-8111

RE: Request for Compliance Extension
Environmental Response Actions
Wisconsin Air National Guard – Truax Field
BRRTS # 02-13-581254

SENT VIA E-MAIL

Dear Col. Philpot,

The Wisconsin Department of Natural Resources (DNR) is in receipt of your Memorandum dated April 7, 2020, requesting an extension to complete certain environmental response actions specified in our letter to you dated March 13, 2020. Those response activities and the associated timelines are repeated follows:

- By May 4, 2020, WANG will submit a site investigation workplan to the DNR for determining the degree and extent of PFAS contamination coming from WANG.
- By August 17, 2020, WANG will submit to the DNR the results of the site investigation and plan for proposed interim remedial actions to stop the ongoing contaminant discharge of PFAS contamination from the WANG facility.
- By November 30,2020, WANG will have in place and operating the DNR-approved response actions to eliminate the discharge of PFAS contaminants and environmental pollution to the Starkweather Creek watershed from the contaminated groundwater known to exist beneath Truax. This includes mitigating and treating stormwater runoff and groundwater migration into surface waters on, and off-site of the Truax property.

You have indicated that the reason for your request for a timeline extension is that your contracting resources are tied up in addressing and responding to COVID19 issues in response to the national COVID19 emergency. You have indicated you intend to comply with all these requirements, but you request an extension of 60 days to complete each of these tasks.

In light of the COVID19 emergency and the associated impacts to your operations, the DNR grants your request to extend the timelines to complete the response actions by 60 days. We also ask that you notify us as soon as possible if you are unable to meet the new timelines.

If you have any questions, please feel free to contact me at 608-576-0183 or via e-mail at Michael.Schmoller@wisconsin.gov.

Sincerely,

for

R. Michael Schmoller
Project Manager

CC: Christine Haag, RR CO
Beth Bier, AD/8
Darsi Foss, AD/8
Phil Bower, LS/8
Steven Martin, RR SCR

Former Firefighting Training Areas

Soil and Groundwater Sampling Summary

Dane County Regional Airport

BRRT # 02-13-583366

Prepared by Mead & Hunt, Inc./LimnoTech

November 2020

I, Jessica Bleha, hereby certify that I am a hydrogeologist as that term is defined in s. NR 712.03 (1), Wis. Adm. Code, am registered in accordance with the requirements of Ch. GHSS 2, Wis. Adm. Code, or licensed in accordance with the requirements of Ch. GHSS 3, Wis. Adm. Code, and that, 53 DEPARTMENT OF NATURAL RESOURCES NR 712.11 Published under s. 35.93, Wis. Stats., by the Legislative Reference Bureau. ***Published under s. 35.93, Stats. Updated on the first day of each month. Entire code is always current. The Register date on each page is the date the chapter was last published.*** Register October 2013 No. 694 to the best of my knowledge, all of the information contained in this document is correct and the document was prepared in compliance with all applicable requirements in Chs. NR 700 to 726, Wis. Adm. Code."

Signature	Project Hydrogeologist (PG)	December 9, 2020
Signature	Title	Date

Dane County Regional Airport Preliminary July 2020 Former Firefighting Training Areas Sampling Summary

This document provides a preliminary summary of conditions, locations, and results for soil and groundwater sampling conducted at the Dane County Regional Airport (DCRA) on July 7-8, 2020. Sampling was conducted in response to BRRTS # 02-13-583366, to provide initial information on per- and polyfluorinated alkyl substance (PFAS) constituents in soils and groundwater at two closed former firefighting training areas (FFTAs) at the airport: Pearson Street/East and Darwin Road/West. Sampling procedures and locations were described in the Initial Site Investigation Work Plan (March 2020) that was submitted to the WDNR on March 4, 2020.

Monitoring Locations

Soil and groundwater samples were collected at six (6) locations in each FFTA for a total of 12 locations, using a direct-push rig. Two (2) soil and one (1) groundwater samples were collected at each location. Borings were logged in the field by a LimnoTech geologist and boring logs are included as Attachment 1. Per the approved Work Plan, up to two (2) soil samples were collected above the water table from each soil boring. The first soil sample was collected from the uppermost foot of the soil boring and the second soil sample was collected from unsaturated soil above the water table.

All six soil borings at the former Pearson Street/East FFTA were advanced to 15 feet below ground surface (bgs) and saturated conditions were encountered at approximately 6 to 12 feet bgs. Soil conditions observed at the Pearson Street/East FFTA consisted of variable interbedded sands, silts, and clay in the upper 10 to 12 feet of each boring, overlaying brown or gray fine sand. The nature of the interbedded soil types varied among all borings.

Soil borings at the former Darwin Road/West FFTA were advanced to 15 feet bgs to 25 feet bgs. Saturated conditions were observed starting at approximately 10 to 18 feet bgs. Variable interbedded sands, silts, and clay were noted in soil borings SBT20-01 through SBT20-04 in the upper 4 to 8 feet, below which brown fine sand was uniformly observed. Interbedded non-uniform soil was observed deeper in soil borings SBT20-05 (to approximately 11 feet bgs) and SBT20-06 (to approximately 18 feet bgs). Light brown fine sand was observed uniformly in all borings beneath these interbedded upper soil layers.

Table 1 contains a summary of sample collection locations and depths.

Table 1. DCRA FFTA Soil and Groundwater Sample Collection Locations July 7-8, 2020.

FFTA	Sample Location	Sample I.D. (collection depth interval in feet)	
		Soil	Groundwater
Pearson Street/East	SBP20-01	SBP20-01 (0.5-1)	SBP20-01-GW (10-15)
		SBP20-01 (5-5.5)	
	SBP20-02	SBP20-02 (1-1.5)	SBP20-02-GW (10-15)
		SBP20-02 (5.5-6)	
	SBP20-03	SBP20-03 (1-1.5)	SBP20-03-GW (10-15)
		SBP20-03 (5-5.5)	
	SBP20-04	SBP20-04 (0.5-1)	SBP20-04-GW (10-15)
		SBP20-04-(7-7.5)	
	SBP20-05	SBP20-05 (0.5-1)	SBP20-05-GW (10-15)
		SBP20-05 (6-6.5)	
	SBP20-06	SBP20-06 (0.5-1)	SBP20-06-GW (10-15)
		SBP20-06 (7.4-7.9)	
Darwin Road/West	SBT20-01	SBT20-01 (0.5-1)	SBT20-01-GW (13-23)
		SBT20-01 (10.5-11)	
	SBT20-02	SBT20-02 (0-1)	SBT20-02-GW (15-20)
		SBT20-02 (10-10.5)	
	SBT20-03	SBT20-03 (0-1)	SBT20-03-GW (15-20)
		SBT20-03 (10-10.5)	
	SBT20-04	SBT20-04 (0.5-1)	SBT20-04-GW (9-19)
		SBT20-04 (6-6.5)	
	SBT20-05	SBT20-05 (0.5-1)	SBT20-05-GW (9-19)
		SBT20-05 (10.5-11)	
	SBT20-06	SBT20-06 (0-1)	SBT20-06-GW (13-23)
		SBT20-06 (13-13.5)	

Sampling locations and reported perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) results in soil and groundwater are shown in Figures 1 through 4.

In addition to the soil and groundwater samples, three equipment blanks, one field blank, two groundwater duplicates, and one soil duplicate were collected to evaluate sampling and equipment decontamination procedures.

Initial Summary of Reported Results

Samples were submitted to Vista Analytical Laboratory in El Dorado Hills, California for PFAS analysis using method 537M. Laboratory reports are included as Attachment 2. The reported PFOA and PFOS concentrations for soil samples collected are shown in Table 2.

Table 2. July 2020 FFTA Soil PFOA and PFOS Results.

Sample I.D.	PFOA (ng/g)	PFOS (ng/g)
Pearson Street/East		
SBP20-01 (0.5-1)	0.503	126
SBP20-01 (5-5.5)	ND (<0.467)	136

Sample I.D.	PFOA (ng/g)	PFOS (ng/g)
SBP20-02 (1-1.5)	ND (<0.469)	81.5
SBP20-02 (5.5-6)	ND (<0.471)	ND (<0.431)
SBP20-03 (1-1.5)	ND (<0.470)	ND (<0.430)
SBP20-03 (5-5.5)	ND (<0.470)	17
SBP20-04 (0.5-1)	0.684	83.9
SBP20-04-(7-7.5)	1.77	ND (<0.419)
SBP20-05 (0.5-1)	1.42	20.2
SBP20-05 (6-6.5)	6.37	619 (D)
SBP20-06 (0.5-1)	ND (<0.453)	69.1
SBP20-06 (7.4-7.9)	ND (<0.457)	ND (<0.418)
Darwin Road/West		
SBT20-01 (0.5-1)	2.05	19.8
SBT20-01 (10.5-11)	279	ND (<0.415)
SBT20-02 (0-1)	2.37	68
SBT20-02 (10-10.5)	ND (0.464)	1.7
SBT20-03 (0-1)	24.4	363
SBT20-03 (10-10.5)	38.5	ND (<0.425)
SBT20-04 (0.5-1)	0.538	8.35 (Q)
SBT20-04 (6-6.5)	0.573 (Q)	2.4
SBT20-05-(0.5-1)	ND (<0.466)	3.31 (Q)
SBT20-05 (10.5-11)	0.581	6.67
SBT20-06 (0-1)	3.71	49.4
SBT20-06 (13-13.5)	ND (<0.457)	ND (<0.418)
Soil Duplicate A (SBT20-05-(0.5-1))	ND (<0.462)	3.48
(D)=Dilution		
(Q)=Ion transition ratio outside acceptance criteria		

The (D) flag indicates that the sample required dilution prior to analysis so that one or more PFAS compounds at elevated concentrations were quantitated within the calibration range of the instrument.

The (Q) flag indicates that the ratio of the characteristic mass ions used to positively identify the PFAS analyte was outside the specified laboratory quality criteria in the sample. The ion transition ratio is one of several analysis outputs used to confirm the presence of a PFAS analyte in a sample. Thus, failure to meet the ion transition ratio alone does not mean the PFAS compound is not present, but rather, that the calculated concentration has more uncertainty, and the result is qualified to indicate the additional uncertainty in the reported value.

The reported PFOA and PFOS concentrations for groundwater samples collected are shown in Table 3.

Table 3. July 2020 FFTA Groundwater PFOA and PFOS Results.

Sample I.D.	PFOA (ng/L)	PFOS (ng/L)
Pearson Street/East		
SBP20-01-GW	1,420	18,300 (D)
SBP20-02-GW	126	1,680
SBP20-03-GW	895	11,000 (D)
SBP20-04-GW	2,300	18,900 (D)
SBP20-05-GW	1,120	11,800 (D)
SBP20-06-GW	465	11,800 (D)

Sample I.D.	PFOA (ng/L)	PFOS (ng/L)
Darwin Road/ West		
SBT20-01-GW	67,300 (D)	1,360 (Q)
SBT20-02-GW	11,300	559
SBT20-03-GW	7,130 (D)	1,360 (Q)
SBT20-04-GW	54.9	193
SBT20-05-GW	1,090	1,900
SBT20-06-GW	65,300 (D)	230
GW Duplicate A (SBT20-06)	66,600 (D)	175
GW Duplicate B (SBP20-04)	2,150	44,200 (D)
Equipment Blank A	ND (<0.754)	ND (<0.935)
Geoprobe decon blank	2.56 (J)	1.09 (J,Q)
Equipment Blank-070920	ND (<0.716)	ND (<0.888)
Field Blank A	ND (<0.686)	ND (<0.851)
(J)=Estimated value, amount detected is below the Reporting Limit/LOQ		
(D)=Dilution		
(Q)=Ion transition ratio outside acceptance criteria		

LimnoTech conducted a quality assurance/quality control (QA/QC) review of the data reports provided by Vista Analytical. Review elements included calibration and continuing calibration standards, method and instrument blanks, blank spikes, field blanks and duplicates, dilutions, and internal standard surrogate recoveries.

Summary observations of the QA/QC review include the following:

- Equipment and field blanks were non-detect for all PFAS compounds.
- The average relative percent differences (RPDs) observed in the two groundwater and one soil sample field duplicates for compounds detected at greater than five times the detection limit was 2.5% and ranged from -80% to 34%. The -80% RPD was observed for PFOS in the groundwater sample and field duplicate for SBP20-04-GW. PFOS was detected at high concentrations in this sample (18,900 and 44,200 ng/L in the sample and duplicate, respectively), necessitating a 1:5 dilution. The dilution may have added uncertainty that affected the RPD calculation.
- Three compounds were detected in the sample collected from the Geoprobe water tank (sample ID = Geoprobe decon blank). This is the water provided by and used by the drilling contractor for drilling equipment decontamination. The results for this sample showed measurable concentrations of PFOA (2.56 ng/l), PFOS (1.09 ng/l), and PFOSA (32.3 ng/l), indicating that the water used for equipment decontamination was not PFAS-free. However, the two equipment blank samples that were generated for the Geoprobe equipment using PFAS-free water were both non-detect for all PFAS compounds. These results show that, in spite of the presence of PFAS in the decontamination water, there is no indication PFAS compounds were transferred to the drilling equipment or soil and groundwater samples collected during this investigation.

Based on the above observations and QA review, all data generated indicated satisfactory laboratory performance and data of acceptable quality. The QA/QC review is included as Attachment 3.

Figures 1 through 4 below show reported PFOA and PFOS results for soil and groundwater samples at the both former FFTAs sampled.

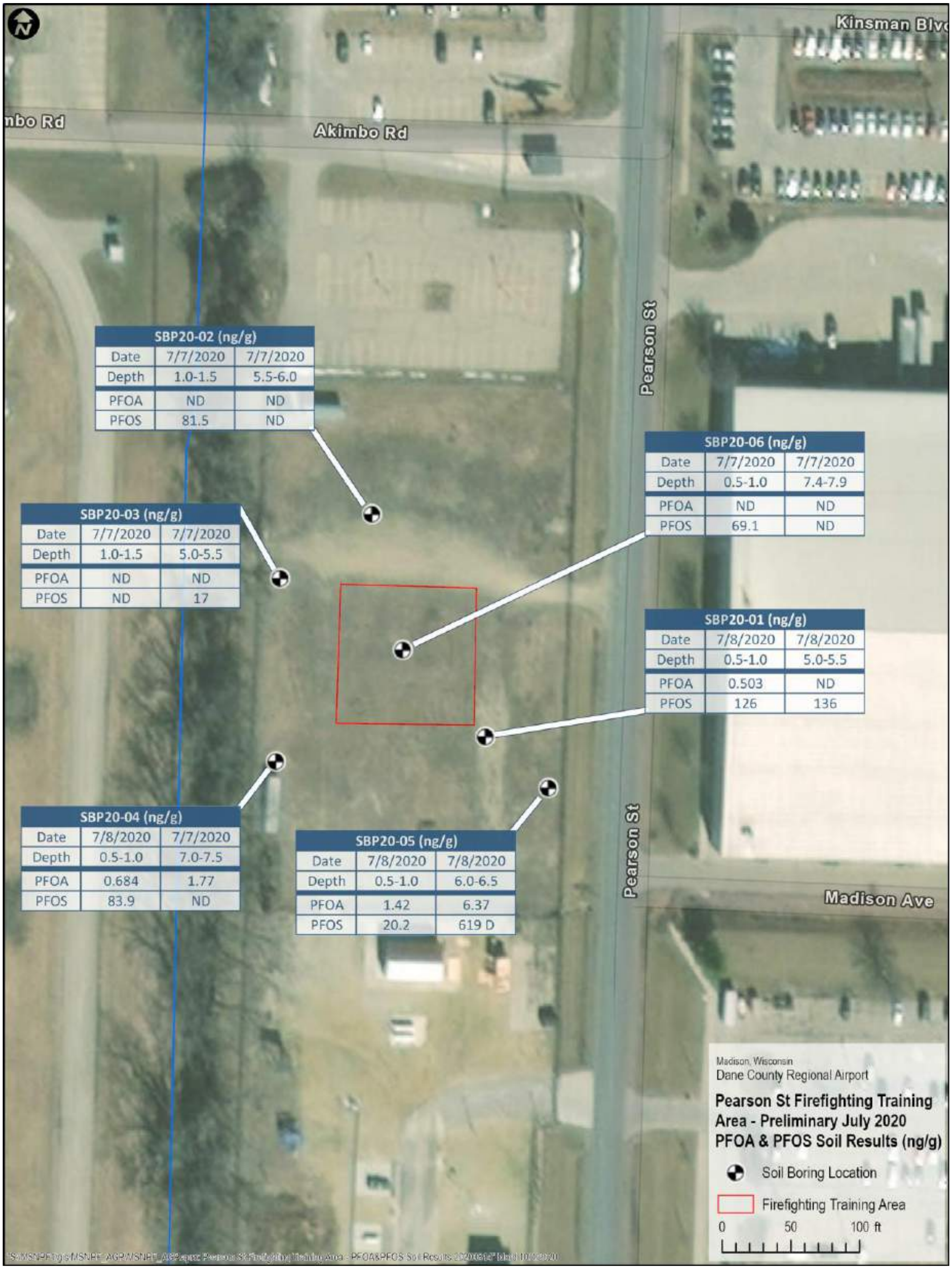

Figure 1. July 7-8 PFOA and PFOS Soil Results at Pearson Street/East FFTA.

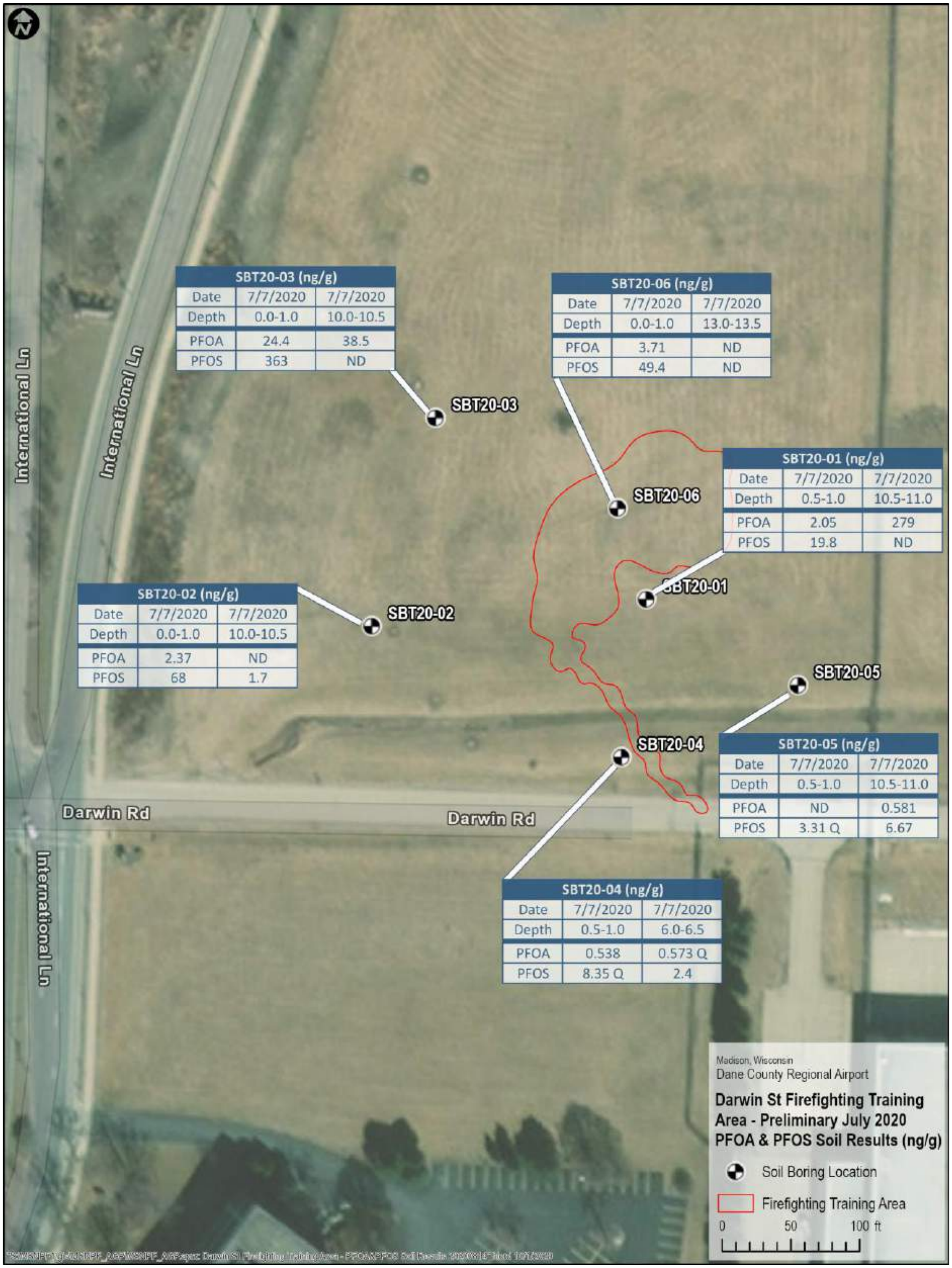

Figure 2. July 7 PFOA and PFOS Soil Results at Darwin Road/West FFTA.

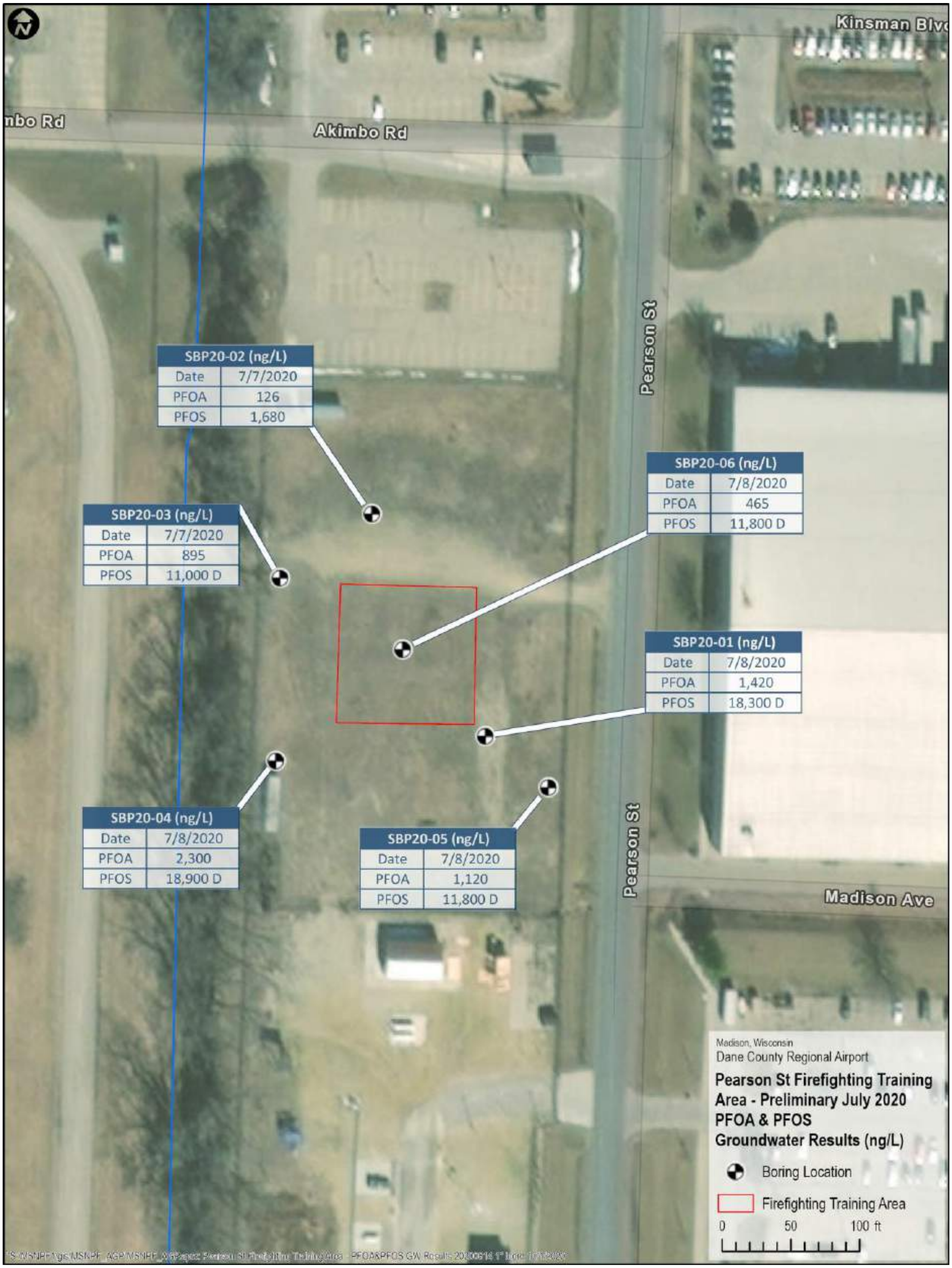

Figure 3. July 7-8 PFOA and PFOS Groundwater Results at Pearson Street/East FFTA.

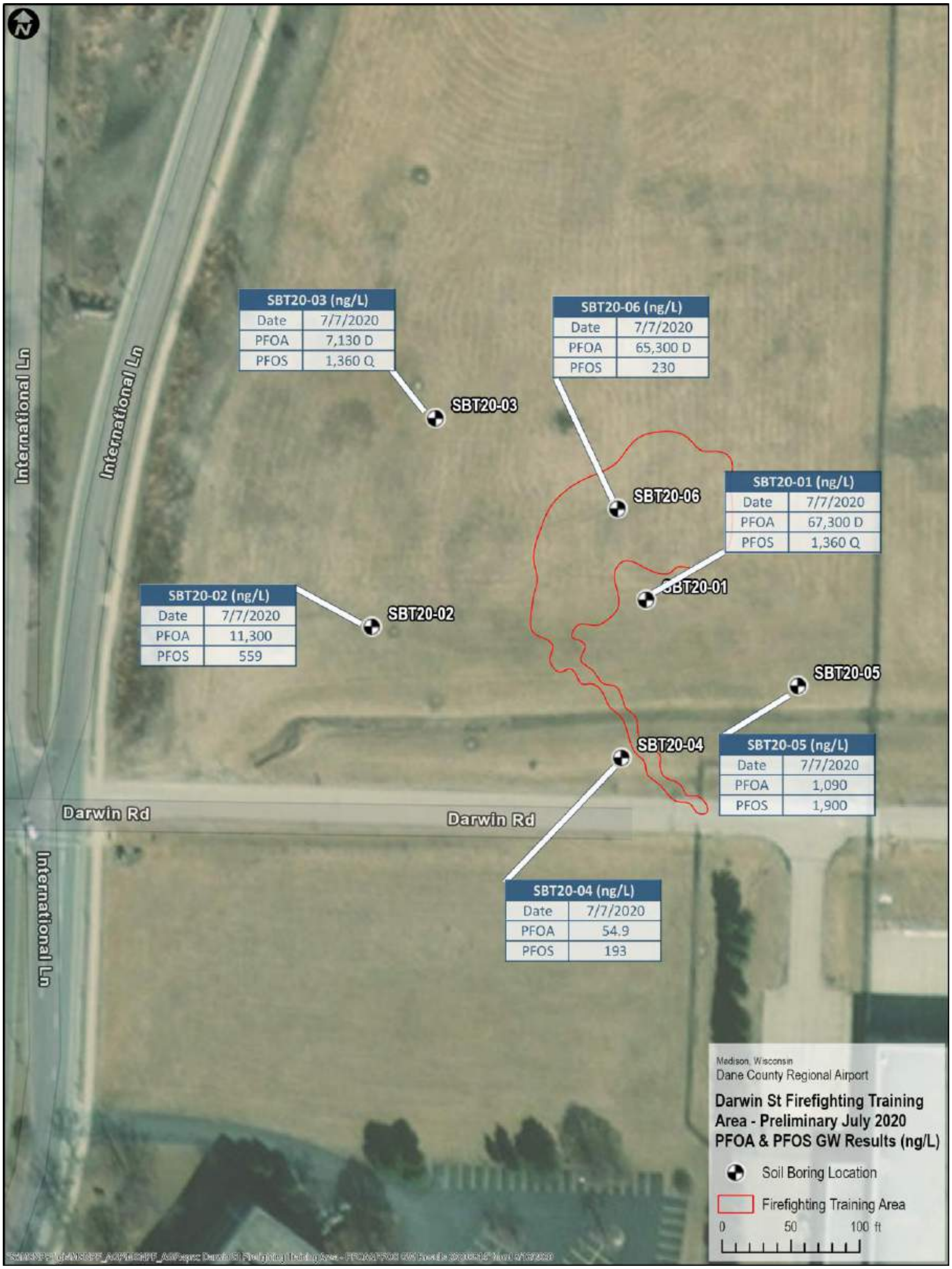

Figure 4. July 7 PFOA and PFOS Groundwater Results at Darwin Road/West FFTA.

Tables 5 and 6 contain a summary of reported soil and groundwater results, respectively, for all analyzed PFAS compounds.

Table 5. July 7-8, 2020 FFTA Soil PFAS Results (ng/g).

Location	units	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTriA/PFTrDA	PFTeA/PFTeDA	PFBS
SBP20-01 (0.5-1)	ng/g	<0.342	<0.394	0.364 (J,Q)	<0.473	0.503	0.787	1.18	<0.255	<0.400	<0.398	<0.261	<0.301
SBP20-01 (5-5.5)	ng/g	<0.344	<0.395	0.403 (J)	<0.475	<0.467	<0.310	<0.449	<0.256	<0.401	<0.399	<0.262	<0.302
SBP20-02 (1-1.5)	ng/g	<0.345	<0.397	<0.215	<0.477	<0.469	<0.311	<0.451	<0.257	<0.403	<0.401	<0.263	<0.303
SBP20-02 (5.5-6)	ng/g	0.776	2.23	5.09	1.04	<0.471	<0.313	<0.453	<0.259	<0.405	<0.403	<0.265	4.25
SBP20-03 (1-1.5)	ng/g	<0.346	<0.398	<0.216	<0.478	<0.470	0.871	0.614	<0.258	<0.404	<0.402	<0.264	<0.304
SBP20-03 (5-5.5)	ng/g	<0.346	<0.398	0.671	0.918 (Q)	<0.470	<0.312	<0.452	<0.258	<0.404	<0.402	<0.264	<0.304
SBP20-04 (0.5-1)	ng/g	<0.337	<0.388	0.232 (J,Q)	<0.466	0.684	1.39	0.941 (Q)	<0.251	<0.394	<0.392	<0.257	<0.296
SBP20-04-(7-7.5)	ng/g	<0.337	<0.388	0.594	0.835 (Q)	1.77	1.05	<0.440	<0.251	<0.394	<0.392	<0.257	<0.296
SBP20-05 (0.5-1)	ng/g	<0.342	<0.394	0.321 (J,Q)	0.627	1.42	3.31	8.56	0.584	<0.400	<0.398	<0.261	<0.301
SBP20-05 (6-6.5)	ng/g	0.364 (J)	2.54	2.62	3.76	6.37	3.21	0.673	<0.257	<0.402	<0.400	<0.263	<0.302
SBP20-06 (0.5-1)	ng/g	<0.333	<0.383	0.245 (J,Q)	<0.461	<0.453	0.674	0.609	<0.249	<0.389	<0.387	<0.254	<0.293
SBP20-06 (7.4-7.9)	ng/g	0.457 (J)	0.97	3.37	1.18	<0.457	<0.304	<0.440	<0.251	<0.393	<0.391	<0.257	2.37
SBT20-01 (0.5-1)	ng/g	<0.335	0.529	1.44 (Q)	<0.463	2.05	0.546 (Q)	<0.438	<0.250	<0.391	<0.389	<0.256	<0.294
SBT20-01 (10.5-11)	ng/g	1.37	5.58	31.9	10.8	279	<0.301	<0.436	<0.249	<0.390	<0.388	<0.255	4.98
SBT20-02 (0-1)	ng/g	1.28	2.02	1.12	0.681	2.37	2.26	0.452	0.472	<0.400	<0.398	<0.261	<0.301
SBT20-02 (10-10.5)	ng/g	<0.341	<0.393	<0.213	<0.472	<0.464	<0.308	<0.446	<0.255	<0.399	<0.397	<0.261	<0.300
SBT20-03 (0-1)	ng/g	2.17	6.71	9.77	4.52	24.4	8.38	4.2	4.44	<0.400	<0.398	<0.261	1.84
SBT20-03 (10-10.5)	ng/g	<0.342	1.25	3.45	5.1	38.5	<0.308	<0.446	<0.255	<0.399	<0.397	<0.261	0.761
SBT20-04 (0.5-1)	ng/g	0.395 (J)	<0.394	0.438 (J)	<0.473	0.538	<0.309	<0.447	<0.255	<0.400	<0.398	<0.261	<0.301
SBT20-04 (6-6.5)	ng/g	<0.344	<0.396	0.331 (J)	<0.475	0.573 (Q)	<0.310	<0.449	<0.256	<0.402	<0.400	<0.262	<0.302
SBT20-05 (10.5-11)	ng/g	<0.344	<0.395	0.222 (J,Q)	<0.475	0.581	<0.310	<0.449	<0.256	<0.401	<0.399	<0.262	<0.302
SBT20-05-(0.5-1)	ng/g	<0.343	<0.394	<0.214	<0.473	<0.466	<0.309	<0.448	<0.256	<0.400	<0.398	<0.262	<0.301
SBT20-06 (0-1)	ng/g	0.858	2.38	3.27	1.61	3.71	1.42	<0.447	0.285 (J,Q)	<0.399	<0.397	<0.261	0.537
SBT20-06 (13-13.5)	ng/g	<0.336	0.672	1.61	<0.465	<0.457	<0.303	<0.439	<0.251	<0.393	<0.391	<0.257	0.301

Location	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFOSA	MeFOSAA	EtFOSAA	4:2 FTS	6:2 FTS	8:2 FTS
SBP20-01 (0.5-1)	<0.651	0.624	<0.730	126	<1.14	<0.683	3.68	<0.728	<0.681	1.09	24.6	84.2
SBP20-01 (5-5.5)	<0.654	0.447 (J)	<0.733	136	<1.14	<0.686	<1.00	<0.731	<0.684	<0.358	5.25	7.18
SBP20-02 (1-1.5)	<0.656	<0.389	<0.736	81.5	<1.15	<0.688	<1.01	<0.734	<0.686	<0.359	7.3	12.6
SBP20-02 (5.5-6)	5.77	11.1	<0.740	<0.431	<1.15	<0.692	<1.01	<0.738	<0.690	0.577	8.42	<0.724
SBP20-03 (1-1.5)	<0.658	<0.390	<0.738	<0.430	<1.15	<0.690	3.21	<0.736	<0.688	<0.360	0.913 (J)	1.18
SBP20-03 (5-5.5)	<0.659	20.4	<0.739	17	<1.15	<0.691	<1.01	<0.737	<0.689	<0.360	10.2	<0.723
SBP20-04 (0.5-1)	<0.641	<0.380	<0.719	83.9	<1.12	<0.672	7.98	<0.717	<0.670	<0.351	4.83	51.1
SBP20-04-(7-7.5)	<0.641	8.26	8.61	<0.419	<1.12	<0.672	<0.982	<0.717	<0.670	<0.351	4.08	<0.703
SBP20-05 (0.5-1)	<0.651	<0.386	<0.730	20.2	<1.14	<0.683	<0.998	<0.728	<0.681	0.378 (J,Q)	11.3	29.9
SBP20-05 (6-6.5)	<0.654	12.8	5.85	619 (D)	<1.14	<0.686	<1.00	<0.732	<0.684	<0.358	19.5	2.15
SBP20-06 (0.5-1)	<0.634	<0.376	<0.711	69.1	<1.11	<0.665	<0.971	<0.709	<0.663	<0.347	<0.630	<0.696
SBP20-06 (7.4-7.9)	6.68	64.8	3.94	<0.418	<1.12	<0.671	<0.981	<0.716	<0.669	<0.350	36.3	<0.702
SBT20-01 (0.5-1)	<0.637	10.1	<0.714	19.8	<1.11	<0.668	<0.976	<0.712	<0.666	<0.348	<0.633	<0.699
SBT20-01 (10.5-11)	6.05	250	<0.712	<0.415	<1.11	<0.665	<0.972	<0.710	<0.663	<0.347	2.06	<0.696
SBT20-02 (0-1)	<0.651	4.37	<0.730	68	<1.14	<0.682	1.29	<0.728	<0.680	<0.356	<0.647	<0.714
SBT20-02 (10-10.5)	<0.649	0.563	<0.728	1.7	<1.13	<0.681	<0.995	<0.726	<0.679	<0.355	<0.645	<0.713
SBT20-03 (0-1)	2.29	107	2.9	363	<1.14	1.46	7.22	<0.728	<0.681	<0.356	3.36	7.27
SBT20-03 (10-10.5)	2.41	188	<0.729	<0.425	<1.14	<0.682	<0.996	<0.727	<0.680	<0.356	1.13	<0.713
SBT20-04 (0.5-1)	<0.651	2.27	<0.730	8.35 (Q)	<1.14	<0.683	<0.997	<0.728	<0.681	<0.356	<0.647	<0.714
SBT20-04 (6-6.5)	<0.654	0.715	<0.733	2.4	<1.14	<0.686	<1.00	<0.731	<0.684	<0.358	<0.650	<0.718
SBT20-05 (10.5-11)	<0.654	1.96	<0.733	6.67	<1.14	<0.686	<1.00	<0.731	<0.684	<0.358	<0.650	<0.717
SBT20-05-(0.5-1)	<0.652	0.679 (Q)	<0.731	3.31 (Q)	<1.14	<0.683	<0.999	<0.729	<0.682	<0.357	<0.648	<0.715
SBT20-06 (0-1)	<0.650	15.3	<0.729	49.4	<1.14	<0.682	<0.996	<0.727	<0.680	<0.356	<0.646	<0.713
SBT20-06 (13-13.5)	<0.639	<0.379	<0.717	<0.418	<1.12	<0.671	<0.980	<0.715	<0.669	<0.350	<0.636	<0.702

Location	10:2 FTS	HFPO-DA	PFODA	EtFOSE	MeFOSE	MeFOSA	EtFOSA	PFHxDA	9Cl-PF3ONS	11Cl-PF3OUdS	PFDoS	ADONA
SBP20-01 (0.5-1)	<1.01	<1.17	<0.495	<5.32	<4.91	<5.72	<3.80	<0.168	<0.366	<0.714	<0.594	<0.336
SBP20-01 (5-5.5)	<1.01	<1.17	<0.497	<5.35	<4.93	<5.74	<3.82	<0.169	<0.368	<0.717	<0.596	<0.338
SBP20-02 (1-1.5)	<1.01	<1.18	<0.499	<5.36	<4.95	<5.76	<3.83	<0.169	<0.369	<0.720	<0.598	<0.339
SBP20-02 (5.5-6)	<1.02	<1.18	<0.501	<5.39	<4.97	<5.80	<3.85	<0.170	<0.371	<0.724	<0.602	<0.341
SBP20-03 (1-1.5)	<1.02	<1.18	<0.500	<5.38	<4.96	<5.78	<3.84	<0.170	<0.370	<0.722	<0.600	<0.340
SBP20-03 (5-5.5)	<1.02	<1.18	<0.500	<5.38	<4.96	<5.78	<3.84	<0.170	<0.370	<0.723	<0.600	<0.340
SBP20-04 (0.5-1)	<0.990	<1.15	<0.487	<5.24	<4.83	<5.63	<3.74	<0.166	<0.361	<0.703	<0.585	<0.331
SBP20-04-(7-7.5)	<0.990	<1.15	<0.487	<5.24	<4.83	<5.63	<3.74	<0.166	<0.360	<0.703	<0.584	<0.331
SBP20-05 (0.5-1)	1.68	<1.17	<0.495	<5.32	<4.91	<5.72	<3.80	<0.168	<0.366	<0.715	<0.594	<0.336
SBP20-05 (6-6.5)	<1.01	<1.17	<0.497	<5.35	<4.93	<5.75	<3.82	<0.169	<0.368	<0.718	<0.597	<0.338
SBP20-06 (0.5-1)	<0.979	<1.14	<0.482	<5.18	<4.78	<5.57	<3.70	<0.164	<0.357	<0.696	<0.578	<0.328
SBP20-06 (7.4-7.9)	<0.988	<1.15	<0.486	<5.23	<4.83	<5.62	<3.74	<0.165	<0.360	<0.702	<0.584	<0.331
SBT20-01 (0.5-1)	<0.983	<1.14	<0.484	<5.21	<4.80	<5.59	<3.72	<0.165	<0.358	<0.699	<0.581	<0.329
SBT20-01 (10.5-11)	<0.980	<1.14	<0.482	<5.19	<4.78	<5.57	<3.70	<0.164	<0.357	<0.696	<0.579	<0.328
SBT20-02 (0-1)	<1.00	<1.17	<0.495	<5.32	<4.91	<5.72	<3.80	<0.168	<0.366	<0.714	<0.593	<0.336
SBT20-02 (10-10.5)	<1.00	<1.16	<0.493	<5.31	<4.89	<5.70	<3.79	<0.168	<0.365	<0.713	<0.592	<0.336
SBT20-03 (0-1)	<1.01	<1.17	<0.495	<5.32	<4.91	<5.72	<3.80	<0.168	<0.366	<0.714	0.656 (J)	<0.336
SBT20-03 (10-10.5)	<1.00	<1.17	<0.494	<5.31	<4.90	<5.71	<3.79	<0.168	<0.365	<0.713	<0.593	<0.336
SBT20-04 (0.5-1)	<1.01	<1.17	<0.495	<5.32	<4.91	<5.72	<3.80	<0.168	<0.366	<0.714	<0.594	<0.336
SBT20-04 (6-6.5)	<1.01	<1.17	<0.497	<5.35	<4.93	<5.74	<3.82	<0.169	<0.368	<0.718	<0.596	<0.338
SBT20-05 (10.5-11)	<1.01	<1.17	<0.497	<5.35	<4.93	<5.74	<3.82	<0.169	<0.368	<0.717	<0.596	<0.338
SBT20-05-(0.5-1)	<1.01	<1.17	<0.495	<5.33	<4.91	<5.73	<3.80	<0.168	<0.367	<0.715	<0.594	<0.337
SBT20-06 (0-1)	<1.00	<1.17	<0.494	<5.31	<4.90	<5.71	<3.79	<0.168	<0.366	<0.713	<0.593	<0.336
SBT20-06 (13-13.5)	<0.987	<1.15	<0.486	<5.23	<4.82	<5.62	<3.73	<0.165	<0.360	<0.702	<0.583	<0.330

(J) = amount detected is below the Reporting Limit/LOQ

(D) = Dilution

(Q) = ion transistion ratio outside of the acceptance criteria

Table 6. July 7-8, 2020 FFTA Groundwater PFAS Results (ng/L).

Location	units	PFBA	PFPeA	PFHxA	PFHpA	PFOA	PFNA	PFDA	PFUnA	PFDoA	PFTriA/PFTrDA	PFTeA/PFTeDA
SBP20-01-GW	ng/L	256	989	1320	546	1420	104	<1.70	<1.20	<0.902	<0.562	<0.860
SBP20-02-GW	ng/L	110	271	489	115	126	15.8	<1.68	<1.18	<0.890	<0.555	<0.849
SBP20-03-GW	ng/L	293	877	1420	394	895	41.4	8.51 (Q)	<1.16	<0.872	<0.544	<0.831
SBP20-04-GW	ng/L	586	2190	2250	1320	2300	120	3.99 (J)	<1.14	<0.862	<0.538	<0.822
SBP20-05-GW	ng/L	488	1960	1210	1190	1120	231	3.86 (J)	<1.15	<0.865	<0.540	<0.825
SBP20-06-GW	ng/L	162	496	611	299	465	70.1	<1.67	<1.18	<0.887	<0.553	<0.846
SBT20-01-GW	ng/L	298	800	3020	856	67300 (D)	301	1.67 (J)	<1.12	<0.842	<0.525	<0.803
SBT20-02-GW	ng/L	113	213	132	117	11300	31.9	<1.61	<1.14	<0.857	<0.535	<0.817
SBT20-03-GW	ng/L	1250	3610	4280	1090	7130 (D)	1640	<1.62	<1.14	<0.860	<0.536	<0.820
SBT20-04-GW	ng/L	9.25	34.3	31	13.4	54.9	13.5	7.53	<1.05	<0.790	<0.493	<0.753
SBT20-05-GW	ng/L	50.6	104	349	81.7	1090	143	1.71 (J)	<1.17	<0.882	<0.550	<0.841
SBT20-06-GW	ng/L	16100 (D)	43000 (D)	53800 (D)	26200 (D)	65300 (D)	3.98 (J)	<1.66	<1.17	<0.881	<0.549	<0.840

Location	PFBS	PFPeS	PFHxS	PFHpS	PFOS	PFNS	PFDS	PFOSA	MeFOSAA	EtFOSAA	4:2 FTS	6:2 FTS	8:2 FTS
SBP20-01-GW	166	386	6490 (D)	1520	18300 (D)	<4.41	<1.40	19.3 (Q)	<1.88	<1.56	67.8	6940 (D)	334
SBP20-02-GW	302	322	1420	29.3	1680	<4.35	1.76 (J,Q)	16.7	<1.86	<1.54	19.7	537	28.4
SBP20-03-GW	590	876	7700 (D)	316	11000 (D)	5.22	<1.35	169	<1.82	<1.51	51.8	5220 (D)	628
SBP20-04-GW	206	623	9640 (D)	1550	18900 (D)	<4.21	<1.34	20.5 9 (Q)	<1.80	<1.49	94.5	11000 (D)	480
SBP20-05-GW	35.7	102	2370	367	11800 (D)	<4.23	<1.34	18.2 (Q)	<1.80	<1.50	23.1	3030	332
SBP20-06-GW	140	185	2640	405	11800 (D)	<4.33	<1.38	46	<1.85	<1.53	<1.56	631	213
SBT20-01-GW	377	260	8530 (D)	1740	1360 (Q)	<4.11	<1.31	19.4 (Q)	<1.75	<1.46	<1.48	378	8.61
SBT20-02-GW	37.2	48.2	1690	31.3	559	<4.19	<1.33	4.99	<1.79	<1.48	<1.50	<2.16	<2.23
SBT20-03-GW	1230	771	18700 (D)	2460	1360 (Q)	<4.20	<1.34	4.04 (J,Q)	<1.79	<1.49	<1.51	24.4	<2.24
SBT20-04-GW	14.1	5.67	228	2.29 (J,Q)	193	<3.86	<1.23	2.01 (J)	<1.65	<1.37	<1.39	<2.00	<2.06
SBT20-05-GW	95.9	106	4740 (D)	66.1	1900	<4.31	<1.37	10.9	<1.84	<1.53	<1.55	8.35	53.6
SBT20-06-GW	20200 (D)	23700 (D)	79900 (D)	104	230	<4.30	<1.37	10.3	<1.84	<1.52	194	5880 (D)	34.9

Location	10:2 FTS	HFPO-DA	PFODA	EtFOSE	MeFOSE	MeFOSA	EtFOSA	PFHxDA	9Cl-PF3ONS	11Cl-PF3OUdS	PFDoS	ADONA
SBP20-01-GW	<3.56	<5.49	<6.99	<10.7	<6.91	<4.36	<5.82	<0.335	<1.65	<2.74	<4.75	<0.822
SBP20-02-GW	<3.52	<5.42	<6.90	<10.6	<6.82	<4.31	<5.75	<0.331	<1.63	<2.71	<4.69	<0.812
SBP20-03-GW	<3.45	<5.31	<6.76	<10.4	<6.68	<4.22	<5.63	<0.324	<1.60	<2.65	<4.59	<0.795
SBP20-04-GW	<3.41	<5.25	<6.68	<10.3	<6.61	<4.17	<5.56	<0.320	<1.58	<2.62	<4.54	<0.786
SBP20-05-GW	<3.42	<5.27	<6.71	<10.3	<6.63	<4.18	<5.58	<0.321	<1.58	<2.63	<4.56	<0.789
SBP20-06-GW	<3.51	<5.40	<6.88	<10.6	<6.80	<4.29	<5.72	<0.329	<1.62	<2.70	<4.67	<0.809
SBT20-01-GW	<3.33	<5.12	<6.53	<10.0	<6.45	<4.07	<5.43	<0.313	<1.54	<2.56	<4.43	<0.767
SBT20-02-GW	<3.39	<5.22	<6.65	<10.2	<6.57	<4.15	<5.53	<0.318	<1.57	<2.61	<4.51	<0.782
SBT20-03-GW	<3.40	<5.23	<6.67	<10.2	<6.59	<4.16	<5.55	<0.319	<1.57	<2.62	<4.53	<0.784
SBT20-04-GW	<3.12	<4.81	<6.13	<9.42	<6.06	<3.82	<5.10	<0.293	<1.45	<2.40	<4.16	<0.720
SBT20-05-GW	<3.49	<5.37	<6.84	<10.5	<6.76	<4.27	<5.69	<0.327	<1.62	<2.68	<4.64	<0.804
SBT20-06-GW	<3.48	<5.36	<6.83	<10.5	<6.75	<4.26	<5.68	<0.327	<1.61	<2.68	<4.64	<0.803

(J) = estimated value, result between the Method Detection (MDL) and Reporting Limt (RL) [SGS]; amount detected is below the Reporting Limit/LOQ [Vista]

(D) = Dilution [Vista]

(Q) = ion transistion ratio outside of the acceptance criteria [Vista]

Attachment 1

Boring Logs

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LOG OF BORING SBP20-01

(Page 1 of 1)

Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/8/20		
Date Completed	: 7/8/20	Total Logged Depth	: 15'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 12'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.123761, -89.337042

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	GRAPHIC	DESCRIPTION	Water Level
0		3.0'/5.0'	Soil Sample (0.5'-1.0')		dry	GP		Fine GRAVEL with fine sand. (6")	
						SP		Brown fine SAND with silt, trace fine gravel. (7")	
1						SP/ML		Fine GRAVEL with fine sand. (2")	
2						SP/GP		Brown fine SAND and SILT. (6")	
						CL		Light brown fine SAND and GRAVEL. (4")	
								Dark brown CLAY with silt and fine sand. (12")	
3								No Recovery	
5		1.5'/5.0'	Soil Sample (5.0'-5.5')		v.moist	SP		Brown fine to medium SAND, trace coarse sand and gravel. (10")	
6						ML		Dark gray SILT with clay. (8")	
7								No Recovery	
10		3.9'/5.0'	GW Sample (10'-15')		wet	ML		Same as above. (6")	
11					wet	SP		Dark gray fine SAND with silt. (6")	
								Gray fine SAND. (2")	
					v.moist	ML		Dark gray SILT with clay. (8")	▼
12					wet	SP		Gray fine SAND. (24")	
14								No Recovery	
15								End of Boring. Borehole sealed with bentonite chips upon completion.	

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LOG OF BORING SBP20-02

(Page 1 of 1)

Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/7/20		
Date Completed	: 7/7/20	Total Logged Depth	: 15'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 10'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.124205, -89.337351

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	DESCRIPTION	Water Level
0–1		5.0'/5.0'	Soil Sample (1.0'-1.5')		dry	GP	Light brown to tan rock fragments with fine sand. (12")	
1–1.6					dry	SP	Light brown fine SAND. (7")	
1.6–3					dry	SP	Dark brown fine to medium SAND with silt. Some clay and fine gravel. (17")	
3–5					moist	SP	Same as above. (24")	
5–5.9		1.4'/5.0'	Soil Sample (5.5'-6.0')		v.moist	ML	Black sticky SILT. (11")	
5.9–6.4					v.moist	ML	Dark gray sandy SILT. (6")	
6.4–10							No Recovery	▼ (10')
10–10.6		4.9'/5.0'	GW Sample (10'-15')		wet	SP	Brown / gray fine SAND. (7")	
10.6–10.8					wet		Dark gray SILT with fine sand. (2")	
10.8–14.2					wet	SP	Brown fine SAND, trace medium sand. (5")	
14.2–14.9					wet	SW	Brown fine to medium SAND, trace coarse sand and fine gravel. (8")	
14.9–15							No Recovery	

End of Boring.
Borehole sealed with bentonite chips upon completion.

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LOG OF BORING SBP20-03

(Page 1 of 1)

Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/7/20		
Date Completed	: 7/7/20	Total Logged Depth	: 15'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 6.3'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.124077, -89.337601

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	GRAPHIC	DESCRIPTION	Water Level
0		2.8'/5.0'	Soil Sample (1.0'-1.5')		dry			Grass and organics at surface. (2")	
0–1						SP/GP		Tan fine SAND and pulverized GRAVEL. (11")	
1–2						SP		Light brown to brown fine SAND, trace silt. (11")	
2–3					moist/dry	CL		Hard brown CLAY with silt. (10")	
3–5								No Recovery	
5–6		2.8'/5.0'	Soil Sample (5.0'-5.5')		moist	ML		Black sticky SILT with clay. (16")	▼
6–7					wet	SP/GP		Fine to medium SAND and fine GRAVEL. (6")	
7–10								No Recovery	
10–15		4.7'/5.0'	GW Sample (10'-15')		wet	SP		Brown fine SAND. (56")	
15								No Recovery	

End of Boring.
Borehole sealed with bentonite chips upon completion.

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LOG OF BORING SBP20-04

(Page 1 of 1)

Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/8/20		
Date Completed	: 7/8/20	Total Logged Depth	: 15'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 12.1'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.123712, -89.337613

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	GRAPHIC	DESCRIPTION	Water Level
0–0.4		2.2'/5.0'	Soil Sample (0.5'-1.0')		dry	GP		Gravel, road material, some fine to medium sand. (5")	
0.4–1.2					dry	SP		Brown fine SAND with silt. (10")	
1.2–2.2					moist	CL		Brown firm CLAY with silt. (12")	
2.2–5								No Recovery	
5–6.3		3.2'/5.0'	Soil Sample (7.0'-7.5')			CL		Same as above. (16")	
6.3–6.5								Light gray very fine to fine SAND. (2")	
6.5–8.2						ML		Soft dark gray SILT with clay. (22")	
8.2–10								No Recovery	
10–11.3		3.6'/5.0'	GW Sample (10'-15')			SM		Soft gray SILTY SAND. (16")	
11.3–12.1						ML/CL		Gray SILT/CLAY. (10")	▼
12.1–13.6					wet	SP		Gray fine SAND, trace medium sand and fine gravel. (18")	
13.6–15								No Recovery	
15								End of Boring. Borehole sealed with bentonite chips upon completion.	

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LOG OF BORING SBP20-05

(Page 1 of 1)

Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/8/20		
Date Completed	: 7/8/20	Total Logged Depth	: 15'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 7.6'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.123639, -89.336866

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	GRAPHIC	DESCRIPTION	Water Level
0		2.2'/5.0'	Soil Sample (0.5'-1.0')		dry	GP		Gravel, road material, some fine sand. (5")	
					dry	SP		Light brown fine SAND. (6")	
1					dry			Fine GRAVEL layer. (2")	
					↑ moist ↓	ML		Light brown SILT with very fine sand. (10")	
2								Brown fine SAND. (2")	
								Brown hard CLAY. (2")	
3–5								No Recovery	
5		3.3'/5.0'	Soil Sample (6.0'-6.5')		moist/dry	ML		Same as above, some silt present. (12")	
6					moist	ML		Softer gray SILT with trace clay. (19")	▼
7.6					wet	SP		Gray fine SAND. (8")	
8.3–10								No Recovery	
10		4.9'/5.0'	GW Sample (10'-15')		wet	SP		Same as above. (11")	
11					v. moist	ML/CL		Soft gray SILT/CLAY. (12")	
12					wet	SP		Gray fine to medium SAND. (36")	
15								No Recovery	

End of Boring.
Borehole sealed with bentonite chips upon completion.

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LOG OF BORING SBP20-06

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Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/7/20		
Date Completed	: 7/7/20	Total Logged Depth	: 15'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 11.1'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.123934, -89.337267

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	GRAPHIC	DESCRIPTION	Water Level
0–3.5		3.5'/5.0'	Soil Sample (0.5'-1.0')		dry/moist	SP		Light brown fine SAND, trace fine gravel. (42")	
3.5–5								No Recovery	
5–7		2.9'/5.0'	Soil Sample (7.4'-7.9')		v.moist	SP		Same as above. (24")	
7–7.4						ML/CL		Brown SILT/CLAY. (5")	
7.4–7.9						ML		Dark gray SILT with clay. (6")	
7.9–10					moist			No Recovery	
10–10.7		3.3'/5.0'	GW Sample (10'-15')			SP		Brown / gray fine SAND, trace silt. (8")	
10.7–11.1						ML		Soft gray SILT. (5")	▼
11.1–13.3					wet	SP		Brown fine SAND, some medium sand. (26")	
13.3–15								No Recovery	

End of Boring.
Borehole sealed with bentonite chips upon completion.

Depth scale: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

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LOG OF BORING SBT20-01

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Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/7/20		
Date Completed	: 7/7/20	Total Logged Depth	: 25'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 12'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.129179, -89.346894

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	GRAPHIC	DESCRIPTION	Water Level
0–3		4.3'/5.0'	Soil Sample (0.5'-1.0')		dry	SP/ML		SAND, SILT, CLAY mix. Looks like fill. (36")	
3–4.3						ML/CL		Gray / black SILT and CLAY. (16")	
4.3–5						SP		No Recovery	
5–6.5		2.7'/5.0'				ML/CL		Dark brown SILT/CLAY. (18")	
6.5–6.7						CL		Light brown fine SAND. (2")	
6.7–7.4					moist	SP		Light brown / gray CLAY with silt. (8")	
7.4–7.8								Brown fine SAND with silt. (5")	
7.8–10								No Recovery	
10–12		3.0'/5.0'	Soil Sample (10.5'-11')			SP		Light brown fine SAND. (24")	▼ (12')
12–13						SP		Light brown fine SAND with fine gravel. (12")	
13–15								No Recovery	
15–18.9		4.9'/5.0'	GW Sample (13'-23')			SP		Light brown soft fine SAND with silt. (47")	
18.9–19.9					wet	SP		Light brown hard fine SAND with fine gravel. (12")	
19.9–20								No Recovery	
20–23.4		4.9'/5.0'				SP		Soft, light brown fine SAND with silt. (41")	
23.4–24.9						SP		Tightly packed light brown very fine SAND with silt. (18")	
24.9–25								No Recovery	

End of Boring.
Borehole sealed with bentonite chips upon completion.

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LOG OF BORING SBT20-02

(Page 1 of 1)

Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/7/20		
Date Completed	: 7/7/20	Total Logged Depth	: 15'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 11.2'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.129126, -89.347641

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	DESCRIPTION	Water Level
0–1.1		4.1'/5.0' (0–5)	Soil Sample (0.0'-1.0')		dry	ML/SP	Dark brown topsoil (silt with some fine sand). (13")	
1.1–4.0						CL	Soft, light brown to brown CLAY with silt. (35")	
4.0–4.7						SP	Light brown fine SAND. (2")	
							No Recovery	
5–9.1		4.1'/5.0' (5–10)			moist	SP	Light brown fine SAND. Fine gravel observed at 6.4' and 8.3'. (49")	
9.1–10							No Recovery	
10–11.2		4.3'/5.0' (10–15)	Soil Sample (10'-10.5')			SP	Light brown fine SAND. (14")	▼
11.2–14					wet	SP	Light brown fine SAND. (22")	
14–14.3					moist	GP	Fine GRAVEL, dark in color. Driller identified this layer as "Olivine". (4")	
							No Recovery	
15–20			GW Sample (15'-20')				End of Boring. Borehole sealed with bentonite chips upon completion. Drove temporary PVC groundwater screen beyond logged interval due to poor GW recharge at intially installed depth of 10'-15'.	

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LOG OF BORING SBT20-03

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Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/7/20		
Date Completed	: 7/7/20	Total Logged Depth	: 20'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 15'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.129541, -89.347467

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	GRAPHIC	DESCRIPTION	Water Level
0–4		4.9'/5.0'	Soil Sample (0.0'-1.0')		dry	ML/SP		Light to dark brown / black SILT and fine SAND. (48")	
4–5						CL		Dark gray CLAY with silt. (11")	
5–6.7		3.9'/5.0'				CL		No Recovery Dark gray CLAY with silt. (19")	
6.7–8					moist	SP		Fine brown SAND with silt. (17")	
8–9.9						SP		Light brown fine SAND. Gravel piece observed at 8.8'. (11") No Recovery	
10–10.9		3.0'/5.0'	Soil Sample (10'-10.5')			SP		Light brown fine SAND. (11")	
10.9–13					v.moist to wet	SP		Light brown fine SAND with silt. (25")	
13–15								No Recovery	▼ (15')
15–18.4		3.4'/5.0'	GW Sample (15'-20')		wet	SP		Light brown fine SAND with silt. (41")	
18.4–20								No Recovery	

End of Boring.
Borehole sealed with bentonite chips upon completion.
Very little groundwater observed at this location during sampling procedure.

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LOG OF BORING SBT20-04

(Page 1 of 1)

Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/7/20		
Date Completed	: 7/7/20	Total Logged Depth	: 20'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 10'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.128864, -89.346961

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	DESCRIPTION	Water Level
0, 1, 2		4.4'/5.0'	Soil Sample (0.5'-1.0')		dry	SP/ML	Light brown to brown SAND/SILT mix. (28")	
						GP	Gravel, fractured stone (road base?). (5")	
3, 4					moist	CL	Brown, soft CLAY with silt. (20")	
							No Recovery	
5, 6		3.3'/5.0'	Soil Sample (6.0'-6.5')		moist	CL	Brown soft CLAY with silt. (24")	
7, 8					moist/wet	SP	Brown very fine to fine SAND with some fine gravel. (16")	
9							No Recovery	▼
10, 11, 12		3.9'/5.0'			wet	SP	Light brown fine SAND, trace fine gravel. (25")	
							Horizontally oriented rock fragments. (2")	
13						SP	Light brown fine SAND with silt. (19")	
14							No Recovery	
15, 16		4.0'/5.0'	GW Sample (9'-19')			SP/ML	Soft light brown fine to very fine SAND and SILT. (22")	
17, 18						SP/ML	More firm light brown fine to very fine SAND and SILT. (26")	
19							No Recovery	
20							End of Boring. Borehole sealed with bentonite chips upon completion.	
21, 22, 23, 24, 25, 26, 27, 28								

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LOG OF BORING SBT20-05

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Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/7/20		
Date Completed	: 7/7/20	Total Logged Depth	: 20'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 11.4'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.129007, -89.346480

Depth in Feet	Recovery (in.)	Sample Type
0–5	3.6'/5.0'	Soil Sample (0.5'-1.0')
5–10	4.4'/5.0'	Soil Sample (10.5'-11')
10–15	2.8'/5.0'	
15–20	4.8'/5.0'	GW Sample (9'-19')

Moisture Content	USCS	DESCRIPTION
dry	SP/ML	Light brown to brown fine SAND / SILT. (32")
dry	ML	Dark brown SILT with fine sand. (11")
dry		No Recovery
dry	ML	Dark brown / black SILT. (17")
moist	CL	Brown / gray CLAY with silt. (31")
dry	SP/GP	Light brown / tan fine SAND and fine GRAVEL. (5")
		No Recovery
dry/moist	SP/GP	Same as above. (5")
dry		Pulverized gravel? (2")
moist	ML	Gray SILT with clay. (10")
wet	SP	Brown fine SAND. (14")
		No Recovery
wet	SP	Light brown fine SAND with silt and fine gravel. (58")
		No Recovery

Water Level: ▼ 11.4'

End of Boring.
Borehole sealed with bentonite chips upon completion.

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LOG OF BORING SBT20-06

(Page 1 of 1)

Dane County Regional Airport
4000 International Ln,
Madison, WI, 53704

Date Started	: 7/7/20		
Date Completed	: 7/7/20	Total Logged Depth	: 25'
Drilling Method	: Geoprobe	Depth to water (bgs)	: 17.9'
Drilling Contractor	: On Site	Ground Elevation	:
Logged By	: CB	Lat/Long	: 43.129361, -89.346971

Depth in Feet	Surf. Elev.	Recovery (in.)	Sample Type	PID (ppm)	Moisture Content	USCS	GRAPHIC	DESCRIPTION	Water Level
0–3.4		4.8'/5.0' (0–5)	Soil Sample (0.5'-1.0')		dry	ML/SP		Dark brown SILT and fine SAND / CLAY. (41")	
3.4–4					dry/moist	CL		Light brown / brown CLAY. (7")	
4–4.8						CL		Dark brown / gray CLAY. (10")	
4.8–5								No Recovery	
5–6.4		2.0'/5.0' (5–10)				CL		Same as above, harder. (17")	
6.4–6.8					moist	SP		Brown fine SAND, tightly packed. (4")	
6.8–7.1					moist	CL		Hard gray CLAY. (4")	
7.1–10								No Recovery	
10–11.8		3.7'/5.0' (10–15)			moist/dry	CL		Same as above. (22")	
11.8–13.4					dry	SP/ML		Gray fine SAND/SILT. (19")	
13.4–13.7			Soil Sample (13'-13.5')		moist	ML/SP		Light brown SILT and very fine SAND. (4")	
13.7–15								No Recovery	
15–15.5		4.9'/5.0' (15–20)	GW Sample (13'-23')		moist	ML/SP		Same as above. (6")	
15.5–16.4					v.moist	SP		Gray fine SAND with silt. (11")	
16.4–16.6								Fine GRAVEL with fine sand and silt. (2")	
16.6–17						SP		Fine SAND with fine gravel. (5")	
17–17.2					moist	ML		Black SILT / fine SAND zone. (2")	
17.2–18								Gray SILT. (10")	▼ (17.9')
18–19.9					wet	SP		Light brown fine SAND. (24")	
19.9–20								No Recovery	
20–24		4.8'/5.0' (20–25)			wet	SP		Light brown fine SAND with silt, trace fine gravel. (48")	
24–24.9						SP		Light brown very fine SAND. (11")	
24.9–25								No Recovery	
25								End of Boring. Borehole sealed with bentonite chips upon completion.	

Attachment 2

Laboratory Reports

August 04, 2020

Vista Work Order No. 2001473

Mr. Chris Cieciek
LimnoTech, Inc.
501 Avis Drive
Ann Arbor, MI 48108

Dear Mr. Cieciek,

Enclosed are the results for the sample set received at Vista Analytical Laboratory on July 14, 2020 under your Project Name 'MSN FFTA Samples'.

Vista Analytical Laboratory is committed to serving you effectively. If you require additional information, please contact me at 916-673-1520 or by email at mmaier@vista-analytical.com.

Thank you for choosing Vista as part of your analytical support team.

Sincerely,

Martha Maier

Martha Maier
Laboratory Director

Vista Analytical Laboratory certifies that the report herein meets all the requirements set forth by NELAP for those applicable test methods. Results relate only to the samples as received by the laboratory. This report should not be reproduced except in full without the written approval of Vista.

Vista Work Order No. 2001473
Case Narrative

Sample Condition on Receipt:

Thirteen soil samples and seven aqueous samples were received in good condition and within the method temperature requirements. The samples were received and stored securely in accordance with Vista standard operating procedures and EPA methodology.

Analytical Notes:

PFAS Isotope Dilution Method - Solid

The soil samples were extracted and analyzed for a selected list of PFAS using Vista's Isotope Dilution Method. The results for PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Results for all other analytes include the linear isomers only.

Holding Times

The samples were extracted and analyzed within the method hold times.

Quality Control

The Initial Calibration and Continuing Calibration Verifications met the method acceptance criteria.

A Method Blank and Ongoing Precision and Recovery (OPR) sample were extracted and analyzed with the preparation batch. No analytes were detected in the Method Blank above the Reporting Limit (RL). The recovery of PFODA was below 50% in the OPR. The reported sample results for this analyte may be biased low. The recoveries of all other analytes were within the acceptance criteria.

The internal standard recoveries outside the acceptance criteria are flagged with an "H" qualifier.

PFAS Isotope Dilution Method - Aqueous

The aqueous samples were extracted and analyzed for a selected list of PFAS using Vista's PFAS Isotope Dilution Method. The results for PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Results for all other analytes include the linear isomers only.

The following samples contained particulate and were centrifuged prior to extraction:

Laboratory ID	Sample Name
2001473-02	SBT20-01-GW
2001473-06	SBT20-05-GW
2001473-08	SBT20-02-GW
2001473-09	SBT20-04-GW
2001473-16	SBT20-03-GW
2001473-19	SBT20-06-GW

Holding Times

The samples were extracted and analyzed within the method hold times.

Quality Control

The Initial Calibration and Continuing Calibration Verifications met the acceptance criteria.

A Method Blank and Ongoing Precision and Recovery (OPR) sample were extracted and analyzed with each preparation batch. No analytes were detected in the Method Blank above the Reporting Limit. The OPR recoveries were within the method acceptance criteria.

The internal standard recoveries outside the acceptance criteria are flagged with an "H" qualifier.

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Sample Inventory Report

Vista Sample ID	Client Sample ID	Sampled	Received	Components/Containers
2001473-01	SBT20-01 (10.5-11)	07-Jul-20 11:00	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-02	SBT20-01-GW	07-Jul-20 11:35	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001473-03	SBT20-05-(0.5-1)	07-Jul-20 11:45	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-04	SBT20-05 (10.5-11)	07-Jul-20 12:10	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-05	SBT20-04 (0.5-1)	07-Jul-20 12:20	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-06	SBT20-05-GW	07-Jul-20 12:55	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001473-07	SBT20-04 (6-6.5)	07-Jul-20 12:30	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-08	SBT20-02-GW	07-Jul-20 13:10	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001473-09	SBT20-04-GW	07-Jul-20 13:35	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001473-10	SOIL DUPLICATE A	07-Jul-20 00:00	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-11	SBT20-02 (0-1)	07-Jul-20 08:05	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-12	EQUIPMENT BLANK A	07-Jul-20 08:40	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001473-13	SBT20-02 (10-10.5)	07-Jul-20 08:15	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-14	SBT20-03 (0-1)	07-Jul-20 08:50	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-15	SBT20-03 (10-10.5)	07-Jul-20 09:05	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-16	SBT20-03-GW	07-Jul-20 09:40	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001473-17	SBT20-06 (0-1)	07-Jul-20 10:00	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-18	SBT20-06 (13-13.5)	07-Jul-20 10:10	14-Jul-20 09:11	HDPE Jar, 6 oz
2001473-19	SBT20-06-GW	07-Jul-20 10:40	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001473-20	SBT20-01 (0.5-1)	07-Jul-20 10:50	14-Jul-20 09:11	HDPE Jar, 6 oz

Vista Project: 2001473

Client Project: MSN FFTA Samples

ANALYTICAL RESULTS

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Solid	Lab Sample:	B0G0144-BLK1	Column:	BEH C18
Project:	MSN FFTA Samples						

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.346	0.346	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFPeA	2706-90-3	<0.398	0.398	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFBS	375-73-5	<0.304	0.304	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
4:2 FTS	757124-72-4	<0.360	0.360	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFHxA	307-24-4	<0.216	0.216	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFPeS	2706-91-4	<0.658	0.658	1.00		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
HFPO-DA	13252-13-6	<1.18	1.18	1.50		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFHpA	375-85-9	<0.478	0.478	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
ADONA	919005-14-4	<0.340	0.340	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFHxS	355-46-4	<0.390	0.390	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
6:2 FTS	27619-97-2	<0.654	0.654	1.00		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFOA	335-67-1	<0.470	0.470	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFHpS	375-92-8	<0.738	0.738	1.00		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFNA	375-95-1	<0.312	0.312	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFOSA	754-91-6	<1.01	1.01	1.50		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFOS	1763-23-1	<0.430	0.430	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
9Cl-PF3ONS	756426-58-1	<0.370	0.370	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFDA	335-76-2	<0.452	0.452	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
8:2 FTS	39108-34-4	<0.722	0.722	1.00		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFNS	68259-12-1	<1.15	1.15	1.50		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
MeFOSAA	2355-31-9	<0.736	0.736	1.00		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
EtFOSAA	2991-50-6	<0.688	0.688	1.00		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFUnA	2058-94-8	<0.258	0.258	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFDS	335-77-3	<0.690	0.690	1.00		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
11Cl-PF3OUdS	763051-92-9	<0.722	0.722	1.00		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
10:2 FTS	120226-60-0	<1.02	1.02	1.50		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFDoA	307-55-1	<0.404	0.404	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
MeFOSA	31506-32-8	<5.78	5.78	10.0		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFTrDA	72629-94-8	<0.402	0.402	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFDoS	79780-39-5	<0.600	0.600	1.00		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFTeDA	376-06-7	<0.264	0.264	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
EtFOSA	4151-50-2	<3.84	3.84	10.0		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFHxDA	67905-19-5	<0.170	0.170	0.500		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
PFODA	16517-11-6	<0.500	0.500	1.00		B0G0144	20-Jul-20	1.00 g	27-Jul-20 18:12	1
MeFOSE	24448-09-7	<4.96	4.96	10.0		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
EtFOSE	1691-99-2	<5.38	5.38	10.0		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	84.1	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1

SR079

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data
Name: LimnoTech, Inc. Matrix: Solid
Project: MSN FFTA Samples

Laboratory Data
Lab Sample: B0G0144-BLK1 Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	76.3	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C3-PFBS	IS	83.1	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C3-HFPO-DA	IS	67.5	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-4:2 FTS	IS	82.0	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-PFHxA	IS	68.0	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C4-PFHpA	IS	67.8	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C3-PFHxS	IS	84.9	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-6:2 FTS	IS	84.1	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C5-PFNA	IS	66.4	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C8-PFOSA	IS	33.6	10 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-PFOA	IS	70.6	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C8-PFOS	IS	70.4	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-PFDA	IS	54.6	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-8:2 FTS	IS	85.3	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
d3-MeFOSAA	IS	49.0	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-PFUnA	IS	41.4	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
d5-EtFOSAA	IS	49.3	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-10:2 FTS	IS	70.1	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-PFDoA	IS	41.6	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
d3-MeFOSA	IS	8.80	10 - 150	H	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-PFTeDA	IS	45.9	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
d5-EtFOSA	IS	6.70	10 - 150	H	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
13C2-PFHxDA	IS	37.4	25 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
d7-MeFOSE	IS	21.0	10 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1
d9-EtFOSE	IS	19.2	10 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:11	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Solid

Laboratory Data

Lab Sample: B0G0144-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/g)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	0.910	1.00	91.0	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFPeA	2706-90-3	0.930	1.00	93.0	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFBS	375-73-5	0.992	1.00	99.2	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
4:2 FTS	757124-72-4	1.01	1.00	101	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFHxA	307-24-4	0.875	1.00	87.5	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFPeS	2706-91-4	0.901	1.00	90.1	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
HFPO-DA	13252-13-6	0.868	1.00	86.8	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFHpA	375-85-9	0.897	1.00	89.7	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
ADONA	919005-14-4	0.609	1.00	60.9	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFHxS	355-46-4	0.997	1.00	99.7	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
6:2 FTS	27619-97-2	0.809	1.00	80.9	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFOA	335-67-1	0.907	1.00	90.7	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFHpS	375-92-8	1.14	1.00	114	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFNA	375-95-1	0.885	1.00	88.5	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFOSA	754-91-6	0.960	1.00	96.0	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFOS	1763-23-1	1.29	1.00	129	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
9Cl-PF3ONS	756426-58-1	1.02	1.00	102	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFDA	335-76-2	1.08	1.00	108	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
8:2 FTS	39108-34-4	1.10	1.00	110	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFNS	68259-12-1	0.716	1.00	71.6	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
MeFOSAA	2355-31-9	0.986	1.00	98.6	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
EtFOSAA	2991-50-6	0.546	1.00	54.6	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFUnA	2058-94-8	0.897	1.00	89.7	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFDS	335-77-3	0.764	1.00	76.4	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
11Cl-PF3OUdS	763051-92-9	1.36	1.00	136	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
10:2 FTS	120226-60-0	0.784	1.00	78.4	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFDoA	307-55-1	0.918	1.00	91.8	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
MeFOSA	31506-32-8	5.58	5.00	112	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFTrDA	72629-94-8	0.959	1.00	95.9	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFDoS	79780-39-5	1.08	1.00	108	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFTeDA	376-06-7	0.847	1.00	84.7	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
EtFOSA	4151-50-2	5.61	5.00	112	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFHxDA	67905-19-5	0.846	1.00	84.6	50 - 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
PFODA	16517-11-6	0.431	1.00	43.1	50 - 150	J, H	B0G0144	20-Jul-20	1.00 g	27-Jul-20 18:22	1

Vista Analytical Laboratory

Sample ID: OPR | **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Solid

Laboratory Data

Lab Sample: B0G0144-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/g)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
MeFOSE	24448-09-7	4.97	5.00	99.4	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
EtFOSE	1691-99-2	5.90	5.00	118	50 - 150	J	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1

Labeled Standards	Type	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	101	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C3-PFPeA	IS	89.8	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C3-PFBS	IS	91.5	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C3-HFPO-DA	IS	84.7	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-4:2 FTS	IS	86.5	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-PFHxA	IS	84.9	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C4-PFHpA	IS	82.9	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C3-PFHxS	IS	82.8	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-6:2 FTS	IS	92.6	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C5-PFNA	IS	79.3	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C8-PFOSA	IS	36.7	10- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-PFOA	IS	84.9	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C8-PFOS	IS	79.0	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-PFDA	IS	67.9	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-8:2 FTS	IS	93.8	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
d3-MeFOSAA	IS	48.4	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-PFUnA	IS	51.1	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
d5-EtFOSAA	IS	52.5	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-10:2 FTS	IS	65.4	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-PFDoA	IS	47.8	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
d3-MeFOSA	IS	11.8	10- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-PFTeDA	IS	53.4	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
d5-EtFOSA	IS	9.10	10- 150	H	B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
13C2-PFHxDA	IS	45.6	25- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
d7-MeFOSE	IS	21.1	10- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1
d9-EtFOSE	IS	18.0	10- 150		B0G0144	20-Jul-20	1.00 g	23-Jul-20 14:22	1

Vista Analytical Laboratory

Sample ID: SBT20-01 (10.5-11) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-01	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 11:00	Date Received:	14-Jul-20 09:11		
				% Solids:	92.6		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	1.37	0.334	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFPeA	2706-90-3	5.58	0.384	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFBS	375-73-5	4.98	0.293	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
4:2 FTS	757124-72-4	<0.347	0.347	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFHxA	307-24-4	31.9	0.208	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFPeS	2706-91-4	6.05	0.634	0.964		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
HFPO-DA	13252-13-6	<1.14	1.14	1.45		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFHpA	375-85-9	10.8	0.461	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
ADONA	919005-14-4	<0.328	0.328	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFHxS	355-46-4	250	0.376	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
6:2 FTS	27619-97-2	2.06	0.631	0.964		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFOA	335-67-1	279	0.453	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFHpS	375-92-8	<0.712	0.712	0.964		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFNA	375-95-1	<0.301	0.301	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFOSA	754-91-6	<0.972	0.972	1.45		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFOS	1763-23-1	<0.415	0.415	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
9Cl-PF3ONS	756426-58-1	<0.357	0.357	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFDA	335-76-2	<0.436	0.436	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
8:2 FTS	39108-34-4	<0.696	0.696	0.964		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFNS	68259-12-1	<1.11	1.11	1.45		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
MeFOSAA	2355-31-9	<0.710	0.710	0.964		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
EtFOSAA	2991-50-6	<0.663	0.663	0.964		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFUnA	2058-94-8	<0.249	0.249	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFDS	335-77-3	<0.665	0.665	0.964		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
11Cl-PF3OUdS	763051-92-9	<0.696	0.696	0.964		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
10:2 FTS	120226-60-0	<0.980	0.980	1.45		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFDoA	307-55-1	<0.390	0.390	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
MeFOSA	31506-32-8	<5.57	5.57	9.64		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFTrDA	72629-94-8	<0.388	0.388	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFDoS	79780-39-5	<0.579	0.579	0.964		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFTeDA	376-06-7	<0.255	0.255	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
EtFOSA	4151-50-2	<3.70	3.70	9.64		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFHxDA	67905-19-5	<0.164	0.164	0.482		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
PFODA	16517-11-6	<0.482	0.482	0.964		B0G0144	20-Jul-20	1.12 g	27-Jul-20 18:33	1
MeFOSE	24448-09-7	<4.78	4.78	9.64		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
EtFOSE	1691-99-2	<5.19	5.19	9.64		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	101	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1

SR083

Vista Analytical Laboratory

Sample ID: SBT20-01 (10.5-11) **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Soil
Date Collected: 07-Jul-20 11:00

Laboratory Data

Lab Sample: 2001473-01
Date Received: 14-Jul-20 09:11
% Solids: 92.6
Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	85.3	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C3-PFBS	IS	89.6	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C3-HFPO-DA	IS	75.7	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-4:2 FTS	IS	87.4	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-PFHxA	IS	78.6	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C4-PFHpA	IS	77.6	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C3-PFHxS	IS	75.3	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-6:2 FTS	IS	98.4	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C5-PFNA	IS	79.9	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C8-PFOSA	IS	46.7	10 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-PFOA	IS	81.1	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C8-PFOS	IS	82.8	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-PFDA	IS	67.3	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-8:2 FTS	IS	89.5	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
d3-MeFOSAA	IS	68.8	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-PFUnA	IS	59.2	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
d5-EtFOSAA	IS	67.1	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-10:2 FTS	IS	70.1	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-PFDoA	IS	56.2	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
d3-MeFOSA	IS	10.7	10 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-PFTeDA	IS	65.3	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
d5-EtFOSA	IS	8.20	10 - 150	H	B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
13C2-PFHxDA	IS	65.2	25 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
d7-MeFOSE	IS	26.7	10 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1
d9-EtFOSE	IS	27.1	10 - 150		B0G0144	20-Jul-20	1.12 g	23-Jul-20 14:32	1

MDL - Method Detection Limit   RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-05-(0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-03	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 11:45	Date Received:	14-Jul-20 09:11		
				% Solids:	89.3		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.343	0.343	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFPeA	2706-90-3	<0.394	0.394	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFBS	375-73-5	<0.301	0.301	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
4:2 FTS	757124-72-4	<0.357	0.357	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFHxA	307-24-4	<0.214	0.214	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFPeS	2706-91-4	<0.652	0.652	0.991		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
HFPO-DA	13252-13-6	<1.17	1.17	1.49		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFHpA	375-85-9	<0.473	0.473	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
ADONA	919005-14-4	<0.337	0.337	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFHxS	355-46-4	0.679	0.386	0.495	Q	B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
6:2 FTS	27619-97-2	<0.648	0.648	0.991		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFOA	335-67-1	<0.466	0.466	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFHpS	375-92-8	<0.731	0.731	0.991		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFNA	375-95-1	<0.309	0.309	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFOSA	754-91-6	<0.999	0.999	1.49		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFOS	1763-23-1	3.31	0.426	0.495	Q	B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
9Cl-PF3ONS	756426-58-1	<0.367	0.367	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFDA	335-76-2	<0.448	0.448	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
8:2 FTS	39108-34-4	<0.715	0.715	0.991		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFNS	68259-12-1	<1.14	1.14	1.49		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
MeFOSAA	2355-31-9	<0.729	0.729	0.991		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
EtFOSAA	2991-50-6	<0.682	0.682	0.991		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFUnA	2058-94-8	<0.256	0.256	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFDS	335-77-3	<0.683	0.683	0.991		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
11Cl-PF3OUdS	763051-92-9	<0.715	0.715	0.991		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
10:2 FTS	120226-60-0	<1.01	1.01	1.49		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFDoA	307-55-1	<0.400	0.400	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
MeFOSA	31506-32-8	<5.73	5.73	9.91		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFTrDA	72629-94-8	<0.398	0.398	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFDoS	79780-39-5	<0.594	0.594	0.991		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFTeDA	376-06-7	<0.262	0.262	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
EtFOSA	4151-50-2	<3.80	3.80	9.91		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFHxDA	67905-19-5	<0.168	0.168	0.495		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
PFODA	16517-11-6	<0.495	0.495	0.991		B0G0144	20-Jul-20	1.13 g	27-Jul-20 18:43	1
MeFOSE	24448-09-7	<4.91	4.91	9.91		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
EtFOSE	1691-99-2	<5.33	5.33	9.91		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	92.9	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1

SR085

Vista Analytical Laboratory

Sample ID: SBT20-05-(0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-03	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 11:45	Date Received:	14-Jul-20 09:11		
				% Solids:	89.3		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	77.3	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C3-PFBS	IS	80.9	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C3-HFPO-DA	IS	71.5	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-4:2 FTS	IS	77.4	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-PFHxA	IS	69.9	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C4-PFHpA	IS	65.3	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C3-PFHxS	IS	81.2	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-6:2 FTS	IS	81.4	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C5-PFNA	IS	61.1	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C8-PFOSA	IS	46.5	10 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-PFOA	IS	70.8	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C8-PFOS	IS	70.2	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-PFDA	IS	55.5	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-8:2 FTS	IS	76.7	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
d3-MeFOSAA	IS	55.6	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-PFUnA	IS	55.9	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
d5-EtFOSAA	IS	57.2	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-10:2 FTS	IS	68.6	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-PFDoA	IS	58.1	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
d3-MeFOSA	IS	19.4	10 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-PFTeDA	IS	61.7	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
d5-EtFOSA	IS	15.6	10 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
13C2-PFHxDA	IS	43.9	25 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
d7-MeFOSE	IS	32.7	10 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1
d9-EtFOSE	IS	33.0	10 - 150		B0G0144	20-Jul-20	1.13 g	23-Jul-20 14:43	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-05 (10.5-11) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-04	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 12:10	Date Received:	14-Jul-20 09:11		
				% Solids:	91.5		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.344	0.344	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFPeA	2706-90-3	<0.395	0.395	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFBS	375-73-5	<0.302	0.302	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
4:2 FTS	757124-72-4	<0.358	0.358	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFHxA	307-24-4	0.222	0.215	0.497	J, Q	B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFPeS	2706-91-4	<0.654	0.654	0.994		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
HFPO-DA	13252-13-6	<1.17	1.17	1.49		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFHpA	375-85-9	<0.475	0.475	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
ADONA	919005-14-4	<0.338	0.338	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFHxS	355-46-4	1.96	0.388	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
6:2 FTS	27619-97-2	<0.650	0.650	0.994		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFOA	335-67-1	0.581	0.467	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFHpS	375-92-8	<0.733	0.733	0.994		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFNA	375-95-1	<0.310	0.310	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFOSA	754-91-6	<1.00	1.00	1.49		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFOS	1763-23-1	6.67	0.427	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
9Cl-PF3ONS	756426-58-1	<0.368	0.368	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFDA	335-76-2	<0.449	0.449	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
8:2 FTS	39108-34-4	<0.717	0.717	0.994		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFNS	68259-12-1	<1.14	1.14	1.49		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
MeFOSAA	2355-31-9	<0.731	0.731	0.994		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
EtFOSAA	2991-50-6	<0.684	0.684	0.994		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFUnA	2058-94-8	<0.256	0.256	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFDS	335-77-3	<0.686	0.686	0.994		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
11Cl-PF3OUdS	763051-92-9	<0.717	0.717	0.994		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
10:2 FTS	120226-60-0	<1.01	1.01	1.49		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFDoA	307-55-1	<0.401	0.401	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
MeFOSA	31506-32-8	<5.74	5.74	9.94		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFTrDA	72629-94-8	<0.399	0.399	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFDoS	79780-39-5	<0.596	0.596	0.994		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFTeDA	376-06-7	<0.262	0.262	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
EtFOSA	4151-50-2	<3.82	3.82	9.94		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFHxDA	67905-19-5	<0.169	0.169	0.497		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
PFODA	16517-11-6	<0.497	0.497	0.994		B0G0144	20-Jul-20	1.10 g	27-Jul-20 18:54	1
MeFOSE	24448-09-7	<4.93	4.93	9.94		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
EtFOSE	1691-99-2	<5.35	5.35	9.94		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	105	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1

SR087

Vista Analytical Laboratory

Sample ID: SBT20-05 (10.5-11) **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-04	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 12:10	Date Received:	14-Jul-20 09:11		
				% Solids:	91.5		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	88.8	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C3-PFBS	IS	85.0	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C3-HFPO-DA	IS	82.7	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-4:2 FTS	IS	80.3	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-PFHxA	IS	78.2	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C4-PFHpA	IS	81.0	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C3-PFHxS	IS	83.9	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-6:2 FTS	IS	85.4	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C5-PFNA	IS	73.6	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C8-PFOSA	IS	43.9	10 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-PFOA	IS	80.4	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C8-PFOS	IS	70.6	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-PFDA	IS	64.0	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-8:2 FTS	IS	82.1	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
d3-MeFOSAA	IS	50.0	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-PFUnA	IS	53.1	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
d5-EtFOSAA	IS	52.3	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-10:2 FTS	IS	65.1	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-PFDoA	IS	49.6	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
d3-MeFOSA	IS	10.7	10 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-PFTeDA	IS	55.3	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
d5-EtFOSA	IS	7.90	10 - 150	H	B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
13C2-PFHxDA	IS	39.5	25 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
d7-MeFOSE	IS	24.8	10 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1
d9-EtFOSE	IS	23.7	10 - 150		B0G0144	20-Jul-20	1.10 g	23-Jul-20 14:54	1

MDL - Method Detection Limit

RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-04 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-05	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 12:20	Date Received:	14-Jul-20 09:11		
				% Solids:	86.4		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	0.395	0.342	0.495	J	B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFPeA	2706-90-3	<0.394	0.394	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFBS	375-73-5	<0.301	0.301	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
4:2 FTS	757124-72-4	<0.356	0.356	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFHxA	307-24-4	0.438	0.214	0.495	J	B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFPeS	2706-91-4	<0.651	0.651	0.989		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
HFPO-DA	13252-13-6	<1.17	1.17	1.48		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFHpA	375-85-9	<0.473	0.473	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
ADONA	919005-14-4	<0.336	0.336	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFHxS	355-46-4	2.27	0.386	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
6:2 FTS	27619-97-2	<0.647	0.647	0.989		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFOA	335-67-1	0.538	0.465	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFHpS	375-92-8	<0.730	0.730	0.989		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFNA	375-95-1	<0.309	0.309	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFOSA	754-91-6	<0.997	0.997	1.48		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFOS	1763-23-1	8.35	0.425	0.495	Q	B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
9Cl-PF3ONS	756426-58-1	<0.366	0.366	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFDA	335-76-2	<0.447	0.447	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
8:2 FTS	39108-34-4	<0.714	0.714	0.989		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFNS	68259-12-1	<1.14	1.14	1.48		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
MeFOSAA	2355-31-9	<0.728	0.728	0.989		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
EtFOSAA	2991-50-6	<0.681	0.681	0.989		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFUnA	2058-94-8	<0.255	0.255	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFDS	335-77-3	<0.683	0.683	0.989		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
11Cl-PF3OUdS	763051-92-9	<0.714	0.714	0.989		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
10:2 FTS	120226-60-0	<1.01	1.01	1.48		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFDoA	307-55-1	<0.400	0.400	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
MeFOSA	31506-32-8	<5.72	5.72	9.89		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFTrDA	72629-94-8	<0.398	0.398	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFDoS	79780-39-5	<0.594	0.594	0.989		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFTeDA	376-06-7	<0.261	0.261	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
EtFOSA	4151-50-2	<3.80	3.80	9.89		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFHxDA	67905-19-5	<0.168	0.168	0.495		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
PFODA	16517-11-6	<0.495	0.495	0.989		B0G0144	20-Jul-20	1.17 g	27-Jul-20 19:05	1
MeFOSE	24448-09-7	<4.91	4.91	9.89		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
EtFOSE	1691-99-2	<5.32	5.32	9.89		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	93.4	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1

SR089

Vista Analytical Laboratory

Sample ID: SBT20-04 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-05	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 12:20	Date Received:	14-Jul-20 09:11		
				% Solids:	86.4		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	75.9	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C3-PFBS	IS	80.9	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C3-HFPO-DA	IS	70.6	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-4:2 FTS	IS	82.5	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-PFHxA	IS	69.8	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C4-PFHpA	IS	69.9	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C3-PFHxS	IS	83.4	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-6:2 FTS	IS	86.2	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C5-PFNA	IS	63.7	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C8-PFOSA	IS	47.6	10 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-PFOA	IS	72.7	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C8-PFOS	IS	78.0	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-PFDA	IS	52.6	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-8:2 FTS	IS	77.4	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
d3-MeFOSAA	IS	57.7	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-PFUnA	IS	59.4	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
d5-EtFOSAA	IS	63.2	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-10:2 FTS	IS	71.1	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-PFDoA	IS	61.9	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
d3-MeFOSA	IS	19.3	10 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-PFTeDA	IS	60.5	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
d5-EtFOSA	IS	18.7	10 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
13C2-PFHxDA	IS	38.6	25 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
d7-MeFOSE	IS	35.1	10 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1
d9-EtFOSE	IS	38.9	10 - 150		B0G0144	20-Jul-20	1.17 g	23-Jul-20 15:36	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

SR090

Vista Analytical Laboratory

Sample ID: SBT20-04 (6-6.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-07	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 12:30	Date Received:	14-Jul-20 09:11		
				% Solids:	83.2		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.344	0.344	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFPeA	2706-90-3	<0.396	0.396	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFBS	375-73-5	<0.302	0.302	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
4:2 FTS	757124-72-4	<0.358	0.358	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFHxA	307-24-4	0.331	0.215	0.497	J	B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFPeS	2706-91-4	<0.654	0.654	0.994		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
HFPO-DA	13252-13-6	<1.17	1.17	1.49		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFHpA	375-85-9	<0.475	0.475	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
ADONA	919005-14-4	<0.338	0.338	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFHxS	355-46-4	0.715	0.388	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
6:2 FTS	27619-97-2	<0.650	0.650	0.994		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFOA	335-67-1	0.573	0.467	0.497	Q	B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFHpS	375-92-8	<0.733	0.733	0.994		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFNA	375-95-1	<0.310	0.310	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFOSA	754-91-6	<1.00	1.00	1.49		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFOS	1763-23-1	2.40	0.427	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
9Cl-PF3ONS	756426-58-1	<0.368	0.368	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFDA	335-76-2	<0.449	0.449	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
8:2 FTS	39108-34-4	<0.718	0.718	0.994		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFNS	68259-12-1	<1.14	1.14	1.49		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
MeFOSAA	2355-31-9	<0.731	0.731	0.994		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
EtFOSAA	2991-50-6	<0.684	0.684	0.994		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFUnA	2058-94-8	<0.256	0.256	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFDS	335-77-3	<0.686	0.686	0.994		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
11Cl-PF3OUdS	763051-92-9	<0.718	0.718	0.994		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
10:2 FTS	120226-60-0	<1.01	1.01	1.49		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFDoA	307-55-1	<0.402	0.402	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
MeFOSA	31506-32-8	<5.74	5.74	9.94		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFTrDA	72629-94-8	<0.400	0.400	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFDoS	79780-39-5	<0.596	0.596	0.994		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFTeDA	376-06-7	<0.262	0.262	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
EtFOSA	4151-50-2	<3.82	3.82	9.94		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFHxDA	67905-19-5	<0.169	0.169	0.497		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
PFODA	16517-11-6	<0.497	0.497	0.994		B0G0144	20-Jul-20	1.21 g	27-Jul-20 19:15	1
MeFOSE	24448-09-7	<4.93	4.93	9.94		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
EtFOSE	1691-99-2	<5.35	5.35	9.94		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	83.3	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1

Vista Analytical Laboratory

Sample ID: SBT20-04 (6-6.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-07	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 12:30	Date Received:	14-Jul-20 09:11		
				% Solids:	83.2		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	69.0	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C3-PFBS	IS	80.1	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C3-HFPO-DA	IS	59.7	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-4:2 FTS	IS	80.8	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-PFHxA	IS	62.1	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C4-PFHpA	IS	62.9	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C3-PFHxS	IS	78.8	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-6:2 FTS	IS	79.4	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C5-PFNA	IS	50.9	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C8-PFOSA	IS	41.2	10 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-PFOA	IS	63.7	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C8-PFOS	IS	62.4	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-PFDA	IS	48.2	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-8:2 FTS	IS	70.9	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
d3-MeFOSAA	IS	57.9	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-PFUnA	IS	54.4	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
d5-EtFOSAA	IS	58.4	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-10:2 FTS	IS	66.9	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-PFDoA	IS	56.6	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
d3-MeFOSA	IS	12.7	10 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-PFTeDA	IS	56.0	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
d5-EtFOSA	IS	9.60	10 - 150	H	B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
13C2-PFHxDA	IS	36.7	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
d7-MeFOSE	IS	28.5	10 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1
d9-EtFOSE	IS	30.6	10 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 15:46	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SOIL DUPLICATE A **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-10	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 00:00	Date Received:	14-Jul-20 09:11		
				% Solids:	85.5		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.340	0.340	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFPeA	2706-90-3	<0.391	0.391	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFBS	375-73-5	<0.299	0.299	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
4:2 FTS	757124-72-4	<0.354	0.354	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFHxA	307-24-4	<0.212	0.212	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFPeS	2706-91-4	<0.647	0.647	0.983		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
HFPO-DA	13252-13-6	<1.16	1.16	1.47		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFHpA	375-85-9	<0.470	0.470	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
ADONA	919005-14-4	<0.334	0.334	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFHxS	355-46-4	0.786	0.383	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
6:2 FTS	27619-97-2	<0.643	0.643	0.983		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFOA	335-67-1	<0.462	0.462	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFHpS	375-92-8	<0.726	0.726	0.983		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFNA	375-95-1	<0.307	0.307	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFOSA	754-91-6	<0.991	0.991	1.47		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFOS	1763-23-1	3.48	0.423	0.492	Q	B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
9Cl-PF3ONS	756426-58-1	<0.364	0.364	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFDA	335-76-2	<0.444	0.444	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
8:2 FTS	39108-34-4	<0.710	0.710	0.983		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFNS	68259-12-1	<1.13	1.13	1.47		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
MeFOSAA	2355-31-9	<0.724	0.724	0.983		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
EtFOSAA	2991-50-6	<0.677	0.677	0.983		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFUnA	2058-94-8	<0.254	0.254	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFDS	335-77-3	<0.678	0.678	0.983		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
11Cl-PF3OUdS	763051-92-9	<0.710	0.710	0.983		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
10:2 FTS	120226-60-0	<0.999	0.999	1.47		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFDoA	307-55-1	<0.397	0.397	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
MeFOSA	31506-32-8	<5.68	5.68	9.83		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFTrDA	72629-94-8	<0.395	0.395	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFDoS	79780-39-5	<0.590	0.590	0.983		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFTeDA	376-06-7	<0.260	0.260	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
EtFOSA	4151-50-2	<3.78	3.78	9.83		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFHxDA	67905-19-5	<0.167	0.167	0.492		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
PFODA	16517-11-6	<0.492	0.492	0.983		B0G0144	20-Jul-20	1.19 g	27-Jul-20 19:58	1
MeFOSE	24448-09-7	<4.88	4.88	9.83		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
EtFOSE	1691-99-2	<5.29	5.29	9.83		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	85.3	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1

Vista Analytical Laboratory

Sample ID: SOIL DUPLICATE A **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-10	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 00:00	Date Received:	14-Jul-20 09:11		
				% Solids:	85.5		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	70.3	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C3-PFBS	IS	80.6	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C3-HFPO-DA	IS	66.9	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-4:2 FTS	IS	80.0	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-PFHxA	IS	65.8	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C4-PFHpA	IS	65.0	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C3-PFHxS	IS	80.6	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-6:2 FTS	IS	85.6	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C5-PFNA	IS	60.8	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C8-PFOSA	IS	37.4	10 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-PFOA	IS	65.1	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C8-PFOS	IS	69.6	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-PFDA	IS	53.7	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-8:2 FTS	IS	81.6	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
d3-MeFOSAA	IS	54.5	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-PFUnA	IS	55.7	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
d5-EtFOSAA	IS	62.1	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-10:2 FTS	IS	63.0	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-PFDoA	IS	57.8	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
d3-MeFOSA	IS	13.9	10 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-PFTeDA	IS	59.2	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
d5-EtFOSA	IS	12.4	10 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
13C2-PFHxDA	IS	41.7	25 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
d7-MeFOSE	IS	27.1	10 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1
d9-EtFOSE	IS	29.0	10 - 150		B0G0144	20-Jul-20	1.19 g	23-Jul-20 15:57	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

SR094

Vista Analytical Laboratory

Sample ID: SBT20-02 (0-1) **PFAS Isotope Dilution Method**

Client Data
Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Soil
Date Collected: 07-Jul-20 08:05

Laboratory Data
Lab Sample: 2001473-11
Date Received: 14-Jul-20 09:11
% Solids: 80.2
Column: BEH C18

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	1.28	0.342	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFPeA	2706-90-3	2.02	0.394	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFBS	375-73-5	<0.301	0.301	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
4:2 FTS	757124-72-4	<0.356	0.356	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFHxA	307-24-4	1.12	0.214	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFPeS	2706-91-4	<0.651	0.651	0.989		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
HFPO-DA	13252-13-6	<1.17	1.17	1.48		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFHpA	375-85-9	0.681	0.473	0.495	Q	B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
ADONA	919005-14-4	<0.336	0.336	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFHxS	355-46-4	4.37	0.386	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
6:2 FTS	27619-97-2	<0.647	0.647	0.989		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFOA	335-67-1	2.37	0.465	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFHpS	375-92-8	<0.730	0.730	0.989		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFNA	375-95-1	2.26	0.309	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFOSA	754-91-6	1.29	0.997	1.48	J	B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFOS	1763-23-1	68.0	0.425	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
9Cl-PF3ONS	756426-58-1	<0.366	0.366	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFDA	335-76-2	0.452	0.447	0.495	J	B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
8:2 FTS	39108-34-4	<0.714	0.714	0.989		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFNS	68259-12-1	<1.14	1.14	1.48		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
MeFOSAA	2355-31-9	<0.728	0.728	0.989		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
EtFOSAA	2991-50-6	<0.680	0.680	0.989		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFUnA	2058-94-8	0.472	0.255	0.495	J	B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFDS	335-77-3	<0.682	0.682	0.989		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
11Cl-PF3OUdS	763051-92-9	<0.714	0.714	0.989		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
10:2 FTS	120226-60-0	<1.00	1.00	1.48		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFDoA	307-55-1	<0.400	0.400	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
MeFOSA	31506-32-8	<5.72	5.72	9.89		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFTrDA	72629-94-8	<0.398	0.398	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFDoS	79780-39-5	<0.593	0.593	0.989		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFTeDA	376-06-7	<0.261	0.261	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
EtFOSA	4151-50-2	<3.80	3.80	9.89		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFHxDA	67905-19-5	<0.168	0.168	0.495		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
PFODA	16517-11-6	<0.495	0.495	0.989		B0G0144	20-Jul-20	1.26 g	27-Jul-20 20:08	1
MeFOSE	24448-09-7	<4.91	4.91	9.89		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
EtFOSE	1691-99-2	<5.32	5.32	9.89		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	92.0	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1

Vista Analytical Laboratory

Sample ID: SBT20-02 (0-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-11	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 08:05	Date Received:	14-Jul-20 09:11		
				% Solids:	80.2		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	80.4	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C3-PFBS	IS	93.4	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C3-HFPO-DA	IS	72.1	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-4:2 FTS	IS	100	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-PFHxA	IS	79.3	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C4-PFHpA	IS	77.2	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C3-PFHxS	IS	89.0	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-6:2 FTS	IS	95.1	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C5-PFNA	IS	63.8	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C8-PFOSA	IS	47.1	10 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-PFOA	IS	77.0	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C8-PFOS	IS	73.5	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-PFDA	IS	57.6	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-8:2 FTS	IS	87.9	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
d3-MeFOSAA	IS	66.3	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-PFUnA	IS	64.6	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
d5-EtFOSAA	IS	68.0	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-10:2 FTS	IS	72.6	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-PFDoA	IS	71.2	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
d3-MeFOSA	IS	11.3	10 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-PFTeDA	IS	62.5	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
d5-EtFOSA	IS	12.9	10 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
13C2-PFHxDA	IS	40.0	25 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
d7-MeFOSE	IS	36.6	10 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1
d9-EtFOSE	IS	39.3	10 - 150		B0G0144	20-Jul-20	1.26 g	23-Jul-20 16:08	1

MDL - Method Detection Limit

RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-02 (10-10.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-13	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 08:15	Date Received:	14-Jul-20 09:11		
				% Solids:	83.7		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.341	0.341	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFPeA	2706-90-3	<0.393	0.393	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFBS	375-73-5	<0.300	0.300	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
4:2 FTS	757124-72-4	<0.355	0.355	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFHxA	307-24-4	<0.213	0.213	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFPeS	2706-91-4	<0.649	0.649	0.987		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
HFPO-DA	13252-13-6	<1.16	1.16	1.48		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFHpA	375-85-9	<0.472	0.472	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
ADONA	919005-14-4	<0.336	0.336	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFHxS	355-46-4	0.563	0.385	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
6:2 FTS	27619-97-2	<0.645	0.645	0.987		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFOA	335-67-1	<0.464	0.464	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFHpS	375-92-8	<0.728	0.728	0.987		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFNA	375-95-1	<0.308	0.308	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFOSA	754-91-6	<0.995	0.995	1.48		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFOS	1763-23-1	1.70	0.424	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
9Cl-PF3ONS	756426-58-1	<0.365	0.365	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFDA	335-76-2	<0.446	0.446	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
8:2 FTS	39108-34-4	<0.713	0.713	0.987		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFNS	68259-12-1	<1.13	1.13	1.48		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
MeFOSAA	2355-31-9	<0.726	0.726	0.987		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
EtFOSAA	2991-50-6	<0.679	0.679	0.987		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFUnA	2058-94-8	<0.255	0.255	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFDS	335-77-3	<0.681	0.681	0.987		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
11Cl-PF3OUdS	763051-92-9	<0.713	0.713	0.987		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
10:2 FTS	120226-60-0	<1.00	1.00	1.48		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFDoA	307-55-1	<0.399	0.399	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
MeFOSA	31506-32-8	<5.70	5.70	9.87		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFTrDA	72629-94-8	<0.397	0.397	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFDoS	79780-39-5	<0.592	0.592	0.987		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFTeDA	376-06-7	<0.261	0.261	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
EtFOSA	4151-50-2	<3.79	3.79	9.87		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFHxDA	67905-19-5	<0.168	0.168	0.493		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
PFODA	16517-11-6	<0.493	0.493	0.987		B0G0144	20-Jul-20	1.21 g	27-Jul-20 20:19	1
MeFOSE	24448-09-7	<4.89	4.89	9.87		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
EtFOSE	1691-99-2	<5.31	5.31	9.87		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	95.0	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1

SR097

Vista Analytical Laboratory

Sample ID: SBT20-02 (10-10.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-13	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 08:15	Date Received:	14-Jul-20 09:11		
				% Solids:	83.7		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	80.4	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C3-PFBS	IS	81.2	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C3-HFPO-DA	IS	69.7	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-4:2 FTS	IS	76.3	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-PFHxA	IS	67.9	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C4-PFHpA	IS	73.7	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C3-PFHxS	IS	81.7	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-6:2 FTS	IS	82.1	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C5-PFNA	IS	64.1	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C8-PFOSA	IS	38.4	10 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-PFOA	IS	72.4	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C8-PFOS	IS	67.6	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-PFDA	IS	53.4	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-8:2 FTS	IS	74.4	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
d3-MeFOSAA	IS	51.7	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-PFUnA	IS	52.7	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
d5-EtFOSAA	IS	54.7	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-10:2 FTS	IS	60.8	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-PFDoA	IS	54.1	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
d3-MeFOSA	IS	9.90	10 - 150	H	B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-PFTeDA	IS	58.4	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
d5-EtFOSA	IS	7.80	10 - 150	H	B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
13C2-PFHxDA	IS	40.7	25 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
d7-MeFOSE	IS	22.1	10 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1
d9-EtFOSE	IS	22.5	10 - 150		B0G0144	20-Jul-20	1.21 g	23-Jul-20 16:18	1

MDL - Method Detection Limit

RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-03 (0-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-14	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 08:50	Date Received:	14-Jul-20 09:11		
				% Solids:	73.2		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	2.17	0.342	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFPeA	2706-90-3	6.71	0.394	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFBS	375-73-5	1.84	0.301	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
4:2 FTS	757124-72-4	<0.356	0.356	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFHxA	307-24-4	9.77	0.214	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFPeS	2706-91-4	2.29	0.651	0.989		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
HFPO-DA	13252-13-6	<1.17	1.17	1.48		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFHpA	375-85-9	4.52	0.473	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
ADONA	919005-14-4	<0.336	0.336	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFHxS	355-46-4	107	0.386	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
6:2 FTS	27619-97-2	3.36	0.647	0.989		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFOA	335-67-1	24.4	0.465	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFHpS	375-92-8	2.90	0.730	0.989		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFNA	375-95-1	8.38	0.309	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFOSA	754-91-6	7.22	0.997	1.48		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFOS	1763-23-1	363	0.425	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
9Cl-PF3ONS	756426-58-1	<0.366	0.366	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFDA	335-76-2	4.20	0.447	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
8:2 FTS	39108-34-4	7.27	0.714	0.989		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFNS	68259-12-1	<1.14	1.14	1.48		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
MeFOSAA	2355-31-9	<0.728	0.728	0.989		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
EtFOSAA	2991-50-6	<0.681	0.681	0.989		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFUnA	2058-94-8	4.44	0.255	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFDS	335-77-3	1.46	0.683	0.989		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
11Cl-PF3OUdS	763051-92-9	<0.714	0.714	0.989		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
10:2 FTS	120226-60-0	<1.01	1.01	1.48		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFDoA	307-55-1	<0.400	0.400	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
MeFOSA	31506-32-8	<5.72	5.72	9.89		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFTrDA	72629-94-8	<0.398	0.398	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFDoS	79780-39-5	0.656	0.594	0.989	J	B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFTeDA	376-06-7	<0.261	0.261	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
EtFOSA	4151-50-2	<3.80	3.80	9.89		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFHxDA	67905-19-5	<0.168	0.168	0.495		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
PFODA	16517-11-6	<0.495	0.495	0.989		B0G0144	20-Jul-20	1.38 g	27-Jul-20 20:29	1
MeFOSE	24448-09-7	<4.91	4.91	9.89		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
EtFOSE	1691-99-2	<5.32	5.32	9.89		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	90.2	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1

SR099

Vista Analytical Laboratory

Sample ID: SBT20-03 (0-1) | **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-14	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 08:50	Date Received:	14-Jul-20 09:11		
				% Solids:	73.2		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	77.8	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C3-PFBS	IS	82.0	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C3-HFPO-DA	IS	68.6	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-4:2 FTS	IS	90.9	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-PFHxA	IS	78.7	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C4-PFHpA	IS	74.2	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C3-PFHxS	IS	74.6	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-6:2 FTS	IS	93.8	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C5-PFNA	IS	68.5	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C8-PFOSA	IS	46.6	10 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-PFOA	IS	75.8	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C8-PFOS	IS	68.1	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-PFDA	IS	63.1	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-8:2 FTS	IS	84.1	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
d3-MeFOSAA	IS	61.4	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-PFUnA	IS	63.2	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
d5-EtFOSAA	IS	60.5	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-10:2 FTS	IS	71.4	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-PFDoA	IS	67.1	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
d3-MeFOSA	IS	29.4	10 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-PFTeDA	IS	60.1	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
d5-EtFOSA	IS	29.3	10 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
13C2-PFHxDA	IS	31.0	25 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
d7-MeFOSE	IS	37.1	10 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1
d9-EtFOSE	IS	42.4	10 - 150		B0G0144	20-Jul-20	1.38 g	23-Jul-20 16:31	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

SR0100

Vista Analytical Laboratory

Sample ID: SBT20-03 (10-10.5) **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-15	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 09:05	Date Received:	14-Jul-20 09:11		
				% Solids:	92.9		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.342	0.342	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFPeA	2706-90-3	1.25	0.393	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFBS	375-73-5	0.761	0.300	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
4:2 FTS	757124-72-4	<0.356	0.356	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFHxA	307-24-4	3.45	0.213	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFPeS	2706-91-4	2.41	0.650	0.988		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
HFPO-DA	13252-13-6	<1.17	1.17	1.48		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFHpA	375-85-9	5.10	0.472	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
ADONA	919005-14-4	<0.336	0.336	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFHxS	355-46-4	188	0.385	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
6:2 FTS	27619-97-2	1.13	0.646	0.988		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFOA	335-67-1	38.5	0.464	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFHpS	375-92-8	<0.729	0.729	0.988		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFNA	375-95-1	<0.308	0.308	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFOSA	754-91-6	<0.996	0.996	1.48		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFOS	1763-23-1	<0.425	0.425	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
9Cl-PF3ONS	756426-58-1	<0.365	0.365	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFDA	335-76-2	<0.446	0.446	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
8:2 FTS	39108-34-4	<0.713	0.713	0.988		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFNS	68259-12-1	<1.14	1.14	1.48		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
MeFOSAA	2355-31-9	<0.727	0.727	0.988		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
EtFOSAA	2991-50-6	<0.680	0.680	0.988		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFUnA	2058-94-8	<0.255	0.255	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFDS	335-77-3	<0.682	0.682	0.988		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
11Cl-PF3OUdS	763051-92-9	<0.713	0.713	0.988		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
10:2 FTS	120226-60-0	<1.00	1.00	1.48		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFDoA	307-55-1	<0.399	0.399	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
MeFOSA	31506-32-8	<5.71	5.71	9.88		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFTrDA	72629-94-8	<0.397	0.397	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFDoS	79780-39-5	<0.593	0.593	0.988		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFTeDA	376-06-7	<0.261	0.261	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
EtFOSA	4151-50-2	<3.79	3.79	9.88		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFHxDA	67905-19-5	<0.168	0.168	0.494		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
PFODA	16517-11-6	<0.494	0.494	0.988		B0G0144	20-Jul-20	1.09 g	24-Jul-20 18:22	1
MeFOSE	24448-09-7	<4.90	4.90	9.88		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
EtFOSE	1691-99-2	<5.31	5.31	9.88		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	92.2	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1

Vista Analytical Laboratory

Sample ID: SBT20-03 (10-10.5) **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Soil
Date Collected: 07-Jul-20 09:05

Laboratory Data

Lab Sample: 2001473-15
Date Received: 14-Jul-20 09:11
% Solids: 92.9
Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	81.2	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C3-PFBS	IS	85.3	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C3-HFPO-DA	IS	70.0	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-4:2 FTS	IS	79.9	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-PFHxA	IS	69.8	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C4-PFHpA	IS	74.7	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C3-PFHxS	IS	76.6	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-6:2 FTS	IS	84.1	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C5-PFNA	IS	68.9	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C8-PFOSA	IS	35.3	10 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-PFOA	IS	78.5	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C8-PFOS	IS	75.9	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-PFDA	IS	57.0	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-8:2 FTS	IS	83.1	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
d3-MeFOSAA	IS	50.8	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-PFUnA	IS	51.0	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
d5-EtFOSAA	IS	40.2	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-10:2 FTS	IS	53.5	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-PFDoA	IS	43.3	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
d3-MeFOSA	IS	10.2	10 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-PFTeDA	IS	52.9	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
d5-EtFOSA	IS	7.60	10 - 150	H	B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
13C2-PFHxDA	IS	27.0	25 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
d7-MeFOSE	IS	21.3	10 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1
d9-EtFOSE	IS	20.4	10 - 150		B0G0144	20-Jul-20	1.09 g	23-Jul-20 16:42	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

SR0102

Vista Analytical Laboratory

Sample ID: SBT20-06 (0-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-17	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 10:00	Date Received:	14-Jul-20 09:11		
				% Solids:	85.8		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	0.858	0.342	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFPeA	2706-90-3	2.38	0.393	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFBS	375-73-5	0.537	0.300	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
4:2 FTS	757124-72-4	<0.356	0.356	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFHxA	307-24-4	3.27	0.213	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFPeS	2706-91-4	<0.650	0.650	0.988		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
HFPO-DA	13252-13-6	<1.17	1.17	1.48		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFHpA	375-85-9	1.61	0.472	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
ADONA	919005-14-4	<0.336	0.336	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFHxS	355-46-4	15.3	0.385	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
6:2 FTS	27619-97-2	<0.646	0.646	0.988		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFOA	335-67-1	3.71	0.464	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFHpS	375-92-8	<0.729	0.729	0.988		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFNA	375-95-1	1.42	0.308	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFOSA	754-91-6	<0.996	0.996	1.48		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFOS	1763-23-1	49.4	0.425	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
9Cl-PF3ONS	756426-58-1	<0.366	0.366	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFDA	335-76-2	<0.447	0.447	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
8:2 FTS	39108-34-4	<0.713	0.713	0.988		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFNS	68259-12-1	<1.14	1.14	1.48		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
MeFOSAA	2355-31-9	<0.727	0.727	0.988		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
EtFOSAA	2991-50-6	<0.680	0.680	0.988		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFUnA	2058-94-8	0.285	0.255	0.494	J, Q	B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFDS	335-77-3	<0.682	0.682	0.988		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
11Cl-PF3OUdS	763051-92-9	<0.713	0.713	0.988		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
10:2 FTS	120226-60-0	<1.00	1.00	1.48		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFDoA	307-55-1	<0.399	0.399	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
MeFOSA	31506-32-8	<5.71	5.71	9.88		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFTrDA	72629-94-8	<0.397	0.397	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFDoS	79780-39-5	<0.593	0.593	0.988		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFTeDA	376-06-7	<0.261	0.261	0.494		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
EtFOSA	4151-50-2	<3.79	3.79	9.88		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
PFHxDA	67905-19-5	<0.168	0.168	0.494		B0G0144	20-Jul-20	1.18 g	27-Jul-20 20:50	1
PFODA	16517-11-6	<0.494	0.494	0.988		B0G0144	20-Jul-20	1.18 g	27-Jul-20 20:50	1
MeFOSE	24448-09-7	<4.90	4.90	9.88		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
EtFOSE	1691-99-2	<5.31	5.31	9.88		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	85.7	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1

SR0103

Vista Analytical Laboratory

Sample ID: SBT20-06 (0-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-17	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 10:00	Date Received:	14-Jul-20 09:11		
				% Solids:	85.8		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	74.7	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C3-PFBS	IS	77.2	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C3-HFPO-DA	IS	67.1	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-4:2 FTS	IS	79.9	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-PFHxA	IS	65.9	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C4-PFHpA	IS	68.2	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C3-PFHxS	IS	74.4	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-6:2 FTS	IS	80.5	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C5-PFNA	IS	63.6	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C8-PFOSA	IS	44.4	10 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-PFOA	IS	70.5	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C8-PFOS	IS	64.4	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-PFDA	IS	54.3	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-8:2 FTS	IS	83.2	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
d3-MeFOSAA	IS	54.7	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-PFUnA	IS	51.5	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
d5-EtFOSAA	IS	53.3	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-10:2 FTS	IS	55.4	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-PFDoA	IS	50.6	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
d3-MeFOSA	IS	15.7	10 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-PFTeDA	IS	26.2	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
d5-EtFOSA	IS	13.3	10 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
13C2-PFHxDA	IS	22.6	25 - 150	H	B0G0144	20-Jul-20	1.18 g	27-Jul-20 20:50	1
d7-MeFOSE	IS	32.1	10 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1
d9-EtFOSE	IS	34.6	10 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 16:53	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

SR0104

Vista Analytical Laboratory

Sample ID: SBT20-06 (13-13.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-18	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 10:10	Date Received:	14-Jul-20 09:11		
				% Solids:	87.2		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.336	0.336	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFPeA	2706-90-3	0.672	0.387	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFBS	375-73-5	0.301	0.295	0.486	J	B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
4:2 FTS	757124-72-4	<0.350	0.350	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFHxA	307-24-4	1.61	0.210	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFPeS	2706-91-4	<0.639	0.639	0.972		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
HFPO-DA	13252-13-6	<1.15	1.15	1.46		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFHpA	375-85-9	<0.465	0.465	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
ADONA	919005-14-4	<0.330	0.330	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFHxS	355-46-4	<0.379	0.379	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
6:2 FTS	27619-97-2	<0.636	0.636	0.972		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFOA	335-67-1	<0.457	0.457	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFHpS	375-92-8	<0.717	0.717	0.972		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFNA	375-95-1	<0.303	0.303	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFOSA	754-91-6	<0.980	0.980	1.46		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFOS	1763-23-1	<0.418	0.418	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
9Cl-PF3ONS	756426-58-1	<0.360	0.360	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFDA	335-76-2	<0.439	0.439	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
8:2 FTS	39108-34-4	<0.702	0.702	0.972		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFNS	68259-12-1	<1.12	1.12	1.46		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
MeFOSAA	2355-31-9	<0.715	0.715	0.972		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
EtFOSAA	2991-50-6	<0.669	0.669	0.972		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFUnA	2058-94-8	<0.251	0.251	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFDS	335-77-3	<0.671	0.671	0.972		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
11Cl-PF3OUdS	763051-92-9	<0.702	0.702	0.972		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
10:2 FTS	120226-60-0	<0.987	0.987	1.46		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFDoA	307-55-1	<0.393	0.393	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
MeFOSA	31506-32-8	<5.62	5.62	9.72		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFTrDA	72629-94-8	<0.391	0.391	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFDoS	79780-39-5	<0.583	0.583	0.972		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFTeDA	376-06-7	<0.257	0.257	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
EtFOSA	4151-50-2	<3.73	3.73	9.72		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFHxDA	67905-19-5	<0.165	0.165	0.486		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
PFODA	16517-11-6	<0.486	0.486	0.972		B0G0144	20-Jul-20	1.18 g	27-Jul-20 21:01	1
MeFOSE	24448-09-7	<4.82	4.82	9.72		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
EtFOSE	1691-99-2	<5.23	5.23	9.72		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	93.9	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1

SR0105

Vista Analytical Laboratory

Sample ID: SBT20-06 (13-13.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-18	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 10:10	Date Received:	14-Jul-20 09:11		
				% Solids:	87.2		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	83.2	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C3-PFBS	IS	87.8	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C3-HFPO-DA	IS	73.2	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-4:2 FTS	IS	91.4	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-PFHxA	IS	73.9	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C4-PFHpA	IS	77.6	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C3-PFHxS	IS	81.3	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-6:2 FTS	IS	87.5	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C5-PFNA	IS	73.1	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C8-PFOSA	IS	49.7	10 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-PFOA	IS	80.8	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C8-PFOS	IS	74.6	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-PFDA	IS	64.5	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-8:2 FTS	IS	91.3	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
d3-MeFOSAA	IS	61.5	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-PFUnA	IS	58.4	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
d5-EtFOSAA	IS	61.3	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-10:2 FTS	IS	68.7	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-PFDoA	IS	52.0	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
d3-MeFOSA	IS	16.0	10 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-PFTeDA	IS	48.9	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
d5-EtFOSA	IS	12.3	10 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
13C2-PFHxDA	IS	40.1	25 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
d7-MeFOSE	IS	33.0	10 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1
d9-EtFOSE	IS	32.0	10 - 150		B0G0144	20-Jul-20	1.18 g	23-Jul-20 17:03	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-01 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-20	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 10:50	Date Received:	14-Jul-20 09:11		
				% Solids:	89.1		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.335	0.335	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFPeA	2706-90-3	0.529	0.385	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFBS	375-73-5	<0.294	0.294	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
4:2 FTS	757124-72-4	<0.348	0.348	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFHxA	307-24-4	1.44	0.209	0.484	Q	B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFPeS	2706-91-4	<0.637	0.637	0.968		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
HFPO-DA	13252-13-6	<1.14	1.14	1.45		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFHpA	375-85-9	<0.463	0.463	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
ADONA	919005-14-4	<0.329	0.329	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFHxS	355-46-4	10.1	0.378	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
6:2 FTS	27619-97-2	<0.633	0.633	0.968		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFOA	335-67-1	2.05	0.455	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFHpS	375-92-8	<0.714	0.714	0.968		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFNA	375-95-1	0.546	0.302	0.484	Q	B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFOSA	754-91-6	<0.976	0.976	1.45		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFOS	1763-23-1	19.8	0.416	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
9Cl-PF3ONS	756426-58-1	<0.358	0.358	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFDA	335-76-2	<0.438	0.438	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
8:2 FTS	39108-34-4	<0.699	0.699	0.968		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFNS	68259-12-1	<1.11	1.11	1.45		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
MeFOSAA	2355-31-9	<0.712	0.712	0.968		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
EtFOSAA	2991-50-6	<0.666	0.666	0.968		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFUnA	2058-94-8	<0.250	0.250	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFDS	335-77-3	<0.668	0.668	0.968		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
11Cl-PF3OUdS	763051-92-9	<0.699	0.699	0.968		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
10:2 FTS	120226-60-0	<0.983	0.983	1.45		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFDoA	307-55-1	<0.391	0.391	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
MeFOSA	31506-32-8	<5.59	5.59	9.68		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFTrDA	72629-94-8	<0.389	0.389	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFDoS	79780-39-5	<0.581	0.581	0.968		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFTeDA	376-06-7	<0.256	0.256	0.484		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
EtFOSA	4151-50-2	<3.72	3.72	9.68		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
PFHxDA	67905-19-5	<0.165	0.165	0.484		B0G0144	20-Jul-20	1.16 g	27-Jul-20 21:12	1
PFODA	16517-11-6	<0.484	0.484	0.968		B0G0144	20-Jul-20	1.16 g	27-Jul-20 21:12	1
MeFOSE	24448-09-7	<4.80	4.80	9.68		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
EtFOSE	1691-99-2	<5.21	5.21	9.68		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	99.3	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1

SR0107

Vista Analytical Laboratory

Sample ID: SBT20-01 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001473-20	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 10:50	Date Received:	14-Jul-20 09:11		
				% Solids:	89.1		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	79.6	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C3-PFBS	IS	84.0	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C3-HFPO-DA	IS	72.7	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-4:2 FTS	IS	82.7	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-PFHxA	IS	74.1	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C4-PFHpA	IS	76.8	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C3-PFHxS	IS	78.1	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-6:2 FTS	IS	85.0	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C5-PFNA	IS	66.9	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C8-PFOSA	IS	48.5	10 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-PFOA	IS	76.6	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C8-PFOS	IS	74.3	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-PFDA	IS	62.2	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-8:2 FTS	IS	78.9	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
d3-MeFOSAA	IS	64.3	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-PFUnA	IS	61.9	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
d5-EtFOSAA	IS	65.9	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-10:2 FTS	IS	67.6	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-PFDoA	IS	64.9	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
d3-MeFOSA	IS	18.2	10 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-PFTeDA	IS	51.1	25 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
d5-EtFOSA	IS	16.0	10 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
13C2-PFHxDA	IS	23.2	25 - 150	H	B0G0144	20-Jul-20	1.16 g	27-Jul-20 21:12	1
d7-MeFOSE	IS	34.2	10 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1
d9-EtFOSE	IS	36.1	10 - 150		B0G0144	20-Jul-20	1.16 g	23-Jul-20 17:14	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

SR0108

Vista Analytical Laboratory

Sample ID: Method Blank | **PFAS Isotope Dilution Method**

Client Data
Name: LimnoTech, Inc. Matrix: Aqueous
Project: MSN FFTA Samples

Laboratory Data
Lab Sample: B0G0132-BLK1 Column: BEH C18

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.729	0.729	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFPeA	2706-90-3	<1.28	1.28	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFBS	375-73-5	<1.79	1.79	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
4:2 FTS	757124-72-4	<1.39	1.39	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHxA	307-24-4	<2.18	2.18	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFPeS	2706-91-4	<2.42	2.42	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
HFPO-DA	13252-13-6	<4.82	4.82	5.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHpA	375-85-9	<0.591	0.591	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
ADONA	919005-14-4	<0.722	0.722	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHxS	355-46-4	<0.947	0.947	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
6:2 FTS	27619-97-2	<2.00	2.00	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFOA	335-67-1	<0.651	0.651	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHpS	375-92-8	<0.937	0.937	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFNA	375-95-1	<0.810	0.810	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFOSA	754-91-6	<1.77	1.77	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFOS	1763-23-1	<0.807	0.807	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
9Cl-PF3ONS	756426-58-1	<1.45	1.45	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDA	335-76-2	<1.49	1.49	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
8:2 FTS	39108-34-4	<2.06	2.06	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFNS	68259-12-1	<3.87	3.87	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
MeFOSAA	2355-31-9	<1.65	1.65	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
EtFOSAA	2991-50-6	<1.37	1.37	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFUnA	2058-94-8	<1.05	1.05	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDS	335-77-3	<1.23	1.23	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
11Cl-PF3OUdS	763051-92-9	<2.41	2.41	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
10:2 FTS	120226-60-0	<3.13	3.13	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDoA	307-55-1	<0.792	0.792	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
MeFOSA	31506-32-8	<3.83	3.83	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFTrDA	72629-94-8	<0.494	0.494	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDoS	79780-39-5	<4.17	4.17	5.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFTeDA	376-06-7	<0.755	0.755	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
EtFOSA	4151-50-2	<5.11	5.11	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHxDA	67905-19-5	1.37	0.294	4.00	J, Q	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFODA	16517-11-6	<6.14	6.14	7.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
MeFOSE	24448-09-7	<6.07	6.07	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
EtFOSE	1691-99-2	<9.44	9.44	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	144	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1

SR0109

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data
Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Aqueous

Laboratory Data
Lab Sample: B0G0132-BLK1
Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	101	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C3-PFBS	IS	102	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C3-HFPO-DA	IS	90.2	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-4:2 FTS	IS	97.6	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFHxA	IS	95.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C4-PFHpA	IS	102	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C3-PFHxS	IS	104	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-6:2 FTS	IS	89.1	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C5-PFNA	IS	80.3	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C8-PFOSA	IS	33.9	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFOA	IS	97.6	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C8-PFOS	IS	92.7	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFDA	IS	90.9	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-8:2 FTS	IS	94.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d3-MeFOSAA	IS	77.3	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFUnA	IS	82.3	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d5-EtFOSAA	IS	69.7	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-10:2 FTS	IS	77.9	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFDoA	IS	74.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d3-MeFOSA	IS	10.8	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFTeDA	IS	64.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d5-EtFOSA	IS	9.30	10 - 150	H	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFHxDA	IS	39.2	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d7-MeFOSE	IS	16.0	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d9-EtFOSE	IS	17.2	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	B0G0132-BS1	Column:	BEH C18
Project:	MSN FFTA Samples						

Analyte	CAS Number	Amt Found (ng/L)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	7.82	8.00	97.7	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFPeA	2706-90-3	7.69	8.00	96.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFBS	375-73-5	7.42	8.00	92.7	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
4:2 FTS	757124-72-4	7.81	8.00	97.6	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHxA	307-24-4	7.64	8.00	95.4	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFPeS	2706-91-4	8.20	8.00	103	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
HFPO-DA	13252-13-6	7.51	8.00	93.8	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHpA	375-85-9	7.48	8.00	93.6	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
ADONA	919005-14-4	7.54	8.00	94.2	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHxS	355-46-4	6.14	8.00	76.7	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
6:2 FTS	27619-97-2	8.50	8.00	106	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFOA	335-67-1	7.13	8.00	89.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHpS	375-92-8	7.83	8.00	97.9	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFNA	375-95-1	8.53	8.00	107	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFOSA	754-91-6	10.1	8.00	126	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFOS	1763-23-1	8.96	8.00	112	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
9Cl-PF3ONS	756426-58-1	7.13	8.00	89.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDA	335-76-2	7.48	8.00	93.6	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
8:2 FTS	39108-34-4	6.64	8.00	83.0	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFNS	68259-12-1	7.56	8.00	94.5	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
MeFOSAA	2355-31-9	7.12	8.00	89.0	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
EtFOSAA	2991-50-6	6.42	8.00	80.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFUnA	2058-94-8	7.64	8.00	95.5	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDS	335-77-3	7.21	8.00	90.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
11Cl-PF3OUdS	763051-92-9	7.38	8.00	92.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
10:2 FTS	120226-60-0	8.50	8.00	106	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDoA	307-55-1	7.35	8.00	91.8	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
MeFOSA	31506-32-8	28.9	40.0	72.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFTrDA	72629-94-8	7.23	8.00	90.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDoS	79780-39-5	6.88	8.00	85.9	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFTeDA	376-06-7	7.21	8.00	90.2	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
EtFOSA	4151-50-2	35.5	40.0	88.8	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHxDA	67905-19-5	7.62	8.00	95.3	50 - 150	B	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFODA	16517-11-6	6.65	8.00	83.1	50 - 150	J	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	B0G0132-BS1	Column:	BEH C18
Project:	MSN FFTA Samples						

Analyte	CAS Number	Amt Found (ng/L)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
MeFOSE	24448-09-7	45.9	40.0	115	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
EtFOSE	1691-99-2	26.1	40.0	65.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1

Labeled Standards	Type	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	145	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-PFPeA	IS	97.0	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-PFBS	IS	100	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-HFPO-DA	IS	86.9	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-4:2 FTS	IS	95.8	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFHxA	IS	87.0	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C4-PFHpA	IS	91.2	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-PFHxS	IS	101	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-6:2 FTS	IS	90.4	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C5-PFNA	IS	77.0	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C8-PFOSA	IS	26.2	10- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFOA	IS	90.1	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C8-PFOS	IS	80.2	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFDA	IS	89.6	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-8:2 FTS	IS	85.6	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d3-MeFOSAA	IS	71.1	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFUnA	IS	75.5	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d5-EtFOSAA	IS	70.3	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-10:2 FTS	IS	71.4	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFDoA	IS	81.9	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d3-MeFOSA	IS	7.50	10- 150	H	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFTeDA	IS	74.5	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d5-EtFOSA	IS	5.90	10- 150	H	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFHxDA	IS	61.5	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d7-MeFOSE	IS	11.5	10- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d9-EtFOSE	IS	12.9	10- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	B0G0133-BLK1	Column:	BEH C18
Project:	MSN FFTA Samples						

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.729	0.729	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFPeA	2706-90-3	<1.28	1.28	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFBS	375-73-5	<1.79	1.79	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
4:2 FTS	757124-72-4	<1.39	1.39	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFHxA	307-24-4	<2.18	2.18	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFPeS	2706-91-4	<2.42	2.42	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
HFPO-DA	13252-13-6	<4.82	4.82	5.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFHpA	375-85-9	<0.591	0.591	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
ADONA	919005-14-4	<0.722	0.722	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFHxS	355-46-4	<0.947	0.947	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
6:2 FTS	27619-97-2	<2.00	2.00	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFOA	335-67-1	<0.651	0.651	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFHpS	375-92-8	<0.937	0.937	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFNA	375-95-1	<0.810	0.810	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFOSA	754-91-6	<1.77	1.77	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFOS	1763-23-1	<0.807	0.807	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
9Cl-PF3ONS	756426-58-1	<1.45	1.45	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFDA	335-76-2	<1.49	1.49	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
8:2 FTS	39108-34-4	<2.06	2.06	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFNS	68259-12-1	<3.87	3.87	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
MeFOSAA	2355-31-9	<1.65	1.65	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
EtFOSAA	2991-50-6	<1.37	1.37	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFUnA	2058-94-8	<1.05	1.05	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFDS	335-77-3	<1.23	1.23	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
11Cl-PF3OUdS	763051-92-9	<2.41	2.41	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
10:2 FTS	120226-60-0	<3.13	3.13	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFDoA	307-55-1	<0.792	0.792	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
MeFOSA	31506-32-8	<3.83	3.83	20.0		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFTrDA	72629-94-8	<0.494	0.494	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFDoS	79780-39-5	<4.17	4.17	5.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFTeDA	376-06-7	<0.755	0.755	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
EtFOSA	4151-50-2	<5.11	5.11	20.0		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFHxDA	67905-19-5	<0.294	0.294	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFODA	16517-11-6	<6.14	6.14	7.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
MeFOSE	24448-09-7	<6.07	6.07	20.0		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
EtFOSE	1691-99-2	<9.44	9.44	20.0		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	53.1	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1

SR0113

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc. Matrix: Aqueous

Project: MSN FFTA Samples

Laboratory Data

Lab Sample: B0G0133-BLK1 Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	68.1	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C3-PFBS	IS	73.4	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C3-HFPO-DA	IS	69.6	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-4:2 FTS	IS	84.0	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFHxA	IS	72.2	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C4-PFHpA	IS	73.4	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C3-PFHxS	IS	75.2	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-6:2 FTS	IS	65.8	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C5-PFNA	IS	69.6	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C8-PFOSA	IS	28.9	10 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFOA	IS	74.9	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C8-PFOS	IS	73.7	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFDA	IS	65.2	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-8:2 FTS	IS	89.6	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d3-MeFOSAA	IS	56.7	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFUnA	IS	67.8	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d5-EtFOSAA	IS	52.9	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-10:2 FTS	IS	74.6	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFDoA	IS	59.0	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d3-MeFOSA	IS	9.50	10 - 150	H	B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFTeDA	IS	55.8	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d5-EtFOSA	IS	8.50	10 - 150	H	B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFHxDA	IS	49.0	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d7-MeFOSE	IS	20.8	10 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d9-EtFOSE	IS	24.1	10 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Aqueous

Laboratory Data

Lab Sample: B0G0133-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/L)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	7.56	8.00	94.5	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFPeA	2706-90-3	7.54	8.00	94.2	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFBS	375-73-5	7.92	8.00	99.0	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
4:2 FTS	757124-72-4	7.62	8.00	95.3	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFHxA	307-24-4	7.92	8.00	99.0	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFPeS	2706-91-4	9.00	8.00	112	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
HFPO-DA	13252-13-6	6.32	8.00	79.0	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFHpA	375-85-9	8.80	8.00	110	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
ADONA	919005-14-4	7.03	8.00	87.9	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFHxS	355-46-4	5.71	8.00	71.4	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
6:2 FTS	27619-97-2	8.41	8.00	105	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFOA	335-67-1	8.22	8.00	103	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFHpS	375-92-8	9.65	8.00	121	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFNA	375-95-1	7.74	8.00	96.7	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFOSA	754-91-6	8.71	8.00	109	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFOS	1763-23-1	7.04	8.00	88.0	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
9Cl-PF3ONS	756426-58-1	7.30	8.00	91.3	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFDA	335-76-2	9.39	8.00	117	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
8:2 FTS	39108-34-4	7.79	8.00	97.4	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFNS	68259-12-1	7.01	8.00	87.6	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
MeFOSAA	2355-31-9	8.75	8.00	109	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
EtFOSAA	2991-50-6	6.91	8.00	86.4	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFUnA	2058-94-8	8.11	8.00	101	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFDS	335-77-3	6.95	8.00	86.9	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
11Cl-PF3OUdS	763051-92-9	9.41	8.00	118	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
10:2 FTS	120226-60-0	10.1	8.00	126	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFDoA	307-55-1	8.12	8.00	101	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
MeFOSA	31506-32-8	51.6	40.0	129	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFTrDA	72629-94-8	9.11	8.00	114	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFDoS	79780-39-5	8.12	8.00	102	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFTeDA	376-06-7	8.70	8.00	109	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
EtFOSA	4151-50-2	39.4	40.0	98.6	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFHxDA	67905-19-5	8.20	8.00	102	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFODA	16517-11-6	6.24	8.00	78.0	50 - 150	J	B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1

Vista Analytical Laboratory

Sample ID: OPR — **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Aqueous

Laboratory Data

Lab Sample: B0G0133-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/L)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
MeFOSE	24448-09-7	54.3	40.0	136	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
EtFOSE	1691-99-2	26.7	40.0	66.8	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1

Labeled Standards	Type	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	87.8	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C3-PFPeA	IS	71.5	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C3-PFBS	IS	74.0	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C3-HFPO-DA	IS	70.6	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-4:2 FTS	IS	73.4	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFHxA	IS	68.4	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C4-PFHpA	IS	74.2	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C3-PFHxS	IS	78.0	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-6:2 FTS	IS	72.2	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C5-PFNA	IS	67.5	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C8-PFOSA	IS	29.7	10- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFOA	IS	74.4	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C8-PFOS	IS	69.2	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFDA	IS	61.4	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-8:2 FTS	IS	75.8	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d3-MeFOSAA	IS	55.5	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFUnA	IS	63.9	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d5-EtFOSAA	IS	56.7	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-10:2 FTS	IS	43.9	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFDoA	IS	52.4	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d3-MeFOSA	IS	10.3	10- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFTeDA	IS	52.0	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d5-EtFOSA	IS	10.8	10- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFHxDA	IS	42.2	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d7-MeFOSE	IS	22.6	10- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d9-EtFOSE	IS	25.2	10- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1

Vista Analytical Laboratory

Sample ID: SBT20-01-GW **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001473-02	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 11:35	Date Received:	14-Jul-20 09:11		

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	298	0.775	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFPeA	2706-90-3	800	1.36	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFBS	375-73-5	377	1.90	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
4:2 FTS	757124-72-4	<1.48	1.48	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFHxA	307-24-4	3020	2.32	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFPeS	2706-91-4	260	2.57	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
HFPO-DA	13252-13-6	<5.12	5.12	5.31		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFHpA	375-85-9	856	0.628	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
ADONA	919005-14-4	<0.767	0.767	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFHxS	355-46-4	8530	5.03	21.3	D	B0G0132	17-Jul-20	0.118 L	23-Jul-20 17:36	5
6:2 FTS	27619-97-2	378	2.13	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFOA	335-67-1	67300	34.6	213	D	B0G0132	17-Jul-20	0.118 L	27-Jul-20 11:14	50
PFHpS	375-92-8	1740	0.996	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFNA	375-95-1	301	0.861	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFOSA	754-91-6	19.4	1.88	4.25	Q	B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFOS	1763-23-1	1360	0.858	4.25	Q	B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
9Cl-PF3ONS	756426-58-1	<1.54	1.54	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFDA	335-76-2	1.67	1.58	4.25	J	B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
8:2 FTS	39108-34-4	8.61	2.19	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFNS	68259-12-1	<4.11	4.11	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
MeFOSAA	2355-31-9	<1.75	1.75	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
EtFOSAA	2991-50-6	<1.46	1.46	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFUnA	2058-94-8	<1.12	1.12	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFDS	335-77-3	<1.31	1.31	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
11Cl-PF3OUdS	763051-92-9	<2.56	2.56	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
10:2 FTS	120226-60-0	<3.33	3.33	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFDoA	307-55-1	<0.842	0.842	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
MeFOSA	31506-32-8	<4.07	4.07	21.3		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFTrDA	72629-94-8	<0.525	0.525	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFDoS	79780-39-5	<4.43	4.43	5.31		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFTeDA	376-06-7	<0.803	0.803	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
EtFOSA	4151-50-2	<5.43	5.43	21.3		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFHxDA	67905-19-5	<0.313	0.313	4.25		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
PFODA	16517-11-6	<6.53	6.53	7.44		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
MeFOSE	24448-09-7	<6.45	6.45	21.3		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
EtFOSE	1691-99-2	<10.0	10.0	21.3		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	99.6	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1

Vista Analytical Laboratory

Sample ID: SBT20-01-GW **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001473-02	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 11:35	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	92.3	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C3-PFBS	IS	85.5	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C3-HFPO-DA	IS	88.8	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C2-4:2 FTS	IS	96.1	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C2-PFHxA	IS	76.6	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C4-PFHpA	IS	88.5	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C3-PFHxS	IS	81.5	25 - 150	D	B0G0132	17-Jul-20	0.118 L	23-Jul-20 17:36	5
13C2-6:2 FTS	IS	74.0	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C5-PFNA	IS	83.8	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C8-PFOSA	IS	67.6	10 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C2-PFOA	IS	137	25 - 150	D	B0G0132	17-Jul-20	0.118 L	27-Jul-20 11:14	50
13C8-PFOS	IS	92.4	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C2-PFDA	IS	92.1	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C2-8:2 FTS	IS	88.0	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
d3-MeFOSAA	IS	83.7	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C2-PFUnA	IS	85.7	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
d5-EtFOSAA	IS	84.0	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C2-10:2 FTS	IS	81.8	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C2-PFDoA	IS	99.6	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
d3-MeFOSA	IS	28.5	10 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C2-PFTeDA	IS	80.7	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
d5-EtFOSA	IS	23.2	10 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
13C2-PFHxDA	IS	64.0	25 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
d7-MeFOSE	IS	49.0	10 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1
d9-EtFOSE	IS	54.0	10 - 150		B0G0132	17-Jul-20	0.118 L	22-Jul-20 14:04	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-05-GW **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc. Matrix: Aqueous
Project: MSN FFTA Samples Date Collected: 07-Jul-20 12:55

Laboratory Data

Lab Sample: 2001473-06 Column: BEH C18
Date Received: 14-Jul-20 09:11

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	50.6	0.812	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFPeA	2706-90-3	104	1.43	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFBS	375-73-5	95.9	1.99	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
4:2 FTS	757124-72-4	<1.55	1.55	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFHxA	307-24-4	349	2.43	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFPeS	2706-91-4	106	2.70	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
HFPO-DA	13252-13-6	<5.37	5.37	5.57		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFHpA	375-85-9	81.7	0.658	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
ADONA	919005-14-4	<0.804	0.804	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFHxS	355-46-4	4740	5.27	22.3	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:46	5
6:2 FTS	27619-97-2	8.35	2.23	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFOA	335-67-1	1090	0.725	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFHpS	375-92-8	66.1	1.04	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFNA	375-95-1	143	0.902	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFOSA	754-91-6	10.9	1.97	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFOS	1763-23-1	1900	0.899	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
9Cl-PF3ONS	756426-58-1	<1.62	1.62	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFDA	335-76-2	1.71	1.66	4.46	J	B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
8:2 FTS	39108-34-4	53.6	2.29	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFNS	68259-12-1	<4.31	4.31	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
MeFOSAA	2355-31-9	<1.84	1.84	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
EtFOSAA	2991-50-6	<1.53	1.53	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFUnA	2058-94-8	<1.17	1.17	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFDS	335-77-3	<1.37	1.37	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
11Cl-PF3OUdS	763051-92-9	<2.68	2.68	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
10:2 FTS	120226-60-0	<3.49	3.49	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFDoA	307-55-1	<0.882	0.882	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
MeFOSA	31506-32-8	<4.27	4.27	22.3		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFTrDA	72629-94-8	<0.550	0.550	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFDoS	79780-39-5	<4.64	4.64	5.57		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFTeDA	376-06-7	<0.841	0.841	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
EtFOSA	4151-50-2	<5.69	5.69	22.3		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFHxDA	67905-19-5	<0.327	0.327	4.46		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
PFODA	16517-11-6	<6.84	6.84	7.80		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
MeFOSE	24448-09-7	<6.76	6.76	22.3		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
EtFOSE	1691-99-2	<10.5	10.5	22.3		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	120	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1

Vista Analytical Laboratory

Sample ID: SBT20-05-GW **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001473-06	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 12:55	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	84.0	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C3-PFBS	IS	93.1	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C3-HFPO-DA	IS	79.5	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C2-4:2 FTS	IS	83.4	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C2-PFHxA	IS	80.6	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C4-PFHpA	IS	84.2	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C3-PFHxS	IS	81.5	25 - 150	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:46	5
13C2-6:2 FTS	IS	89.1	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C5-PFNA	IS	76.7	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C8-PFOSA	IS	47.7	10 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C2-PFOA	IS	83.1	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C8-PFOS	IS	87.8	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C2-PFDA	IS	82.8	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C2-8:2 FTS	IS	82.6	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
d3-MeFOSAA	IS	81.5	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C2-PFUnA	IS	76.3	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
d5-EtFOSAA	IS	74.4	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C2-10:2 FTS	IS	60.4	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C2-PFDoA	IS	69.9	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
d3-MeFOSA	IS	13.0	10 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C2-PFTeDA	IS	55.9	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
d5-EtFOSA	IS	10.6	10 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
13C2-PFHxDA	IS	48.5	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
d7-MeFOSE	IS	33.0	10 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1
d9-EtFOSE	IS	41.2	10 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 17:57	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-02-GW **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001473-08	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 13:10	Date Received:	14-Jul-20 09:11		

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	113	0.789	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFPeA	2706-90-3	213	1.39	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFBS	375-73-5	37.2	1.94	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
4:2 FTS	757124-72-4	<1.50	1.50	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFHxA	307-24-4	132	2.36	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFPeS	2706-91-4	48.2	2.62	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
HFPO-DA	13252-13-6	<5.22	5.22	5.41		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFHpA	375-85-9	117	0.640	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
ADONA	919005-14-4	<0.782	0.782	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFHxS	355-46-4	1690	1.03	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
6:2 FTS	27619-97-2	<2.16	2.16	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFOA	335-67-1	11300	3.52	21.6	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:17	5
PFHpS	375-92-8	31.3	1.01	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFNA	375-95-1	31.9	0.877	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFOSA	754-91-6	4.99	1.92	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFOS	1763-23-1	559	0.874	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
9Cl-PF3ONS	756426-58-1	<1.57	1.57	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFDA	335-76-2	<1.61	1.61	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
8:2 FTS	39108-34-4	<2.23	2.23	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFNS	68259-12-1	<4.19	4.19	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
MeFOSAA	2355-31-9	<1.79	1.79	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
EtFOSAA	2991-50-6	<1.48	1.48	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFUnA	2058-94-8	<1.14	1.14	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFDS	335-77-3	<1.33	1.33	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
11Cl-PF3OUdS	763051-92-9	<2.61	2.61	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
10:2 FTS	120226-60-0	<3.39	3.39	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFDoA	307-55-1	<0.857	0.857	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
MeFOSA	31506-32-8	<4.15	4.15	21.6		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFTrDA	72629-94-8	<0.535	0.535	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFDoS	79780-39-5	<4.51	4.51	5.41		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFTeDA	376-06-7	<0.817	0.817	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
EtFOSA	4151-50-2	<5.53	5.53	21.6		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFHxDA	67905-19-5	<0.318	0.318	4.33		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
PFODA	16517-11-6	<6.65	6.65	7.58		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
MeFOSE	24448-09-7	<6.57	6.57	21.6		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
EtFOSE	1691-99-2	<10.2	10.2	21.6		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	82.9	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1

Vista Analytical Laboratory

Sample ID: SBT20-02-GW **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Aqueous
Date Collected: 07-Jul-20 13:10

Laboratory Data

Lab Sample: 2001473-08
Date Received: 14-Jul-20 09:11
Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	93.1	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C3-PFBS	IS	98.4	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C3-HFPO-DA	IS	95.5	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-4:2 FTS	IS	88.2	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-PFHxA	IS	93.6	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C4-PFHpA	IS	91.2	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C3-PFHxS	IS	82.7	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-6:2 FTS	IS	99.1	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C5-PFNA	IS	86.0	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C8-PFOSA	IS	75.4	10 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-PFOA	IS	107	25 - 150	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:17	5
13C8-PFOS	IS	108	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-PFDA	IS	88.8	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-8:2 FTS	IS	93.5	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
d3-MeFOSAA	IS	90.8	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-PFUnA	IS	84.7	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
d5-EtFOSAA	IS	84.4	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-10:2 FTS	IS	83.8	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-PFDoA	IS	80.6	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
d3-MeFOSA	IS	38.2	10 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-PFTeDA	IS	74.0	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
d5-EtFOSA	IS	30.1	10 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
13C2-PFHxDA	IS	70.0	25 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
d7-MeFOSE	IS	43.4	10 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1
d9-EtFOSE	IS	47.9	10 - 150		B0G0132	17-Jul-20	0.115 L	23-Jul-20 18:28	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-04-GW **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Aqueous
Date Collected: 07-Jul-20 13:35

Laboratory Data

Lab Sample: 2001473-09
Date Received: 14-Jul-20 09:11
Column: BEH C18

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	9.25	0.727	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFPeA	2706-90-3	34.3	1.28	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFBS	375-73-5	14.1	1.79	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
4:2 FTS	757124-72-4	<1.39	1.39	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFHxA	307-24-4	31.0	2.17	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFPeS	2706-91-4	5.67	2.41	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
HFPO-DA	13252-13-6	<4.81	4.81	4.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFHpA	375-85-9	13.4	0.590	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
ADONA	919005-14-4	<0.720	0.720	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFHxS	355-46-4	228	0.945	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
6:2 FTS	27619-97-2	<2.00	2.00	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFOA	335-67-1	54.9	0.649	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFHpS	375-92-8	2.29	0.935	3.99	J, Q	B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFNA	375-95-1	13.5	0.808	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFOSA	754-91-6	2.01	1.77	3.99	J	B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFOS	1763-23-1	193	0.805	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
9Cl-PF3ONS	756426-58-1	<1.45	1.45	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFDA	335-76-2	7.53	1.49	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
8:2 FTS	39108-34-4	<2.06	2.06	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFNS	68259-12-1	<3.86	3.86	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
MeFOSAA	2355-31-9	<1.65	1.65	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
EtFOSAA	2991-50-6	<1.37	1.37	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFUnA	2058-94-8	<1.05	1.05	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFDS	335-77-3	<1.23	1.23	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
11Cl-PF3OUdS	763051-92-9	<2.40	2.40	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
10:2 FTS	120226-60-0	<3.12	3.12	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFDoA	307-55-1	<0.790	0.790	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
MeFOSA	31506-32-8	<3.82	3.82	20.0		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFTrDA	72629-94-8	<0.493	0.493	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFDoS	79780-39-5	<4.16	4.16	4.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFTeDA	376-06-7	<0.753	0.753	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
EtFOSA	4151-50-2	<5.10	5.10	20.0		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFHxDA	67905-19-5	<0.293	0.293	3.99		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
PFODA	16517-11-6	<6.13	6.13	6.98		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
MeFOSE	24448-09-7	<6.06	6.06	20.0		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
EtFOSE	1691-99-2	<9.42	9.42	20.0		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	110	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1

Vista Analytical Laboratory

Sample ID: SBT20-04-GW **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Aqueous
Date Collected: 07-Jul-20 13:35

Laboratory Data

Lab Sample: 2001473-09
Date Received: 14-Jul-20 09:11
Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	83.5	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C3-PFBS	IS	95.3	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C3-HFPO-DA	IS	85.7	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-4:2 FTS	IS	82.6	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-PFHxA	IS	87.3	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C4-PFHpA	IS	78.8	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C3-PFHxS	IS	89.7	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-6:2 FTS	IS	86.9	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C5-PFNA	IS	75.5	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C8-PFOSA	IS	58.6	10 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-PFOA	IS	86.8	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C8-PFOS	IS	90.5	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-PFDA	IS	82.6	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-8:2 FTS	IS	76.9	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
d3-MeFOSAA	IS	79.6	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-PFUnA	IS	72.1	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
d5-EtFOSAA	IS	72.3	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-10:2 FTS	IS	55.9	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-PFDoA	IS	59.4	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
d3-MeFOSA	IS	17.9	10 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-PFTeDA	IS	28.4	25 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
d5-EtFOSA	IS	11.7	10 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
13C2-PFHxDA	IS	19.5	25 - 150	H	B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
d7-MeFOSE	IS	26.8	10 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1
d9-EtFOSE	IS	26.0	10 - 150		B0G0132	17-Jul-20	0.125 L	23-Jul-20 18:48	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

SR0124

Vista Analytical Laboratory

Sample ID: EQUIPMENT BLANK A | **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001473-12	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 08:40	Date Received:	14-Jul-20 09:11		

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.845	0.845	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFPeA	2706-90-3	<1.48	1.48	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFBS	375-73-5	<2.07	2.07	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
4:2 FTS	757124-72-4	<1.61	1.61	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFHxA	307-24-4	<2.53	2.53	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFPeS	2706-91-4	<2.80	2.80	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
HFPO-DA	13252-13-6	<5.58	5.58	5.79		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFHpA	375-85-9	<0.685	0.685	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
ADONA	919005-14-4	<0.837	0.837	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFHxS	355-46-4	<1.10	1.10	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
6:2 FTS	27619-97-2	<2.32	2.32	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFOA	335-67-1	<0.754	0.754	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFHpS	375-92-8	<1.09	1.09	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFNA	375-95-1	<0.938	0.938	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFOSA	754-91-6	<2.05	2.05	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFOS	1763-23-1	<0.935	0.935	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
9Cl-PF3ONS	756426-58-1	<1.68	1.68	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFDA	335-76-2	<1.73	1.73	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
8:2 FTS	39108-34-4	<2.39	2.39	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFNS	68259-12-1	<4.48	4.48	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
MeFOSAA	2355-31-9	<1.91	1.91	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
EtFOSAA	2991-50-6	<1.59	1.59	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFUnA	2058-94-8	<1.22	1.22	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFDS	335-77-3	<1.43	1.43	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
11Cl-PF3OUdS	763051-92-9	<2.79	2.79	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
10:2 FTS	120226-60-0	<3.63	3.63	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFDoA	307-55-1	<0.918	0.918	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
MeFOSA	31506-32-8	<4.07	4.07	21.3		B0G0133	25-Jul-20	0.118 L	27-Jul-20 13:19	1
PFTrDA	72629-94-8	<0.572	0.572	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFDoS	79780-39-5	<4.83	4.83	5.79		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFTeDA	376-06-7	<0.875	0.875	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
EtFOSA	4151-50-2	<5.43	5.43	21.3		B0G0133	25-Jul-20	0.118 L	27-Jul-20 13:19	1
PFHxDA	67905-19-5	<0.341	0.341	4.63		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
PFODA	16517-11-6	<7.11	7.11	8.11		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
MeFOSE	24448-09-7	<7.03	7.03	23.2		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
EtFOSE	1691-99-2	<10.9	10.9	23.2		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	124	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1

Vista Analytical Laboratory

Sample ID: EQUIPMENT BLANK A **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001473-12	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 08:40	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	86.4	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C3-PFBS	IS	97.3	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C3-HFPO-DA	IS	90.2	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C2-4:2 FTS	IS	83.0	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C2-PFHxA	IS	85.3	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C4-PFHpA	IS	87.5	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C3-PFHxS	IS	84.7	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C2-6:2 FTS	IS	101	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C5-PFNA	IS	87.5	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C8-PFOSA	IS	42.6	10 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C2-PFOA	IS	91.4	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C8-PFOS	IS	95.5	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C2-PFDA	IS	89.2	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C2-8:2 FTS	IS	86.2	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
d3-MeFOSAA	IS	83.0	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C2-PFUnA	IS	80.8	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
d5-EtFOSAA	IS	80.3	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C2-10:2 FTS	IS	64.6	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
13C2-PFDoA	IS	75.9	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
d3-MeFOSA	IS	12.9	10 - 150		B0G0133	25-Jul-20	0.118 L	27-Jul-20 13:19	1
13C2-PFTeDA	IS	62.5	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
d5-EtFOSA	IS	12.7	10 - 150		B0G0133	25-Jul-20	0.118 L	27-Jul-20 13:19	1
13C2-PFHxDA	IS	51.4	25 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
d7-MeFOSE	IS	25.9	10 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1
d9-EtFOSE	IS	24.5	10 - 150		B0G0132	17-Jul-20	0.108 L	23-Jul-20 18:59	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-03-GW **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Aqueous
Date Collected: 07-Jul-20 09:40

Laboratory Data

Lab Sample: 2001473-16
Date Received: 14-Jul-20 09:11
Column: BEH C18

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	1250	0.791	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFPeA	2706-90-3	3610	1.39	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFBS	375-73-5	1230	1.94	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
4:2 FTS	757124-72-4	<1.51	1.51	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFHxA	307-24-4	4280	2.37	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFPeS	2706-91-4	771	2.63	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
HFPO-DA	13252-13-6	<5.23	5.23	5.43		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFHpA	375-85-9	1090	0.642	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
ADONA	919005-14-4	<0.784	0.784	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFHxS	355-46-4	18700	10.3	43.4	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 19:09	10
6:2 FTS	27619-97-2	24.4	2.17	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFOA	335-67-1	7130	7.07	43.4	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 19:09	10
PFHpS	375-92-8	2460	1.02	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFNA	375-95-1	1640	0.879	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFOSA	754-91-6	4.04	1.92	4.34	J, Q	B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFOS	1763-23-1	1360	0.876	4.34	Q	B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
9Cl-PF3ONS	756426-58-1	<1.57	1.57	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFDA	335-76-2	<1.62	1.62	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
8:2 FTS	39108-34-4	<2.24	2.24	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFNS	68259-12-1	<4.20	4.20	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
MeFOSAA	2355-31-9	<1.79	1.79	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
EtFOSAA	2991-50-6	<1.49	1.49	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFUnA	2058-94-8	<1.14	1.14	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFDS	335-77-3	<1.34	1.34	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
11Cl-PF3OUdS	763051-92-9	<2.62	2.62	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
10:2 FTS	120226-60-0	<3.40	3.40	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFDoA	307-55-1	<0.860	0.860	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
MeFOSA	31506-32-8	<4.16	4.16	21.7		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFTrDA	72629-94-8	<0.536	0.536	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFDoS	79780-39-5	<4.53	4.53	5.43		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFTeDA	376-06-7	<0.820	0.820	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
EtFOSA	4151-50-2	<5.55	5.55	21.7		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFHxDA	67905-19-5	<0.319	0.319	4.34		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
PFODA	16517-11-6	<6.67	6.67	7.60		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
MeFOSE	24448-09-7	<6.59	6.59	21.7		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
EtFOSE	1691-99-2	<10.2	10.2	21.7		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	111	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1

Vista Analytical Laboratory

Sample ID: SBT20-03-GW **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA Samples
Matrix: Aqueous
Date Collected: 07-Jul-20 09:40

Laboratory Data

Lab Sample: 2001473-16
Date Received: 14-Jul-20 09:11
Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	86.1	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C3-PFBS	IS	86.0	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C3-HFPO-DA	IS	80.2	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C2-4:2 FTS	IS	93.5	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C2-PFHxA	IS	76.5	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C4-PFHpA	IS	84.7	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C3-PFHxS	IS	110	25 - 150	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 19:09	10
13C2-6:2 FTS	IS	82.6	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C5-PFNA	IS	78.1	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C8-PFOSA	IS	54.7	10 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C2-PFOA	IS	139	25 - 150	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 19:09	10
13C8-PFOS	IS	84.9	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C2-PFDA	IS	97.4	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C2-8:2 FTS	IS	82.3	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
d3-MeFOSAA	IS	79.1	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C2-PFUnA	IS	87.5	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
d5-EtFOSAA	IS	81.3	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C2-10:2 FTS	IS	88.3	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C2-PFDoA	IS	92.6	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
d3-MeFOSA	IS	21.2	10 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C2-PFTeDA	IS	69.3	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
d5-EtFOSA	IS	16.1	10 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
13C2-PFHxDA	IS	66.7	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
d7-MeFOSE	IS	45.5	10 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1
d9-EtFOSE	IS	45.4	10 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 14:56	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBT20-06-GW **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001473-19	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 10:40	Date Received:	14-Jul-20 09:11		

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	16100	12.2	66.7	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 20:12	15
PFPeA	2706-90-3	43000	21.4	66.7	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 20:12	15
PFBS	375-73-5	20200	29.9	66.7	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 20:12	15
4:2 FTS	757124-72-4	194	1.55	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFHxA	307-24-4	53800	84.9	156	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 19:30	35
PFPeS	2706-91-4	23700	40.4	66.7	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 20:12	15
HFPO-DA	13252-13-6	<5.36	5.36	5.56		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFHpA	375-85-9	26200	23.0	156	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 19:30	35
ADONA	919005-14-4	<0.803	0.803	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFHxS	355-46-4	79900	36.9	156	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 19:30	35
6:2 FTS	27619-97-2	5880	33.4	66.7	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 20:12	15
PFOA	335-67-1	65300	25.3	156	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 19:30	35
PFHpS	375-92-8	104	1.04	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFNA	375-95-1	3.98	0.901	4.45	J	B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFOSA	754-91-6	10.3	1.97	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFOS	1763-23-1	230	0.898	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
9Cl-PF3ONS	756426-58-1	<1.61	1.61	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFDA	335-76-2	<1.66	1.66	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
8:2 FTS	39108-34-4	34.9	2.29	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFNS	68259-12-1	<4.30	4.30	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
MeFOSAA	2355-31-9	<1.84	1.84	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
EtFOSAA	2991-50-6	<1.52	1.52	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFUnA	2058-94-8	<1.17	1.17	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFDS	335-77-3	<1.37	1.37	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
11Cl-PF3OUdS	763051-92-9	<2.68	2.68	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
10:2 FTS	120226-60-0	<3.48	3.48	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFDoA	307-55-1	<0.881	0.881	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
MeFOSA	31506-32-8	<4.26	4.26	22.2		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFTrDA	72629-94-8	<0.549	0.549	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFDoS	79780-39-5	<4.64	4.64	5.56		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFTeDA	376-06-7	<0.840	0.840	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
EtFOSA	4151-50-2	<5.68	5.68	22.2		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFHxDA	67905-19-5	<0.327	0.327	4.45		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
PFODA	16517-11-6	<6.83	6.83	7.79		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
MeFOSE	24448-09-7	<6.75	6.75	22.2		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
EtFOSE	1691-99-2	<10.5	10.5	22.2		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	72.0	25 - 150	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 20:12	15

SR0129

Vista Analytical Laboratory

Sample ID: SBT20-06-GW **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001473-19	Column:	BEH C18
Project:	MSN FFTA Samples	Date Collected:	07-Jul-20 10:40	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	70.5	25 - 150	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 20:12	15
13C3-PFBS	IS	76.5	25 - 150	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 20:12	15
13C3-HFPO-DA	IS	64.4	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C2-4:2 FTS	IS	71.2	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C2-PFHxA	IS	137	25 - 150	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 19:30	35
13C4-PFHpA	IS	84.0	25 - 150	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 19:30	35
13C3-PFHxS	IS	66.5	25 - 150	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 19:30	35
13C2-6:2 FTS	IS	129	25 - 150	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 20:12	15
13C5-PFNA	IS	94.9	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C8-PFOSA	IS	71.5	10 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C2-PFOA	IS	126	25 - 150	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 19:30	35
13C8-PFOS	IS	87.0	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C2-PFDA	IS	99.7	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C2-8:2 FTS	IS	94.9	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
d3-MeFOSAA	IS	86.5	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C2-PFUnA	IS	91.1	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
d5-EtFOSAA	IS	88.6	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C2-10:2 FTS	IS	86.0	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C2-PFDoA	IS	102	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
d3-MeFOSA	IS	22.4	10 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C2-PFTeDA	IS	82.8	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
d5-EtFOSA	IS	20.9	10 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
13C2-PFHxDA	IS	71.1	25 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
d7-MeFOSE	IS	51.9	10 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1
d9-EtFOSE	IS	59.2	10 - 150		B0G0132	17-Jul-20	0.112 L	22-Jul-20 15:06	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

DATA QUALIFIERS & ABBREVIATIONS

B	This compound was also detected in the method blank
Conc.	Concentration
CRS	Cleanup Recovery Standard
D	Dilution
DL	Detection Limit
E	The associated compound concentration exceeded the calibration range of the instrument
H	Recovery and/or RPD was outside laboratory acceptance limits
I	Chemical Interference
IS	Internal Standard
J	The amount detected is below the Reporting Limit/LOQ
LOD	Limit of Detection
LOQ	Limit of Quantitation
M	Estimated Maximum Possible Concentration (CA Region 2 projects only)
MDL	Method Detection Limit
NA	Not applicable
ND	Not Detected
OPR	Ongoing Precision and Recovery sample
P	The reported concentration may include contribution from chlorinated diphenyl ether(s).
Q	The ion transition ratio is outside of the acceptance criteria.
RL	Reporting Limit
TEQ	Toxic Equivalency
U	Not Detected (specific projects only)
*	See Cover Letter

Unless otherwise noted, solid sample results are reported in dry weight. Tissue samples are reported in wet weight.

Vista Analytical Laboratory Certifications

Accrediting Authority	Certificate Number
Alaska Department of Environmental Conservation	17-013
Arkansas Department of Environmental Quality	19-013-0
California Department of Health – ELAP	2892
DoD ELAP - A2LA Accredited - ISO/IEC 17025:2005	3091.01
Florida Department of Health	E87777-23
Hawaii Department of Health	N/A
Louisiana Department of Environmental Quality	01977
Maine Department of Health	2018017
Massachusetts Department of Environmental Protection	N/A
Michigan Department of Environmental Quality	9932
Minnesota Department of Health	1521520
New Hampshire Environmental Accreditation Program	207718-B
New Jersey Department of Environmental Protection	190001
New York Department of Health	11411
Oregon Laboratory Accreditation Program	4042-010
Pennsylvania Department of Environmental Protection	016
Texas Commission on Environmental Quality	T104704189-19-10
Vermont Department of Health	VT-4042
Virginia Department of General Services	10272
Washington Department of Ecology	C584-19
Wisconsin Department of Natural Resources	998036160

Current certificates and lists of licensed parameters are located in the Quality Assurance office and are available upon request.

NELAP Accredited Test Methods

MATRIX: Air	
Description of Test	**Method**
Determination of Polychlorinated p-Dioxins & Polychlorinated Dibenzofurans	EPA 23
Determination of Polychlorinated p-Dioxins & Polychlorinated Dibenzofurans	EPA TO-9A

MATRIX: Biological Tissue	
Description of Test	**Method**
Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613B
Brominated Diphenyl Ethers by HRGC/HRMS	EPA 1614A
Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by GC/HRMS	EPA 1668A/C
Pesticides in Water, Soil, Sediment, Biosolids, and Tissue by HRGC/HRMS	EPA 1699
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans by GC/HRMS	EPA 8280A/B
Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by GC/HRMS	EPA 8290/8290A

MATRIX: Drinking Water	
Description of Test	**Method**
2,3,7,8-Tetrachlorodibenzo- p-dioxin (2,3,7,8-TCDD) GC/HRMS	EPA 1613/1613B
1,4-Dioxane (1,4-Diethyleneoxide) analysis by GC/HRMS	EPA 522
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	ISO 25101 2009

MATRIX: Non-Potable Water	
Description of Test	**Method**
Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613B
Brominated Diphenyl Ethers by HRGC/HRMS	EPA 1614A
Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by GC/HRMS	EPA 1668A/C
Pesticides in Water, Soil, Sediment, Biosolids, and Tissue by HRGC/HRMS	EPA 1699
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Dioxin by GC/HRMS	EPA 613
Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans by GC/HRMS	EPA 8280A/B
Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by GC/HRMS	EPA 8290/8290A

MATRIX: Solids	
Description of Test	**Method**
Tetra-Octa Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613
Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613B
Brominated Diphenyl Ethers by HRGC/HRMS	EPA 1614A
Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by GC/HRMS	EPA 1668A/C
Pesticides in Water, Soil, Sediment, Biosolids, and Tissue by HRGC/HRMS	EPA 1699
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans by GC/HRMS	EPA 8280A/B
Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by GC/HRMS	EPA 8290/8290A

Vista Analytical Laboratory

CHAIN OF CUSTODY

For Laboratory Use Only
Work Order #: 2001473 Temp: 1.4 °C
Storage ID: R-13, WR-2 Storage Secured: Yes ☒ No ☐

Project ID: MSN FFTA SAMPLES PO#: MSNPF1 Sampler: C. Behnke (name)

TAT (check one): Standard: ☒ 21 days Rush (surcharge may apply) ☐ 14 days ☐ 7 days Specify:

Relinquished by (printed name and signature)	Date	Time	Received by (printed name and signature)	Date	Time
[signature]	7/13/20	1300	William R Wright [signature]	07/14/20	09:11

SHIP TO: Vista Analytical Laboratory
1104 Windfield Way
El Dorado Hills, CA 95762
(916) 673-1520 * Fax (916) 673-0106

ATTN:

Method of Shipment:

Tracking No.:

Add Analysis(es) Requested — Container(s); PFAS by Isotope Dilution; EPA Method 537 (DW only)

Sample ID	Date	Time	Location/ Sample Description	Quantity	Type	Matrix	PFOA/ PFOS	UCMR3 PFAS List:6	537.1 List: 14 or 18 (Circle One)	EPA Draft List of 24	OTHER: Please attach analyte list	PFOA/ PFOS	UCMR3 PFAS List:6	537.1 List of 14	537.1 List of 18	Comments
SBT20-01 (10.5-11)	7/7/20	1100		1	PJ	SO					*					
SBT20-01-GW	7/7/20	1135		2	P	AQ					*					* WISCONSIN PFAS
SBT20-05-(0.5-1)	7/7/20	1145		1	PJ	SO					*					LIST
SBT20-05 (10.5-11)	7/7/20	1210		1	PJ	SO					*					
SBT20-04 (0.5-1)	7/7/20	1220		1	PJ	SO					*					
SBT20-05-GW	7/7/20	1255		2	P	AQ					*					
SBT20-04 (6-6.5)	7/7/20	1230		1	PJ	SO					*					
SBT20-02-GW	7/7/20	1310		2	P	AQ					*					
SBT20-04-GW	7/7/20	1335		2	P	AQ					*					
SOIL DUPLICATE A	7/7/20	—		1	PJ	SO					*					

Special Instructions/Comments:

SEND DOCUMENTATION AND RESULTS TO:
Name: CHRIS CIECIEK
Company: LIMNOTECH
Address: 501 AVIS DRIVE
City: ANN ARBOR MI 48108
Phone: 734 332 1200
Email: CCIECIEK@LIMNO.COM

Container Types: P= HDPE, PJ= HDPE Jar
PY= Polypropylene, O = Other:

Bottle Preservation Type:
TZ = Trizma:

Matrix Types: AQ = Aqueous, DW = Drinking Water, EF = Effluent, PP = Pulp/Paper, SD = Sediment, SL = Sludge, SO = Soil, WW = Wastewater, B = Blood/Serum, O = Other:

ID: LR-537COC Rev. No. 1 Rev. Date: 8/16/2019 Page: 1 of 1

SR0135

Vista Analytical Laboratory

CHAIN OF CUSTODY

For Laboratory Use Only
Work Order #: 2001473 Temp: 1.4 °C
Storage ID: R-13, WR-2 Storage Secured: Yes ☑ No ☐

Project ID: MSN FFTA SAMPLES PO#: MSNPF1 Sampler: C. Behnke (name)

TAT (check one): Standard: ☒ 21 days Rush (surcharge may apply) ☐ 14 days ☐ 7 days Specify: ______

Relinquished by (printed name and signature)	Date	Time	Received by (printed name and signature)	Date	Time
[signature]	7/13/20	1300	William R Wright [signature]	07/14/2020	09:11

SHIP TO: Vista Analytical Laboratory
1104 Windfield Way
El Dorado Hills, CA 95762
(916) 673-1520 • Fax (916) 673-0106
ATTN:

Method of Shipment:
Tracking No.:

Add Analysis(es) Requested — PFAS by Isotope Dilution; EPA Method 537 (DW only)

Sample ID	Date	Time	Location/ Sample Description	Quantity	Type	Matrix	PFOA/PFOS	UCMR3 PFAS List:6	537.1 List: 14 or 18 (Circle One)	EPA Draft List of 24	OTHER: Please attach analyte list	PFOA/PFOS	UCMR3 PFAS List:6	537.1 List of 14	537.1 List of 18	Comments
SBT20-02 (0-1)	7/7/20	0805		1	PJ	SO					*					
EQUIPMENT BLANK A	7/7/20	0840		2	P	AQ					*					* WISCONSIN PFAS
SBT20-02 (10-10.5)	7/7/20	0815		1	PJ	SO					*					LIST
SBT20-03 (0-1)	7/7/20	0850		1	PJ	SO					*					
SBT20-03 (10-10.5)	7/7/20	0905		1	PJ	SO					*					
SBT20-03-GW	7/7/20	0940		2	P	AQ					*					
SBT20-06 (0-1)	7/7/20	1000		1	PJ	SO					*					
SBT20-06 (13-13.5)	7/7/20	1010		1	PJ	SO					*					
SBT20-06-GW	7/7/20	1040		2	P	AQ					*					
SBT20-01 (0.5-1)	7/7/20	1050		1	PJ	SO					*					

Special Instructions/Comments:

SEND DOCUMENTATION AND RESULTS TO:
Name: CHRIS CIECIEK
Company: LIMNOTECH
Address: 501 AVIS DRIVE
City: ANN ARBOR MI 48108
Phone: 734 332 1200
Email: cciecielk@limno.com

Container Types: P= HDPE, PJ= HDPE Jar, PY= Polypropylene, O = Other: ______
Bottle Preservation Type: TZ = Trizma: ______
Matrix Types: AQ = Aqueous, DW = Drinking Water, EF = Effluent, PP = Pulp/Paper, SD = Sediment, SL = Sludge, SO = Soil, WW = Wastewater, B = Blood/Serum, O = Other. ______

Vista Analytical Laboratory

Sample Log-In Checklist

Page # 1 of 1

Vista Work Order #: 2001473 TAT std

Samples Arrival:	Date/Time 07/14/20 09:11		Initials: WRW		Location: WR-2 Shelf/Rack: NA	
Delivered By:	FedEx	UPS	On Trac	GLS	DHL	Hand Delivered	Other
Preservation:	Ice		Blue Ice		Dry Ice		None
Temp °C: 1.4 (uncorrected)		Probe used: Y / N			Thermometer ID: IR-3	
Temp °C: 1.4 (corrected)						

	YES	NO	NA
Shipping Container(s) Intact?	✓		
Shipping Custody Seals Intact?	✓		
Airbill 3 of 4 Trk # 3947 7925 1814	✓	✓	
Shipping Documentation Present?	✓		
Shipping Container: Vista / Client / Retain / Return / Dispose			
Chain of Custody / Sample Documentation Present?	✓		
Chain of Custody / Sample Documentation Complete?	✓		
Holding Time Acceptable?	✓		

Logged In:	Date/Time 07/14/20 1333	Initials: WWS	Location: R-13, WR-2 Shelf/Rack: 2-2, F-4

	YES	NO	NA
COC Anomaly/Sample Acceptance Form completed?		✓	✓

Comments:

CoC/Label Reconciliation Report WO# 2001473

LabNumber		CoC Sample ID		SampleAlias	Sample Date/Time		Container	BaseMatrix	Sample Comments
2001473-01	A	SBT20-01 (10.5-11)	☑		07-Jul-20 11:00	☑	HDPE Jar, 6 oz	Solid	
2001473-02	A	SBT20-01-GW	☑		07-Jul-20 11:35	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-02	B	SBT20-01-GW	☑		07-Jul-20 11:35	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-03	A	SBT20-05-(0.5-1)	☐ A		07-Jul-20 11:45	☑	HDPE Jar, 6 oz	Solid	
2001473-04	A	SBT20-05 (10.5-11)	☑		07-Jul-20 12:10	☑	HDPE Jar, 6 oz	Solid	
2001473-05	A	SBT20-04 (0.5-1)	☑		07-Jul-20 12:20	☑	HDPE Jar, 6 oz	Solid	
2001473-06	A	SBT20-05-GW	☑		07-Jul-20 12:55	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-06	B	SBT20-05-GW	☑		07-Jul-20 12:55	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-07	A	SBT20-04 (6-6.5)	☑		07-Jul-20 12:30	☑	HDPE Jar, 6 oz	Solid	
2001473-08	A	SBT20-02-GW	☑		07-Jul-20 13:10	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-08	B	SBT20-02-GW	☑		07-Jul-20 13:10	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-09	A	SBT20-04-GW	☑		07-Jul-20 13:35	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-09	B	SBT20-04-GW	☑		07-Jul-20 13:35	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-10	A	SOIL DUPLICATE A	☑		07-Jul-20 00:00	☐ B	HDPE Jar, 6 oz	Solid	
2001473-11	A	SBT20-02 (0-1)	☑		07-Jul-20 08:05	☑	HDPE Jar, 6 oz	Solid	
2001473-12	A	EQUIPMENT BLANK A	☑		07-Jul-20 08:40	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-12	B	EQUIPMENT BLANK A	☑		07-Jul-20 08:40	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-13	A	SBT20-02 (10-10.5)	☑		07-Jul-20 08:15	☑	HDPE Jar, 6 oz	Solid	
2001473-14	A	SBT20-03 (0-1)	☑		07-Jul-20 08:50	☑	HDPE Jar, 6 oz	Solid	
2001473-15	A	SBT20-03 (10-10.5)	☑		07-Jul-20 09:05	☑	HDPE Jar, 6 oz	Solid	
2001473-16	A	SBT20-03-GW	☑		07-Jul-20 09:40	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-16	B	SBT20-03-GW	☑		07-Jul-20 09:40	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-17	A	SBT20-06 (0-1)	☑		07-Jul-20 10:00	☑	HDPE Jar, 6 oz	Solid	
2001473-18	A	SBT20-06 (13-13.5)	☑		07-Jul-20 10:10	☑	HDPE Jar, 6 oz	Solid	
2001473-19	A	SBT20-06-GW	☑		07-Jul-20 10:40	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-19	B	SBT20-06-GW	☑		07-Jul-20 10:40	☑	HDPE Bottle, 125 mL	Aqueous	
2001473-20	A	SBT20-01 (0.5-1)	☑		07-Jul-20 10:50	☑	HDPE Jar, 6 oz	Solid	

Checkmarks indicate that information on the COC reconciled with the sample label.
Any discrepancies are noted in the following columns.

	Yes	No	NA
Sample Container Intact?	✓		
Sample Custody Seals Intact?			✓
Adequate Sample Volume?	✓		
Container Type Appropriate for Analysis(es)	✓		
Preservation Documented: Na2S2O3 Trizma None Other		✓	✓
If Chlorinated or Drinking Water Samples, Acceptable Preservation?			✓

Comments: (A) Sample label SBT02-05 (0.5-1)

(B) No time on sample label

All Aqueous samples Except EB contain particulate

Verifed by/Date: KA. 07/14/20

August 03, 2020

Vista Work Order No. 2001475

Mr. Chris Cieciek
LimnoTech, Inc.
501 Avis Drive
Ann Arbor, MI 48108

Dear Mr. Cieciek,

Enclosed are the results for the sample set received at Vista Analytical Laboratory on July 14, 2020 under your Project Name 'MSN FFTA SAMPLES'.

Vista Analytical Laboratory is committed to serving you effectively. If you require additional information, please contact me at 916-673-1520 or by email at mmaier@vista-analytical.com.

Thank you for choosing Vista as part of your analytical support team.

Sincerely,

Martha Maier

Martha Maier
Laboratory Director

Vista Analytical Laboratory certifies that the report herein meets all the requirements set forth by NELAP for those applicable test methods. Results relate only to the samples as received by the laboratory. This report should not be reproduced except in full without the written approval of Vista.

Vista Work Order No. 2001475
Case Narrative

Sample Condition on Receipt:

Seven soil samples and six aqueous samples were received in good condition and within the method temperature requirements. The samples were received and stored securely in accordance with Vista standard operating procedures and EPA methodology. A relinquishing signature was not included on the Chain-of-Custody (CoC).

Analytical Notes:

PFAS Isotope Dilution Method - Solid

The soil samples were extracted and analyzed for a selected list of PFAS using Vista's Isotope Dilution Method. The results for PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Results for all other analytes include the linear isomers only.

Holding Times

The samples were extracted and analyzed within the method hold times.

Quality Control

The Initial Calibration and Continuing Calibration Verifications met the method acceptance criteria.

A Method Blank and Ongoing Precision and Recovery (OPR) sample were extracted and analyzed with the preparation batch. No analytes were detected in the Method Blank above the Reporting Limit (RL). The recoveries of 11Cl-PF3OUdS and PFDoS were greater than 135% in the OPR. These analytes were not detected in the samples. The recoveries of all other analytes were within the acceptance criteria.

The internal standard recoveries outside the acceptance criteria are flagged with an "H" qualifier.

PFAS Isotope Dilution Method - Aqueous

The following samples contained particulate and were centrifuged prior to extraction:

Laboratory ID	Sample Name
2001475-07	SBP20-02-GW
2001475-08	SBP20-03-GW
2001475-12	GW Duplicate A
2001475-13	GW Duplicate B

The aqueous samples were extracted and analyzed for a selected list of PFAS using Vista's PFAS Isotope Dilution Method. The results for PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Results for all other analytes include the linear isomers only.

Holding Times

The samples were extracted and analyzed within the method hold times.

Quality Control

The Initial Calibration and Continuing Calibration Verifications met the acceptance criteria.

A Method Blank and Ongoing Precision and Recovery (OPR) sample were extracted and analyzed with the preparation batch. No analytes were detected in the Method Blank above the Reporting Limit. The OPR recoveries were within the method acceptance criteria.

The labeled standard recoveries for all QC and field samples were within the acceptance criteria.

TABLE OF CONTENTS

Sample Inventory Report

Vista Sample ID	Client Sample ID	Sampled	Received	Components/Containers
2001475-01	SBP20-02 (1-1.5)	07-Jul-20 15:05	14-Jul-20 09:11	HDPE Jar, 6 oz
2001475-02	SBP20-02 (5.5-6)	07-Jul-20 15:15	14-Jul-20 09:11	HDPE Jar, 6 oz
2001475-03	SBP20-03 (1-1.5)	07-Jul-20 15:30	14-Jul-20 09:11	HDPE Jar, 6 oz
2001475-04	SBP20-03 (5-5.5)	07-Jul-20 15:40	14-Jul-20 09:11	HDPE Jar, 6 oz
2001475-05	SBP20-06 (0.5-1)	07-Jul-20 16:00	14-Jul-20 09:11	HDPE Jar, 6 oz
2001475-06	SBP20-06 (7.4-7.9)	07-Jul-20 16:05	14-Jul-20 09:11	HDPE Jar, 6 oz
2001475-07	SBP20-02-GW	07-Jul-20 16:10	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001475-08	SBP20-03-GW	07-Jul-20 16:35	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001475-09	SBP20-04-(7-7.5)	08-Jul-20 07:40	14-Jul-20 09:11	HDPE Jar, 6 oz
2001475-10	Geoprobe decon blank	08-Jul-20 09:30	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001475-11	EQUIPMENT BLANK-070920	09-Jul-20 16:30	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001475-12	GW Duplicate A	09-Jul-20 00:00	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001475-13	GW Duplicate B	09-Jul-20 00:00	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL

ANALYTICAL RESULTS

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data
Name: LimnoTech, Inc. Matrix: Solid
Project: MSN FFTA SAMPLES

Laboratory Data
Lab Sample: B0G0151-BLK1 Column: BEH C18

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.346	0.346	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFPeA	2706-90-3	<0.398	0.398	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFBS	375-73-5	<0.304	0.304	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
4:2 FTS	757124-72-4	<0.360	0.360	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFHxA	307-24-4	<0.216	0.216	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFPeS	2706-91-4	<0.658	0.658	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
HFPO-DA	13252-13-6	<1.18	1.18	1.50		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFHpA	375-85-9	<0.478	0.478	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
ADONA	919005-14-4	<0.340	0.340	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFHxS	355-46-4	<0.390	0.390	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
6:2 FTS	27619-97-2	<0.654	0.654	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFOA	335-67-1	<0.470	0.470	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFHpS	375-92-8	<0.738	0.738	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFNA	375-95-1	<0.312	0.312	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFOSA	754-91-6	<1.01	1.01	1.50		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFOS	1763-23-1	<0.430	0.430	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
9Cl-PF3ONS	756426-58-1	<0.370	0.370	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFDA	335-76-2	<0.452	0.452	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
8:2 FTS	39108-34-4	<0.722	0.722	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFNS	68259-12-1	<1.15	1.15	1.50		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
MeFOSAA	2355-31-9	<0.736	0.736	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
EtFOSAA	2991-50-6	<0.688	0.688	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFUnA	2058-94-8	<0.258	0.258	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFDS	335-77-3	<0.690	0.690	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
11Cl-PF3OUdS	763051-92-9	<0.722	0.722	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
10:2 FTS	120226-60-0	<1.02	1.02	1.50		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFDoA	307-55-1	<0.404	0.404	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
MeFOSA	31506-32-8	<5.78	5.78	10.0		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFTrDA	72629-94-8	<0.402	0.402	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFDoS	79780-39-5	<0.600	0.600	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFTeDA	376-06-7	<0.264	0.264	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
EtFOSA	4151-50-2	<3.84	3.84	10.0		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFHxDA	67905-19-5	<0.170	0.170	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFODA	16517-11-6	<0.500	0.500	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
MeFOSE	24448-09-7	<4.96	4.96	10.0		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
EtFOSE	1691-99-2	<5.38	5.38	10.0		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	109	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Solid	Lab Sample:	B0G0151-BLK1	Column:	BEH C18
Project:	MSN FFTA SAMPLES						

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	65.3	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C3-PFBS	IS	78.0	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C3-HFPO-DA	IS	57.7	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-4:2 FTS	IS	66.1	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFHxA	IS	66.8	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C4-PFHpA	IS	65.6	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C3-PFHxS	IS	73.6	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-6:2 FTS	IS	65.2	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C5-PFNA	IS	59.5	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C8-PFOSA	IS	27.4	10 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFOA	IS	56.7	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C8-PFOS	IS	66.4	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFDA	IS	50.7	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-8:2 FTS	IS	72.5	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d3-MeFOSAA	IS	48.5	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFUnA	IS	41.0	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d5-EtFOSAA	IS	41.1	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-10:2 FTS	IS	54.1	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFDoA	IS	38.9	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d3-MeFOSA	IS	4.40	10 - 150	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFTeDA	IS	45.1	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d5-EtFOSA	IS	4.40	10 - 150	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFHxDA	IS	32.0	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d7-MeFOSE	IS	20.5	10 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d9-EtFOSE	IS	20.1	10 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1

MDL - Method Detection Limit   RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

SR0147

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Solid

Laboratory Data

Lab Sample: B0G0151-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/g)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	10.7	10.0	107	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFPeA	2706-90-3	10.3	10.0	103	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFBS	375-73-5	10.7	10.0	107	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
4:2 FTS	757124-72-4	10.2	10.0	102	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFHxA	307-24-4	10.7	10.0	107	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFPeS	2706-91-4	11.4	10.0	114	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
HFPO-DA	13252-13-6	11.1	10.0	111	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFHpA	375-85-9	10.8	10.0	108	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
ADONA	919005-14-4	11.1	10.0	111	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFHxS	355-46-4	9.72	10.0	97.2	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
6:2 FTS	27619-97-2	9.33	10.0	93.3	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFOA	335-67-1	10.9	10.0	109	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFHpS	375-92-8	11.6	10.0	116	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFNA	375-95-1	12.0	10.0	120	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFOSA	754-91-6	10.6	10.0	106	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFOS	1763-23-1	11.0	10.0	110	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
9Cl-PF3ONS	756426-58-1	10.6	10.0	106	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFDA	335-76-2	10.1	10.0	101	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
8:2 FTS	39108-34-4	8.49	10.0	84.9	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFNS	68259-12-1	10.8	10.0	108	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
MeFOSAA	2355-31-9	10.2	10.0	102	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
EtFOSAA	2991-50-6	11.2	10.0	112	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFUnA	2058-94-8	9.57	10.0	95.7	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFDS	335-77-3	9.61	10.0	96.1	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
11Cl-PF3OUdS	763051-92-9	18.0	10.0	180	60 - 135	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
10:2 FTS	120226-60-0	11.0	10.0	110	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFDoA	307-55-1	10.1	10.0	101	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
MeFOSA	31506-32-8	53.4	50.0	107	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFTrDA	72629-94-8	11.1	10.0	111	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFDoS	79780-39-5	14.9	10.0	149	60 - 135	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFTeDA	376-06-7	10.7	10.0	107	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
EtFOSA	4151-50-2	48.0	50.0	96.0	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFHxDA	67905-19-5	10.3	10.0	103	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFODA	16517-11-6	9.37	10.0	93.7	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Solid

Laboratory Data

Lab Sample: B0G0151-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/g)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
MeFOSE	24448-09-7	57.8	50.0	116	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
EtFOSE	1691-99-2	51.3	50.0	103	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1

Labeled Standards	Type	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	108	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C3-PFPeA	IS	62.1	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C3-PFBS	IS	84.9	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C3-HFPO-DA	IS	58.5	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-4:2 FTS	IS	91.1	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFHxA	IS	63.6	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C4-PFHpA	IS	62.8	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C3-PFHxS	IS	84.3	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-6:2 FTS	IS	77.5	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C5-PFNA	IS	53.6	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C8-PFOSA	IS	28.5	10- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFOA	IS	59.5	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C8-PFOS	IS	81.4	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFDA	IS	54.3	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-8:2 FTS	IS	88.2	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d3-MeFOSAA	IS	51.9	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFUnA	IS	42.8	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d5-EtFOSAA	IS	48.6	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-10:2 FTS	IS	61.7	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFDoA	IS	37.9	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d3-MeFOSA	IS	5.10	10- 150	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFTeDA	IS	43.0	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d5-EtFOSA	IS	4.80	10- 150	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFHxDA	IS	36.3	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d7-MeFOSE	IS	21.3	10- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d9-EtFOSE	IS	21.9	10- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1

Vista Analytical Laboratory

Sample ID: SBP20-02 (1-1.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-01	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 15:05	Date Received:	14-Jul-20 09:11		
				% Solids:	93.7		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.345	0.345	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFPeA	2706-90-3	<0.397	0.397	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFBS	375-73-5	<0.303	0.303	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
4:2 FTS	757124-72-4	<0.359	0.359	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFHxA	307-24-4	<0.215	0.215	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFPeS	2706-91-4	<0.656	0.656	0.997		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
HFPO-DA	13252-13-6	<1.18	1.18	1.50		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFHpA	375-85-9	<0.477	0.477	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
ADONA	919005-14-4	<0.339	0.339	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFHxS	355-46-4	<0.389	0.389	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
6:2 FTS	27619-97-2	7.30	0.652	0.997		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFOA	335-67-1	<0.469	0.469	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFHpS	375-92-8	<0.736	0.736	0.997		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFNA	375-95-1	<0.311	0.311	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFOSA	754-91-6	<1.01	1.01	1.50		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFOS	1763-23-1	81.5	0.429	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
9Cl-PF3ONS	756426-58-1	<0.369	0.369	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFDA	335-76-2	<0.451	0.451	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
8:2 FTS	39108-34-4	12.6	0.720	0.997		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFNS	68259-12-1	<1.15	1.15	1.50		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
MeFOSAA	2355-31-9	<0.734	0.734	0.997		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
EtFOSAA	2991-50-6	<0.686	0.686	0.997		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFUnA	2058-94-8	<0.257	0.257	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFDS	335-77-3	<0.688	0.688	0.997		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
11Cl-PF3OUdS	763051-92-9	<0.720	0.720	0.997		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
10:2 FTS	120226-60-0	<1.01	1.01	1.50		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFDoA	307-55-1	<0.403	0.403	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
MeFOSA	31506-32-8	<5.76	5.76	9.97		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFTrDA	72629-94-8	<0.401	0.401	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFDoS	79780-39-5	<0.598	0.598	0.997		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFTeDA	376-06-7	<0.263	0.263	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
EtFOSA	4151-50-2	<3.83	3.83	9.97		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFHxDA	67905-19-5	<0.169	0.169	0.499		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
PFODA	16517-11-6	<0.499	0.499	0.997		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
MeFOSE	24448-09-7	<4.95	4.95	9.97		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
EtFOSE	1691-99-2	<5.36	5.36	9.97		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	117	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1

SR0150

Vista Analytical Laboratory

Sample ID: SBP20-02 (1-1.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-01	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 15:05	Date Received:	14-Jul-20 09:11		
				% Solids:	93.7		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	67.5	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C3-PFBS	IS	79.4	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C3-HFPO-DA	IS	69.0	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-4:2 FTS	IS	81.7	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-PFHxA	IS	71.0	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C4-PFHpA	IS	67.9	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C3-PFHxS	IS	81.4	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-6:2 FTS	IS	83.5	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C5-PFNA	IS	51.4	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C8-PFOSA	IS	42.1	10 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-PFOA	IS	61.5	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C8-PFOS	IS	69.2	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-PFDA	IS	45.4	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-8:2 FTS	IS	85.8	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
d3-MeFOSAA	IS	52.6	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-PFUnA	IS	49.5	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
d5-EtFOSAA	IS	54.2	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-10:2 FTS	IS	67.8	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-PFDoA	IS	49.7	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
d3-MeFOSA	IS	9.60	10 - 150	H	B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-PFTeDA	IS	55.4	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
d5-EtFOSA	IS	10.1	10 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
13C2-PFHxDA	IS	43.3	25 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
d7-MeFOSE	IS	32.1	10 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1
d9-EtFOSE	IS	33.5	10 - 150		B0G0151	22-Jul-20	1.07 g	27-Jul-20 16:57	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-02 (5.5-6) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-02	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 15:15	Date Received:	14-Jul-20 09:11		
				% Solids:	66.5		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	0.776	0.347	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFPeA	2706-90-3	2.23	0.399	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFBS	375-73-5	4.25	0.305	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
4:2 FTS	757124-72-4	0.577	0.361	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFHxA	307-24-4	5.09	0.217	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFPeS	2706-91-4	5.77	0.660	1.00		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
HFPO-DA	13252-13-6	<1.18	1.18	1.50		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFHpA	375-85-9	1.04	0.479	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
ADONA	919005-14-4	<0.341	0.341	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFHxS	355-46-4	11.1	0.391	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
6:2 FTS	27619-97-2	8.42	0.656	1.00		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFOA	335-67-1	<0.471	0.471	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFHpS	375-92-8	<0.740	0.740	1.00		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFNA	375-95-1	<0.313	0.313	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFOSA	754-91-6	<1.01	1.01	1.50		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFOS	1763-23-1	<0.431	0.431	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
9Cl-PF3ONS	756426-58-1	<0.371	0.371	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFDA	335-76-2	<0.453	0.453	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
8:2 FTS	39108-34-4	<0.724	0.724	1.00		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFNS	68259-12-1	<1.15	1.15	1.50		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
MeFOSAA	2355-31-9	<0.738	0.738	1.00		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
EtFOSAA	2991-50-6	<0.690	0.690	1.00		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFUnA	2058-94-8	<0.259	0.259	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFDS	335-77-3	<0.692	0.692	1.00		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
11Cl-PF3OUdS	763051-92-9	<0.724	0.724	1.00		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
10:2 FTS	120226-60-0	<1.02	1.02	1.50		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFDoA	307-55-1	<0.405	0.405	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
MeFOSA	31506-32-8	<5.80	5.80	10.0		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFTrDA	72629-94-8	<0.403	0.403	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFDoS	79780-39-5	<0.602	0.602	1.00		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFTeDA	376-06-7	<0.265	0.265	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
EtFOSA	4151-50-2	<3.85	3.85	10.0		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFHxDA	67905-19-5	<0.170	0.170	0.501		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
PFODA	16517-11-6	<0.501	0.501	1.00		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
MeFOSE	24448-09-7	<4.97	4.97	10.0		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
EtFOSE	1691-99-2	<5.39	5.39	10.0		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	116	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1

SR0152

Vista Analytical Laboratory

Sample ID: SBP20-02 (5.5-6) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-02	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 15:15	Date Received:	14-Jul-20 09:11		
				% Solids:	66.5		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	69.9	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C3-PFBS	IS	76.1	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C3-HFPO-DA	IS	69.3	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-4:2 FTS	IS	82.6	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-PFHxA	IS	72.9	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C4-PFHpA	IS	69.0	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C3-PFHxS	IS	81.5	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-6:2 FTS	IS	66.5	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C5-PFNA	IS	64.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C8-PFOSA	IS	47.5	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-PFOA	IS	63.5	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C8-PFOS	IS	67.5	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-PFDA	IS	60.5	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-8:2 FTS	IS	80.3	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
d3-MeFOSAA	IS	69.8	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-PFUnA	IS	63.0	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
d5-EtFOSAA	IS	65.8	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-10:2 FTS	IS	64.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-PFDoA	IS	57.0	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
d3-MeFOSA	IS	24.6	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-PFTeDA	IS	44.7	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
d5-EtFOSA	IS	30.5	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
13C2-PFHxDA	IS	21.6	25 - 150	H	B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
d7-MeFOSE	IS	43.9	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1
d9-EtFOSE	IS	43.4	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 17:07	1

MDL - Method Detection Limit

RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

SR0153

Vista Analytical Laboratory

Sample ID: SBP20-03 (1-1.5) **PFAS Isotope Dilution Method**

Client Data
Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Soil
Date Collected: 07-Jul-20 15:30

Laboratory Data
Lab Sample: 2001475-03
Date Received: 14-Jul-20 09:11
% Solids: 95.3
Column: BEH C18

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.346	0.346	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFPeA	2706-90-3	<0.398	0.398	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFBS	375-73-5	<0.304	0.304	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
4:2 FTS	757124-72-4	<0.360	0.360	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFHxA	307-24-4	<0.216	0.216	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFPeS	2706-91-4	<0.658	0.658	1.00		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
HFPO-DA	13252-13-6	<1.18	1.18	1.50		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFHpA	375-85-9	<0.478	0.478	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
ADONA	919005-14-4	<0.340	0.340	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFHxS	355-46-4	<0.390	0.390	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
6:2 FTS	27619-97-2	0.913	0.654	1.00	J	B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFOA	335-67-1	<0.470	0.470	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFHpS	375-92-8	<0.738	0.738	1.00		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFNA	375-95-1	0.871	0.312	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFOSA	754-91-6	3.21	1.01	1.50		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFOS	1763-23-1	<0.430	0.430	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
9Cl-PF3ONS	756426-58-1	<0.370	0.370	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFDA	335-76-2	0.614	0.452	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
8:2 FTS	39108-34-4	1.18	0.722	1.00		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFNS	68259-12-1	<1.15	1.15	1.50		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
MeFOSAA	2355-31-9	<0.736	0.736	1.00		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
EtFOSAA	2991-50-6	<0.688	0.688	1.00		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFUnA	2058-94-8	<0.258	0.258	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFDS	335-77-3	<0.690	0.690	1.00		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
11Cl-PF3OUdS	763051-92-9	<0.722	0.722	1.00		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
10:2 FTS	120226-60-0	<1.02	1.02	1.50		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFDoA	307-55-1	<0.404	0.404	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
MeFOSA	31506-32-8	<5.78	5.78	10.0		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFTrDA	72629-94-8	<0.402	0.402	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFDoS	79780-39-5	<0.600	0.600	1.00		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFTeDA	376-06-7	<0.264	0.264	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
EtFOSA	4151-50-2	<3.84	3.84	10.0		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFHxDA	67905-19-5	<0.170	0.170	0.500		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
PFODA	16517-11-6	<0.500	0.500	1.00		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
MeFOSE	24448-09-7	<4.96	4.96	10.0		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
EtFOSE	1691-99-2	<5.38	5.38	10.0		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	129	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1

Vista Analytical Laboratory

Sample ID: SBP20-03 (1-1.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-03	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 15:30	Date Received:	14-Jul-20 09:11		
				% Solids:	95.3		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	80.7	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C3-PFBS	IS	89.1	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C3-HFPO-DA	IS	79.7	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-4:2 FTS	IS	80.6	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-PFHxA	IS	84.6	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C4-PFHpA	IS	78.1	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C3-PFHxS	IS	83.2	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-6:2 FTS	IS	80.0	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C5-PFNA	IS	78.6	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C8-PFOSA	IS	41.3	10 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-PFOA	IS	80.2	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C8-PFOS	IS	75.9	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-PFDA	IS	60.8	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-8:2 FTS	IS	88.2	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
d3-MeFOSAA	IS	55.8	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-PFUnA	IS	57.7	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
d5-EtFOSAA	IS	59.2	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-10:2 FTS	IS	69.9	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-PFDoA	IS	55.8	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
d3-MeFOSA	IS	11.0	10 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-PFTeDA	IS	60.8	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
d5-EtFOSA	IS	11.3	10 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
13C2-PFHxDA	IS	52.2	25 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
d7-MeFOSE	IS	30.8	10 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1
d9-EtFOSE	IS	32.1	10 - 150		B0G0151	22-Jul-20	1.05 g	27-Jul-20 17:49	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-03 (5-5.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-04	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 15:40	Date Received:	14-Jul-20 09:11		
				% Solids:	78.1		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.346	0.346	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFPeA	2706-90-3	<0.398	0.398	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFBS	375-73-5	<0.304	0.304	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
4:2 FTS	757124-72-4	<0.360	0.360	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFHxA	307-24-4	0.671	0.216	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFPeS	2706-91-4	<0.659	0.659	1.00		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
HFPO-DA	13252-13-6	<1.18	1.18	1.50		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFHpA	375-85-9	0.918	0.478	0.500	Q	B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
ADONA	919005-14-4	<0.340	0.340	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFHxS	355-46-4	20.4	0.390	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
6:2 FTS	27619-97-2	10.2	0.655	1.00		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFOA	335-67-1	<0.470	0.470	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFHpS	375-92-8	<0.739	0.739	1.00		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFNA	375-95-1	<0.312	0.312	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFOSA	754-91-6	<1.01	1.01	1.50		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFOS	1763-23-1	17.0	0.430	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
9Cl-PF3ONS	756426-58-1	<0.370	0.370	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFDA	335-76-2	<0.452	0.452	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
8:2 FTS	39108-34-4	<0.723	0.723	1.00		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFNS	68259-12-1	<1.15	1.15	1.50		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
MeFOSAA	2355-31-9	<0.737	0.737	1.00		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
EtFOSAA	2991-50-6	<0.689	0.689	1.00		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFUnA	2058-94-8	<0.258	0.258	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFDS	335-77-3	<0.691	0.691	1.00		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
11Cl-PF3OUdS	763051-92-9	<0.723	0.723	1.00		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
10:2 FTS	120226-60-0	<1.02	1.02	1.50		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFDoA	307-55-1	<0.404	0.404	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
MeFOSA	31506-32-8	<5.78	5.78	10.0		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFTrDA	72629-94-8	<0.402	0.402	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFDoS	79780-39-5	<0.600	0.600	1.00		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFTeDA	376-06-7	<0.264	0.264	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
EtFOSA	4151-50-2	<3.84	3.84	10.0		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFHxDA	67905-19-5	<0.170	0.170	0.500		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
PFODA	16517-11-6	<0.500	0.500	1.00		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
MeFOSE	24448-09-7	<4.96	4.96	10.0		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
EtFOSE	1691-99-2	<5.38	5.38	10.0		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	114	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1

SR0156

Vista Analytical Laboratory

Sample ID: SBP20-03 (5-5.5) **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-04	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 15:40	Date Received:	14-Jul-20 09:11		
				% Solids:	78.1		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	70.8	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C3-PFBS	IS	75.5	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C3-HFPO-DA	IS	70.3	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-4:2 FTS	IS	82.5	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-PFHxA	IS	76.9	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C4-PFHpA	IS	73.9	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C3-PFHxS	IS	78.3	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-6:2 FTS	IS	74.7	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C5-PFNA	IS	66.0	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C8-PFOSA	IS	46.6	10 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-PFOA	IS	72.9	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C8-PFOS	IS	77.5	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-PFDA	IS	65.2	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-8:2 FTS	IS	80.6	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
d3-MeFOSAA	IS	67.1	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-PFUnA	IS	65.6	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
d5-EtFOSAA	IS	65.1	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-10:2 FTS	IS	69.2	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-PFDoA	IS	61.2	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
d3-MeFOSA	IS	19.0	10 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-PFTeDA	IS	57.0	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
d5-EtFOSA	IS	20.5	10 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
13C2-PFHxDA	IS	38.8	25 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
d7-MeFOSE	IS	41.1	10 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1
d9-EtFOSE	IS	46.2	10 - 150		B0G0151	22-Jul-20	1.28 g	27-Jul-20 17:59	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-06 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-05	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 16:00	Date Received:	14-Jul-20 09:11		
				% Solids:	95.2		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.333	0.333	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFPeA	2706-90-3	<0.383	0.383	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFBS	375-73-5	<0.293	0.293	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
4:2 FTS	757124-72-4	<0.347	0.347	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFHxA	307-24-4	0.245	0.208	0.482	J, Q	B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFPeS	2706-91-4	<0.634	0.634	0.964		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
HFPO-DA	13252-13-6	<1.14	1.14	1.45		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFHpA	375-85-9	<0.461	0.461	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
ADONA	919005-14-4	<0.328	0.328	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFHxS	355-46-4	<0.376	0.376	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
6:2 FTS	27619-97-2	<0.630	0.630	0.964		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFOA	335-67-1	<0.453	0.453	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFHpS	375-92-8	<0.711	0.711	0.964		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFNA	375-95-1	0.674	0.301	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFOSA	754-91-6	<0.971	0.971	1.45		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFOS	1763-23-1	69.1	0.414	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
9Cl-PF3ONS	756426-58-1	<0.357	0.357	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFDA	335-76-2	0.609	0.436	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
8:2 FTS	39108-34-4	<0.696	0.696	0.964		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFNS	68259-12-1	<1.11	1.11	1.45		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
MeFOSAA	2355-31-9	<0.709	0.709	0.964		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
EtFOSAA	2991-50-6	<0.663	0.663	0.964		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFUnA	2058-94-8	<0.249	0.249	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFDS	335-77-3	<0.665	0.665	0.964		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
11Cl-PF3OUdS	763051-92-9	<0.696	0.696	0.964		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
10:2 FTS	120226-60-0	<0.979	0.979	1.45		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFDoA	307-55-1	<0.389	0.389	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
MeFOSA	31506-32-8	<5.57	5.57	9.64		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFTrDA	72629-94-8	<0.387	0.387	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFDoS	79780-39-5	<0.578	0.578	0.964		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFTeDA	376-06-7	<0.254	0.254	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
EtFOSA	4151-50-2	<3.70	3.70	9.64		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFHxDA	67905-19-5	<0.164	0.164	0.482		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
PFODA	16517-11-6	<0.482	0.482	0.964		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
MeFOSE	24448-09-7	<4.78	4.78	9.64		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
EtFOSE	1691-99-2	<5.18	5.18	9.64		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	124	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1

Vista Analytical Laboratory

Sample ID: SBP20-06 (0.5-1) **PFAS Isotope Dilution Method**

Client Data

Name:	LimnoTech, Inc.	Matrix:	Soil
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 16:00

Laboratory Data

Lab Sample:	2001475-05	Column:	BEH C18
Date Received:	14-Jul-20 09:11		
% Solids:	95.2		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	76.2	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C3-PFBS	IS	81.3	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C3-HFPO-DA	IS	81.6	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-4:2 FTS	IS	80.0	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-PFHxA	IS	79.4	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C4-PFHpA	IS	73.6	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C3-PFHxS	IS	73.1	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-6:2 FTS	IS	79.3	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C5-PFNA	IS	68.0	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C8-PFOSA	IS	49.0	10 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-PFOA	IS	68.7	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C8-PFOS	IS	73.7	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-PFDA	IS	62.9	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-8:2 FTS	IS	90.7	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
d3-MeFOSAA	IS	66.1	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-PFUnA	IS	66.8	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
d5-EtFOSAA	IS	61.1	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-10:2 FTS	IS	78.7	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-PFDoA	IS	59.0	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
d3-MeFOSA	IS	24.3	10 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-PFTeDA	IS	63.2	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
d5-EtFOSA	IS	26.8	10 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
13C2-PFHxDA	IS	62.4	25 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
d7-MeFOSE	IS	37.0	10 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1
d9-EtFOSE	IS	41.0	10 - 150		B0G0151	22-Jul-20	1.09 g	27-Jul-20 18:10	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-06 (7.4-7.9) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-06	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 16:05	Date Received:	14-Jul-20 09:11		
				% Solids:	68.5		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	0.457	0.337	0.486	J	B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFPeA	2706-90-3	0.970	0.387	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFBS	375-73-5	2.37	0.296	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
4:2 FTS	757124-72-4	<0.350	0.350	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFHxA	307-24-4	3.37	0.210	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFPeS	2706-91-4	6.68	0.640	0.973		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
HFPO-DA	13252-13-6	<1.15	1.15	1.46		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFHpA	375-85-9	1.18	0.465	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
ADONA	919005-14-4	<0.331	0.331	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFHxS	355-46-4	64.8	0.379	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
6:2 FTS	27619-97-2	36.3	0.636	0.973		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFOA	335-67-1	<0.457	0.457	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFHpS	375-92-8	3.94	0.718	0.973		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFNA	375-95-1	<0.304	0.304	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFOSA	754-91-6	<0.981	0.981	1.46		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFOS	1763-23-1	<0.418	0.418	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
9Cl-PF3ONS	756426-58-1	<0.360	0.360	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFDA	335-76-2	<0.440	0.440	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
8:2 FTS	39108-34-4	<0.702	0.702	0.973		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFNS	68259-12-1	<1.12	1.12	1.46		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
MeFOSAA	2355-31-9	<0.716	0.716	0.973		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
EtFOSAA	2991-50-6	<0.669	0.669	0.973		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFUnA	2058-94-8	<0.251	0.251	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFDS	335-77-3	<0.671	0.671	0.973		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
11Cl-PF3OUdS	763051-92-9	<0.702	0.702	0.973		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
10:2 FTS	120226-60-0	<0.988	0.988	1.46		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFDoA	307-55-1	<0.393	0.393	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
MeFOSA	31506-32-8	<5.62	5.62	9.73		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFTrDA	72629-94-8	<0.391	0.391	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFDoS	79780-39-5	<0.584	0.584	0.973		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFTeDA	376-06-7	<0.257	0.257	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
EtFOSA	4151-50-2	<3.74	3.74	9.73		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFHxDA	67905-19-5	<0.165	0.165	0.486		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
PFODA	16517-11-6	<0.486	0.486	0.973		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
MeFOSE	24448-09-7	<4.83	4.83	9.73		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
EtFOSE	1691-99-2	<5.23	5.23	9.73		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	105	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1

Vista Analytical Laboratory

Sample ID: SBP20-06 (7.4-7.9) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-06	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 16:05	Date Received:	14-Jul-20 09:11		
				% Solids:	68.5		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	67.3	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C3-PFBS	IS	80.3	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C3-HFPO-DA	IS	67.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-4:2 FTS	IS	75.3	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-PFHxA	IS	64.5	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C4-PFHpA	IS	61.8	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C3-PFHxS	IS	76.1	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-6:2 FTS	IS	81.2	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C5-PFNA	IS	51.5	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C8-PFOSA	IS	45.7	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-PFOA	IS	62.9	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C8-PFOS	IS	65.0	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-PFDA	IS	56.7	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-8:2 FTS	IS	84.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
d3-MeFOSAA	IS	54.1	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-PFUnA	IS	48.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
d5-EtFOSAA	IS	55.6	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-10:2 FTS	IS	57.0	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-PFDoA	IS	38.9	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
d3-MeFOSA	IS	19.8	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-PFTeDA	IS	15.8	25 - 150	H	B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
d5-EtFOSA	IS	21.9	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
13C2-PFHxDA	IS	10.6	25 - 150	H	B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
d7-MeFOSE	IS	41.7	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1
d9-EtFOSE	IS	50.5	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 18:20	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-04-(7-7.5) **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Soil
Date Collected: 08-Jul-20 07:40

Laboratory Data

Lab Sample: 2001475-09
Date Received: 14-Jul-20 09:11
% Solids: 74.9
Column: BEH C18

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.337	0.337	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFPeA	2706-90-3	<0.388	0.388	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFBS	375-73-5	<0.296	0.296	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
4:2 FTS	757124-72-4	<0.351	0.351	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFHxA	307-24-4	0.594	0.210	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFPeS	2706-91-4	<0.641	0.641	0.974		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
HFPO-DA	13252-13-6	<1.15	1.15	1.46		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFHpA	375-85-9	0.835	0.466	0.487	Q	B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
ADONA	919005-14-4	<0.331	0.331	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFHxS	355-46-4	8.26	0.380	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
6:2 FTS	27619-97-2	4.08	0.637	0.974		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFOA	335-67-1	1.77	0.458	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFHpS	375-92-8	8.61	0.719	0.974		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFNA	375-95-1	1.05	0.304	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFOSA	754-91-6	<0.982	0.982	1.46		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFOS	1763-23-1	<0.419	0.419	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
9Cl-PF3ONS	756426-58-1	<0.360	0.360	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFDA	335-76-2	<0.440	0.440	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
8:2 FTS	39108-34-4	<0.703	0.703	0.974		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFNS	68259-12-1	<1.12	1.12	1.46		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
MeFOSAA	2355-31-9	<0.717	0.717	0.974		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
EtFOSAA	2991-50-6	<0.670	0.670	0.974		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFUnA	2058-94-8	<0.251	0.251	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFDS	335-77-3	<0.672	0.672	0.974		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
11Cl-PF3OUdS	763051-92-9	<0.703	0.703	0.974		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
10:2 FTS	120226-60-0	<0.990	0.990	1.46		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFDoA	307-55-1	<0.394	0.394	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
MeFOSA	31506-32-8	<5.63	5.63	9.74		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFTrDA	72629-94-8	<0.392	0.392	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFDoS	79780-39-5	<0.584	0.584	0.974		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFTeDA	376-06-7	<0.257	0.257	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
EtFOSA	4151-50-2	<3.74	3.74	9.74		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFHxDA	67905-19-5	<0.166	0.166	0.487		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
PFODA	16517-11-6	<0.487	0.487	0.974		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
MeFOSE	24448-09-7	<4.83	4.83	9.74		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
EtFOSE	1691-99-2	<5.24	5.24	9.74		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	75.7	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1

SR0162

Vista Analytical Laboratory

Sample ID: SBP20-04-(7-7.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001475-09	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 07:40	Date Received:	14-Jul-20 09:11		
				% Solids:	74.9		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	76.2	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C3-PFBS	IS	76.2	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C3-HFPO-DA	IS	82.6	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-4:2 FTS	IS	101	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-PFHxA	IS	84.8	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C4-PFHpA	IS	83.2	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C3-PFHxS	IS	82.9	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-6:2 FTS	IS	71.8	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C5-PFNA	IS	65.4	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C8-PFOSA	IS	55.5	10 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-PFOA	IS	75.3	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C8-PFOS	IS	66.7	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-PFDA	IS	57.1	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-8:2 FTS	IS	88.6	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
d3-MeFOSAA	IS	60.8	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-PFUnA	IS	63.1	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
d5-EtFOSAA	IS	53.9	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-10:2 FTS	IS	79.3	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-PFDoA	IS	54.9	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
d3-MeFOSA	IS	24.8	10 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-PFTeDA	IS	34.2	25 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
d5-EtFOSA	IS	24.6	10 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
13C2-PFHxDA	IS	15.5	25 - 150	H	B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
d7-MeFOSE	IS	39.3	10 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1
d9-EtFOSE	IS	41.2	10 - 150		B0G0151	22-Jul-20	1.37 g	28-Jul-20 17:10	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	B0G0132-BLK1	Column:	BEH C18
Project:	MSN FFTA SAMPLES						

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.729	0.729	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFPeA	2706-90-3	<1.28	1.28	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFBS	375-73-5	<1.79	1.79	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
4:2 FTS	757124-72-4	<1.39	1.39	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHxA	307-24-4	<2.18	2.18	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFPeS	2706-91-4	<2.42	2.42	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
HFPO-DA	13252-13-6	<4.82	4.82	5.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHpA	375-85-9	<0.591	0.591	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
ADONA	919005-14-4	<0.722	0.722	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHxS	355-46-4	<0.947	0.947	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
6:2 FTS	27619-97-2	<2.00	2.00	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFOA	335-67-1	<0.651	0.651	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHpS	375-92-8	<0.937	0.937	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFNA	375-95-1	<0.810	0.810	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFOSA	754-91-6	<1.77	1.77	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFOS	1763-23-1	<0.807	0.807	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
9Cl-PF3ONS	756426-58-1	<1.45	1.45	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDA	335-76-2	<1.49	1.49	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
8:2 FTS	39108-34-4	<2.06	2.06	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFNS	68259-12-1	<3.87	3.87	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
MeFOSAA	2355-31-9	<1.65	1.65	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
EtFOSAA	2991-50-6	<1.37	1.37	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFUnA	2058-94-8	<1.05	1.05	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDS	335-77-3	<1.23	1.23	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
11Cl-PF3OUdS	763051-92-9	<2.41	2.41	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
10:2 FTS	120226-60-0	<3.13	3.13	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDoA	307-55-1	<0.792	0.792	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
MeFOSA	31506-32-8	<3.83	3.83	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFTrDA	72629-94-8	<0.494	0.494	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDoS	79780-39-5	<4.17	4.17	5.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFTeDA	376-06-7	<0.755	0.755	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
EtFOSA	4151-50-2	<5.11	5.11	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHxDA	67905-19-5	1.37	0.294	4.00	J, Q	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFODA	16517-11-6	<6.14	6.14	7.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
MeFOSE	24448-09-7	<6.07	6.07	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
EtFOSE	1691-99-2	<9.44	9.44	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	144	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data
Name: LimnoTech, Inc. Matrix: Aqueous
Project: MSN FFTA SAMPLES

Laboratory Data
Lab Sample: B0G0132-BLK1 Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	101	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C3-PFBS	IS	102	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C3-HFPO-DA	IS	90.2	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-4:2 FTS	IS	97.6	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFHxA	IS	95.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C4-PFHpA	IS	102	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C3-PFHxS	IS	104	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-6:2 FTS	IS	89.1	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C5-PFNA	IS	80.3	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C8-PFOSA	IS	33.9	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFOA	IS	97.6	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C8-PFOS	IS	92.7	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFDA	IS	90.9	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-8:2 FTS	IS	94.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d3-MeFOSAA	IS	77.3	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFUnA	IS	82.3	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d5-EtFOSAA	IS	69.7	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-10:2 FTS	IS	77.9	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFDoA	IS	74.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d3-MeFOSA	IS	10.8	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFTeDA	IS	64.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d5-EtFOSA	IS	9.30	10 - 150	H	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFHxDA	IS	39.2	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d7-MeFOSE	IS	16.0	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d9-EtFOSE	IS	17.2	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	B0G0132-BS1	Column:	BEH C18
Project:	MSN FFTA SAMPLES						

Analyte	CAS Number	Amt Found (ng/L)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	7.82	8.00	97.7	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFPeA	2706-90-3	7.69	8.00	96.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFBS	375-73-5	7.42	8.00	92.7	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
4:2 FTS	757124-72-4	7.81	8.00	97.6	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHxA	307-24-4	7.64	8.00	95.4	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFPeS	2706-91-4	8.20	8.00	103	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
HFPO-DA	13252-13-6	7.51	8.00	93.8	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHpA	375-85-9	7.48	8.00	93.6	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
ADONA	919005-14-4	7.54	8.00	94.2	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHxS	355-46-4	6.14	8.00	76.7	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
6:2 FTS	27619-97-2	8.50	8.00	106	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFOA	335-67-1	7.13	8.00	89.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHpS	375-92-8	7.83	8.00	97.9	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFNA	375-95-1	8.53	8.00	107	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFOSA	754-91-6	10.1	8.00	126	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFOS	1763-23-1	8.96	8.00	112	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
9Cl-PF3ONS	756426-58-1	7.13	8.00	89.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDA	335-76-2	7.48	8.00	93.6	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
8:2 FTS	39108-34-4	6.64	8.00	83.0	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFNS	68259-12-1	7.56	8.00	94.5	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
MeFOSAA	2355-31-9	7.12	8.00	89.0	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
EtFOSAA	2991-50-6	6.42	8.00	80.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFUnA	2058-94-8	7.64	8.00	95.5	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDS	335-77-3	7.21	8.00	90.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
11Cl-PF3OUdS	763051-92-9	7.38	8.00	92.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
10:2 FTS	120226-60-0	8.50	8.00	106	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDoA	307-55-1	7.35	8.00	91.8	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
MeFOSA	31506-32-8	28.9	40.0	72.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFTrDA	72629-94-8	7.23	8.00	90.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDoS	79780-39-5	6.88	8.00	85.9	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFTeDA	376-06-7	7.21	8.00	90.2	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
EtFOSA	4151-50-2	35.5	40.0	88.8	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHxDA	67905-19-5	7.62	8.00	95.3	50 - 150	B	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFODA	16517-11-6	6.65	8.00	83.1	50 - 150	J	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Aqueous

Laboratory Data

Lab Sample: B0G0132-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/L)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
MeFOSE	24448-09-7	45.9	40.0	115	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
EtFOSE	1691-99-2	26.1	40.0	65.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1

Labeled Standards	Type	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	145	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-PFPeA	IS	97.0	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-PFBS	IS	100	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-HFPO-DA	IS	86.9	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-4:2 FTS	IS	95.8	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFHxA	IS	87.0	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C4-PFHpA	IS	91.2	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-PFHxS	IS	101	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-6:2 FTS	IS	90.4	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C5-PFNA	IS	77.0	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C8-PFOSA	IS	26.2	10- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFOA	IS	90.1	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C8-PFOS	IS	80.2	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFDA	IS	89.6	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-8:2 FTS	IS	85.6	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d3-MeFOSAA	IS	71.1	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFUnA	IS	75.5	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d5-EtFOSAA	IS	70.3	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-10:2 FTS	IS	71.4	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFDoA	IS	81.9	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d3-MeFOSA	IS	7.50	10- 150	H	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFTeDA	IS	74.5	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d5-EtFOSA	IS	5.90	10- 150	H	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFHxDA	IS	61.5	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d7-MeFOSE	IS	11.5	10- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d9-EtFOSE	IS	12.9	10- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1

Vista Analytical Laboratory

Sample ID: SBP20-02-GW **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc. Matrix: Aqueous
Project: MSN FFTA SAMPLES Date Collected: 07-Jul-20 16:10

Laboratory Data

Lab Sample: 2001475-07 Column: BEH C18
Date Received: 14-Jul-20 09:11

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	110	0.820	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFPeA	2706-90-3	271	1.44	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFBS	375-73-5	302	2.01	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
4:2 FTS	757124-72-4	19.7	1.56	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFHxA	307-24-4	489	2.45	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFPeS	2706-91-4	322	2.72	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
HFPO-DA	13252-13-6	<5.42	5.42	5.62		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFHpA	375-85-9	115	0.664	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
ADONA	919005-14-4	<0.812	0.812	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFHxS	355-46-4	1420	1.06	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
6:2 FTS	27619-97-2	537	2.25	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFOA	335-67-1	126	0.732	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFHpS	375-92-8	29.3	1.05	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFNA	375-95-1	15.8	0.911	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFOSA	754-91-6	16.7	1.99	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFOS	1763-23-1	1680	0.907	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
9Cl-PF3ONS	756426-58-1	<1.63	1.63	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFDA	335-76-2	<1.68	1.68	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
8:2 FTS	39108-34-4	28.4	2.32	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFNS	68259-12-1	<4.35	4.35	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
MeFOSAA	2355-31-9	<1.86	1.86	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
EtFOSAA	2991-50-6	<1.54	1.54	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFUnA	2058-94-8	<1.18	1.18	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFDS	335-77-3	1.76	1.38	4.50	J, Q	B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
11Cl-PF3OUdS	763051-92-9	<2.71	2.71	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
10:2 FTS	120226-60-0	<3.52	3.52	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFDoA	307-55-1	<0.890	0.890	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
MeFOSA	31506-32-8	<4.31	4.31	22.5		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFTrDA	72629-94-8	<0.555	0.555	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFDoS	79780-39-5	<4.69	4.69	5.62		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFTeDA	376-06-7	<0.849	0.849	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
EtFOSA	4151-50-2	<5.75	5.75	22.5		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFHxDA	67905-19-5	<0.331	0.331	4.50		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
PFODA	16517-11-6	<6.90	6.90	7.87		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
MeFOSE	24448-09-7	<6.82	6.82	22.5		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
EtFOSE	1691-99-2	<10.6	10.6	22.5		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	85.6	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1

SR0168

Vista Analytical Laboratory

Sample ID: SBP20-02-GW **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001475-07	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 16:10	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	87.1	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C3-PFBS	IS	95.5	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C3-HFPO-DA	IS	84.2	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-4:2 FTS	IS	84.5	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-PFHxA	IS	85.9	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C4-PFHpA	IS	85.0	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C3-PFHxS	IS	80.3	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-6:2 FTS	IS	85.0	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C5-PFNA	IS	83.3	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C8-PFOSA	IS	64.3	10 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-PFOA	IS	92.3	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C8-PFOS	IS	101	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-PFDA	IS	78.5	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-8:2 FTS	IS	78.6	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
d3-MeFOSAA	IS	88.3	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-PFUnA	IS	79.8	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
d5-EtFOSAA	IS	82.3	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-10:2 FTS	IS	66.0	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-PFDoA	IS	77.9	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
d3-MeFOSA	IS	22.9	10 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-PFTeDA	IS	75.2	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
d5-EtFOSA	IS	20.6	10 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
13C2-PFHxDA	IS	68.3	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
d7-MeFOSE	IS	43.6	10 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1
d9-EtFOSE	IS	46.9	10 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 20:32	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-03-GW **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001475-08	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	07-Jul-20 16:35	Date Received:	14-Jul-20 09:11		

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	293	0.803	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFPeA	2706-90-3	877	1.41	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFBS	375-73-5	590	1.97	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
4:2 FTS	757124-72-4	51.8	1.53	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFHxA	307-24-4	1420	2.40	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFPeS	2706-91-4	876	2.66	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
HFPO-DA	13252-13-6	<5.31	5.31	5.50		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFHpA	375-85-9	394	0.651	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
ADONA	919005-14-4	<0.795	0.795	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFHxS	355-46-4	7700	5.21	22.0	D	B0G0132	17-Jul-20	0.114 L	23-Jul-20 20:43	5
6:2 FTS	27619-97-2	5220	11.0	22.0	D	B0G0132	17-Jul-20	0.114 L	23-Jul-20 20:43	5
PFOA	335-67-1	895	0.717	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFHpS	375-92-8	316	1.03	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFNA	375-95-1	41.4	0.892	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFOSA	754-91-6	169	1.95	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFOS	1763-23-1	11000	4.44	22.0	D	B0G0132	17-Jul-20	0.114 L	23-Jul-20 20:43	5
9Cl-PF3ONS	756426-58-1	<1.60	1.60	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFDA	335-76-2	8.51	1.64	4.40	Q	B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
8:2 FTS	39108-34-4	628	2.27	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFNS	68259-12-1	5.22	4.26	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
MeFOSAA	2355-31-9	<1.82	1.82	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
EtFOSAA	2991-50-6	<1.51	1.51	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFUnA	2058-94-8	<1.16	1.16	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFDS	335-77-3	<1.35	1.35	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
11Cl-PF3OUdS	763051-92-9	<2.65	2.65	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
10:2 FTS	120226-60-0	<3.45	3.45	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFDoA	307-55-1	<0.872	0.872	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
MeFOSA	31506-32-8	<4.22	4.22	22.0		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFTrDA	72629-94-8	<0.544	0.544	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFDoS	79780-39-5	<4.59	4.59	5.50		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFTeDA	376-06-7	<0.831	0.831	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
EtFOSA	4151-50-2	<5.63	5.63	22.0		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFHxDA	67905-19-5	<0.324	0.324	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
PFODA	16517-11-6	<6.76	6.76	7.71		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
MeFOSE	24448-09-7	<6.68	6.68	22.0		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
EtFOSE	1691-99-2	<10.4	10.4	22.0		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	82.4	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1

SR0170

Vista Analytical Laboratory

Sample ID: SBP20-03-GW **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Aqueous
Date Collected: 07-Jul-20 16:35

Laboratory Data

Lab Sample: 2001475-08
Date Received: 14-Jul-20 09:11
Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	103	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C3-PFBS	IS	101	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C3-HFPO-DA	IS	99.7	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C2-4:2 FTS	IS	100	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C2-PFHxA	IS	95.5	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C4-PFHpA	IS	99.6	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C3-PFHxS	IS	73.0	25 - 150	D	B0G0132	17-Jul-20	0.114 L	23-Jul-20 20:43	5
13C2-6:2 FTS	IS	119	25 - 150	D	B0G0132	17-Jul-20	0.114 L	23-Jul-20 20:43	5
13C5-PFNA	IS	89.5	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C8-PFOSA	IS	52.2	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C2-PFOA	IS	96.5	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C8-PFOS	IS	88.0	25 - 150	D	B0G0132	17-Jul-20	0.114 L	23-Jul-20 20:43	5
13C2-PFDA	IS	105	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C2-8:2 FTS	IS	92.3	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
d3-MeFOSAA	IS	96.5	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C2-PFUnA	IS	97.5	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
d5-EtFOSAA	IS	88.3	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C2-10:2 FTS	IS	92.4	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C2-PFDoA	IS	104	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
d3-MeFOSA	IS	21.1	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C2-PFTeDA	IS	84.1	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
d5-EtFOSA	IS	19.4	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
13C2-PFHxDA	IS	64.5	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
d7-MeFOSE	IS	55.5	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1
d9-EtFOSE	IS	52.2	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:27	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: Geoprobe decon blank **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Aqueous
Date Collected: 08-Jul-20 09:30

Laboratory Data

Lab Sample: 2001475-10
Date Received: 14-Jul-20 09:11
Column: BEH C18

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.807	0.807	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFPeA	2706-90-3	<1.42	1.42	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFBS	375-73-5	<1.98	1.98	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
4:2 FTS	757124-72-4	<1.54	1.54	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFHxA	307-24-4	<2.41	2.41	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFPeS	2706-91-4	<2.68	2.68	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
HFPO-DA	13252-13-6	<5.33	5.33	5.53		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFHpA	375-85-9	<0.654	0.654	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
ADONA	919005-14-4	<0.799	0.799	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFHxS	355-46-4	<1.05	1.05	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
6:2 FTS	27619-97-2	<2.21	2.21	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFOA	335-67-1	2.56	0.720	4.43	J	B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFHpS	375-92-8	<1.04	1.04	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFNA	375-95-1	<0.896	0.896	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFOSA	754-91-6	32.2	1.96	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFOS	1763-23-1	1.09	0.893	4.43	J, Q	B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
9Cl-PF3ONS	756426-58-1	<1.60	1.60	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFDA	335-76-2	<1.65	1.65	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
8:2 FTS	39108-34-4	<2.28	2.28	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFNS	68259-12-1	<4.28	4.28	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
MeFOSAA	2355-31-9	<1.83	1.83	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
EtFOSAA	2991-50-6	<1.52	1.52	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFUnA	2058-94-8	<1.16	1.16	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFDS	335-77-3	<1.36	1.36	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
11Cl-PF3OUdS	763051-92-9	<2.67	2.67	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
10:2 FTS	120226-60-0	<3.46	3.46	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFDoA	307-55-1	<0.876	0.876	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
MeFOSA	31506-32-8	<4.24	4.24	22.1		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFTrDA	72629-94-8	<0.547	0.547	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFDoS	79780-39-5	<4.61	4.61	5.53		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFTeDA	376-06-7	<0.835	0.835	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
EtFOSA	4151-50-2	<5.65	5.65	22.1		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFHxDA	67905-19-5	<0.325	0.325	4.43		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
PFODA	16517-11-6	<6.79	6.79	7.74		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
MeFOSE	24448-09-7	<6.72	6.72	22.1		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
EtFOSE	1691-99-2	<10.4	10.4	22.1		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	139	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1

Vista Analytical Laboratory

Sample ID: Geoprobe decon blank **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Aqueous
Date Collected: 08-Jul-20 09:30

Laboratory Data

Lab Sample: 2001475-10
Date Received: 14-Jul-20 09:11
Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	96.3	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C3-PFBS	IS	109	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C3-HFPO-DA	IS	102	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-4:2 FTS	IS	93.0	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-PFHxA	IS	99.2	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C4-PFHpA	IS	89.6	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C3-PFHxS	IS	93.1	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-6:2 FTS	IS	100	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C5-PFNA	IS	91.1	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C8-PFOSA	IS	68.2	10 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-PFOA	IS	101	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C8-PFOS	IS	114	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-PFDA	IS	99.3	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-8:2 FTS	IS	91.9	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
d3-MeFOSAA	IS	92.8	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-PFUnA	IS	91.9	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
d5-EtFOSAA	IS	87.8	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-10:2 FTS	IS	80.5	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-PFDoA	IS	87.2	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
d3-MeFOSA	IS	13.8	10 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-PFTeDA	IS	86.3	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
d5-EtFOSA	IS	10.1	10 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
13C2-PFHxDA	IS	79.2	25 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
d7-MeFOSE	IS	26.8	10 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1
d9-EtFOSE	IS	31.9	10 - 150		B0G0132	17-Jul-20	0.113 L	23-Jul-20 20:53	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: EQUIPMENT BLANK-070920 **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001475-11	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	09-Jul-20 16:30	Date Received:	14-Jul-20 09:11		

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.802	0.802	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFPeA	2706-90-3	<1.41	1.41	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFBS	375-73-5	<1.97	1.97	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
4:2 FTS	757124-72-4	<1.53	1.53	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFHxA	307-24-4	<2.40	2.40	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFPeS	2706-91-4	<2.66	2.66	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
HFPO-DA	13252-13-6	<5.30	5.30	5.50		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFHpA	375-85-9	<0.650	0.650	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
ADONA	919005-14-4	<0.795	0.795	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFHxS	355-46-4	<1.04	1.04	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
6:2 FTS	27619-97-2	<2.20	2.20	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFOA	335-67-1	<0.716	0.716	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFHpS	375-92-8	<1.03	1.03	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFNA	375-95-1	<0.891	0.891	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFOSA	754-91-6	<1.95	1.95	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFOS	1763-23-1	<0.888	0.888	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
9Cl-PF3ONS	756426-58-1	<1.60	1.60	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFDA	335-76-2	<1.64	1.64	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
8:2 FTS	39108-34-4	<2.27	2.27	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFNS	68259-12-1	<4.26	4.26	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
MeFOSAA	2355-31-9	<1.82	1.82	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
EtFOSAA	2991-50-6	<1.51	1.51	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFUnA	2058-94-8	<1.16	1.16	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFDS	335-77-3	<1.35	1.35	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
11Cl-PF3OUdS	763051-92-9	<2.65	2.65	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
10:2 FTS	120226-60-0	<3.44	3.44	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFDoA	307-55-1	<0.872	0.872	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
MeFOSA	31506-32-8	<4.21	4.21	22.0		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFTrDA	72629-94-8	<0.544	0.544	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFDoS	79780-39-5	<4.59	4.59	5.50		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFTeDA	376-06-7	<0.831	0.831	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
EtFOSA	4151-50-2	<5.62	5.62	22.0		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFHxDA	67905-19-5	<0.324	0.324	4.40		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
PFODA	16517-11-6	<6.76	6.76	7.70		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
MeFOSE	24448-09-7	<6.68	6.68	22.0		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
EtFOSE	1691-99-2	<10.4	10.4	22.0		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	142	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1

Vista Analytical Laboratory

Sample ID: EQUIPMENT BLANK-070920 **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001475-11	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	09-Jul-20 16:30	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	97.4	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C3-PFBS	IS	93.8	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C3-HFPO-DA	IS	87.6	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-4:2 FTS	IS	97.8	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-PFHxA	IS	97.3	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C4-PFHpA	IS	102	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C3-PFHxS	IS	106	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-6:2 FTS	IS	99.4	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C5-PFNA	IS	88.6	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C8-PFOSA	IS	40.4	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-PFOA	IS	97.1	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C8-PFOS	IS	85.7	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-PFDA	IS	111	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-8:2 FTS	IS	105	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
d3-MeFOSAA	IS	77.9	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-PFUnA	IS	98.6	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
d5-EtFOSAA	IS	74.2	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-10:2 FTS	IS	76.5	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-PFDoA	IS	92.2	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
d3-MeFOSA	IS	14.5	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-PFTeDA	IS	69.7	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
d5-EtFOSA	IS	13.7	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
13C2-PFHxDA	IS	49.3	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
d7-MeFOSE	IS	18.0	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1
d9-EtFOSE	IS	18.1	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 15:47	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: GW Duplicate A **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001475-12	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	09-Jul-20 00:00	Date Received:	14-Jul-20 09:11		

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	19000	12.3	67.4	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
PFPeA	2706-90-3	41500	21.6	67.4	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
PFBS	375-73-5	19600	30.2	67.4	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
4:2 FTS	757124-72-4	197	1.56	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFHxA	307-24-4	56300	36.8	67.4	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
PFPeS	2706-91-4	23700	40.8	67.4	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
HFPO-DA	13252-13-6	<5.42	5.42	5.62		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFHpA	375-85-9	25400	9.97	67.4	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
ADONA	919005-14-4	<0.812	0.812	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFHxS	355-46-4	85900	31.9	135	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:03	30
6:2 FTS	27619-97-2	6230	33.7	67.4	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
PFOA	335-67-1	66600	11.0	67.4	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
PFHpS	375-92-8	91.5	1.05	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFNA	375-95-1	2.98	0.911	4.50	J	B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFOSA	754-91-6	8.47	1.99	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFOS	1763-23-1	175	0.907	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
9Cl-PF3ONS	756426-58-1	<1.63	1.63	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFDA	335-76-2	<1.67	1.67	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
8:2 FTS	39108-34-4	24.8	2.32	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFNS	68259-12-1	<4.35	4.35	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
MeFOSAA	2355-31-9	<1.85	1.85	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
EtFOSAA	2991-50-6	<1.54	1.54	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFUnA	2058-94-8	<1.18	1.18	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFDS	335-77-3	<1.38	1.38	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
11Cl-PF3OUdS	763051-92-9	<2.71	2.71	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
10:2 FTS	120226-60-0	<3.52	3.52	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFDoA	307-55-1	<0.890	0.890	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
MeFOSA	31506-32-8	<4.31	4.31	22.5		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFTrDA	72629-94-8	<0.555	0.555	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFDoS	79780-39-5	<4.69	4.69	5.62		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFTeDA	376-06-7	<0.849	0.849	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
EtFOSA	4151-50-2	<5.74	5.74	22.5		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFHxDA	67905-19-5	<0.330	0.330	4.50		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
PFODA	16517-11-6	<6.90	6.90	7.87		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
MeFOSE	24448-09-7	<6.82	6.82	22.5		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
EtFOSE	1691-99-2	<10.6	10.6	22.5		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	36.0	25 - 150	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15

SR0176

Vista Analytical Laboratory

Sample ID: GW Duplicate A **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001475-12	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	09-Jul-20 00:00	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	69.0	25 - 150	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
13C3-PFBS	IS	76.5	25 - 150	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
13C3-HFPO-DA	IS	66.2	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C2-4:2 FTS	IS	69.7	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C2-PFHxA	IS	107	25 - 150	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
13C4-PFHpA	IS	75.0	25 - 150	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
13C3-PFHxS	IS	57.0	25 - 150	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:03	30
13C2-6:2 FTS	IS	108	25 - 150	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
13C5-PFNA	IS	83.7	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C8-PFOSA	IS	56.8	10 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C2-PFOA	IS	105	25 - 150	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:14	15
13C8-PFOS	IS	87.6	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C2-PFDA	IS	91.3	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C2-8:2 FTS	IS	83.1	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
d3-MeFOSAA	IS	77.8	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C2-PFUnA	IS	89.8	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
d5-EtFOSAA	IS	82.5	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C2-10:2 FTS	IS	83.8	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C2-PFDoA	IS	95.1	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
d3-MeFOSA	IS	14.4	10 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C2-PFTeDA	IS	76.2	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
d5-EtFOSA	IS	13.6	10 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
13C2-PFHxDA	IS	69.2	25 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
d7-MeFOSE	IS	53.4	10 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1
d9-EtFOSE	IS	55.4	10 - 150		B0G0132	17-Jul-20	0.111 L	22-Jul-20 15:58	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: GW Duplicate B **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Aqueous
Date Collected: 09-Jul-20 00:00

Laboratory Data

Lab Sample: 2001475-13
Date Received: 14-Jul-20 09:11
Column: BEH C18

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	530	0.817	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFPeA	2706-90-3	2130	1.44	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFBS	375-73-5	194	2.01	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
4:2 FTS	757124-72-4	76.5	1.56	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFHxA	307-24-4	2280	2.44	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFPeS	2706-91-4	518	2.71	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
HFPO-DA	13252-13-6	<5.40	5.40	5.61		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFHpA	375-85-9	1200	0.663	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
ADONA	919005-14-4	<0.810	0.810	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFHxS	355-46-4	12000	5.31	22.4	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:34	5
6:2 FTS	27619-97-2	9720	11.2	22.4	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:34	5
PFOA	335-67-1	2150	0.730	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFHpS	375-92-8	1630	1.05	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFNA	375-95-1	110	0.908	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFOSA	754-91-6	16.6	1.98	4.49	Q	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFOS	1763-23-1	44200	9.05	44.9	D	B0G0132	17-Jul-20	0.111 L	28-Jul-20 15:06	10
9Cl-PF3ONS	756426-58-1	<1.63	1.63	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFDA	335-76-2	4.28	1.67	4.49	J, Q	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
8:2 FTS	39108-34-4	443	2.31	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFNS	68259-12-1	<4.34	4.34	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
MeFOSAA	2355-31-9	<1.85	1.85	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
EtFOSAA	2991-50-6	<1.54	1.54	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFUnA	2058-94-8	<1.18	1.18	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFDS	335-77-3	<1.38	1.38	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
11Cl-PF3OUdS	763051-92-9	<2.70	2.70	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
10:2 FTS	120226-60-0	<3.51	3.51	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFDoA	307-55-1	<0.888	0.888	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
MeFOSA	31506-32-8	<4.29	4.29	22.4		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFTrDA	72629-94-8	<0.554	0.554	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFDoS	79780-39-5	<4.68	4.68	5.61		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFTeDA	376-06-7	<0.847	0.847	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
EtFOSA	4151-50-2	<5.73	5.73	22.4		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFHxDA	67905-19-5	<0.330	0.330	4.49		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
PFODA	16517-11-6	<6.88	6.88	7.85		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
MeFOSE	24448-09-7	<6.81	6.81	22.4		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
EtFOSE	1691-99-2	<10.6	10.6	22.4		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	110	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1

Vista Analytical Laboratory

Sample ID: GW Duplicate B **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001475-13	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	09-Jul-20 00:00	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	87.8	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C3-PFBS	IS	112	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C3-HFPO-DA	IS	88.6	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C2-4:2 FTS	IS	101	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C2-PFHxA	IS	88.6	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C4-PFHpA	IS	87.8	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C3-PFHxS	IS	99.8	25 - 150	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:34	5
13C2-6:2 FTS	IS	131	25 - 150	D	B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:34	5
13C5-PFNA	IS	80.6	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C8-PFOSA	IS	59.1	10 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C2-PFOA	IS	93.5	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C8-PFOS	IS	99.0	25 - 150	D	B0G0132	17-Jul-20	0.111 L	28-Jul-20 15:06	10
13C2-PFDA	IS	94.9	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C2-8:2 FTS	IS	91.8	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
d3-MeFOSAA	IS	95.0	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C2-PFUnA	IS	97.8	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
d5-EtFOSAA	IS	96.9	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C2-10:2 FTS	IS	83.4	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C2-PFDoA	IS	85.3	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
d3-MeFOSA	IS	14.3	10 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C2-PFTeDA	IS	82.9	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
d5-EtFOSA	IS	12.2	10 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
13C2-PFHxDA	IS	79.8	25 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
d7-MeFOSE	IS	44.6	10 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1
d9-EtFOSE	IS	49.9	10 - 150		B0G0132	17-Jul-20	0.111 L	23-Jul-20 21:45	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

DATA QUALIFIERS & ABBREVIATIONS

B	This compound was also detected in the method blank
Conc.	Concentration
CRS	Cleanup Recovery Standard
D	Dilution
DL	Detection Limit
E	The associated compound concentration exceeded the calibration range of the instrument
H	Recovery and/or RPD was outside laboratory acceptance limits
I	Chemical Interference
IS	Internal Standard
J	The amount detected is below the Reporting Limit/LOQ
LOD	Limit of Detection
LOQ	Limit of Quantitation
M	Estimated Maximum Possible Concentration (CA Region 2 projects only)
MDL	Method Detection Limit
NA	Not applicable
ND	Not Detected
OPR	Ongoing Precision and Recovery sample
P	The reported concentration may include contribution from chlorinated diphenyl ether(s).
Q	The ion transition ratio is outside of the acceptance criteria.
RL	Reporting Limit
TEQ	Toxic Equivalency
U	Not Detected (specific projects only)
*	See Cover Letter

Unless otherwise noted, solid sample results are reported in dry weight. Tissue samples are reported in wet weight.

Vista Analytical Laboratory Certifications

Accrediting Authority	Certificate Number
Alaska Department of Environmental Conservation	17-013
Arkansas Department of Environmental Quality	19-013-0
California Department of Health – ELAP	2892
DoD ELAP - A2LA Accredited - ISO/IEC 17025:2005	3091.01
Florida Department of Health	E87777-23
Hawaii Department of Health	N/A
Louisiana Department of Environmental Quality	01977
Maine Department of Health	2018017
Massachusetts Department of Environmental Protection	N/A
Michigan Department of Environmental Quality	9932
Minnesota Department of Health	1521520
New Hampshire Environmental Accreditation Program	207718-B
New Jersey Department of Environmental Protection	190001
New York Department of Health	11411
Oregon Laboratory Accreditation Program	4042-010
Pennsylvania Department of Environmental Protection	016
Texas Commission on Environmental Quality	T104704189-19-10
Vermont Department of Health	VT-4042
Virginia Department of General Services	10272
Washington Department of Ecology	C584-19
Wisconsin Department of Natural Resources	998036160

Current certificates and lists of licensed parameters are located in the Quality Assurance office and are available upon request.

NELAP Accredited Test Methods

MATRIX: Air	
Description of Test	**Method**
Determination of Polychlorinated p-Dioxins & Polychlorinated Dibenzofurans	EPA 23
Determination of Polychlorinated p-Dioxins & Polychlorinated Dibenzofurans	EPA TO-9A

MATRIX: Biological Tissue	
Description of Test	**Method**
Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613B
Brominated Diphenyl Ethers by HRGC/HRMS	EPA 1614A
Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by GC/HRMS	EPA 1668A/C
Pesticides in Water, Soil, Sediment, Biosolids, and Tissue by HRGC/HRMS	EPA 1699
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans by GC/HRMS	EPA 8280A/B
Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by GC/HRMS	EPA 8290/8290A

MATRIX: Drinking Water	
Description of Test	**Method**
2,3,7,8-Tetrachlorodibenzo- p-dioxin (2,3,7,8-TCDD) GC/HRMS	EPA 1613/1613B
1,4-Dioxane (1,4-Diethyleneoxide) analysis by GC/HRMS	EPA 522
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	ISO 25101 2009

MATRIX: Non-Potable Water	
Description of Test	**Method**
Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613B
Brominated Diphenyl Ethers by HRGC/HRMS	EPA 1614A
Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by GC/HRMS	EPA 1668A/C
Pesticides in Water, Soil, Sediment, Biosolids, and Tissue by HRGC/HRMS	EPA 1699
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Dioxin by GC/HRMS	EPA 613
Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans by GC/HRMS	EPA 8280A/B
Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by GC/HRMS	EPA 8290/8290A

MATRIX: Solids	
Description of Test	**Method**
Tetra-Octa Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613
Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613B
Brominated Diphenyl Ethers by HRGC/HRMS	EPA 1614A
Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by GC/HRMS	EPA 1668A/C
Pesticides in Water, Soil, Sediment, Biosolids, and Tissue by HRGC/HRMS	EPA 1699
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans by GC/HRMS	EPA 8280A/B
Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by GC/HRMS	EPA 8290/8290A

Vista Analytical Laboratory

CHAIN OF CUSTODY

For Laboratory Use Only
Work Order #: 2001475 Temp: 3.4 °C
Storage ID: R-13, WR-2 Storage Secured: Yes ☑ No ☐

Project ID: MSN FFTA SAMPLES PO#: MSNPF1 Sampler: C. Gehrke (name)

TAT (check one): Standard: ☒ 21 days Rush (surcharge may apply) ☐ 14 days ☐ 7 days Specify:

Relinquished by (printed name and signature)	Date	Time	Received by (printed name and signature)	Date	Time
			William Wright William Wright	07/14/20	09:11

SHIP TO: Vista Analytical Laboratory
1104 Windfield Way
El Dorado Hills, CA 95762
(916) 673-1520 • Fax (916) 673-0106

ATTN:

Method of Shipment:

Tracking No.:

Add Analysis(es) Requested — Container(s) — PFAS by Isotope Dilution — EPA Method 537 (DW only)

Sample ID	Date	Time	Location/ Sample Description	Quantity	Type	Matrix	PFOA/PFOS	UCMR3 PFAS List:6	537.1 List: 14 or 18 (Circle One)	EPA Draft List of 24	OTHER: Please attach analyte list	PFOA/PFOS	UCMR3 PFAS List:6	537.1 List of 14	537.1 List of 18	Comments
SBP20-02 (1-1.5)	7/7/20	1505		1	PJ	SO					*					
SBP20-02 (5.5-6)	7/7/20	1515		1	PJ	SO					*					* WISCONSIN PFAS
SBP20-03 (1-1.5)	7/7/20	1530		1	PJ	SO					*					LIST
SBP20-03 (5-5.5)	7/7/20	1540		1	PJ	SO					*					
SBP20-06 (0.5-1)	7/7/20	1600		1	PJ	SO					*					
SBP20-06 (7.4-7.9)	7/7/20	1605		1	PJ	SO					*					
SBP20-02-GW	7/7/20	1610		2	P	AQ					*					
SBP20-03-GW	7/7/20	1635		2	P	AQ					*					
SBP20-04-(7-7.5)	7/8/20	0740		1	PJ	SO					*					
Geoprobe decon blank	7/8/20	0930		2	P	AQ					*					

Special Instructions/Comments:

SEND DOCUMENTATION AND RESULTS TO:
Name: CHRIS CIECIEK
Company: LIMNOTECH
Address: 501 AVIS DRIVE
City: ANN ARBOR MI 48108
Phone: 734 332 1200
Email: cciecie k@limno.com

Container Types: P= HDPE, PJ= HDPE Jar
PY= Polypropylene, O = Other

Bottle Preservation Type:
TZ = Trizma:

Matrix Types: AQ = Aqueous, DW = Drinking Water, EF = Effluent, PP = Pulp/Paper, SD = Sediment, SL = Sludge, SO = Soil, WW = Wastewater, B = Blood/Serum, O = Other

ID: LR-537COC Rev. No. 1 Rev. Date: 8/16/2019 Page: 1 of 1

Vista Analytical Laboratory

CHAIN OF COUSTODY

For Laboratory Use Only
Work Order #: 2001475 Temp: 3.4 °C
Storage ID: R-13, WR-2 Storage Secured: Yes ☑ No ☐

Project ID: MSN FFTA SAMPLES PO#: MSNPF1 Sampler: C. Schnke (name)

TAT (check one): Standard: ☒ 21 days
Rush (surcharge may apply) ☐ 14 days ☐ 7 days Specify: ____

Relinquished by (printed name and signature)	Date	Time	Received by (printed name and signature)	Date	Time
			William Wright [signature]	07/14/20	09:11

SHIP TO: Vista Analytical Laboratory
1104 Windfield Way
El Dorado Hills, CA 95762
(916) 673-1520 * Fax (916) 673-0106

ATTN:

Method of Shipment:

Tracking No.:

Add Analysis(es) Requested

Sample ID	Date	Time	Location/ Sample Description	Container(s) Quantity	Type	Matrix	PFAS by Isotope Dilution: PFOA/PFOS	UCMR3 PFAS List:6	537.1 List: 14 or 18 (Circle One)	EPA Draft List of 24	OTHER: Please attach analyte list	EPA Method 537 (DW only): PFOA/PFOS	UCMR3 PFAS List:6	537.1 List of 14	537.1 List of 18	Comments
EQUIPMENT BLANK-070920	7/9/20	1630		2	P	AQ					*					* WISCONSIN PFAS
GW Duplicate A	–	–		2	P	AQ					*					LIST
GW Duplicate B	–	–		2	P	AQ					*					

Special Instructions/Comments:

SEND DOCUMENTATION AND RESULTS TO:
Name: CHRIS CIECIEK
Company: LIMNOTECH
Address: 501 AVIS DRIVE
City: ANN ARBOR MI 48108
Phone: 734 332 1200
Email: CCIECIEK @ LIMNO.COM

Container Types: P= HDPE, PJ= HDPE Jar
PY= Polypropylene, O = Other: ____

Bottle Preservation Type:
TZ = Trizma: ____

Matrix Types: AQ = Aqueous, DW = Drinking Water, EF = Effluent, PP = Pulp/Paper, SD = Sediment, SL = Sludge, SO = Soil, WW = Wastewater, B = Blood/Serum, O = Other. ____

Vista Analytical Laboratory

Sample Log-In Checklist

Page # 1 of 1

Vista Work Order #: 2001475 TAT std

Samples Arrival:	Date/Time 07/14/20 09:11	Initials: WRW	Location: WR-2 Shelf/Rack: NA

Delivered By:	FedEx	UPS	On Trac	GLS	DHL	Hand Delivered	Other
Preservation:	Ice		Blue Ice		Dry Ice		None

Temp °C: 3.4 (uncorrected)		Probe used: Y / N	Thermometer ID: IR-3
Temp °C: 3.4 (corrected)			

					YES	NO	NA
Shipping Container(s) Intact?					✓		
Shipping Custody Seals Intact?					✓		
Airbill 4 of 4	Trk # 3947 7925 1825				✓		
Shipping Documentation Present?					✓		
Shipping Container	Vista	Client	Retain	Return	Dispose		
Chain of Custody / Sample Documentation Present?					✓		
Chain of Custody / Sample Documentation Complete?					✓		
Holding Time Acceptable?					✓		

Logged In:	Date/Time 07/14/20 1545	Initials: WWS	Location: R-13, WR-2 Shelf/Rack: 8-3, F-4
COC Anomaly/Sample Acceptance Form completed?			YES: ✓

Comments:

CoC/Label Reconciliation Report WO# 2001475

	LabNumber		CoC Sample ID			SampleAlias	Sample Date/Time			Container	BaseMatrix	Sample Comments
	2001475-01	A	SBP20-02 (1-1.5)	☑			07-Jul-20 15:05	☑		HDPE Jar, 6 oz	Solid	
	2001475-02	A	SBP20-02 (5.5-6)	☑			07-Jul-20 15:15	☑		HDPE Jar, 6 oz	Solid	
	2001475-03	A	SBP20-03 (1-1.5)	☐	A		07-Jul-20 15:30	☑		HDPE Jar, 6 oz	Solid	
	2001475-04	A	SBP20-03 (5-5.5)	☑			07-Jul-20 15:40	☑		HDPE Jar, 6 oz	Solid	
	2001475-05	A	SBP20-06 (0.5-1)	☑			07-Jul-20 16:00	☑		HDPE Jar, 6 oz	Solid	
	2001475-06	A	SBP20-06 (7.4-7.9)	☑			07-Jul-20 16:05	☑		HDPE Jar, 6 oz	Solid	
E	2001475-07	A	SBP20-02-GW	☑			07-Jul-20 16:10	☑		HDPE Bottle, 125 mL	Aqueous	
	2001475-07	B	SBP20-02-GW	☑			07-Jul-20 16:10	☑		HDPE Bottle, 125 mL	Aqueous	
E	2001475-08	A	SBP20-03-GW	☑			07-Jul-20 16:35	☑		HDPE Bottle, 125 mL	Aqueous	
	2001475-08	B	SBP20-03-GW	☑			07-Jul-20 16:35	☑		HDPE Bottle, 125 mL	Aqueous	
	2001475-09	A	SBP20-04-(7-7.5)	☐	B		08-Jul-20 07:40	☑		HDPE Jar, 6 oz	Solid	
	2001475-10	A	Geoprobe decon blank	☐	C		08-Jul-20 09:30	☑		HDPE Bottle, 125 mL	Aqueous	
	2001475-10	B	Geoprobe decon blank	☐			08-Jul-20 09:30	☑		HDPE Bottle, 125 mL	Aqueous	
	2001475-11	A	EQUIPMENT BLANK-070920	☑			09-Jul-20 16:30	☑		HDPE Bottle, 125 mL	Aqueous	
	2001475-11	B	EQUIPMENT BLANK-070920	☑			09-Jul-20 16:30	☑		HDPE Bottle, 125 mL	Aqueous	
E	2001475-12	A	GW Duplicate A	☑			09-Jul-20 00:00	☐	D	HDPE Bottle, 125 mL	Aqueous	
	2001475-12	B	GW Duplicate A	☑			09-Jul-20 00:00	☐		HDPE Bottle, 125 mL	Aqueous	
E	2001475-13	A	GW Duplicate B	☑			09-Jul-20 00:00	☐	D	HDPE Bottle, 125 mL	Aqueous	
	2001475-13	B	GW Duplicate B	☑			09-Jul-20 00:00	☐		HDPE Bottle, 125 mL	Aqueous	

Checkmarks indicate that information on the COC reconciled with the sample label.
Any discrepancies are noted in the following columns.

	Yes	No	NA
Sample Container Intact?	✓		
Sample Custody Seals Intact?			✓
Adequate Sample Volume?	✓		
Container Type Appropriate for Analysis(es)	✓		
Preservation Documented: Na2S2O3 Trizma None Other			✓
If Chlorinated or Drinking Water Samples, Acceptable Preservation?			✓

Verifed by/Date: KA 07/15/20

Comments:

COC Label:	Sample Label:
A) SBP20-03 (1-1.5)	SBP20-03
B) SBP20-04-(7-7.5)	SBP20-04 (7-7.5)
C) Geoprobe decon blank	Geoprobe Decon Blank

D) No date and time on samples labels.

E) Sample contain particulate

ANOMALY FORM

Vista Work Order 2001475

Initial/Date		The following checked issues were noted during sample receipt and login:
	☐	**1. The samples were received out of temperature at (WI-PHT):** ______ Was Ice present: Yes No Melted Blue Ice
WWS 07/15/20	☑	2. The Chain-of-Custody (CoC) was not relinquished properly.
	☐	3. The CoC did not include collection time(s). 00:00 will be used unless notified otherwise.
	☐	4. The sample(s) did not include a sample collection time. All or Sample Name: ______
	☐	5. A sample ID discrepancy was found. See the Reconciliation report. The CoC Sample ID will be used unless notified otherwise.
	☐	6. A sample date and/or time discrepancy was found. See the Reconciliation report. The CoC Sample date/time will be used unless notified otherwise.
	☐	**7. The CoC did not include a sample matrix. The following sample matrix will be used:** ______
	☐	**8. Insufficent volume received for analysis. All or Sample Name:** ______
	☐	9. The backup bottle was received broken. Sample Name: ______
	☐	**10. CoC not received, illegible or destroyed.**
	☐	**11. The sample(s) were received out of holding time. All or Sample Name:** ______
	☐	**12. The CoC did not include an analysis. All or Sample Name:** ______
	☐	**13. Sample(s) received without collection date. All or Sample Name:** ______
	☐	**14. Sample(s) not received. All or Sample Name:** ______
	☐	**15. Sample(s) received broken. All or Sample Name:** ______
	☐	**16. An incorrect container-type was used. All or Sample Name:** ______
	☐	17. Other:

Bolded items require sign-off

Client Contacted: ______

Date of Contact: ______

Vista Client Manager: ______

Resolution:

August 03, 2020

Vista Work Order No. 2001478

Mr. Chris Cieciek
LimnoTech, Inc.
501 Avis Drive
Ann Arbor, MI 48108

Dear Mr. Cieciek,

Enclosed are the results for the sample set received at Vista Analytical Laboratory on July 14, 2020 under your Project Name 'MSN FFTA SAMPLES'.

Vista Analytical Laboratory is committed to serving you effectively. If you require additional information, please contact me at 916-673-1520 or by email at mmaier@vista-analytical.com.

Thank you for choosing Vista as part of your analytical support team.

Sincerely,

Martha Maier
Laboratory Director

Vista Work Order No. 2001478
Case Narrative

Sample Condition on Receipt:

Five aqueous samples and five soil samples were received in good condition and within the method temperature requirements. The samples were received and stored securely in accordance with Vista standard operating procedures and EPA methodology.

Analytical Notes:

PFAS Isotope Dilution Method - Aqueous

The following samples contained particulate and were centrifuged prior to extraction:

Laboratory ID	Sample Name
2001478-01	SBP20-01-GW
2001478-03	SBP20-06-GW
2001478-06	SBP20-05-GW
2001478-10	SBP20-04-GW

The aqueous samples were extracted and analyzed for a selected list of PFAS using Vista's PFAS Isotope Dilution Method. The results for PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Results for all other analytes include the linear isomers only.

Holding Times

The samples were extracted and analyzed within the EPA-recommended hold times.

Quality Control

The Initial Calibration and Continuing Calibration Verifications met the acceptance criteria.

A Method Blank and Ongoing Precision and Recovery (OPR) sample were extracted and analyzed with each preparation batch. No analytes were detected in the Method Blanks above the Reporting Limit. The OPR recoveries were within the method acceptance criteria.

The internal standard recoveries outside the acceptance criteria are flagged with an "H" qualifier.

PFAS Isotope Dilution Method - Solid

The soil samples were extracted and analyzed for a selected list of PFAS using Vista's Isotope Dilution Method. The results for PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Results for all other analytes include the linear isomers only.

Holding Times

The samples were extracted and analyzed within the EPA-recommended hold times.

Quality Control

The Initial Calibration and Continuing Calibration Verifications met the method acceptance criteria.

A Method Blank and Ongoing Precision and Recovery (OPR) sample were extracted and analyzed with the preparation batch. No analytes were detected in the Method Blank above the Reporting Limit. The recoveries of 11Cl-PF3OUdS and PFDoS were greater than 135% in the OPR. These analytes were not detected in the associated samples. The recoveries of all other analytes were within the acceptance criteria.

The internal standard recoveries outside the acceptance criteria are flagged with an "H" qualifier.

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Sample Inventory Report

Vista Sample ID	Client Sample ID	Sampled	Received	Components/Containers
2001478-01	SBP20-01-GW	08-Jul-20 09:40	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001478-02	SBP20-04 (0.5-1)	08-Jul-20 07:35	14-Jul-20 09:11	HDPE Jar, 6 oz
2001478-03	SBP20-06-GW	08-Jul-20 07:50	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001478-04	SBP20-05 (0.5-1)	08-Jul-20 08:10	14-Jul-20 09:11	HDPE Jar, 6 oz
2001478-05	SBP20-05 (6-6.5)	08-Jul-20 08:20	14-Jul-20 09:11	HDPE Jar, 6 oz
2001478-06	SBP20-05-GW	08-Jul-20 08:55	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001478-07	SBP20-01 (0.5-1)	08-Jul-20 09:00	14-Jul-20 09:11	HDPE Jar, 6 oz
2001478-08	SBP20-01 (5-5.5)	08-Jul-20 09:05	14-Jul-20 09:11	HDPE Jar, 6 oz
2001478-09	Field Blank A	08-Jul-20 09:55	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL
2001478-10	SBP20-04-GW	08-Jul-20 10:05	14-Jul-20 09:11	HDPE Bottle, 125 mL
				HDPE Bottle, 125 mL

Vista Project: 2001478

Client Project: MSN FFTA SAMPLES

ANALYTICAL RESULTS

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data
Name: LimnoTech, Inc. Matrix: Aqueous
Project: MSN FFTA SAMPLES

Laboratory Data
Lab Sample: B0G0132-BLK1 Column: BEH C18

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.729	0.729	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFPeA	2706-90-3	<1.28	1.28	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFBS	375-73-5	<1.79	1.79	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
4:2 FTS	757124-72-4	<1.39	1.39	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHxA	307-24-4	<2.18	2.18	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFPeS	2706-91-4	<2.42	2.42	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
HFPO-DA	13252-13-6	<4.82	4.82	5.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHpA	375-85-9	<0.591	0.591	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
ADONA	919005-14-4	<0.722	0.722	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHxS	355-46-4	<0.947	0.947	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
6:2 FTS	27619-97-2	<2.00	2.00	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFOA	335-67-1	<0.651	0.651	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHpS	375-92-8	<0.937	0.937	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFNA	375-95-1	<0.810	0.810	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFOSA	754-91-6	<1.77	1.77	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFOS	1763-23-1	<0.807	0.807	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
9Cl-PF3ONS	756426-58-1	<1.45	1.45	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDA	335-76-2	<1.49	1.49	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
8:2 FTS	39108-34-4	<2.06	2.06	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFNS	68259-12-1	<3.87	3.87	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
MeFOSAA	2355-31-9	<1.65	1.65	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
EtFOSAA	2991-50-6	<1.37	1.37	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFUnA	2058-94-8	<1.05	1.05	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDS	335-77-3	<1.23	1.23	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
11Cl-PF3OUdS	763051-92-9	<2.41	2.41	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
10:2 FTS	120226-60-0	<3.13	3.13	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDoA	307-55-1	<0.792	0.792	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
MeFOSA	31506-32-8	<3.83	3.83	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFTrDA	72629-94-8	<0.494	0.494	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFDoS	79780-39-5	<4.17	4.17	5.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFTeDA	376-06-7	<0.755	0.755	4.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
EtFOSA	4151-50-2	<5.11	5.11	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFHxDA	67905-19-5	1.37	0.294	4.00	J, Q	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
PFODA	16517-11-6	<6.14	6.14	7.00		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
MeFOSE	24448-09-7	<6.07	6.07	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
EtFOSE	1691-99-2	<9.44	9.44	20.0		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	144	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	B0G0132-BLK1	Column:	BEH C18
Project:	MSN FFTA SAMPLES						

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	101	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C3-PFBS	IS	102	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C3-HFPO-DA	IS	90.2	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-4:2 FTS	IS	97.6	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFHxA	IS	95.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C4-PFHpA	IS	102	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C3-PFHxS	IS	104	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-6:2 FTS	IS	89.1	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C5-PFNA	IS	80.3	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C8-PFOSA	IS	33.9	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFOA	IS	97.6	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C8-PFOS	IS	92.7	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFDA	IS	90.9	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-8:2 FTS	IS	94.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d3-MeFOSAA	IS	77.3	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFUnA	IS	82.3	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d5-EtFOSAA	IS	69.7	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-10:2 FTS	IS	77.9	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFDoA	IS	74.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d3-MeFOSA	IS	10.8	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFTeDA	IS	64.5	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d5-EtFOSA	IS	9.30	10 - 150	H	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
13C2-PFHxDA	IS	39.2	25 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d7-MeFOSE	IS	16.0	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1
d9-EtFOSE	IS	17.2	10 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:43	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc. Matrix: Aqueous
Project: MSN FFTA SAMPLES

Laboratory Data

Lab Sample: B0G0132-BS1 Column: BEH C18

Analyte	CAS Number	Amt Found (ng/L)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	7.82	8.00	97.7	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFPeA	2706-90-3	7.69	8.00	96.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFBS	375-73-5	7.42	8.00	92.7	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
4:2 FTS	757124-72-4	7.81	8.00	97.6	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHxA	307-24-4	7.64	8.00	95.4	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFPeS	2706-91-4	8.20	8.00	103	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
HFPO-DA	13252-13-6	7.51	8.00	93.8	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHpA	375-85-9	7.48	8.00	93.6	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
ADONA	919005-14-4	7.54	8.00	94.2	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHxS	355-46-4	6.14	8.00	76.7	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
6:2 FTS	27619-97-2	8.50	8.00	106	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFOA	335-67-1	7.13	8.00	89.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHpS	375-92-8	7.83	8.00	97.9	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFNA	375-95-1	8.53	8.00	107	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFOSA	754-91-6	10.1	8.00	126	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFOS	1763-23-1	8.96	8.00	112	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
9Cl-PF3ONS	756426-58-1	7.13	8.00	89.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDA	335-76-2	7.48	8.00	93.6	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
8:2 FTS	39108-34-4	6.64	8.00	83.0	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFNS	68259-12-1	7.56	8.00	94.5	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
MeFOSAA	2355-31-9	7.12	8.00	89.0	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
EtFOSAA	2991-50-6	6.42	8.00	80.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFUnA	2058-94-8	7.64	8.00	95.5	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDS	335-77-3	7.21	8.00	90.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
11Cl-PF3OUdS	763051-92-9	7.38	8.00	92.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
10:2 FTS	120226-60-0	8.50	8.00	106	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDoA	307-55-1	7.35	8.00	91.8	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
MeFOSA	31506-32-8	28.9	40.0	72.1	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFTrDA	72629-94-8	7.23	8.00	90.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFDoS	79780-39-5	6.88	8.00	85.9	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFTeDA	376-06-7	7.21	8.00	90.2	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
EtFOSA	4151-50-2	35.5	40.0	88.8	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFHxDA	67905-19-5	7.62	8.00	95.3	50 - 150	B	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
PFODA	16517-11-6	6.65	8.00	83.1	50 - 150	J	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	B0G0132-BS1	Column:	BEH C18
Project:	MSN FFTA SAMPLES						

Analyte	CAS Number	Amt Found (ng/L)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
MeFOSE	24448-09-7	45.9	40.0	115	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
EtFOSE	1691-99-2	26.1	40.0	65.3	50 - 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1

Labeled Standards	Type	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	145	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-PFPeA	IS	97.0	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-PFBS	IS	100	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-HFPO-DA	IS	86.9	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-4:2 FTS	IS	95.8	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFHxA	IS	87.0	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C4-PFHpA	IS	91.2	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C3-PFHxS	IS	101	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-6:2 FTS	IS	90.4	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C5-PFNA	IS	77.0	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C8-PFOSA	IS	26.2	10- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFOA	IS	90.1	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C8-PFOS	IS	80.2	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFDA	IS	89.6	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-8:2 FTS	IS	85.6	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d3-MeFOSAA	IS	71.1	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFUnA	IS	75.5	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d5-EtFOSAA	IS	70.3	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-10:2 FTS	IS	71.4	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFDoA	IS	81.9	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d3-MeFOSA	IS	7.50	10- 150	H	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFTeDA	IS	74.5	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d5-EtFOSA	IS	5.90	10- 150	H	B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
13C2-PFHxDA	IS	61.5	25- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d7-MeFOSE	IS	11.5	10- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1
d9-EtFOSE	IS	12.9	10- 150		B0G0132	17-Jul-20	0.125 L	22-Jul-20 13:53	1

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	B0G0133-BLK1	Column:	BEH C18
Project:	MSN FFTA SAMPLES						

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.729	0.729	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFPeA	2706-90-3	<1.28	1.28	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFBS	375-73-5	<1.79	1.79	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
4:2 FTS	757124-72-4	<1.39	1.39	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFHxA	307-24-4	<2.18	2.18	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFPeS	2706-91-4	<2.42	2.42	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
HFPO-DA	13252-13-6	<4.82	4.82	5.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFHpA	375-85-9	<0.591	0.591	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
ADONA	919005-14-4	<0.722	0.722	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFHxS	355-46-4	<0.947	0.947	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
6:2 FTS	27619-97-2	<2.00	2.00	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFOA	335-67-1	<0.651	0.651	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFHpS	375-92-8	<0.937	0.937	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFNA	375-95-1	<0.810	0.810	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFOSA	754-91-6	<1.77	1.77	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFOS	1763-23-1	<0.807	0.807	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
9Cl-PF3ONS	756426-58-1	<1.45	1.45	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFDA	335-76-2	<1.49	1.49	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
8:2 FTS	39108-34-4	<2.06	2.06	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFNS	68259-12-1	<3.87	3.87	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
MeFOSAA	2355-31-9	<1.65	1.65	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
EtFOSAA	2991-50-6	<1.37	1.37	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFUnA	2058-94-8	<1.05	1.05	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFDS	335-77-3	<1.23	1.23	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
11Cl-PF3OUdS	763051-92-9	<2.41	2.41	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
10:2 FTS	120226-60-0	<3.13	3.13	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFDoA	307-55-1	<0.792	0.792	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
MeFOSA	31506-32-8	<3.83	3.83	20.0		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFTrDA	72629-94-8	<0.494	0.494	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFDoS	79780-39-5	<4.17	4.17	5.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFTeDA	376-06-7	<0.755	0.755	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
EtFOSA	4151-50-2	<5.11	5.11	20.0		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFHxDA	67905-19-5	<0.294	0.294	4.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
PFODA	16517-11-6	<6.14	6.14	7.00		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
MeFOSE	24448-09-7	<6.07	6.07	20.0		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
EtFOSE	1691-99-2	<9.44	9.44	20.0		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	53.1	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc. Matrix: Aqueous
Project: MSN FFTA SAMPLES

Laboratory Data

Lab Sample: B0G0133-BLK1 Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	68.1	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C3-PFBS	IS	73.4	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C3-HFPO-DA	IS	69.6	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-4:2 FTS	IS	84.0	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFHxA	IS	72.2	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C4-PFHpA	IS	73.4	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C3-PFHxS	IS	75.2	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-6:2 FTS	IS	65.8	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C5-PFNA	IS	69.6	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C8-PFOSA	IS	28.9	10 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFOA	IS	74.9	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C8-PFOS	IS	73.7	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFDA	IS	65.2	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-8:2 FTS	IS	89.6	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d3-MeFOSAA	IS	56.7	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFUnA	IS	67.8	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d5-EtFOSAA	IS	52.9	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-10:2 FTS	IS	74.6	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFDoA	IS	59.0	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d3-MeFOSA	IS	9.50	10 - 150	H	B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFTeDA	IS	55.8	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d5-EtFOSA	IS	8.50	10 - 150	H	B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
13C2-PFHxDA	IS	49.0	25 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d7-MeFOSE	IS	20.8	10 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1
d9-EtFOSE	IS	24.1	10 - 150		B0G0133	25-Jul-20	0.125 L	28-Jul-20 16:08	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Aqueous

Laboratory Data

Lab Sample: B0G0133-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/L)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	7.56	8.00	94.5	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFPeA	2706-90-3	7.54	8.00	94.2	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFBS	375-73-5	7.92	8.00	99.0	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
4:2 FTS	757124-72-4	7.62	8.00	95.3	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFHxA	307-24-4	7.92	8.00	99.0	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFPeS	2706-91-4	9.00	8.00	112	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
HFPO-DA	13252-13-6	6.32	8.00	79.0	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFHpA	375-85-9	8.80	8.00	110	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
ADONA	919005-14-4	7.03	8.00	87.9	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFHxS	355-46-4	5.71	8.00	71.4	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
6:2 FTS	27619-97-2	8.41	8.00	105	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFOA	335-67-1	8.22	8.00	103	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFHpS	375-92-8	9.65	8.00	121	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFNA	375-95-1	7.74	8.00	96.7	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFOSA	754-91-6	8.71	8.00	109	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFOS	1763-23-1	7.04	8.00	88.0	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
9Cl-PF3ONS	756426-58-1	7.30	8.00	91.3	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFDA	335-76-2	9.39	8.00	117	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
8:2 FTS	39108-34-4	7.79	8.00	97.4	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFNS	68259-12-1	7.01	8.00	87.6	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
MeFOSAA	2355-31-9	8.75	8.00	109	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
EtFOSAA	2991-50-6	6.91	8.00	86.4	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFUnA	2058-94-8	8.11	8.00	101	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFDS	335-77-3	6.95	8.00	86.9	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
11Cl-PF3OUdS	763051-92-9	9.41	8.00	118	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
10:2 FTS	120226-60-0	10.1	8.00	126	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFDoA	307-55-1	8.12	8.00	101	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
MeFOSA	31506-32-8	51.6	40.0	129	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFTrDA	72629-94-8	9.11	8.00	114	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFDoS	79780-39-5	8.12	8.00	102	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFTeDA	376-06-7	8.70	8.00	109	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
EtFOSA	4151-50-2	39.4	40.0	98.6	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFHxDA	67905-19-5	8.20	8.00	102	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
PFODA	16517-11-6	6.24	8.00	78.0	50 - 150	J	B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Aqueous

Laboratory Data

Lab Sample: B0G0133-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/L)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
MeFOSE	24448-09-7	54.3	40.0	136	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
EtFOSE	1691-99-2	26.7	40.0	66.8	50 - 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1

Labeled Standards	Type	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	87.8	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C3-PFPeA	IS	71.5	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C3-PFBS	IS	74.0	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C3-HFPO-DA	IS	70.6	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-4:2 FTS	IS	73.4	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFHxA	IS	68.4	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C4-PFHpA	IS	74.2	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C3-PFHxS	IS	78.0	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-6:2 FTS	IS	72.2	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C5-PFNA	IS	67.5	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C8-PFOSA	IS	29.7	10- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFOA	IS	74.4	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C8-PFOS	IS	69.2	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFDA	IS	61.4	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-8:2 FTS	IS	75.8	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d3-MeFOSAA	IS	55.5	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFUnA	IS	63.9	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d5-EtFOSAA	IS	56.7	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-10:2 FTS	IS	43.9	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFDoA	IS	52.4	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d3-MeFOSA	IS	10.3	10- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFTeDA	IS	52.0	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d5-EtFOSA	IS	10.8	10- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
13C2-PFHxDA	IS	42.2	25- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d7-MeFOSE	IS	22.6	10- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1
d9-EtFOSE	IS	25.2	10- 150		B0G0133	25-Jul-20	0.125 L	27-Jul-20 12:58	1

Vista Analytical Laboratory

Sample ID: SBP20-01-GW **PFAS Isotope Dilution Method**

Client Data
Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Aqueous
Date Collected: 08-Jul-20 09:40

Laboratory Data
Lab Sample: 2001478-01
Date Received: 14-Jul-20 09:11
Column: BEH C18

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	256	0.830	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFPeA	2706-90-3	989	1.46	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFBS	375-73-5	166	2.04	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
4:2 FTS	757124-72-4	67.8	1.58	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFHxA	307-24-4	1320	2.48	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFPeS	2706-91-4	386	2.76	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
HFPO-DA	13252-13-6	<5.49	5.49	5.69		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFHpA	375-85-9	546	0.673	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
ADONA	919005-14-4	<0.822	0.822	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFHxS	355-46-4	6490	5.39	22.8	D	B0G0132	17-Jul-20	0.110 L	23-Jul-20 21:55	5
6:2 FTS	27619-97-2	6940	11.4	22.8	D	B0G0132	17-Jul-20	0.110 L	23-Jul-20 21:55	5
PFOA	335-67-1	1420	0.741	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFHpS	375-92-8	1520	1.07	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFNA	375-95-1	104	0.922	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFOSA	754-91-6	19.3	2.02	4.55	Q	B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFOS	1763-23-1	18300	4.59	22.8	D	B0G0132	17-Jul-20	0.110 L	23-Jul-20 21:55	5
9Cl-PF3ONS	756426-58-1	<1.65	1.65	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFDA	335-76-2	<1.70	1.70	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
8:2 FTS	39108-34-4	334	2.35	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFNS	68259-12-1	<4.41	4.41	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
MeFOSAA	2355-31-9	<1.88	1.88	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
EtFOSAA	2991-50-6	<1.56	1.56	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFUnA	2058-94-8	<1.20	1.20	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFDS	335-77-3	<1.40	1.40	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
11Cl-PF3OUdS	763051-92-9	<2.74	2.74	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
10:2 FTS	120226-60-0	<3.56	3.56	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFDoA	307-55-1	<0.902	0.902	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
MeFOSA	31506-32-8	<4.36	4.36	22.8		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFTrDA	72629-94-8	<0.562	0.562	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFDoS	79780-39-5	<4.75	4.75	5.69		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFTeDA	376-06-7	<0.860	0.860	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
EtFOSA	4151-50-2	<5.82	5.82	22.8		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFHxDA	67905-19-5	<0.335	0.335	4.55		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
PFODA	16517-11-6	<6.99	6.99	7.97		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
MeFOSE	24448-09-7	<6.91	6.91	22.8		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
EtFOSE	1691-99-2	<10.7	10.7	22.8		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	113	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1

Vista Analytical Laboratory

Sample ID: SBP20-01-GW **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001478-01	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 09:40	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	99.3	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C3-PFBS	IS	108	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C3-HFPO-DA	IS	91.6	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C2-4:2 FTS	IS	108	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C2-PFHxA	IS	94.1	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C4-PFHpA	IS	100	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C3-PFHxS	IS	100	25 - 150	D	B0G0132	17-Jul-20	0.110 L	23-Jul-20 21:55	5
13C2-6:2 FTS	IS	107	25 - 150	D	B0G0132	17-Jul-20	0.110 L	23-Jul-20 21:55	5
13C5-PFNA	IS	76.7	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C8-PFOSA	IS	60.2	10 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C2-PFOA	IS	97.5	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C8-PFOS	IS	105	25 - 150	D	B0G0132	17-Jul-20	0.110 L	23-Jul-20 21:55	5
13C2-PFDA	IS	98.1	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C2-8:2 FTS	IS	98.6	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
d3-MeFOSAA	IS	88.0	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C2-PFUnA	IS	82.3	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
d5-EtFOSAA	IS	84.3	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C2-10:2 FTS	IS	88.8	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C2-PFDoA	IS	99.8	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
d3-MeFOSA	IS	23.5	10 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C2-PFTeDA	IS	76.0	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
d5-EtFOSA	IS	19.8	10 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
13C2-PFHxDA	IS	78.6	25 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
d7-MeFOSE	IS	49.3	10 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1
d9-EtFOSE	IS	56.7	10 - 150		B0G0132	17-Jul-20	0.110 L	22-Jul-20 16:50	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-06-GW **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001478-03	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 07:50	Date Received:	14-Jul-20 09:11		

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	162	0.816	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFPeA	2706-90-3	496	1.43	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFBS	375-73-5	140	2.00	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
4:2 FTS	757124-72-4	<1.56	1.56	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFHxA	307-24-4	611	2.44	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFPeS	2706-91-4	185	2.71	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
HFPO-DA	13252-13-6	<5.40	5.40	5.60		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFHpA	375-85-9	299	0.662	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
ADONA	919005-14-4	<0.809	0.809	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFHxS	355-46-4	2640	1.06	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
6:2 FTS	27619-97-2	631	2.24	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFOA	335-67-1	465	0.729	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFHpS	375-92-8	405	1.05	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFNA	375-95-1	70.1	0.907	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFOSA	754-91-6	46.0	1.98	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFOS	1763-23-1	11800	4.52	22.4	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:37	5
9Cl-PF3ONS	756426-58-1	<1.62	1.62	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFDA	335-76-2	<1.67	1.67	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
8:2 FTS	39108-34-4	213	2.31	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFNS	68259-12-1	<4.33	4.33	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
MeFOSAA	2355-31-9	<1.85	1.85	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
EtFOSAA	2991-50-6	<1.53	1.53	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFUnA	2058-94-8	<1.18	1.18	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFDS	335-77-3	<1.38	1.38	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
11Cl-PF3OUdS	763051-92-9	<2.70	2.70	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
10:2 FTS	120226-60-0	<3.51	3.51	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFDoA	307-55-1	<0.887	0.887	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
MeFOSA	31506-32-8	<4.29	4.29	22.4		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFTrDA	72629-94-8	<0.553	0.553	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFDoS	79780-39-5	<4.67	4.67	5.60		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFTeDA	376-06-7	<0.846	0.846	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
EtFOSA	4151-50-2	<5.72	5.72	22.4		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFHxDA	67905-19-5	<0.329	0.329	4.48		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
PFODA	16517-11-6	<6.88	6.88	7.84		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
MeFOSE	24448-09-7	<6.80	6.80	22.4		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
EtFOSE	1691-99-2	<10.6	10.6	22.4		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	85.3	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1

Vista Analytical Laboratory

Sample ID: SBP20-06-GW **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001478-03	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 07:50	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	91.3	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C3-PFBS	IS	109	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C3-HFPO-DA	IS	83.8	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C2-4:2 FTS	IS	103	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C2-PFHxA	IS	92.6	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C4-PFHpA	IS	90.6	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C3-PFHxS	IS	85.0	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C2-6:2 FTS	IS	86.8	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C5-PFNA	IS	82.1	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C8-PFOSA	IS	55.2	10 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C2-PFOA	IS	98.7	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C8-PFOS	IS	103	25 - 150	D	B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:37	5
13C2-PFDA	IS	96.7	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C2-8:2 FTS	IS	96.1	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
d3-MeFOSAA	IS	97.5	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C2-PFUnA	IS	89.1	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
d5-EtFOSAA	IS	96.0	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C2-10:2 FTS	IS	83.4	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C2-PFDoA	IS	81.4	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
d3-MeFOSA	IS	15.9	10 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C2-PFTeDA	IS	85.7	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
d5-EtFOSA	IS	14.1	10 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
13C2-PFHxDA	IS	76.6	25 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
d7-MeFOSE	IS	44.1	10 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1
d9-EtFOSE	IS	50.0	10 - 150		B0G0132	17-Jul-20	0.112 L	23-Jul-20 22:47	1

MDL - Method Detection Limit   RL - Reporting limit   Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-05-GW | **PFAS Isotope Dilution Method**

Client Data
Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Aqueous
Date Collected: 08-Jul-20 08:55

Laboratory Data
Lab Sample: 2001478-06
Date Received: 14-Jul-20 09:11
Column: BEH C18

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	488	0.796	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFPeA	2706-90-3	1960	1.40	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFBS	375-73-5	35.7	1.96	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
4:2 FTS	757124-72-4	23.1	1.52	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFHxA	307-24-4	1210	2.38	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFPeS	2706-91-4	102	2.64	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
HFPO-DA	13252-13-6	<5.27	5.27	5.46		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFHpA	375-85-9	1190	0.646	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
ADONA	919005-14-4	<0.789	0.789	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFHxS	355-46-4	2370	1.03	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
6:2 FTS	27619-97-2	3030	2.19	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFOA	335-67-1	1120	0.711	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFHpS	375-92-8	367	1.02	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFNA	375-95-1	231	0.885	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFOSA	754-91-6	18.2	1.93	4.37	Q	B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFOS	1763-23-1	11800	4.41	21.9	D	B0G0132	17-Jul-20	0.114 L	23-Jul-20 22:57	5
9Cl-PF3ONS	756426-58-1	<1.58	1.58	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFDA	335-76-2	3.86	1.63	4.37	J	B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
8:2 FTS	39108-34-4	332	2.25	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFNS	68259-12-1	<4.23	4.23	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
MeFOSAA	2355-31-9	<1.80	1.80	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
EtFOSAA	2991-50-6	<1.50	1.50	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFUnA	2058-94-8	<1.15	1.15	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFDS	335-77-3	<1.34	1.34	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
11Cl-PF3OUdS	763051-92-9	<2.63	2.63	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
10:2 FTS	120226-60-0	<3.42	3.42	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFDoA	307-55-1	<0.865	0.865	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
MeFOSA	31506-32-8	<4.18	4.18	21.9		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFTrDA	72629-94-8	<0.540	0.540	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFDoS	79780-39-5	<4.56	4.56	5.46		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFTeDA	376-06-7	<0.825	0.825	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
EtFOSA	4151-50-2	<5.58	5.58	21.9		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFHxDA	67905-19-5	<0.321	0.321	4.37		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
PFODA	16517-11-6	<6.71	6.71	7.65		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
MeFOSE	24448-09-7	<6.63	6.63	21.9		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
EtFOSE	1691-99-2	<10.3	10.3	21.9		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	104	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1

Vista Analytical Laboratory

Sample ID: SBP20-05-GW **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Aqueous
Date Collected: 08-Jul-20 08:55

Laboratory Data

Lab Sample: 2001478-06
Date Received: 14-Jul-20 09:11
Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	91.9	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C3-PFBS	IS	98.7	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C3-HFPO-DA	IS	84.2	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C2-4:2 FTS	IS	80.7	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C2-PFHxA	IS	89.7	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C4-PFHpA	IS	86.0	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C3-PFHxS	IS	89.8	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C2-6:2 FTS	IS	78.4	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C5-PFNA	IS	84.1	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C8-PFOSA	IS	53.3	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C2-PFOA	IS	89.3	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C8-PFOS	IS	87.5	25 - 150	D	B0G0132	17-Jul-20	0.114 L	23-Jul-20 22:57	5
13C2-PFDA	IS	101	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C2-8:2 FTS	IS	87.1	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
d3-MeFOSAA	IS	86.0	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C2-PFUnA	IS	89.1	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
d5-EtFOSAA	IS	82.6	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C2-10:2 FTS	IS	69.7	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C2-PFDoA	IS	95.5	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
d3-MeFOSA	IS	14.7	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C2-PFTeDA	IS	80.7	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
d5-EtFOSA	IS	12.7	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
13C2-PFHxDA	IS	76.7	25 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
d7-MeFOSE	IS	44.7	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1
d9-EtFOSE	IS	46.5	10 - 150		B0G0132	17-Jul-20	0.114 L	22-Jul-20 17:10	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: Field Blank A **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001478-09	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 09:55	Date Received:	14-Jul-20 09:11		

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.769	0.769	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFPeA	2706-90-3	<1.35	1.35	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFBS	375-73-5	<1.89	1.89	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
4:2 FTS	757124-72-4	<1.47	1.47	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFHxA	307-24-4	<2.30	2.30	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFPeS	2706-91-4	<2.55	2.55	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
HFPO-DA	13252-13-6	<5.08	5.08	5.27		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFHpA	375-85-9	<0.623	0.623	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
ADONA	919005-14-4	<0.761	0.761	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFHxS	355-46-4	<0.999	0.999	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
6:2 FTS	27619-97-2	<2.11	2.11	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFOA	335-67-1	<0.686	0.686	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFHpS	375-92-8	<0.988	0.988	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFNA	375-95-1	<0.854	0.854	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFOSA	754-91-6	<1.87	1.87	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFOS	1763-23-1	<0.851	0.851	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
9Cl-PF3ONS	756426-58-1	<1.53	1.53	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFDA	335-76-2	<1.57	1.57	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
8:2 FTS	39108-34-4	<2.17	2.17	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFNS	68259-12-1	<4.08	4.08	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
MeFOSAA	2355-31-9	<1.74	1.74	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
EtFOSAA	2991-50-6	<1.44	1.44	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFUnA	2058-94-8	<1.11	1.11	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFDS	335-77-3	<1.30	1.30	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
11Cl-PF3OUdS	763051-92-9	<2.54	2.54	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
10:2 FTS	120226-60-0	<3.30	3.30	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFDoA	307-55-1	<0.835	0.835	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
MeFOSA	31506-32-8	<4.26	4.26	22.2		B0G0133	25-Jul-20	0.112 L	27-Jul-20 13:30	1
PFTrDA	72629-94-8	<0.521	0.521	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFDoS	79780-39-5	<4.40	4.40	5.27		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFTeDA	376-06-7	<0.796	0.796	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
EtFOSA	4151-50-2	<5.68	5.68	22.2		B0G0133	25-Jul-20	0.112 L	27-Jul-20 13:30	1
PFHxDA	67905-19-5	<0.310	0.310	4.22		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
PFODA	16517-11-6	<6.47	6.47	7.38		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
MeFOSE	24448-09-7	<6.40	6.40	21.1		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
EtFOSE	1691-99-2	<9.95	9.95	21.1		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	139	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1

Vista Analytical Laboratory

Sample ID: Field Blank A **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001478-09	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 09:55	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	106	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C3-PFBS	IS	98.8	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C3-HFPO-DA	IS	78.7	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C2-4:2 FTS	IS	100	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C2-PFHxA	IS	98.6	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C4-PFHpA	IS	102	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C3-PFHxS	IS	104	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C2-6:2 FTS	IS	87.8	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C5-PFNA	IS	89.8	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C8-PFOSA	IS	43.0	10 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C2-PFOA	IS	94.9	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C8-PFOS	IS	92.2	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C2-PFDA	IS	106	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C2-8:2 FTS	IS	104	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
d3-MeFOSAA	IS	83.9	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C2-PFUnA	IS	93.3	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
d5-EtFOSAA	IS	81.1	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C2-10:2 FTS	IS	82.6	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
13C2-PFDoA	IS	92.7	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
d3-MeFOSA	IS	12.0	10 - 150		B0G0133	25-Jul-20	0.112 L	27-Jul-20 13:30	1
13C2-PFTeDA	IS	79.0	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
d5-EtFOSA	IS	11.9	10 - 150		B0G0133	25-Jul-20	0.112 L	27-Jul-20 13:30	1
13C2-PFHxDA	IS	72.7	25 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
d7-MeFOSE	IS	23.7	10 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1
d9-EtFOSE	IS	26.8	10 - 150		B0G0132	17-Jul-20	0.119 L	22-Jul-20 17:21	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-04-GW **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001478-10	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 10:05	Date Received:	14-Jul-20 09:11		

Analyte	CAS Number	Conc. (ng/L)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	586	0.794	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFPeA	2706-90-3	2190	1.39	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFBS	375-73-5	206	1.95	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
4:2 FTS	757124-72-4	94.5	1.51	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFHxA	307-24-4	2250	2.37	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFPeS	2706-91-4	623	2.63	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
HFPO-DA	13252-13-6	<5.25	5.25	5.44		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFHpA	375-85-9	1320	0.643	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
ADONA	919005-14-4	<0.786	0.786	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFHxS	355-46-4	9640	5.15	21.8	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 23:18	5
6:2 FTS	27619-97-2	11000	10.9	21.8	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 23:18	5
PFOA	335-67-1	2300	0.709	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFHpS	375-92-8	1550	1.02	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFNA	375-95-1	120	0.882	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFOSA	754-91-6	20.5	1.93	4.35	Q	B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFOS	1763-23-1	18900	4.39	21.8	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 23:18	5
9Cl-PF3ONS	756426-58-1	<1.58	1.58	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFDA	335-76-2	3.99	1.62	4.35	J	B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
8:2 FTS	39108-34-4	480	2.24	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFNS	68259-12-1	<4.21	4.21	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
MeFOSAA	2355-31-9	<1.80	1.80	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
EtFOSAA	2991-50-6	<1.49	1.49	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFUnA	2058-94-8	<1.14	1.14	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFDS	335-77-3	<1.34	1.34	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
11Cl-PF3OUdS	763051-92-9	<2.62	2.62	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
10:2 FTS	120226-60-0	<3.41	3.41	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFDoA	307-55-1	<0.862	0.862	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
MeFOSA	31506-32-8	<4.17	4.17	21.8		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFTrDA	72629-94-8	<0.538	0.538	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFDoS	79780-39-5	<4.54	4.54	5.44		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFTeDA	376-06-7	<0.822	0.822	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
EtFOSA	4151-50-2	<5.56	5.56	21.8		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFHxDA	67905-19-5	<0.320	0.320	4.35		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
PFODA	16517-11-6	<6.68	6.68	7.62		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
MeFOSE	24448-09-7	<6.61	6.61	21.8		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
EtFOSE	1691-99-2	<10.3	10.3	21.8		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	105	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1

Vista Analytical Laboratory

Sample ID: SBP20-04-GW **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Aqueous	Lab Sample:	2001478-10	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 10:05	Date Received:	14-Jul-20 09:11		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	89.6	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C3-PFBS	IS	95.4	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C3-HFPO-DA	IS	84.3	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C2-4:2 FTS	IS	92.7	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C2-PFHxA	IS	87.4	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C4-PFHpA	IS	86.1	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C3-PFHxS	IS	75.0	25 - 150	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 23:18	5
13C2-6:2 FTS	IS	88.7	25 - 150	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 23:18	5
13C5-PFNA	IS	77.7	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C8-PFOSA	IS	56.1	10 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C2-PFOA	IS	86.5	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C8-PFOS	IS	92.5	25 - 150	D	B0G0132	17-Jul-20	0.115 L	23-Jul-20 23:18	5
13C2-PFDA	IS	105	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C2-8:2 FTS	IS	98.1	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
d3-MeFOSAA	IS	83.9	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C2-PFUnA	IS	99.5	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
d5-EtFOSAA	IS	85.3	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C2-10:2 FTS	IS	69.2	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C2-PFDoA	IS	97.1	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
d3-MeFOSA	IS	19.7	10 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C2-PFTeDA	IS	77.0	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
d5-EtFOSA	IS	16.8	10 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
13C2-PFHxDA	IS	76.0	25 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
d7-MeFOSE	IS	46.4	10 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1
d9-EtFOSE	IS	53.5	10 - 150		B0G0132	17-Jul-20	0.115 L	22-Jul-20 17:31	1

MDL - Method Detection Limit RL - Reporting limit Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Solid	Lab Sample:	B0G0151-BLK1	Column:	BEH C18
Project:	MSN FFTA SAMPLES						

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.346	0.346	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFPeA	2706-90-3	<0.398	0.398	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFBS	375-73-5	<0.304	0.304	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
4:2 FTS	757124-72-4	<0.360	0.360	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFHxA	307-24-4	<0.216	0.216	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFPeS	2706-91-4	<0.658	0.658	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
HFPO-DA	13252-13-6	<1.18	1.18	1.50		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFHpA	375-85-9	<0.478	0.478	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
ADONA	919005-14-4	<0.340	0.340	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFHxS	355-46-4	<0.390	0.390	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
6:2 FTS	27619-97-2	<0.654	0.654	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFOA	335-67-1	<0.470	0.470	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFHpS	375-92-8	<0.738	0.738	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFNA	375-95-1	<0.312	0.312	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFOSA	754-91-6	<1.01	1.01	1.50		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFOS	1763-23-1	<0.430	0.430	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
9Cl-PF3ONS	756426-58-1	<0.370	0.370	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFDA	335-76-2	<0.452	0.452	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
8:2 FTS	39108-34-4	<0.722	0.722	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFNS	68259-12-1	<1.15	1.15	1.50		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
MeFOSAA	2355-31-9	<0.736	0.736	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
EtFOSAA	2991-50-6	<0.688	0.688	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFUnA	2058-94-8	<0.258	0.258	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFDS	335-77-3	<0.690	0.690	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
11Cl-PF3OUdS	763051-92-9	<0.722	0.722	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
10:2 FTS	120226-60-0	<1.02	1.02	1.50		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFDoA	307-55-1	<0.404	0.404	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
MeFOSA	31506-32-8	<5.78	5.78	10.0		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFTrDA	72629-94-8	<0.402	0.402	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFDoS	79780-39-5	<0.600	0.600	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFTeDA	376-06-7	<0.264	0.264	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
EtFOSA	4151-50-2	<3.84	3.84	10.0		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFHxDA	67905-19-5	<0.170	0.170	0.500		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
PFODA	16517-11-6	<0.500	0.500	1.00		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
MeFOSE	24448-09-7	<4.96	4.96	10.0		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
EtFOSE	1691-99-2	<5.38	5.38	10.0		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	109	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1

Vista Analytical Laboratory

Sample ID: Method Blank **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Solid	Lab Sample:	B0G0151-BLK1	Column:	BEH C18
Project:	MSN FFTA SAMPLES						

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	65.3	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C3-PFBS	IS	78.0	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C3-HFPO-DA	IS	57.7	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-4:2 FTS	IS	66.1	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFHxA	IS	66.8	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C4-PFHpA	IS	65.6	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C3-PFHxS	IS	73.6	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-6:2 FTS	IS	65.2	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C5-PFNA	IS	59.5	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C8-PFOSA	IS	27.4	10 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFOA	IS	56.7	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C8-PFOS	IS	66.4	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFDA	IS	50.7	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-8:2 FTS	IS	72.5	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d3-MeFOSAA	IS	48.5	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFUnA	IS	41.0	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d5-EtFOSAA	IS	41.1	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-10:2 FTS	IS	54.1	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFDoA	IS	38.9	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d3-MeFOSA	IS	4.40	10 - 150	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFTeDA	IS	45.1	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d5-EtFOSA	IS	4.40	10 - 150	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
13C2-PFHxDA	IS	32.0	25 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d7-MeFOSE	IS	20.5	10 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1
d9-EtFOSE	IS	20.1	10 - 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:36	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: OPR | **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Solid

Laboratory Data

Lab Sample: B0G0151-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/g)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	10.7	10.0	107	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFPeA	2706-90-3	10.3	10.0	103	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFBS	375-73-5	10.7	10.0	107	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
4:2 FTS	757124-72-4	10.2	10.0	102	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFHxA	307-24-4	10.7	10.0	107	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFPeS	2706-91-4	11.4	10.0	114	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
HFPO-DA	13252-13-6	11.1	10.0	111	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFHpA	375-85-9	10.8	10.0	108	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
ADONA	919005-14-4	11.1	10.0	111	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFHxS	355-46-4	9.72	10.0	97.2	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
6:2 FTS	27619-97-2	9.33	10.0	93.3	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFOA	335-67-1	10.9	10.0	109	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFHpS	375-92-8	11.6	10.0	116	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFNA	375-95-1	12.0	10.0	120	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFOSA	754-91-6	10.6	10.0	106	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFOS	1763-23-1	11.0	10.0	110	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
9Cl-PF3ONS	756426-58-1	10.6	10.0	106	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFDA	335-76-2	10.1	10.0	101	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
8:2 FTS	39108-34-4	8.49	10.0	84.9	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFNS	68259-12-1	10.8	10.0	108	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
MeFOSAA	2355-31-9	10.2	10.0	102	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
EtFOSAA	2991-50-6	11.2	10.0	112	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFUnA	2058-94-8	9.57	10.0	95.7	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFDS	335-77-3	9.61	10.0	96.1	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
11Cl-PF3OUdS	763051-92-9	18.0	10.0	180	60 - 135	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
10:2 FTS	120226-60-0	11.0	10.0	110	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFDoA	307-55-1	10.1	10.0	101	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
MeFOSA	31506-32-8	53.4	50.0	107	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFTrDA	72629-94-8	11.1	10.0	111	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFDoS	79780-39-5	14.9	10.0	149	60 - 135	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFTeDA	376-06-7	10.7	10.0	107	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
EtFOSA	4151-50-2	48.0	50.0	96.0	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFHxDA	67905-19-5	10.3	10.0	103	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
PFODA	16517-11-6	9.37	10.0	93.7	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1

Vista Analytical Laboratory

Sample ID: OPR **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Solid

Laboratory Data

Lab Sample: B0G0151-BS1
Column: BEH C18

Analyte	CAS Number	Amt Found (ng/g)	Spike Amt	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
MeFOSE	24448-09-7	57.8	50.0	116	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
EtFOSE	1691-99-2	51.3	50.0	103	60 - 135		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1

Labeled Standards	Type	% Rec	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	108	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C3-PFPeA	IS	62.1	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C3-PFBS	IS	84.9	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C3-HFPO-DA	IS	58.5	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-4:2 FTS	IS	91.1	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFHxA	IS	63.6	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C4-PFHpA	IS	62.8	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C3-PFHxS	IS	84.3	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-6:2 FTS	IS	77.5	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C5-PFNA	IS	53.6	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C8-PFOSA	IS	28.5	10- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFOA	IS	59.5	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C8-PFOS	IS	81.4	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFDA	IS	54.3	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-8:2 FTS	IS	88.2	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d3-MeFOSAA	IS	51.9	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFUnA	IS	42.8	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d5-EtFOSAA	IS	48.6	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-10:2 FTS	IS	61.7	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFDoA	IS	37.9	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d3-MeFOSA	IS	5.10	10- 150	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFTeDA	IS	43.0	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d5-EtFOSA	IS	4.80	10- 150	H	B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
13C2-PFHxDA	IS	36.3	25- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d7-MeFOSE	IS	21.3	10- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1
d9-EtFOSE	IS	21.9	10- 150		B0G0151	22-Jul-20	1.00 g	27-Jul-20 16:47	1

Vista Analytical Laboratory

Sample ID: SBP20-04 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001478-02	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 07:35	Date Received:	14-Jul-20 09:11		
				% Solids:	90.8		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.337	0.337	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFPeA	2706-90-3	<0.388	0.388	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFBS	375-73-5	<0.296	0.296	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
4:2 FTS	757124-72-4	<0.351	0.351	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFHxA	307-24-4	0.232	0.210	0.487	J, Q	B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFPeS	2706-91-4	<0.641	0.641	0.974		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
HFPO-DA	13252-13-6	<1.15	1.15	1.46		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFHpA	375-85-9	<0.466	0.466	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
ADONA	919005-14-4	<0.331	0.331	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFHxS	355-46-4	<0.380	0.380	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
6:2 FTS	27619-97-2	4.83	0.637	0.974		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFOA	335-67-1	0.684	0.458	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFHpS	375-92-8	<0.719	0.719	0.974		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFNA	375-95-1	1.39	0.304	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFOSA	754-91-6	7.98	0.982	1.46		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFOS	1763-23-1	83.9	0.419	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
9Cl-PF3ONS	756426-58-1	<0.361	0.361	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFDA	335-76-2	0.941	0.440	0.487	Q	B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
8:2 FTS	39108-34-4	51.1	0.703	0.974		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFNS	68259-12-1	<1.12	1.12	1.46		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
MeFOSAA	2355-31-9	<0.717	0.717	0.974		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
EtFOSAA	2991-50-6	<0.670	0.670	0.974		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFUnA	2058-94-8	<0.251	0.251	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFDS	335-77-3	<0.672	0.672	0.974		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
11Cl-PF3OUdS	763051-92-9	<0.703	0.703	0.974		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
10:2 FTS	120226-60-0	<0.990	0.990	1.46		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFDoA	307-55-1	<0.394	0.394	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
MeFOSA	31506-32-8	<5.63	5.63	9.74		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFTrDA	72629-94-8	<0.392	0.392	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFDoS	79780-39-5	<0.585	0.585	0.974		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFTeDA	376-06-7	<0.257	0.257	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
EtFOSA	4151-50-2	<3.74	3.74	9.74		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFHxDA	67905-19-5	<0.166	0.166	0.487		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
PFODA	16517-11-6	<0.487	0.487	0.974		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
MeFOSE	24448-09-7	<4.83	4.83	9.74		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
EtFOSE	1691-99-2	<5.24	5.24	9.74		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	116	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1

Vista Analytical Laboratory

Sample ID: SBP20-04 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				**Laboratory Data**			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001478-02	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 07:35	Date Received:	14-Jul-20 09:11		
				% Solids:	90.8		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	72.8	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C3-PFBS	IS	80.8	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C3-HFPO-DA	IS	65.4	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-4:2 FTS	IS	91.1	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-PFHxA	IS	76.9	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C4-PFHpA	IS	73.5	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C3-PFHxS	IS	87.2	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-6:2 FTS	IS	84.0	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C5-PFNA	IS	65.6	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C8-PFOSA	IS	29.1	10 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-PFOA	IS	66.8	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C8-PFOS	IS	71.0	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-PFDA	IS	49.7	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-8:2 FTS	IS	82.6	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
d3-MeFOSAA	IS	53.7	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-PFUnA	IS	48.0	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
d5-EtFOSAA	IS	53.6	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-10:2 FTS	IS	69.1	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-PFDoA	IS	52.7	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
d3-MeFOSA	IS	5.60	10 - 150	H	B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-PFTeDA	IS	62.4	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
d5-EtFOSA	IS	5.50	10 - 150	H	B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
13C2-PFHxDA	IS	53.8	25 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
d7-MeFOSE	IS	20.8	10 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1
d9-EtFOSE	IS	23.0	10 - 150		B0G0151	22-Jul-20	1.13 g	27-Jul-20 18:41	1

MDL - Method Detection Limit   RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-05 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001478-04	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 08:10	Date Received:	14-Jul-20 09:11		
				% Solids:	93.6		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.342	0.342	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFPeA	2706-90-3	<0.394	0.394	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFBS	375-73-5	<0.301	0.301	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
4:2 FTS	757124-72-4	0.378	0.356	0.495	J, Q	B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFHxA	307-24-4	0.321	0.214	0.495	J, Q	B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFPeS	2706-91-4	<0.651	0.651	0.990		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
HFPO-DA	13252-13-6	<1.17	1.17	1.48		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFHpA	375-85-9	0.627	0.473	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
ADONA	919005-14-4	<0.336	0.336	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFHxS	355-46-4	<0.386	0.386	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
6:2 FTS	27619-97-2	11.3	0.647	0.990		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFOA	335-67-1	1.42	0.465	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFHpS	375-92-8	<0.730	0.730	0.990		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFNA	375-95-1	3.31	0.309	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFOSA	754-91-6	<0.998	0.998	1.48		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFOS	1763-23-1	20.2	0.426	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
9Cl-PF3ONS	756426-58-1	<0.366	0.366	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFDA	335-76-2	8.56	0.447	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
8:2 FTS	39108-34-4	29.9	0.715	0.990		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFNS	68259-12-1	<1.14	1.14	1.48		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
MeFOSAA	2355-31-9	<0.728	0.728	0.990		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
EtFOSAA	2991-50-6	<0.681	0.681	0.990		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFUnA	2058-94-8	0.584	0.255	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFDS	335-77-3	<0.683	0.683	0.990		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
11Cl-PF3OUdS	763051-92-9	<0.715	0.715	0.990		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
10:2 FTS	120226-60-0	1.68	1.01	1.48		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFDoA	307-55-1	<0.400	0.400	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
MeFOSA	31506-32-8	<5.72	5.72	9.90		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFTrDA	72629-94-8	<0.398	0.398	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFDoS	79780-39-5	<0.594	0.594	0.990		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFTeDA	376-06-7	<0.261	0.261	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
EtFOSA	4151-50-2	<3.80	3.80	9.90		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFHxDA	67905-19-5	<0.168	0.168	0.495		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
PFODA	16517-11-6	<0.495	0.495	0.990		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
MeFOSE	24448-09-7	<4.91	4.91	9.90		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
EtFOSE	1691-99-2	<5.32	5.32	9.90		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	122	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1

SR0220

Vista Analytical Laboratory

Sample ID: SBP20-05 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001478-04	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 08:10	Date Received:	14-Jul-20 09:11		
				% Solids:	93.6		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	76.9	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C3-PFBS	IS	76.8	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C3-HFPO-DA	IS	68.4	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-4:2 FTS	IS	85.4	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-PFHxA	IS	80.5	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C4-PFHpA	IS	74.9	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C3-PFHxS	IS	82.1	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-6:2 FTS	IS	79.2	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C5-PFNA	IS	67.6	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C8-PFOSA	IS	40.9	10 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-PFOA	IS	73.6	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C8-PFOS	IS	79.5	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-PFDA	IS	60.1	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-8:2 FTS	IS	80.9	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
d3-MeFOSAA	IS	58.2	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-PFUnA	IS	62.4	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
d5-EtFOSAA	IS	66.9	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-10:2 FTS	IS	75.6	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-PFDoA	IS	56.7	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
d3-MeFOSA	IS	11.3	10 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-PFTeDA	IS	62.9	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
d5-EtFOSA	IS	13.1	10 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
13C2-PFHxDA	IS	70.9	25 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
d7-MeFOSE	IS	36.8	10 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1
d9-EtFOSE	IS	36.4	10 - 150		B0G0151	22-Jul-20	1.08 g	27-Jul-20 18:51	1

MDL - Method Detection Limit

RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-05 (6-6.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001478-05	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 08:20	Date Received:	14-Jul-20 09:11		
				% Solids:	67.0		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	0.364	0.344	0.497	J	B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFPeA	2706-90-3	2.54	0.396	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFBS	375-73-5	<0.302	0.302	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
4:2 FTS	757124-72-4	<0.358	0.358	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFHxA	307-24-4	2.62	0.215	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFPeS	2706-91-4	<0.654	0.654	0.994		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
HFPO-DA	13252-13-6	<1.17	1.17	1.49		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFHpA	375-85-9	3.76	0.475	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
ADONA	919005-14-4	<0.338	0.338	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFHxS	355-46-4	12.8	0.388	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
6:2 FTS	27619-97-2	19.5	0.650	0.994		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFOA	335-67-1	6.37	0.467	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFHpS	375-92-8	5.85	0.734	0.994		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFNA	375-95-1	3.21	0.310	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFOSA	754-91-6	<1.00	1.00	1.49		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFOS	1763-23-1	619	2.14	2.49	D	B0G0151	22-Jul-20	1.50 g	28-Jul-20 18:02	5
9Cl-PF3ONS	756426-58-1	<0.368	0.368	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFDA	335-76-2	0.673	0.449	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
8:2 FTS	39108-34-4	2.15	0.718	0.994		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFNS	68259-12-1	<1.14	1.14	1.49		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
MeFOSAA	2355-31-9	<0.732	0.732	0.994		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
EtFOSAA	2991-50-6	<0.684	0.684	0.994		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFUnA	2058-94-8	<0.257	0.257	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFDS	335-77-3	<0.686	0.686	0.994		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
11Cl-PF3OUdS	763051-92-9	<0.718	0.718	0.994		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
10:2 FTS	120226-60-0	<1.01	1.01	1.49		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFDoA	307-55-1	<0.402	0.402	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
MeFOSA	31506-32-8	<5.75	5.75	9.94		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFTrDA	72629-94-8	<0.400	0.400	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFDoS	79780-39-5	<0.597	0.597	0.994		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFTeDA	376-06-7	<0.263	0.263	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
EtFOSA	4151-50-2	<3.82	3.82	9.94		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFHxDA	67905-19-5	<0.169	0.169	0.497		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
PFODA	16517-11-6	<0.497	0.497	0.994		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
MeFOSE	24448-09-7	<4.93	4.93	9.94		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
EtFOSE	1691-99-2	<5.35	5.35	9.94		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	117	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1

Vista Analytical Laboratory

Sample ID: SBP20-05 (6-6.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001478-05	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 08:20	Date Received:	14-Jul-20 09:11		
				% Solids:	67.0		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	71.1	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C3-PFBS	IS	83.1	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C3-HFPO-DA	IS	72.2	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C2-4:2 FTS	IS	90.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C2-PFHxA	IS	74.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C4-PFHpA	IS	67.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C3-PFHxS	IS	85.2	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C2-6:2 FTS	IS	84.7	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C5-PFNA	IS	65.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C8-PFOSA	IS	54.6	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C2-PFOA	IS	68.8	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C8-PFOS	IS	73.5	25 - 150	D	B0G0151	22-Jul-20	1.50 g	28-Jul-20 18:02	5
13C2-PFDA	IS	61.7	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C2-8:2 FTS	IS	98.6	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
d3-MeFOSAA	IS	69.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C2-PFUnA	IS	69.5	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
d5-EtFOSAA	IS	73.7	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C2-10:2 FTS	IS	79.4	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C2-PFDoA	IS	62.1	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
d3-MeFOSA	IS	36.6	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C2-PFTeDA	IS	55.2	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
d5-EtFOSA	IS	42.2	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
13C2-PFHxDA	IS	35.0	25 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
d7-MeFOSE	IS	56.8	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1
d9-EtFOSE	IS	49.7	10 - 150		B0G0151	22-Jul-20	1.50 g	27-Jul-20 19:01	1

MDL - Method Detection Limit

RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-01 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001478-07	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 09:00	Date Received:	14-Jul-20 09:11		
				% Solids:	93.6		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.342	0.342	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFPeA	2706-90-3	<0.394	0.394	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFBS	375-73-5	<0.301	0.301	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
4:2 FTS	757124-72-4	1.09	0.356	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFHxA	307-24-4	0.364	0.214	0.495	J, Q	B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFPeS	2706-91-4	<0.651	0.651	0.989		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
HFPO-DA	13252-13-6	<1.17	1.17	1.48		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFHpA	375-85-9	<0.473	0.473	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
ADONA	919005-14-4	<0.336	0.336	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFHxS	355-46-4	0.624	0.386	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
6:2 FTS	27619-97-2	24.6	0.647	0.989		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFOA	335-67-1	0.503	0.465	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFHpS	375-92-8	<0.730	0.730	0.989		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFNA	375-95-1	0.787	0.309	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFOSA	754-91-6	3.68	0.997	1.48		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFOS	1763-23-1	126	0.425	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
9Cl-PF3ONS	756426-58-1	<0.366	0.366	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFDA	335-76-2	1.18	0.447	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
8:2 FTS	39108-34-4	84.2	0.714	0.989		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFNS	68259-12-1	<1.14	1.14	1.48		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
MeFOSAA	2355-31-9	<0.728	0.728	0.989		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
EtFOSAA	2991-50-6	<0.681	0.681	0.989		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFUnA	2058-94-8	<0.255	0.255	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFDS	335-77-3	<0.683	0.683	0.989		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
11Cl-PF3OUdS	763051-92-9	<0.714	0.714	0.989		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
10:2 FTS	120226-60-0	<1.01	1.01	1.48		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFDoA	307-55-1	<0.400	0.400	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
MeFOSA	31506-32-8	<5.72	5.72	9.89		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFTrDA	72629-94-8	<0.398	0.398	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFDoS	79780-39-5	<0.594	0.594	0.989		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFTeDA	376-06-7	<0.261	0.261	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
EtFOSA	4151-50-2	<3.80	3.80	9.89		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFHxDA	67905-19-5	<0.168	0.168	0.495		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
PFODA	16517-11-6	<0.495	0.495	0.989		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
MeFOSE	24448-09-7	<4.91	4.91	9.89		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
EtFOSE	1691-99-2	<5.32	5.32	9.89		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	65.1	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1

Vista Analytical Laboratory

Sample ID: SBP20-01 (0.5-1) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001478-07	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 09:00	Date Received:	14-Jul-20 09:11		
				% Solids:	93.6		

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	66.3	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C3-PFBS	IS	84.3	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C3-HFPO-DA	IS	70.3	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-4:2 FTS	IS	97.6	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-PFHxA	IS	73.3	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C4-PFHpA	IS	69.8	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C3-PFHxS	IS	82.5	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-6:2 FTS	IS	77.0	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C5-PFNA	IS	62.7	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C8-PFOSA	IS	38.7	10 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-PFOA	IS	73.7	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C8-PFOS	IS	79.1	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-PFDA	IS	51.4	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-8:2 FTS	IS	85.7	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
d3-MeFOSAA	IS	52.3	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-PFUnA	IS	53.3	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
d5-EtFOSAA	IS	51.2	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-10:2 FTS	IS	60.5	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-PFDoA	IS	54.9	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
d3-MeFOSA	IS	8.10	10 - 150	H	B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-PFTeDA	IS	38.8	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
d5-EtFOSA	IS	7.10	10 - 150	H	B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
13C2-PFHxDA	IS	29.3	25 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
d7-MeFOSE	IS	31.0	10 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1
d9-EtFOSE	IS	29.9	10 - 150		B0G0151	22-Jul-20	1.08 g	28-Jul-20 18:12	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

Vista Analytical Laboratory

Sample ID: SBP20-01 (5-5.5) **PFAS Isotope Dilution Method**

Client Data				Laboratory Data			
Name:	LimnoTech, Inc.	Matrix:	Soil	Lab Sample:	2001478-08	Column:	BEH C18
Project:	MSN FFTA SAMPLES	Date Collected:	08-Jul-20 09:05	Date Received:	14-Jul-20 09:11		
				% Solids:	89.9		

Analyte	CAS Number	Conc. (ng/g)	MDL	RL	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
PFBA	375-22-4	<0.344	0.344	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFPeA	2706-90-3	<0.395	0.395	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFBS	375-73-5	<0.302	0.302	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
4:2 FTS	757124-72-4	<0.358	0.358	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFHxA	307-24-4	0.403	0.215	0.497	J	B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFPeS	2706-91-4	<0.654	0.654	0.994		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
HFPO-DA	13252-13-6	<1.17	1.17	1.49		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFHpA	375-85-9	<0.475	0.475	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
ADONA	919005-14-4	<0.338	0.338	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFHxS	355-46-4	0.447	0.388	0.497	J	B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
6:2 FTS	27619-97-2	5.25	0.650	0.994		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFOA	335-67-1	<0.467	0.467	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFHpS	375-92-8	<0.733	0.733	0.994		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFNA	375-95-1	<0.310	0.310	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFOSA	754-91-6	<1.00	1.00	1.49		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFOS	1763-23-1	136	0.427	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
9Cl-PF3ONS	756426-58-1	<0.368	0.368	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFDA	335-76-2	<0.449	0.449	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
8:2 FTS	39108-34-4	7.18	0.717	0.994		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFNS	68259-12-1	<1.14	1.14	1.49		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
MeFOSAA	2355-31-9	<0.731	0.731	0.994		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
EtFOSAA	2991-50-6	<0.684	0.684	0.994		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFUnA	2058-94-8	<0.256	0.256	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFDS	335-77-3	<0.686	0.686	0.994		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
11Cl-PF3OUdS	763051-92-9	<0.717	0.717	0.994		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
10:2 FTS	120226-60-0	<1.01	1.01	1.49		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFDoA	307-55-1	<0.401	0.401	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
MeFOSA	31506-32-8	<5.74	5.74	9.94		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFTrDA	72629-94-8	<0.399	0.399	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFDoS	79780-39-5	<0.596	0.596	0.994		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFTeDA	376-06-7	<0.262	0.262	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
EtFOSA	4151-50-2	<3.82	3.82	9.94		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFHxDA	67905-19-5	<0.169	0.169	0.497		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
PFODA	16517-11-6	<0.497	0.497	0.994		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
MeFOSE	24448-09-7	<4.93	4.93	9.94		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
EtFOSE	1691-99-2	<5.35	5.35	9.94		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFBA	IS	107	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1

Vista Analytical Laboratory

Sample ID: SBP20-01 (5-5.5) **PFAS Isotope Dilution Method**

Client Data

Name: LimnoTech, Inc.
Project: MSN FFTA SAMPLES
Matrix: Soil
Date Collected: 08-Jul-20 09:05

Laboratory Data

Lab Sample: 2001478-08
Date Received: 14-Jul-20 09:11
% Solids: 89.9
Column: BEH C18

Labeled Standards	Type	% Recovery	Limits	Qualifiers	Batch	Extracted	Samp Size	Analyzed	Dilution
13C3-PFPeA	IS	66.2	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C3-PFBS	IS	76.9	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C3-HFPO-DA	IS	68.4	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-4:2 FTS	IS	67.0	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-PFHxA	IS	64.7	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C4-PFHpA	IS	59.5	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C3-PFHxS	IS	68.4	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-6:2 FTS	IS	74.2	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C5-PFNA	IS	50.3	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C8-PFOSA	IS	33.1	10 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-PFOA	IS	60.6	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C8-PFOS	IS	66.7	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-PFDA	IS	45.2	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-8:2 FTS	IS	75.8	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
d3-MeFOSAA	IS	49.9	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-PFUnA	IS	47.9	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
d5-EtFOSAA	IS	52.5	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-10:2 FTS	IS	51.5	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-PFDoA	IS	47.6	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
d3-MeFOSA	IS	6.50	10 - 150	H	B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-PFTeDA	IS	63.1	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
d5-EtFOSA	IS	7.60	10 - 150	H	B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
13C2-PFHxDA	IS	59.8	25 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
d7-MeFOSE	IS	24.5	10 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1
d9-EtFOSE	IS	28.2	10 - 150		B0G0151	22-Jul-20	1.12 g	27-Jul-20 19:22	1

MDL - Method Detection Limit RL - Reporting limit

The results are reported in dry weight.
The sample size is reported in wet weight.
Results reported to MDL.

When reported, PFHxS, PFOA, PFOS, MeFOSAA and EtFOSAA include both linear and branched isomers. Only the linear isomer is reported for all other analytes.

DATA QUALIFIERS & ABBREVIATIONS

B	This compound was also detected in the method blank
Conc.	Concentration
CRS	Cleanup Recovery Standard
D	Dilution
DL	Detection Limit
E	The associated compound concentration exceeded the calibration range of the instrument
H	Recovery and/or RPD was outside laboratory acceptance limits
I	Chemical Interference
IS	Internal Standard
J	The amount detected is below the Reporting Limit/LOQ
LOD	Limit of Detection
LOQ	Limit of Quantitation
M	Estimated Maximum Possible Concentration (CA Region 2 projects only)
MDL	Method Detection Limit
NA	Not applicable
ND	Not Detected
OPR	Ongoing Precision and Recovery sample
P	The reported concentration may include contribution from chlorinated diphenyl ether(s).
Q	The ion transition ratio is outside of the acceptance criteria.
RL	Reporting Limit
TEQ	Toxic Equivalency
U	Not Detected (specific projects only)
*	See Cover Letter

Unless otherwise noted, solid sample results are reported in dry weight. Tissue samples are reported in wet weight.

Vista Analytical Laboratory Certifications

Accrediting Authority	Certificate Number
Alaska Department of Environmental Conservation	17-013
Arkansas Department of Environmental Quality	19-013-0
California Department of Health – ELAP	2892
DoD ELAP - A2LA Accredited - ISO/IEC 17025:2005	3091.01
Florida Department of Health	E87777-23
Hawaii Department of Health	N/A
Louisiana Department of Environmental Quality	01977
Maine Department of Health	2018017
Massachusetts Department of Environmental Protection	N/A
Michigan Department of Environmental Quality	9932
Minnesota Department of Health	1521520
New Hampshire Environmental Accreditation Program	207718-B
New Jersey Department of Environmental Protection	190001
New York Department of Health	11411
Oregon Laboratory Accreditation Program	4042-010
Pennsylvania Department of Environmental Protection	016
Texas Commission on Environmental Quality	T104704189-19-10
Vermont Department of Health	VT-4042
Virginia Department of General Services	10272
Washington Department of Ecology	C584-19
Wisconsin Department of Natural Resources	998036160

Current certificates and lists of licensed parameters are located in the Quality Assurance office and are available upon request.

NELAP Accredited Test Methods

MATRIX: Air	
Description of Test	**Method**
Determination of Polychlorinated p-Dioxins & Polychlorinated Dibenzofurans	EPA 23
Determination of Polychlorinated p-Dioxins & Polychlorinated Dibenzofurans	EPA TO-9A

MATRIX: Biological Tissue	
Description of Test	**Method**
Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613B
Brominated Diphenyl Ethers by HRGC/HRMS	EPA 1614A
Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by GC/HRMS	EPA 1668A/C
Pesticides in Water, Soil, Sediment, Biosolids, and Tissue by HRGC/HRMS	EPA 1699
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans by GC/HRMS	EPA 8280A/B
Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by GC/HRMS	EPA 8290/8290A

MATRIX: Drinking Water	
Description of Test	**Method**
2,3,7,8-Tetrachlorodibenzo- p-dioxin (2,3,7,8-TCDD) GC/HRMS	EPA 1613/1613B
1,4-Dioxane (1,4-Diethyleneoxide) analysis by GC/HRMS	EPA 522
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	ISO 25101 2009

MATRIX: Non-Potable Water	
Description of Test	**Method**
Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613B
Brominated Diphenyl Ethers by HRGC/HRMS	EPA 1614A
Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by GC/HRMS	EPA 1668A/C
Pesticides in Water, Soil, Sediment, Biosolids, and Tissue by HRGC/HRMS	EPA 1699
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Dioxin by GC/HRMS	EPA 613
Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans by GC/HRMS	EPA 8280A/B
Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by GC/HRMS	EPA 8290/8290A

MATRIX: Solids	
Description of Test	**Method**
Tetra-Octa Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613
Tetra- through Octa-Chlorinated Dioxins and Furans by Isotope Dilution GC/HRMS	EPA 1613B
Brominated Diphenyl Ethers by HRGC/HRMS	EPA 1614A
Chlorinated Biphenyl Congeners in Water, Soil, Sediment, and Tissue by GC/HRMS	EPA 1668A/C
Pesticides in Water, Soil, Sediment, Biosolids, and Tissue by HRGC/HRMS	EPA 1699
Perfluorinated Alkyl Acids in Drinking Water by SPE and LC/MS/MS	EPA 537
Polychlorinated Dibenzo-p-Dioxins and Polychlorinated Dibenzofurans by GC/HRMS	EPA 8280A/B
Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) by GC/HRMS	EPA 8290/8290A

Vista Analytical Laboratory

CHAIN OF CUSTODY

For Laboratory Use Only
Work Order #: 2001478 Temp: 3.4 °C
Storage ID: R-13, WR-2 Storage Secured: Yes ☑ No ☐

Project ID: MSN FFTA SAMPLES PO#: MSNPF1 Sampler: C. Gehrke (name)

TAT (check one): Standard: ☒ 21 days
Rush (surcharge may apply) ☐ 14 days ☐ 7 days Specify:

Relinquished by (printed name and signature)	Date	Time	Received by (printed name and signature)	Date	Time
[signature]	7/13/20	1300	William R Wright [signature]	07/14/20	09:11

SHIP TO: Vista Analytical Laboratory
1104 Windfield Way
El Dorado Hills, CA 95762
(916) 673-1520 * Fax (916) 673-0106

ATTN:

Method of Shipment:

Tracking No.:

Add Analysis(es) Requested

Sample ID	Date	Time	Location/ Sample Description	Container(s) Quantity	Type	Matrix	PFAS by Isotope Dilution: PFOA/PFOS	UCMR3 PFAS List:6	537.1 List: 14 or 18 (Circle One)	EPA Draft List of 24	OTHER: Please attach analyte list	EPA Method 537 (DW only): PFOA/PFOS	UCMR3 PFAS List:6	537.1 List of 14	537.1 List of 18	Comments
SBP20-01-GW	7/8/20	0940		2	P	AQ					*					
SBP20-04 (0.5-1)	7/8/20	0735		1	PJ	SO					*					* WISCONSIN PFAS
SBP20-06-GW	7/8/20	0750		2	P	AQ					*					LIST
SBP20-05 (0.5-1)	7/8/20	0810		1	PJ	SO					*					
SBP20-05 (6-6.5)	7/8/20	0820		1	PJ	SO					*					
SBP20-05-GW	7/8/20	0855		2	P	AQ					*					
SBP20-01 (0.5-1)	7/8/20	0900		1	PJ	SO					*					
SBP20-01 (5-5.5)	7/8/20	0905		1	PJ	SO					*					
Field Blank A	7/8/20	0955		2	P	AQ					*					
SBP20-04-GW	7/8/20	1005		2	P	AQ					*					

Special Instructions/Comments:

SEND DOCUMENTATION AND RESULTS TO:
Name: CHRIS CIECIEK
Company: LIMNOTECH
Address: 501 AVIS DRIVE
City: ANN ARBOR MI 48108
Phone: 734 332 1200
Email: cciecieк@limno.com

Container Types: P= HDPE, PJ= HDPE Jar, PY= Polypropylene, O = Other:

Bottle Preservation Type: TZ = Trizma:

Matrix Types: AQ = Aqueous, DW = Drinking Water, EF = Effluent, PP = Pulp/Paper, SD = Sediment, SL = Sludge, SO = Soil, WW = Wastewater, B = Blood/Serum, O = Other:

ID: LR-537COC Rev. No. 1 Rev. Date: 8/16/2019 Page: 1 of 1

SR0232

Vista Analytical Laboratory

Sample Log-In Checklist

Page # 1 of 1

Vista Work Order #: 2001478 **TAT** std

Samples Arrival:	**Date/Time** 07/14/20 09:11		**Initials:** WRW		**Location:** WR-2 **Shelf/Rack:** NA	
Delivered By:	FedEx	UPS	On Trac	GLS	DHL	Hand Delivered	Other
Preservation:	Ice		Blue Ice		Dry Ice		None
Temp °C: 3.4 (uncorrected)		**Probe used:** Y / N			**Thermometer ID:** IR-3	
Temp °C: 3.4 (corrected)						

					YES	NO	NA
Shipping Container(s) Intact?					✓		
Shipping Custody Seals Intact?					✓		
Airbill 4 of 4	Trk # 3947 7925 1825				✓		
Shipping Documentation Present?					✓		
Shipping Container	Vista	Client	Retain	Return		Dispose	
Chain of Custody / Sample Documentation Present?					✓		
Chain of Custody / Sample Documentation Complete?					✓		
Holding Time Acceptable?					✓		

Logged In:	**Date/Time** 07/15/20 0817	**Initials:** WWS	**Location:** R-13, WR-2 **Shelf/Rack:** 2-3, F-4

	YES	NO	NA
COC Anomaly/Sample Acceptance Form completed?		✓	✓

Comments:

CoC/Label Reconciliation Report WO# 2001478

LabNumber	CoC Sample ID		SampleAlias	Sample Date/Time		Container	BaseMatrix	Sample Comments
2001478-01	A SBP20-01-GW	✓		08-Jul-20 09:40	✓	HDPE Bottle, 125 mL	Aqueous	
2001478-01	B SBP20-01-GW	✓		08-Jul-20 09:40	✓	HDPE Bottle, 125 mL	Aqueous	
2001478-02	A SBP20-04 (0.5-1)	✓		08-Jul-20 07:35	✓	HDPE Jar, 6 oz	Solid	
2001478-03	A SBP20-06-GW	✓		08-Jul-20 07:50	✓	HDPE Bottle, 125 mL	Aqueous	
2001478-03	B SBP20-06-GW	✓		08-Jul-20 07:50	✓	HDPE Bottle, 125 mL	Aqueous	
2001478-04	A SBP20-05 (0.5-1)	✓		08-Jul-20 08:10	✓	HDPE Jar, 6 oz	Solid	
2001478-05	A SBP20-05 (6-6.5)	✓		08-Jul-20 08:20	✓	HDPE Jar, 6 oz	Solid	
2001478-06	A SBP20-05-GW	✓		08-Jul-20 08:55	✓	HDPE Bottle, 125 mL	Aqueous	
2001478-06	B SBP20-05-GW	✓		08-Jul-20 08:55	✓	HDPE Bottle, 125 mL	Aqueous	
2001478-07	A SBP20-01 (0.5-1)	☐ A		08-Jul-20 09:00	✓	HDPE Jar, 6 oz	Solid	
2001478-08	A SBP20-01 (5-5.5)	✓		08-Jul-20 09:05	✓	HDPE Jar, 6 oz	Solid	
2001478-09	A Field Blank A	✓		08-Jul-20 09:55	✓	HDPE Bottle, 125 mL	Aqueous	
2001478-09	B Field Blank A	✓		08-Jul-20 09:55	✓	HDPE Bottle, 125 mL	Aqueous	
2001478-10	A SBP20-04-GW	✓		08-Jul-20 10:05	✓	HDPE Bottle, 125 mL	Aqueous	
2001478-10	B SBP20-04-GW	✓		08-Jul-20 10:05	✓	HDPE Bottle, 125 mL	Aqueous	

Checkmarks indicate that information on the COC reconciled with the sample label.
Any discrepancies are noted in the following columns.

	Yes	No	NA
Sample Container Intact?	✓		
Sample Custody Seals Intact?			✓
Adequate Sample Volume?	✓		
Container Type Appropriate for Analysis(es)	✓		
Preservation Documented: Na2S2O3 Trizma None Other		✓	✓
If Chlorinated or Drinking Water Samples, Acceptable Preservation?			✓

Comments: A) COC label: SBP20-01 (0.5-1) Sample label: SBP20-01

All samples Except Field Blank contain particulate

Verifed by/Date: KD 07/15/20

Attachment 3

QA/QC Review

LimnoTech
Water Environment | Scientists Engineers

501 Avis Drive
Ann Arbor, MI 48108
734.332.1200
www.limno.com

Memorandum

From: Carrie Turner
To: Chris Cieciek
Date: August 24, 2020
Project: MSNPFTA (BRRTS #02-13-583366)
CC:

SUBJECT: **Review of PFAS Analytical Data from Vista Job Numbers 2001473, 2001475 and 2001478 (Sampling Dates 7/7-9/2020)**

Summary

An independent data review was conducted for twenty-four (24) soil samples, twelve (12) water samples, one (1) field duplicate soil sample, two (2) field duplicate water sample, and four (4) field, equipment, and geoprobe decon water blanks. Samples were collected in the field and received at the Vista El Dorado (CA) laboratory as shown in Table 1.

Table 1. Summary of Sample Collection and Delivery to the Laboratory.

Sample Collection Date	No. of Soil Samples	No. of Water Samples	No. of Field QC Samples[1]	Laboratory Receipt Date	Laboratory Job Number
7/7/2020	12	6	2	7/14/2020	2001473
7/7/2020	6	2	0	7/14/2020	2001475
7/8/2020	1	0	1	7/14/2020	2001475
7/8/2020	5	4	1	7/14/2020	2001478
7/9/2020	0	0	3	7/14/2020	2001475
Total	24	12	7		

[1] Field QC samples include field blanks, equipment blanks and field duplicate samples.

Sample analysis was conducted using Vista's PFAS Isotope Dilution analytical method. Key modifications from method 537 1.1 include its application to soil and non-drinking water aqueous sample media, quantification using isotope dilution, and a standard analyte list of thirty-six (36) PFAS compounds.

Samples were analyzed in three laboratory batches corresponding to the sampling dates noted in Table 1. The analytical data packages were provided to LimnoTech on August 3, 2020 for job numbers 2001475 and 2001478; and on August 4, 2020 for job number 2001473.

I have no quality concerns with the results for these samples except as noted below. The analyses were completed with few QA/QC problems. Several samples had low recoveries for several isotope internal standards. Most of the corresponding analytes quantitated with these isotopes were non-detect or at low levels (less than 5x RL) in the affected samples. Several samples also had one or more PFAS analytes with ion transition ratios outside the specified quality critieria. Most of these analytes were detected at low levels (less than 5x RL).

Analytical Quality Measures

All of the samples were extracted and analyzed within method specified hold times. Each laboratory preparation batch was prepared with a method blank and an ongoing precision and recovery (OPR) standard. The preparation batches are shown in Table 2 by job number. No matrix spikes or replicates were prepared for this set of samples.

Table 2. Summary of QA/QC Measures in Preparation Batches

Laboratory Job Number	Soil Preparation Batch	Media Type	No. of Samples	Date of Preparation	MB	OPR	MS	Rep
2001473	BOG0144	Soil	13	7/20/2020	Y	Y		
2001473	BOG0132	Aqueous	6	7/17/2020	Y	Y		
2001473	BOD0133	Aqueous	2*	7/25/2020	Y	Y		
2001475	BOD0151	Soil	7	7/22/2020	Y	Y		
2001475	BOG0132	Aqueous	6	7/17/2020	Y	Y		
2001478	BOD0151	Soil	5	7/22/2020	Y	Y		
2001478	BOG0132	Aqueous	5	7/17/2020	Y	Y		
2001478	BOG0133	Aqueous	1*	7/25/2020	Y	Y		
**Associated samples are re-extracted volume to confirm low isotope surrogate recovery.*								

QA/QC results can be summarized as follows:

- Laboratory QC:
    - All calibration and continuing calibration standards met applicable QA/QC requirements in all analytical batches.
    - Method and instrument blanks for each preparation batch did not have any target analytes with concentrations above the reporting limit, with the following exception:
        - One aqueous method blank for prep batch BOG0132 had one compound, PFHxDA, with a concentration of 1.37 ng/L, which was higher than the method detection limit (0.294 ng/L) but less than the reporting limit (4.0 ng/L). All associated samples were non-detect for this analyte.
    - All blank spikes met the recovery targets for each analyte.
- Field QC:
    - The Geoprobe Decon blank had PFOSA measured at 32.3 ng/L (RL = 4.43 ng/L). Soil samples tended to have levels of this compound at similar levels.

In addition, several PFAS compounds were measured above the method detection limit but below the reporting limit in the Geoprobe Decon blank: PFOA = 2.56 ng/L (RL =4.43 ng/L); PFOS = 1.093 (RL = 4.43 ng/L). Soil samples tended to have concentrations of these compounds at greater levels than those measured in this blank.
Field notes indicate that well water was used to rinse and prepare this blank, rather than certified PFAS-free water. Based on this information, the contamination appears to have originated within the source of the water used to prepare the blank rather than any sample carryover or field practices causing contamination.

- Other field and equipment blanks did not have any target analytes with concentrations above the method detection limit.
- Three field duplicates – one soil and two groundwater – were collected. The field duplicates matched well with the original samples (client IDs SBT20-05 (0.5-1) [soil], SBT20-06-GW, and SBP20-04-GW), with the same analytes detected in each pair of samples and field duplicates and at similar levels.
  The RPDs tended to be less than 20% for most PFAS analytes. However, the RPD for PFOS in the sample and field duplicate for SBP20-04-GW was -80%. PFOS was detected at a very high level (~20,000 ng/L) and required a 1:5 dilution to quantitate. The dilution may have added uncertainty that affected the RPD calculation.
  RPDs were not calculated for analytes with detected concentrations within five times the corresponding reporting limit, as per standard EPA data validation methods. The soil sample and field duplicate had one PFAS analyte concentration in this range and both groundwater samples and field duplicates had two PFAS analyte concentrations in this range.

Sample QA/QC

A summary of the quality of each sample is provided in Table 3. Recoveries of the surrogates (e.g. extracted internal standards) for individual samples were within the specified QA/QC windows, except as indicated. Table 3 also provides a list of the PFAS analytes that exhibited matrix interference based on isotope surrogate recovery.

Table 3. QA/QC Sample Results

Client Sample ID	Sample Date	Media	Lab Sample ID	Prep Batch	Dilutions	PFAS Analytes Requiring Dilution	PFAS Analytes with Ion Transition Ratios Outside Crtieria	Isotope Surrogates with % Recoveries Outside Limits
SBT20-01 (10.5-11)	7/7/20	Soil	2001473-01	BOG0144	1:1			d5-EtFOSA
SBT20-01-GW	7/7/20	GW	2001473-02	BOG0132	1:1; 1:5; 1:50	PFHxS (1:5) PFOS (1:50)	PFOSA; PFOS	
SBT20-05 (0.5-1)	7/7/20	Soil	2001473-03	BOG0144	1:1		PFHxS; PFOS	
SBT20-05 (10.5-11)	7/7/20	Soil	2001473-04	BOG0144	1:1		PFHxA	d5-EtFOSA
SBT20-04 (0.5-1)	7/7/20	Soil	2001473-05	BOG0144	1:1		PFOS	
SBT20-05-GW	7/7/20	GW	2001473-06	BOG0132	1:1; 1:5	PFHxS (1:5)		
SBT20-04 (6-6.5)	7/7/20	Soil	2001473-07	BOG0144	1:1		PFOA	d5-EtFOSA
SBT20-02-GW	7/7/20	GW	2001473-08	BOG0132	1:1; 1:5	PFOA (1:5)		
SBT20-04-GW	7/7/20	GW	2001473-09	BOG0132	1:1		PFHpS	13C2-PFHxDA
SOIL DUPLICATE A	7/7/20	Soil	2001473-10	BOG0144	1:1		PFOS	
SBT20-02 (0-1)	7/7/20	Soil	2001473-11	BOG0144	1:1		PFHpA	
EQUIPMENT BLANK A	7/7/20	Field QC	2001473-12	BOG0132	1:1			
SBT20-02 (10-10.5)	7/7/20	Soil	2001473-13	BOG0144	1:1			d3-MeFOSA; d5-EtFOSA
SBT20-03 (0-1)	7/7/20	Soil	2001473-14	BOG0144	1:1			
SBT20-03 (10-10.5)	7/7/20	Soil	2001473-15	BOG0144	1:1			d5-EtFOSA
SBT20-03-GW	7/7/20	GW	2001473-16	BOG0132	1:1; 1:10	PFHxS (1:10) PFOA (1:10)	PFOSA; PFOS	

Client Sample ID	Sample Date	Media	Lab Sample ID	Prep Batch	Dilutions	PFAS Analytes Requiring Dilution	PFAS Analytes with Ion Transition Ratios Outside Crtieria	Isotope Surrogates with % Recoveries Outside Limits
SBT20-06 (0-1)	7/7/20	Soil	2001473-17	BOG0144	1:1		PFUnA	13C2-PFHxDA
SBT20-06 (13-13.5)	7/7/20	Soil	2001473-18	BOG0144	1:1			
SBT20-06-GW	7/7/20	GW	2001473-19	BOG0132	1:1; 1:15; 1:35	PFBA (1:15) PFPeA (1:15) PFBS (1:15) PFHxA (1:35) PFPeS (1:15) PFHpA (1:35) PFHxS (1:35) 6:2FTS (1:15) PFOA (1:35)		
SBT20-01 (0.5-1)	7/7/20	Soil	2001473-20	BOG0144	1:1		PFHxA; PFNA	13C2-PFHxDA
SBP20-02 (1-1.5)	7/7/20	Soil	2001475-01	BOG0151	1:1			d3-MeFOSA
SBP20-02 (5.5-6)	7/7/20	Soil	2001475-02	BOG0151	1:1			13C2-PFHxDA
SBP20-03 (1-1.5)	7/7/20	Soil	2001475-03	BOG0151	1:1			
SBP20-03 (5-5.5)	7/7/20	Soil	2001475-04	BOG0151	1:1		PFHpA	
SBP20-06 (0.5-1)	7/7/20	Soil	2001475-05	BOG0151	1:1		PFHxA	
SBP20-06 (7.4-7.9)	7/7/20	Soil	2001475-06	BOG0151	1:1			13C2-PFTeDA; 13C2-PFHxDA
SBP20-02-GW	7/7/20	GW	2001475-07	BOG0132	1:1		PFDS	

Client Sample ID	Sample Date	Media	Lab Sample ID	Prep Batch	Dilutions	PFAS Analytes Requiring Dilution	PFAS Analytes with Ion Transition Ratios Outside Crtieria	Isotope Surrogates with % Recoveries Outside Limits
SBP20-03-GW	7/7/20	GW	2001475-08	BOG0132	1:1; 1:5	PFHxS (1:5) 6:2 FTS (1:5) PFOS (1:5)	PFDA	
SBP20-04 (7-7.5)	7/8/20	Soil	2001475-09	BOG0151	1:1		PFHpA	13C2-PFHxDA
Geoprobe Decon Blank	7/8/20	Field QC	2001475-10	BOG0132	1:1		PFOS	
Equipment Blank-070920	7/9/20	Field QC	2001475-11	BOG0132	1:1			
GW Duplicate A	7/9/20	GW	2001475-12	BOG0132	1:1; 1:15; 1:35	PFBA (1:15) PFPeA (1:15) PFBS (1:15) PFHxA (1:15) PFPeS (1:15) PFHpA (1:15) PFHxS (1:30) 6:2FTS (1:15) PFOA (1:15)		
GW Duplicate B	7/9/20	GW	2001475-13	BOG0132	1:1; 1:5; 1:10	PFHxS (1:5) 6:2 FTS (1:5) PFOS (1:10)	PFDA; PFOSA	
SBP20-01-GW	7/8/20	GW	2001478-01	BOG0132	1:1; 1:5	PFHxS (1:5) 6:2 FTS (1:5) PFOS (1:5)	PFOSA	
SBP20-04 (0.5-1)	7/8/20	Soil	2001478-02	BOG0151	1:1		PFDA; PFHxA	d3-MeFOSA; d5-EtFOSA

Client Sample ID	Sample Date	Media	Lab Sample ID	Prep Batch	Dilutions	PFAS Analytes Requiring Dilution	PFAS Analytes with Ion Transition Ratios Outside Crtieria	Isotope Surrogates with % Recoveries Outside Limits
SBP20-06-GW	7/8/20	GW	2001478-03	BOG0132	1:1; 1:5	PFOS (1:5)		
SBP20-05 (0.5-1)	7/8/20	Soil	2001478-04	BOG0151	1:1		4:2 FTS; PFHxA	
SBP20-05 (6-6.5)	7/8/20	Soil	2001478-05	BOG0151	1:1; 1:5	PFOS (1:5)		
SBP20-05-GW	7/8/20	GW	2001478-06	BOG0132	1:1; 1:5	PFOS (1:5)	PFOSA	
SBP20-01 (0.5-1)	7/8/20	Soil	2001478-07	BOG0151	1:1		PFHxA	d3-MeFOSA; d5-EtFOSA
SBP20-01 (5-5.5)	7/8/20	Soil	2001478-08	BOG0151	1:1			d3-MeFOSA; d5-EtFOSA
Field Blank A	7/8/20	Field QC	2001478-09	BOG0132 BOG0133	1:1			
SBP20-04-GW	7/8/20	GW	2001478-10	BOG0132	1:1; 1:5	PFHxS (1:5) 6:2 FTS (1:5) PFOS (1:5)	PFOSA	

Notes:

State of Wisconsin
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April 28, 2021

Sent Via E-Mail

Mr. Mike Kirchner
Director of Engineering
Dane County Regional Airport
4000 International Lane
Madison, WI 53704

Subject: Proposed Interim Action Plan for PFAS Contamination of Starkweather Creek at Dane County Regional Airport, BRRTs #02-13-584369 and 02-13-584472

Dear Mr. Kirchner:

On April 16, 2021 the Wisconsin Department of Natural Resources received your report outlining the proposed interim remedial actions to be taken by Dane County, the City of Madison, and the Wisconsin Air National Guard to address the movement of PFAS compounds from the Dane County Regional Airport via Starkweather Creek. The report was prepared by Mead & Hunt.

The report mentions contamination from three source areas within the airport boundaries. These are the former fire training areas at Darwin Road, the former fire training area at Pearson Street, and the PFAS present in the stormwater system servicing the airport. The Mead & Hunt report indicates that the upcoming Remedial Investigation to be completed by the Wisconsin Air National Guard and the National Guard Bureau will include both the former fire training areas on Darwin Road and Pearson Street. The primary focus of the April 16, 2021 report was to identify interim actions to reduce PFAS loading from the stormwater system to Starkweather Creek.

The proposed interim actions outlined in the April 16, 2021 document are **approved**, subject to the conditions presented later in this letter.

<u>Proposed Actions</u>

Two primary tasks are proposed to address the stormwater system.

- Task 1 – Locate the specific areas where PFAS contaminated groundwater is entering the stormwater pipes through leaky/broken pipes, loose joints, etc. Once identified, these areas will be remediated to stop the infiltration through techniques such as re-lining the pipe, replacing/repairing broken pipes, grouting leaking joints, and other remedial measures as needed. In addition, the County will continue operating their pilot test of the BAM treatment technology at Outfall 21.
- Task 2 – Complete additional sampling of Starkweather Creek to better define the distribution and concentrations of PFAS in the creek in locations within and just downstream of the airport boundary. A dye test will be completed on Starkweather Creek in the area immediately south of the airport to gain a better understanding of the mixing of two streams on airport property and how it affects measurements of PFAS in the creek. There will be sampling of the surface water in Starkweather Creek prior to, and after, the investigative and repair work on the stormwater

system has been completed to determine the efficacy of the repair work in reducing PFAS concentrations.

Conditions of Approval

The dye test to determine the proper monitoring location of Starkweather Creek south of the airport will involve placing rhodamine dye into the stream and then watching where it becomes fully mixed into the stream. Starkweather Creek is a public water body and therefore WPDES General Permit WI-0066575 for Low Impact Discharges will be needed prior to completing the test. To obtain the permit you should contact Trevor Moen at 920-410-5192 and Trevor.Moen@wisconsin.gov. Mr. Moen will be able to guide you through the steps for obtaining this general permit.

The Department appreciates the efforts by Dane County, the City of Madison, and the Wisconsin Air National Guard to implement these remedial measures to address the PFAS contamination leaving the airport property through Starkweather Creek. Should you have any questions regarding this approval please contact Steve Ales at 608-400-9187 or stephenm.ales@wisconsin.gov.

Sincerely,

Steven L. Martin, P.G.
Remediation & Redevelopment Team Supervisor
South Central Region

Cc: Steve Ales – Remediation & Redevelopment Program (sent via E-mail)
Trevor Moen – Wastewater Program (sent via E-mail)
Christie Baumel – City of Madison (sent via E-mail)
Lt. Col. Dan Statz – Wisconsin Air National Guard (sent via E-mail)

Mead & Hunt, Inc.

Memo

To: Dane County Regional Airport | Date: June 29, 2021

Project: MSN PFAS BRRTS #02-13-584472 | Project No.:2309936-200091.01

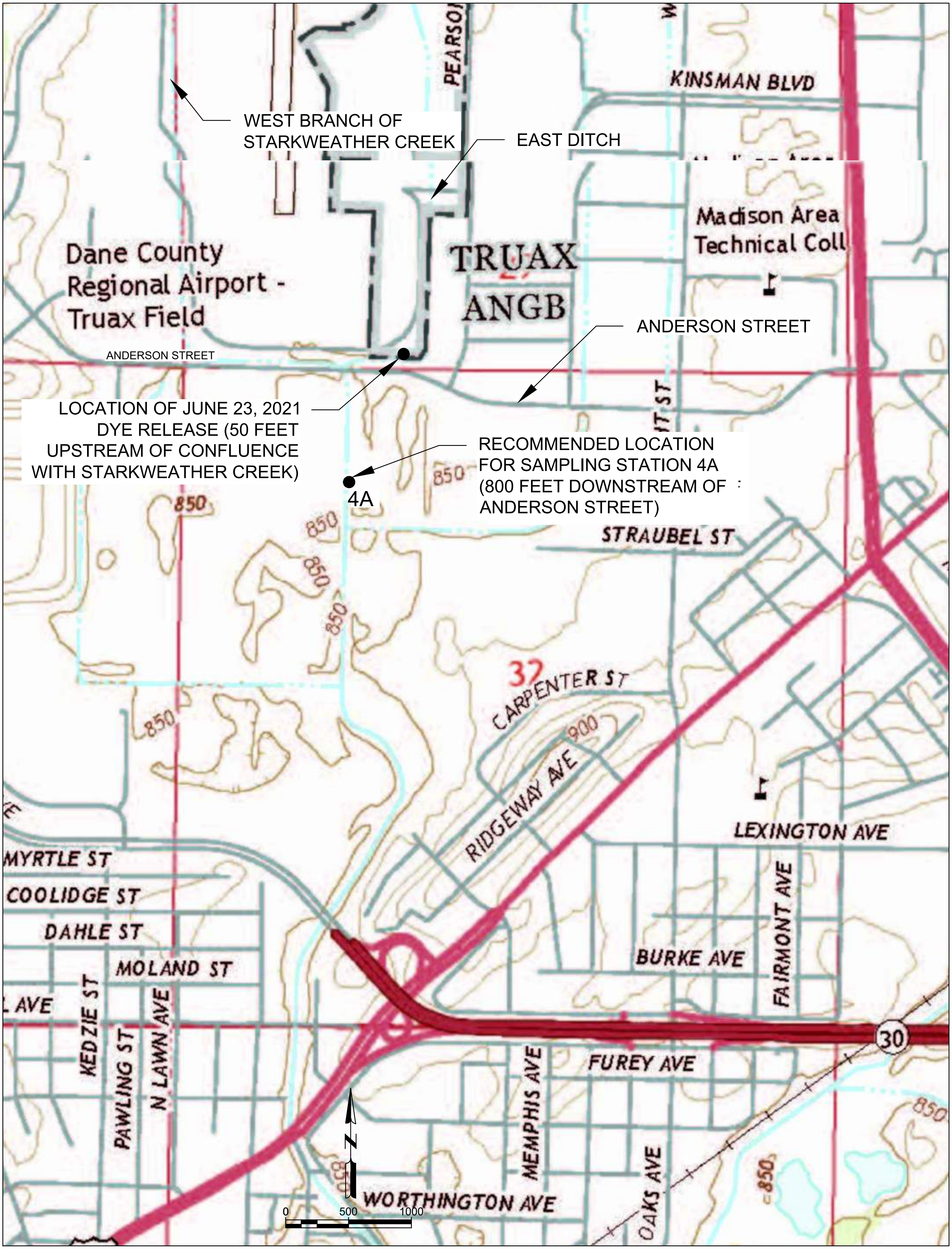
Subject: Dye Test on Tributary to West Branch of Starkweather Creek at Dane County Regional Airport (BRRTS Activity #02-13-584369 and #02-13-584472

This memo describes the dye test conducted on the tributary (East Ditch) to the West Branch of Starkweather Creek (Creek) located at the south east end of the Dane County Regional Airport (Airport). The location of the dye test is shown in **Figure 1**. The purpose of this dye test was to determine the appropriate location for collecting water quality samples downstream of Anderson Street that would provide a representative sample of the well mixed combination of flows from the East Ditch and the Creek.

The first dye test was conducted on June 21, 2021. The dye test was conducted in accordance with the requirements of the Airport's Low Impact Discharge General Permit WI-0066575-01-0. A half cup of Fluorescent Red 50 dye was released to the East Ditch approximately 1,500 feet upstream of the confluent of the East Ditch with the Creek at 6:30 PM. The movement of the dye in the East Ditch was observed for approximately 30 minutes. The dye was moving northerly in the East Ditch and away from the confluence of the East Ditch with the Creek. A second release of a half cup of the dye was conducted in the East Ditch approximately 100 feet upstream of the confluence of the East Ditch and the Creek at 7:08 PM (See **Photo 1**). The movement of the dye in the East Ditch was observed for approximately 35 minutes after the dye release. The dye was moving easterly in the East Ditch away for the confluence of the East Ditch with the Creek (See **Photo 2**). The flow in the Creek upstream of Anderson Street was approximately 65 cubic feet per second (cfs) as measured at the Airport's flow monitoring station where the Creek crosses International Lane.

A second dye test was conducted on June 23, 2021. A half cup of dye was released approximately 50 feet upstream of the confluence of the East Ditch and the Creek at 1:57 PM (See **Photo 3**). The dye was observed to flow southwesterly into the Creek (See **Photo 4**). The dye continued to flow south in the Creek and remained along the east bank of the Creek for several hundred feet (See **Photo 5**). At about 600 feet downstream of Anderson Street, the dye appeared to be evenly distributed across the width of the Creek. The flow in the Creek upstream of Anderson Street was approximately 2 cfs as measured at the Airports flow monitoring station where the Creek crosses International Lane.

Weather conditions before the dye test were generally lower than average precipitation for the previous 4 months. There was 0.1 inch of rainfall reported at the Airport between June 1-16. A total of 1.48 inches



6/25/2021 2:19:24 PM
X:\2309936\REF\MASTER WCCS\DRAINAGE AREAS\2020\PFAS_TELEVISE.DWG

Figure 1 - June 23, 2021 DYE TEST LOCATION

of rain fell on June 17-18 and another 0.48 inches of rain fell on June 19-20. No rainfall was recorded during the dye tests between June 21-23.

The streambed of the East Ditch and the Creek had a dense growth of aquatic plants during the dye tests. During the June 21 test the water in the Creek was deep enough that the attached aquatic plants did not extend to the surface of the Creek (See **Photo 6** which is looking south on the Creek at Anderson Street). During the June 23 test the water level in the Creek and East Ditch had fallen and the attached aquatic plants generally extended to the water surface across the width of the flow channels. The attached aquatic plants appeared to be limiting the mixing of the flow from the East Ditch.

Based on the dye test observations, we recommend that future samples collected to represent a completely mixed combination of the East Ditch and the Creek should be collected approximately 800 feet downstream of Anderson Street, shown as 4A in Figure 1. This is where we propose to collect samples as part of the work plan submitted to Wisconsin Department of Natural Resources dated April 16, 2021. We proposed to designate this sampling location as 4A to distinguish it from sampling location 4 which is much closer to Anderson Street. The proposed location of sampling point 4A is approximately 500 feet upstream of where an unnamed tributary enters the Creek from the east.

Photo 1. Dye Release in East Ditch On June 21, 2021

Photo 2. Dye Movement in East Ditch On June 21, 2021 (Looking East on North Side of Anderson Street)

Photo 3. Dye Release in East Ditch On June 23, 2021

Photo 4. Dye Movement On June 23, 2021 (Looking North from Anderson Street)

Photo 5. Dye Movement in Creek Along East Bank On June 23, 2021

Photo 6. Creek Flow and Vegetation On June 21, 2021

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January 21, 2021

Michael Kirchner
Director of Engineering
Dane County Regional Airport
4000 International Lane
Madison, WI 53704

Re: Interim Action Plan for Treating PFAS contaminated water in Starkweather Creek: BRRTs # 02-13-584369

Dear Mr. Kirchner:

The Department of Natural Resources (DNR) is directing the responsible parties for the BRRTs #02-13-584369 to implement an interim action under Wis. Admin. Code § NR 708.11 to prevent PFAS contamination in the surface water of Starkweather Creek from leaving the Dane County Airport property. A plan for the design and implementation of this interim action must be submitted to the DNR by April 16, 2021.

Background:

Firefighting training activities have caused per and poly fluoroalkyl substance (PFAS) contamination of soil and groundwater at the Dane County Airport. Data collected by Dane County in 2020 shows that PFAS contamination is present in water in the stormwater collection system. The airport stormwater system drains into surface water streams located along the south and west sides of the airport, and the south and east sides of the airport. These surface waters are Starkweather Creek.

Sampling of Starkweather Creek by DNR in 2019 from within the boundaries of the airport found elevated levels of PFAS in the creek. Additional sampling of Starkweather Creek by DNR between the airport boundaries and Lake Monona show that PFAS from the airport is reaching and causing measurable concentrations of PFAS in the creek and the lake. Concentrations of PFAS have caused a fish consumption advisory for certain fish in Lake Monona.

DNR recognizes that Dane County has implemented a pilot treatment system on behalf of the responsible parties at one of the stormwater outfalls in order to treat PFAS before it is discharged to Starkweather Creek and appreciates these efforts. DNR understands, however, that there are logistical problems with implementing the treatment media in the outfall structure and thus the treatment process has not proven to be successful in reducing PFAS concentrations from leaving the outfall and entering the surface water. If the County has data which indicates the pilot treatment system is working as intended, please submit that to DNR for review.

Action Required:

Wis. Stat. § 292.11(3) requires persons who possess or control a hazardous substance discharge, or who caused the discharge of a hazardous substance (the "responsible party or parties") to take actions necessary to restore the environment to the extent practicable and minimize the harmful effects of the discharge to air, lands and waters of the state.

Wis. Admin. Code § NR 708.11 requires responsible parties to take an interim action where necessary to contain a discharge of a hazardous substance in order to minimize any threat to public health, safety, welfare or the environment.

The DNR is requiring the responsible parties to develop a plan for designing and implementing an interim action for removing PFAS from the surface water of Starkweather Creek prior to the creek leaving the airport property (e.g., a treatment system). The interim action plan must be submitted to the DNR by April 16, 2021 and must include a date by which the interim action will be implemented.

Questions regarding the project can be directed to Steve Ales at stephenm.ales@wisconsin.gov and 608-400-9187.

Sincerely,

Christine Haag, Director
Remediation & Redevelopment Program

Cc: Steve Ales – RR Program, GEF 2
Steve Martin – SCR
Darsi Foss – Division Administrator, DNR
Madison & Dane County Public Health
Brita Kilburg-Basnyat – DHS

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WISCONSIN DEPT. OF NATURAL RESOURCES

January 21, 2021

Mayor Satya Rhodes-Conway
City of Madison
210 Martin Luther King Jr. Blvd. Room #403
Madison, WI 53703

Re: Interim Action Plan for Treating PFAS contaminated water in Starkweather Creek: BRRTs # 02-13-584369

Dear Mayor Rhodes-Conway:

The Department of Natural Resources (DNR) is directing the responsible parties for the BRRTs #02-13-584369, to implement an interim action under Wis. Admin. Code § NR 708.11 to prevent PFAS contamination in the surface water of Starkweather Creek from leaving the Dane County Airport property. A plan for the design and implementation of this interim action must be submitted to the DNR by April 16, 2021.

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The DNR is requiring the responsible parties to develop a plan for designing and implementing an interim action for removing PFAS from the surface water of Starkweather Creek prior to the creek leaving the airport property (e.g., a treatment system). The interim action plan must be submitted to the DNR by April 16, 2021 and must include a date by which the interim action will be implemented.

Questions regarding the project can be directed to Steve Ales at stephenm.ales@wisconsin.gov and 608-400-9187.

Sincerely,

Christine Haag, Director
Remediation & Redevelopment Program

Cc: Steve Ales – RR Program, GEF 2
Steve Martin – SCR
Darsi Foss – Division Administrator, DNR
Madison & Dane County Public Health
Brita Kilburg-Basnyat – DHS

Airport PFAS Information

PFAS Information Page

Welcome to the Per- and polyfluoroalkyl substances (PFAS) information page for the Dane County Regional Airport (DCRA). Here you will find information regarding PFAS and DCRA's ongoing efforts related to investigation, mitigation and remediation. This page is will help answer your questions regarding PFAS at DCRA and let you know of any upcoming public meetings. PFAS is a problem that airports and cities across the nation are working to resolve. DCRA and Dane County are committed to working with its partners on the local, state, regional and national levels to develop sound policies and apply the best science to the challenge of removing PFAS from the environment.

Below is a video presentation created by Dane County and DCRA consultant Mead & Hunt explaining PFAS history, testing and mitigation. The presentation highlights the Dane County Regional Airport, the historical use of PFAS, and the investigation and remediation process. All work plans and testing results are submitted to the Wisconsin Department of Natural Resources (WDNR). They can be found on their Bureau for Remediation and Redevelopment Tracking System (BRRTS) website: https://dnr.wi.gov/topic/Brownfields/botw.html (https://dnr.wi.gov/topic/Brownfields/botw.html).

BRRTS Case Numbers
02-13-584472 – DANE CNTY REGIONAL AIRPORT
02-13-581254 – WANG-115TH FIGHTER WING
02-13-583366 – DANE COUNTY FIRE TRAINING AREAS
02-13-584369 – STARK WEATHER CRK TRUAX FIELD
02-13-585319 – WANG F35 BUILDING CONSTRUCTIONS
07-13-586274 – DANE CNTY REGIONAL AIRPORT (FedEx Construction)

PFAS Site Activity Summary:
Dane County Regional Airport Site Activity Summary (PDF) (/documents/pdf/DCRA-site-activity-through-May-2021.pdf)
(as of May 2021)

Updates

6/29/21 - Mead & Hunt provides the DNR with Dye Test results conducted on Starkweather creek. Results can be found on the BRRTS website: https://dnr.wi.gov/topic/Brownfields/botw.html (https://dnr.wi.gov/topic/Brownfields/botw.html).

6/3/21 - The 115th Fighter Wing and Wisconsin National Guard provided an update and overview of their Remdial Investigation (RI) to the Dane County Board. You can watch that update here (http://dane.granicus.com/player/clip/1450?view_id=1&redirect=true).

- The Air National Guard Readiness Center selected Truax Field and Volk Field as two of the ten bases across the nation to receive a RI for PFAS. It is very fortunate that Truax was selected as the DOD has over 100 sites around the country with PFAS contamination and they tend to prioritize areas that have drinking water levels above the 70 ppt standard. Dozens of DOD sites in other states have drinking well levels above the 70 ppt standard and the DOD provides alternative water sources at those sites. No drinking wells in Madison were above that level and none of the wells are even above the lower level being proposed by the WI Department of Health Services. https://madison.com/wsj/news/local/environment/madison-water-utility-finds-pfas-in-every-well-levels-below-proposed-state-heath-guidelines/article_dd118ff7-06a0-5857-88f3-49141fc20cad.html (https://madison.com/wsj/news/local/environment/madison-water-utility-finds-pfas-in-every-well-levels-below-proposed-state-heath-guidelines/article_dd118ff7-06a0-5857-88f3-49141fc20cad.html)
- The RI is a multi-year effort coordinated by the U.S. Army Corps of Engineers that involves collecting data to characterize site conditions, determine the nature and extent of PFOS/PFOA, assess the exposure pathways to potential receptors, and assess risk to human health and the environment. During the RI, information necessary to adequately characterize the site for the purpose of developing and evaluating effective remedial alternatives will be collected. This information is critical for determining the most effective long-term cleanup remedies. You can see more information about the DOD timeline and process here: https://dma.wi.gov/DMA/pfas-actions/115FW_PFAS_FINAL.pdf (https://dma.wi.gov/DMA/pfas-actions/115FW_PFAS_FINAL.pdf)

5/28/21 - DNR begins 30-month rulemaking process for establishing limits regarding PFAS.

5/10/21 - Mead & Hunt began an inspection of areas of the storm sewers in which elevated PFAS concentrations were detected to determine repairs needed to reduce PFAS-contaminated groundwater entering the system. Based on inspection results, corrective actions such as slip lining and grouting will be taken later in the year. Thereafter, additional testing will occur to measure the effects in the Creek.

2/3/21 - Kick-off coordination meeting between the Wisconsin National Guard, Dane County Regional Airport, and the Wisconsin DNR for the Remidal Investiagion (RI) process.

12/15/20 - The second phase of storm water sampling results and the fire training area sampling results have been posted to the BRRTS website under the case numbers 02-13-584472 and 02-13-583366. Responsible parties are currently collaborating with the Wisconsin DNR and Mead & Hunt on next steps.

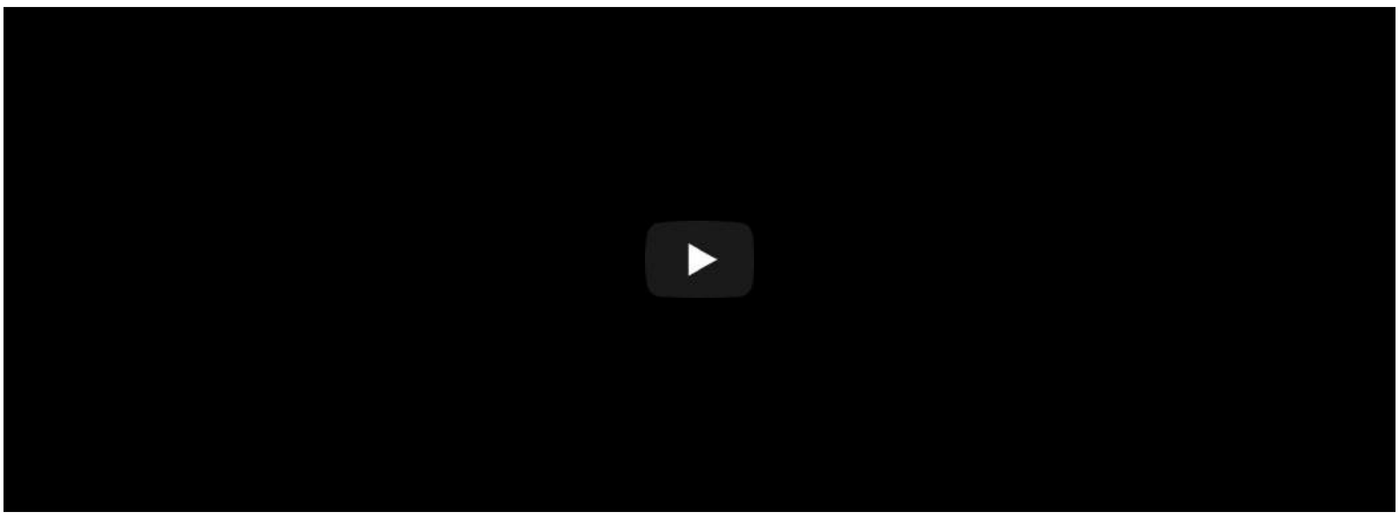
10/7/20 - Submitted questions from 8/19/20 - 9/2/20 and the responses have been posted to this web page. **You can find the PDF document below the FAQ section.**

10/6/20 - Questions submitted from 8/19/20 - 9/2/20 are still under review and responses will be posted as soon as they are complete.

9/3/20 - Thank you to all that submitted questions. The questions submission form is now closed. We anticipate having the questions and responses posted to the FAQ section the week of September 14th.

8/19/20 - Linked at the bottom of the web page is a public question submission form. Click "Submit a Question" and fill out the form. We will be accepting questions on PFAS at DCRA from 8/19/20 to 9/2/20. Please keep your questions specific and related to PFAS at DCRA so we can provide accurate responses. Review the information provided on this page to see if your question has already been answered. ***Submitted questions and the respective responses will be added to the FAQ section below.***

DCRA Video Presentation



DCRA Informational Document (PDF) (/documents/pdf/PFAS-Informational-Document.pdf)

Additional Resources

US Environmental Protection Agency (EPA) PFAS page - https://www.epa.gov/pfas (https://www.epa.gov/pfas)

Interstate Technology Regulatory Council (ITRC) - https://pfas-1.itrcweb.org/ (https://pfas-1.itrcweb.org/)

CDC PFAS Factsheet - https://www.cdc.gov/biomonitoring/PFAS_FactSheet.html (https://www.cdc.gov/biomonitoring /PFAS_FactSheet.html)

Agency for Toxic Substances and Disease Registry - https://www.atsdr.cdc.gov/pfas/index.html (https://www.atsdr.cdc.gov /pfas/index.html)

US Food & Drug Administration PFAS page - https://www.fda.gov/food/chemicals/and-polyfluoroalkyl-substances-pfas (https://www.fda.gov/food/chemicals/and-polyfluoroalkyl-substances-pfas)

Wisconsin Department of Natural Resources - https://dnr.wi.gov/topic/Contaminants/PFAS.html (https://dnr.wi.gov/topic/Contaminants/PFAS.html)

Wisconsin Water and Fish PFAS Sampling - https://dnr.wisconsin.gov/topic/PFAS/SWFish.html (https://dnr.wisconsin.gov/topic/PFAS/SWFish.html)

Wisconsin Department of Health Services - https://www.dhs.wisconsin.gov/chemical/pfas.htm (https://www.dhs.wisconsin.gov/chemical/pfas.htm)

Public Health Madison & Dane County - https://www.publichealthmdc.com/environmental-health/environmental-hazards/per-and-polyfluoroalkyl-substances-pfas-1 (https://www.publichealthmdc.com/environmental-health/environmental-hazards/per-and-polyfluoroalkyl-substances-pfas-1)

City of Madison - Madison Water Utility - MadisonWater.org/PFAS (http://MadisonWater.org/PFAS)

Wisconsin National Guard PFAS Information Page - https://dma.wi.gov/DMA/pfas (https://dma.wi.gov/DMA/pfas)

FAQs

Q: Why does the DCRA still use firefighting foam with PFAS? When will DCRA stop using it?
A: The Federal Aviation Administration (FAA) regulations continue to legally mandate that airports use a firefighting agent containing PFAS known as Aqueous-Film-Forming Foam (AFFF) for real-life emergencies. FAA believes AFFF is the most effective chemical available to quickly extinguish aircraft fires and save lives. Due to AFFF's environmental impact, Congress directed the FAA to change its regulations and allow airports to use alternative foam by October 2021.

Q: Do training exercises with the firefighting foams containing PFAS still happen at the airport?
A: No. FAA requires yearly testing of the Aircraft Rescue & Firefighting (ARFF) vehicle fire systems. This test is to ensure that the fire system is producing the correct mixture of foam and water. Testing the system is an integral part of keeping ARFF vehicles in optimal condition for emergency response. In 2019, the FAA created an exemption to this rule, allowing ARFF agencies to use testing equipment that does not require dispensing the foam. The Wisconsin Air National Guard (WI ANG) provides ARFF services to DCRA, and currently uses this equipment. Before this exception, AFFF was contained and disposed of safely when these tests occurred. There were also two historical burn pits at the airport that have not been used for multiple years. The period and use of these burn pits are currently being investigated.

Q: Who used the fire training areas over the years?
A: This question is currently being investigated. It is generally known that various firefighting organizations in the Dane County area used the burn pits for training.

Q: Are the fire training areas a source of PFAS contamination?
A: We don't know at this time. Investigation of the soils and groundwater in the area of the former burn pits is currently underway. Also, developing an understanding of the historical use of the burn pits, including the extent to which PFAS-based foam was sprayed in the fire pits, will assist in answering this question.

Q: Was the DCRA cell phone lot constructed over the Darwin Street fire training area?
A: The evidence to date indicates the answer is no. The County of Dane (County) and its partners are currently investigating the Darwin Street fire training area, which is located near the cell phone lot.

Q: Has the County completed all of the testing and sampling?
A: No. Further sampling and other investigation processes are planned and ongoing to refine our understanding of the PFAS sources to continue developing mitigation cleanup strategies. These plans include investigation of the historical fire training areas and further investigation of the stormwater system.

Q: Does all of the testing need to be completed before any mitigation happens?
A: No. The County is taking immediate action at one of the "hotspots" found in the sampling earlier this year with a pilot project to remove PFAS from the stormwater system. The pilot includes continuous testing to evaluate whether the technology being used is successful. If the results are promising, DCRA will expand the use of this new technology to other areas of the airport property where PFAS has been detected.

Q: Is the state working to create legal standards for PFOA and PFOS for groundwater, surface water, and drinking water? Where can I get information on that?

A: Yes. In October 2019, the Wisconsin Department of Natural Resources (WDNR) started the rulemaking process to develop legal standards for Wisconsin. The rulemaking process can take up to three years. You can get more information on how that process is going at the following WDNR websites:

- Surface water rule: https://dnr.wisconsin.gov/topic/SurfaceWater/NR105.html (https://dnr.wisconsin.gov/topic/SurfaceWater/NR105.html)
- Groundwater rule: https://dnr.wisconsin.gov/topic/Groundwater/NR140.html (https://dnr.wisconsin.gov/topic/Groundwater/NR140.html)
- Drinking water rule: https://dnr.wisconsin.gov/topic/DrinkingWater/nr809.html (https://dnr.wisconsin.gov/topic/DrinkingWater/nr809.html)

Q: Where can I find the current mitigation plans and sampling results from testing done so far at the Dane County Regional Airport?

A: You can find the stormwater investigation work plan and stormwater sampling results by going to the WDNR Bureau for Remediation and Redevelopment Tracking System (BRRTS) site and searching for investigation number 02-13-584472. The fire training areas' work plan can be found by searching for investigation number 02-13-583366. To start the search, go the following WDNR website: dnr.wi.gov/topic /Brownfields/botw.html. (http://dnr.wi.gov/topic/Brownfields/botw.html.)

Q: Where is the PFAS detected in the DCRA stormwater system originating?

A: We don't know precisely at this time. Waters in the stormwater system have been sampled at various locations, and various concentrations have been detected. It will take additional sampling and likely further investigation to determine the origin of PFAS.

Q: PFAS contamination is discharging from the DCRA stormwater system into Starkweather Creek. What is being done to stop that discharge?

A: DCRA has implimented a pilot project to capture and remove PFAS contamination at the location where the highest PFAS concentrations have been detected. The pilot project is implementing a technology called bioavailable absorbent media ("BAM"). Based on previous pilot tests using the technology in Michigan, the hope is that the BAM will significantly reduce the PFAS concentrations.

Q: Is the WI ANG working with the County to clean up the Airport site?

A: Yes. The County is working in cooperation with the WI ANG and City of Madison. The County is leading several concurrent activities to address the PFAS contamination discovered at and near the Airport and meeting regularly with the WDNR to develop plans to address PFAS at the Airport.

Q: The Airport Joint Use Agreement (AJUA) is up for renewal. Can members of the public get a copy of the initial draft when it is prepared by the State and Federal Government and submitted to DCRA?

A: No. It is in draft form and subject to further negotiations. Nonetheless, the public will get an opportunity to provide input about the AJUA. When received by DCRA, the draft AJUA will be a preliminary working document that will likely be subject to significant revisions by DCRA and the State and Federal Government. After DCRA and the State and Federal Government reach concurrence with respect to the contents of the AJUA, and well before it becomes a basis for the relationship between DCRA and the State and Federal Government, the document will be made available to the public and taken up during the public deliberations of the Dane County Airport Commission, two standing committees of the Dane County Board of Supervisors, and the County Board itself. Based on the foregoing, DCRA has determined that it will maintain its past practice of not releasing versions of the AJUA until discussions between DCRA and the State and Federal Government have resulted in a comprehensive document that is ready for consideration by the Dane County Board, its committees, and the Airport Commission.

Q: Can the county use the Airport Joint Use Agreement (AJUA) to force the WI ANG to clean up PFAS before they build any new structures at the airport?

A: No. The DNR is the agency working with the WI ANG on how to proceed with building projects on the Guard Base and regulating management of soils and other media containing PFAS through material management plans (MMPs). The DNR recently approved MMPs for the F-35 flight simulator facility and other construction. Last month the WI ANG announced they awarded the contract for the flight simulator facility to Findorff. The 18-month project will begin this May and you can find that detailed here (https://madison.com/wsj/news/local/govt-and-politics/findorff-gets-first-f-35-contract-to-construct-flight-simulator-facility-at-truax/article—8a452d57-2353-500f-8aa4-e09133323e90.html#tracking-source=home-top-story-1).

Q: Can the county stop the WI ANG from doing any construction at the airport through the lease or AJUA?

A: No. The Guard has the right to use the airport under federal law and under the deed of conveyance by which Dane County obtained the property. The lease grants the Government the right to attach fixtures and erect structures during the lease term. Neither the lease nor the AJUA grants the County rights to oversee or regulate the Government's construction activities.

Q: What is the AJUA for then?
A: The AJUA is an agreement with the United States of America acting through the National Guard Bureau and the state of Wisconsin that details responsibilities for jointly used flying facilities and includes the WI ANG's commitment to provide FAA-required firefighting services as part of their partnership with the airport.

Q: If the county doesn't renew AJUA with the Guard does that mean they can't use the airport for their fighter jets or bring the F-35s to Truax?
A: No. The Guard will continue to use their base without having the AJUA in place. If the Guard elected to stop providing FAA-required firefighting services to the airport, the airport would have to arrange for those services at substantial additional expense.

Q: Why doesn't Dane County just stop having the WI ANG do fire services and have the county provide the service or contract with the Madison Fire Department to do it?
A: In order to comply with FAA regulations the county would have to build another fire station and acquire all of the equipment necessary to have 24/7 fire services available, which would costs tens of millions of dollars initially and then millions more in payroll to have the fire station staffed 24/7 with the minimum staffing levels required by the FAA. The trucks would also have to be filled with firefighting foam with PFAS because it is still required by the FAA. The WI ANG would still maintain their fire station, which would result in the DCRA having two sets of fire trucks with PFAS foam on site. The Madison Fire Department cannot provide the service fast enough to meet FAA regulations and the city recently made the decision to get rid of their PFAS foam so they would no longer have any trucks that could even service the airport.

Q: Why does this process take so long?
A: PFAS are an emerging contaminant and there is still much being learned about the best cleanup strategies. Environmental cleanups of this scale take time, but the Biden Administration and Congress have indicated they would like to see this move faster. This is a shift from the last administration and should bring additional resources both to research and mitigation. Action has started at the federal level that could help speed resources to address PFAS. The House Armed Services Committee has created an entire subcommittee on remediation and impact of PFAS at DOD sites, a bipartisan caucus in the House of Representatives has recreated a PFAS taskforce, and President Biden has pledged to designate them a hazardous substance with standards and accelerated research timelines.

Q: Where can I find more information about what the WI ANG is doing on this issue?
A: They maintain an informational webpage here: https://dma.wi.gov/DMA/pfas and a timeline of their activities here: https://dma.wi.gov /DMA/pfas-actions/115FW_PFAS_FINAL.pdf (https://dma.wi.gov/DMA/pfas-actions/115FW_PFAS_FINAL.pdf)

Q: Was the Airport's cell phone lot was constructed over a historic burn pit?
A: No. The historic burn pit in the vicinity of Darwin Road is entirely separate from the cell phone lot, which is accessed from International Lane.

Submitted PFAS Questions 8/19/20 - 9/2/20 (PDF) (/documents/pdf/Submitted-PFAS-Questions-8.19.20---9.2.20.pdf)

Noise FAQ (/about/ecomentality/noise_faq)

Noise Report Form (/about/ecomentality/noise_report_form)

Facilities & Maps (/about/facilities_maps)

Airport Operations (/about/operations)

Contact Us (/about/contact)

About Us

Need information on Dane County Regional Airport? Click here to learn more about the people who keep things running along with our commitment to environmental sustainability and responsibility. Or need the latest news on airport routes, carriers and special events, you'll find it here.

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Parking & Transportation (/parking_transportation)
Dining, Shopping & Services (/dining_shopping)
About MSN Airport (/about)
Contact Us (/about/contact/contact_us)

Basic Information on PFAS

PFAS News

Read the latest news from EPA about PFAS.

Per- and polyfluoroalkyl substances (PFAS) are a group of man-made chemicals that includes PFOA, PFOS, GenX, and many other chemicals. PFAS have been manufactured and used in a variety of industries around the globe, including in the United States since the 1940s. PFOA and PFOS have been the most extensively produced and studied of these chemicals. Both chemicals are very persistent in the environment and in the human body – meaning they don't break down and they can accumulate over time. There is evidence that exposure to PFAS can lead to adverse human health effects.

PFAS can be found in:

- **Food** packaged in PFAS-containing materials, processed with equipment that used PFAS, or grown in PFAS-contaminated soil or water.
- **Commercial household products**, including stain- and water-repellent fabrics, nonstick products (e.g., Teflon), polishes, waxes, paints, cleaning products, and fire-fighting foams (a major source of groundwater contamination at airports and military bases where firefighting training occurs).
- **Workplace**, including production facilities or industries (e.g., chrome plating, electronics manufacturing or oil recovery) that use PFAS.
- **Drinking water**, typically localized and associated with a specific facility (e.g., manufacturer, landfill, wastewater treatment plant, firefighter training facility).
- **Living organisms**, including fish, animals and humans, where PFAS have the ability to build up and persist over time.

Certain PFAS chemicals are no longer manufactured in the United States as a result of phase outs including the PFOA Stewardship Program in which eight major chemical manufacturers agreed to eliminate the use of PFOA and PFOA-related chemicals in their products and as emissions from their facilities. Although PFOA and PFOS are no longer manufactured in the United States, they are still produced internationally and can be imported into the United States in consumer goods such as carpet, leather and apparel, textiles, paper and packaging, coatings, rubber and plastics.

On this page:

Why are PFAS important?

PFAS are found in a wide range of consumer products that people use daily such as cookware, pizza boxes and stain repellants. Most people have been exposed to PFAS. Certain PFAS can accumulate and stay in the human body for long periods of time. There is evidence that exposure to PFAS can lead to adverse health outcomes in humans. The most-studied PFAS chemicals are PFOA and PFOS. Studies indicate that PFOA and PFOS can cause reproductive and developmental, liver and kidney, and immunological effects in laboratory animals. Both chemicals have caused tumors in animals. The most consistent findings are increased cholesterol levels among exposed populations, with more limited findings related to:

- low infant birth weights,
- effects on the immune system,
- cancer (for PFOA), and
- thyroid hormone disruption (for PFOS).

What is the difference between PFOA, PFOS and GenX and other replacement PFAS?

Per- and polyfluoroalkyl substances (PFAS) are a group of man-made chemicals that have been in use since the 1940s, and are (or have been) found in many consumer products like cookware, food packaging, and stain repellants. PFAS manufacturing and processing facilities, airports, and military installations that use firefighting foams are some of the main sources of PFAS. PFAS may be released into the air, soil, and water, including sources of drinking water. PFOA and PFOS are the most studied PFAS chemicals and have been voluntarily phased out by industry, though they are still persistent in the environment. There are many other PFAS, including GenX chemicals and PFBS in use throughout our economy.

GenX is a trade name for a technology that is used to make high performance fluoropolymers (e.g., some nonstick coatings) without the use of perfluorooctanoic acid (PFOA). HFPO dimer acid and its ammonium salt are the major chemicals associated with the GenX technology. GenX chemicals have been found in surface water, groundwater, finished drinking water, rainwater, and air emissions in some areas. As part of EPA's draft toxicity assessment, EPA has developed draft oral reference doses (RfDs) for GenX chemicals.

Perfluorobutane sulfonic acid (PFBS) has been used as a replacement chemical for PFOS. PFBS has been identified in environmental media and consumer products, including surface water, wastewater, drinking water, dust, carpeting and carpet cleaners, and floor wax. EPA has developed RfDs for PFBS as part of EPA's efforts to increase the amount of research and information that is publicly available on chemicals in the PFAS family.

- Learn about the Human Health Toxicity Assessment for PFBS
- Learn about the GenX Chemicals Toxicity Assessment

How are people exposed to PFAS?

There are a variety of ways that people can be exposed to these chemicals and at different levels of exposure. For example, people can be exposed to low levels of PFAS through *food*, which can become contaminated through:

- Contaminated soil and water used to grow the food,
- Food packaging containing PFAS, and
- Equipment that used PFAS during food processing.

People can also be exposed to PFAS chemicals if they are released during normal *use, biodegradation, or disposal of consumer products* that contain PFAS. People may be exposed to PFAS used in commercially-treated products to make them stain- and water-repellent or nonstick. These goods include carpets, leather and apparel, textiles, paper and packaging materials, and non-stick cookware.

People who *work* at PFAS production facilities, or facilities that manufacture goods made with PFAS, may be exposed in certain occupational settings or through contaminated air.

Drinking water can be a source of exposure in communities where these chemicals have contaminated water supplies. Such contamination is typically localized and associated with a specific facility, for example,

- an industrial facility where PFAS were produced or used to manufacture other products, or
- an oil refinery, airfield or other location at which PFAS were used for firefighting.

PFOA, PFOS, and GenX have been found in a number of drinking water systems due to localized contamination. You can view more information about exposures to PFAS through drinking water on Drinking Water Health Advisories for PFOA and PFOS.

Are there health effects from PFAS?

There is evidence that exposure to PFAS can lead to adverse health outcomes in humans. If humans, or animals, ingest PFAS (by eating or drinking food or water than contain PFAS), the PFAS are absorbed, and can accumulate in the body.

PFAS stay in the human body for long periods of time. As a result, as people are exposed to PFAS from different sources over time, the level of PFAS in their bodies may increase to the point where they suffer from adverse health effects.

Studies indicate that PFOA and PFOS can cause reproductive and developmental, liver and kidney, and immunological effects in laboratory animals. Both chemicals have caused tumors in animal studies. The most consistent findings from human epidemiology studies are increased cholesterol levels among exposed populations, with more limited findings related to: infant birth weights, effects on the immune system, cancer (for PFOA), and thyroid hormone disruption (for PFOS).

Oral exposure studies of PFBS in animals have shown effects on thyroid hormone disruption, reproductive organs and tissues, developing fetus, and kidney. Based on dose-response information across different sexes, lifestages, and durations of exposure, the thyroid appears to be particularly sensitive to oral PFBS exposure. The data are inadequate to evaluate cancer effects associated with PFBS exposure.

- Learn more about the Human Health Toxicity Assessment for PFBS

LAST UPDATED ON APRIL 6, 2021

United States Environmental Protection Agency

FACT SHEET PFOA & PFOS Drinking Water Health Advisories

Overview

EPA has established health advisories for PFOA and PFOS based on the agency's assessment of the latest peer-reviewed science to provide drinking water system operators, and state, tribal and local officials who have the primary responsibility for overseeing these systems, with information on the health risks of these chemicals, so they can take the appropriate actions to protect their residents. EPA is committed to supporting states and public water systems as they determine the appropriate steps to reduce exposure to PFOA and PFOS in drinking water. As science on health effects of these chemicals evolves, EPA will continue to evaluate new evidence.

Background on PFOA and PFOS

PFOA and PFOS are fluorinated organic chemicals that are part of a larger group of chemicals referred to as perfluoroalkyl substances (PFASs). PFOA and PFOS have been the most extensively produced and studied of these chemicals. They have been used to make carpets, clothing, fabrics for furniture, paper packaging for food and other materials (e.g., cookware) that are resistant to water, grease or stains. They are also used for firefighting at airfields and in a number of industrial processes.

Because these chemicals have been used in an array of consumer products, most people have been exposed to them. Between 2000 and 2002, PFOS was voluntarily phased out of production in the U.S. by its primary manufacturer. In 2006, eight major companies voluntarily agreed to phase out their global production of PFOA and PFOA-related chemicals, although there are a limited number of ongoing uses. Scientists have found PFOA and PFOS in the blood of nearly all the people they tested, but these studies show that the levels of PFOA and PFOS in blood have been decreasing. While consumer products and food are a large source of exposure to these chemicals for most people, drinking water can be an additional source in the small percentage of communities where these chemicals have contaminated water supplies. Such contamination is typically localized and associated with a specific facility, for example, an industrial facility where these chemicals were produced or used to manufacture other products or an airfield at which they were used for firefighting.

EPA's 2016 Lifetime Health Advisories

EPA develops health advisories to provide information on contaminants that can cause human health effects and are known or anticipated to occur in drinking water. EPA's health advisories are non-enforceable and non-regulatory and provide technical information to states agencies and other public health officials on health effects, analytical methodologies, and treatment technologies associated with drinking water contamination. In 2009, EPA published provisional health advisories for PFOA and PFOS based on the evidence available at that time. The science has evolved since then and EPA is now replacing the 2009 provisional advisories with new, lifetime health advisories.

FACT SHEET

PFOA & PFOS Drinking Water Health Advisories

EPA's 2016 Lifetime Health Advisories, continued

To provide Americans, including the most sensitive populations, with a margin of protection from a lifetime of exposure to PFOA and PFOS from drinking water, EPA established the health advisory levels at 70 parts per trillion. When both PFOA and PFOS are found in drinking water, the combined concentrations of PFOA and PFOS should be compared with the 70 parts per trillion health advisory level. This health advisory level offers a margin of protection for all Americans throughout their life from adverse health effects resulting from exposure to PFOA and PFOS in drinking water.

How the Health Advisories were developed

EPA's health advisories are based on the best available peer-reviewed studies of the effects of PFOA and PFOS on laboratory animals (rats and mice) and were also informed by epidemiological studies of human populations that have been exposed to PFASs. These studies indicate that exposure to PFOA and PFOS over certain levels may result in adverse health effects, including developmental effects to fetuses during pregnancy or to breastfed infants (e.g., low birth weight, accelerated puberty, skeletal variations), cancer (e.g., testicular, kidney), liver effects (e.g., tissue damage), immune effects (e.g., antibody production and immunity), thyroid effects and other effects (e.g., cholesterol changes).

EPA's health advisory levels were calculated to offer a margin of protection against adverse health effects to the most sensitive populations: fetuses during pregnancy and breastfed infants. The health advisory levels are calculated based on the drinking water intake of lactating women, who drink more water than other people and can pass these chemicals along to nursing infants through breastmilk.

Recommended Actions for Drinking Water Systems

Steps to Assess Contamination

If water sampling results confirm that drinking water contains PFOA and PFOS at individual or combined concentrations greater than 70 parts per trillion, water systems should quickly undertake additional sampling to assess the level, scope and localized source of contamination to inform next steps

Steps to Inform

If water sampling results confirm that drinking water contains PFOA and PFOS at individual or combined concentrations greater than 70 parts per trillion, water systems should promptly notify their State drinking water safety agency (or with EPA in jurisdictions for which EPA is the primary drinking water safety agency) and consult with the relevant agency on the best approach to conduct additional sampling.

Drinking water systems and public health officials should also promptly provide consumers with information about the levels of PFOA and PFOS in their drinking water. This notice should include specific information on the risks to fetuses during pregnancy and breastfed and formula-fed infants from exposure to drinking water with an individual or combined concentration of PFOA and PFOS above EPA's health advisory level of 70 parts per trillion. In addition, the notification should include actions they are taking and identify options that consumers may consider to reduce risk such as seeking an alternative drinking water source, or in the case of parents of formula-fed infants, using formula that does not require adding water.

FACT SHEET

PFOA & PFOS Drinking Water Health Advisories

Recommended Actions for Drinking Water Systems, continued

Steps to Limit Exposure

A number of options are available to drinking water systems to lower concentrations of PFOA and PFOS in their drinking water supply. In some cases, drinking water systems can reduce concentrations of perfluoroalkyl substances, including PFOA and PFOS, by closing contaminated wells or changing rates of blending of water sources. Alternatively, public water systems can treat source water with activated carbon or high pressure membrane systems (e.g., reverse osmosis) to remove PFOA and PFOS from drinking water. These treatment systems are used by some public water systems today, but should be carefully designed and maintained to ensure that they are effective for treating PFOA and PFOS. In some communities, entities have provided bottled water to consumers while steps to reduce or remove PFOA or PFOS from drinking water or to establish a new water supply are completed.

Many home drinking water treatment units are certified by independent accredited third party organizations against American National Standards Institute (ANSI) standards to verify their contaminant removal claims. NSF International (NSF®) has developed a protocol for NSF/ANSI Standards 53 and 58 that establishes minimum requirements for materials, design and construction, and performance of point-of-use (POU) activated carbon drinking water treatment systems and reverse osmosis systems that are designed to reduce PFOA and PFOS in public water supplies. The protocol has been established to certify systems (e.g., home treatment systems) that meet the minimum requirements. The systems are evaluated for contaminant reduction by challenging them with an influent of 1.5±30% µg/L (total of both PFOA and PFOS) and must reduce this concentration by more than 95% to 0.07 µg/L or less (total of both PFOA and PFOS) throughout the manufacturer's stated life of the treatment system. Product certification to this protocol for testing home treatment systems verifies that devices effectively reduces PFOA and PFOS to acceptable levels.

Other Actions Relating to PFOA and PFOS

Between 2000 and 2002, PFOS was voluntarily phased out of production in the U.S. by its primary manufacturer, 3M. EPA also issued regulations to limit future manufacturing, including importation, of PFOS and its precursors, without first having EPA review the new use. A limited set of existing uses for PFOS (fire resistant aviation hydraulic fluids, photography and film products, photomicrolithography process to produce semiconductors, metal finishing and plating baths, component of an etchant) was excluded from these regulations because these uses were ongoing and alternatives were not available.

In 2006, EPA asked eight major companies to commit to working toward the elimination of their production and use of PFOA, and chemicals that degrade to PFOA, from emissions and products by the end of 2015. All eight companies have indicated that they have phased out PFOA, and chemicals that degrade to PFOA, from emissions and products by the end of 2015. Additionally, PFOA is included in EPA's proposed Toxic Substance Control Act's Significant New Use Rule (SNUR) issued in January 2015 which will ensure that EPA has an opportunity to review any efforts to reintroduce the chemical into the marketplace and take action, as necessary, to address potential concerns.

FACT SHEET

PFOA & PFOS Drinking Water Health Advisories

Other Actions Relating to PFOA and PFOS, continued

EPA has not established national primary drinking water regulations for PFOA and PFOS. EPA is evaluating PFOA and PFOS as drinking water contaminants in accordance with the process required by the Safe Drinking Water Act (SDWA). To regulate a contaminant under SDWA, EPA must find that it: (1) may have adverse health effects; (2) occurs frequently (or there is a substantial likelihood that it occurs frequently) at levels of public health concern; and (3) there is a meaningful opportunity for health risk reduction for people served by public water systems.

EPA included PFOA and PFOS among the list of contaminants that water systems are required to monitor under the third Unregulated Contaminant Monitoring Rule (UCMR 3) in 2012. Results of this monitoring effort are updated regularly and can be found on the publicly-available National Contaminant Occurrence Database (NCOD) (https://www.epa.gov/dwucmr/occurrence-data-unregulated-contaminant-monitoring-rule#3). In accordance with SDWA, EPA will consider the occurrence data from UCMR 3, along with the peer reviewed health effects assessments supporting the PFOA and PFOS Health Advisories, to make a regulatory determination on whether to initiate the process to develop a national primary drinking water regulation.

In addition, EPA plans to begin a separate effort to determine the range of PFAS for which an Integrated Risk Information System (IRIS) assessment is needed. The IRIS Program identifies and characterizes the health hazards of chemicals found in the environment. IRIS assessments inform the first two steps of the risk assessment process: hazard identification, and dose-response. As indicated in the 2015 IRIS Multi-Year Agenda, the IRIS Program will be working with other EPA offices to determine the range of PFAS compounds and the scope of assessment required to best meet Agency needs. More about this effort can be found at https://www.epa.gov/iris/iris-agenda.

Non-Drinking Water Exposure to PFOA and PFOS

These health advisories only apply to exposure scenarios involving drinking water. They are not appropriate for use, in identifying risk levels for ingestion of food sources, including: fish, meat produced from livestock that consumes contaminated water, or crops irrigated with contaminated water.

The health advisories are based on exposure from drinking water ingestion, not from skin contact or breathing. The advisory values are calculated based on drinking water consumption and household use of drinking water during food preparation (e.g., cooking or to prepare coffee, tea or soup). To develop the advisories, EPA considered non-drinking water sources of exposure to PFOA and PFOS, including: air, food, dust, and consumer products. In January 2016 the Food and Drug Administration amended its regulations to no longer allow PFOA and PFOS to be added in food packaging, which will likely decrease one source of non-drinking water exposure.

Where Can I Learn More?

- EPA's Drinking Water Health Advisories for PFOA and PFOS can be found at: https://www.epa.gov/ground-water-and-drinking-water/drinking-water-health-advisories-pfoa-and-pfos
- PFOA and PFOS data collected under EPA's Unregulated Contaminant Monitoring Rule are available: https://www.epa.gov/dwucmr/occurrence-data-unregulated-con taminant-monitoring-rule
- EPA's stewardship program for PFAS related to TSCA: https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/and -polyfluoroalkyl-substances-pfass-under-tsca
- EPA's research activities on PFASs can be found at: http://www.epa.gov/chemical-research/perfluorinated-chemical-pfc-research
- The Agency for Toxic Substances and Disease Registry's Perflourinated Chemicals and Your Health webpage at: http://www.atsdr.cdc.gov/PFC/

EPA United States Environmental Protection Agency

World Health Organization

REGIONAL OFFICE FOR Europe

ENVIRONMENTAL NOISE GUIDELINES

for the European Region

Abstract

Noise is an important public health issue. It has negative impacts on human health and well-being and is a growing concern. The WHO Regional Office for Europe has developed these guidelines, based on the growing understanding of these health impacts of exposure to environmental noise. The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. They provide robust public health advice underpinned by evidence, which is essential to drive policy action that will protect communities from the adverse effects of noise. The guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience.

Keyword

NOISE – ADVERSE EFFECTS, PREVENTION AND CONTROL

ENVIRONMENTAL EXPOSURE – ADVERSE EFFECTS, PREVENTION AND CONTROL

GUIDELINES

EUROPE

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Environmental Noise Guidelines for the European Region

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Foreword

Noise is one of the most important environmental risks to health and continues to be a growing concern among policy-makers and the public alike. Based on the assessment threshold specified in the Environmental Noise Directive of the European Union (EU), at least 100 million people in the EU are affected by road traffic noise, and in western Europe alone at least 1.6 million healthy years of life are lost as a result of road traffic noise.

At the request of Member States at the Fifth Ministerial Conference on Environment and Health in Parma, Italy, in March 2010, the WHO Regional Office for Europe has developed these guidelines, based on the growing understanding of the health impacts of exposure to environmental noise. They provide robust public health advice, which is essential to drive policy action that will protect communities from the adverse effects of noise.

These WHO guidelines – the first of their kind globally – provide recommendations for protecting human health from exposure to environmental noise originating from various sources. They not only offer robust public health advice but also serve as a solid basis for future updates, given the growing recognition of the problem and the rapid advances in research on the health impacts of noise. The comprehensive process of developing the guidelines has followed a rigorous methodology; their recommendations are based on systematic reviews of evidence that consider more health outcomes of noise exposure than ever before. Through their potential to influence urban, transport and energy policies, these guidelines contribute to the 2030 Agenda for Sustainable Development and support WHO's vision of creating resilient communities and supportive environments in the European Region.

Following the publication of WHO's community noise guidelines in 1999 and night noise guidelines for Europe in 2009, these latest guidelines represent the next evolutionary step, taking advantage of the growing diversity and quality standards in this research domain. Comprehensive and robust, and underpinned by evidence, they will serve as a sound basis for action. While these guidelines focus on the WHO European Region and provide policy guidance to Member States that is compatible with the noise indicators used in the EU's Environmental Noise Directive, they still have global relevance. Indeed, a large body of the evidence underpinning the recommendations was derived not only from noise effect studies in Europe but also from research in other parts of the world – mainly in Asia, Australia and the United States of America.

I am proud to present these guidelines as another leading example of the normative work undertaken in our Region in the area of environment and health. On behalf of the WHO Regional Office for Europe and our European Centre for Environment and Health in Bonn, Germany, which coordinated the development of the guidelines, I would like to express my gratitude to the large network of experts, partners, colleagues and consultants who have contributed to this excellent publication. I would also like to thank Switzerland and Germany for providing financial support to this complex project, and look forward to following the influence of the guidelines on policy and research in the years to come.

Dr Zsuzsanna Jakab

WHO Regional Director for Europe

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The WHO Regional Office for Europe, through its European Centre for Environment and Health, coordinated the development of these guidelines. The project was coordinated by Marie-Eve Héroux and Dorota Jarosinska, under the overall supervision of Elizabet Paunovic, Head of the European Centre for Environment and Health.

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Abbreviations

%HA	percentage of the population “highly annoyed”
%HSD	percentage of the population “highly sleep-disturbed”
BMI	body mass index
CI	confidence interval
CNG	WHO guidelines for community noise
DALY	disability-adjusted life-year
dB	decibel
DW	disability weight
EC	European Commission
EEA	European Environment Agency
END	European Union Directive 2002/49/EC relating to the assessment and management of environmental noise (Environmental Noise Directive)
ERF	exposure–response function
EU	European Union
GDG	Guideline Development Group
GRADE	Grading of Recommendations Assessment Development and Evaluation
ICBEN	International Commission on Biological Effects of Noise
IHD	ischaemic heart disease
JRC	Joint Research Centre [of the European Commission]
mmHg	milimeters of mercury
NNG	WHO night noise guidelines for Europe
OR	odds ratio
PECCOS	population, exposure, comparator, confounder, outcome and study [framework]
PICOS	population, intervention, comparator, outcome and study [framework]
PLD	personal listening device
RANCH	Road traffic and aircraft noise exposure and children’s cognition and health [study]
RCT	randomized control trial
RR	relative risk
SCENIHR	Scientific Committee on Emerging and Newly Identified Hazards and Risk

Glossary of acoustic terms

A-weighting	A frequency-dependent correction that is applied to a measured or calculated sound of moderate intensity to mimic the varying sensitivity of the ear to sound for different frequencies
C-weighting	A frequency-dependent correction that is applied to a measured or calculated sound of moderate intensity to mimic the varying sensitivity of the ear to sound for different frequencies – C-weighting is usually used for peak measurements
FAST	Fast response has a time constant of 125 milliseconds on a sound level meter
$L_{Aeq,T}$	A-weighted, equivalent continuous sound pressure level during a stated time interval starting at t_1 and ending at t_2, expressed in decibels (dB), at a given point in space[1]
$L_{A,max}$	Maximum time-weighted and A-weighted sound pressure level within a stated time interval starting at t_1 and ending at t_2, expressed in dB[1]
L_{AF}	A-weighted sound pressure level with FAST time constant as specified in IEC 61672-1[1]
$L_{AF,max}$	Maximum time-weighted and A-weighted sound pressure level with FAST time constant within a stated time interval starting at t_1 and ending at t_2, expressed in dB
$L_{AS,max}$	Maximum time-weighted and A-weighted sound pressure level with SLOW time constant within a stated time interval starting at t_1 and ending at t_2, expressed in dB
L_E	Sound energy density level is the logarithmic ratio of the time-averaged sound energy per unit volume to the reference sound energy density Eo = 10-12 J/m^3.
$L_{ex,8h}$	L_{eq} (equivalent continuous sound level) corrected for the length of the working shift, in this case 8 hours
L_{day}	Equivalent continuous sound pressure level when the reference time interval is the day[1]
L_{den}	Day-evening-night-weighted sound pressure level as defined in section 3.6.4 of ISO 1996-1:2016[1]
L_{dn}	Day-night-weighted sound pressure level as defined in section 3.6.4 of ISO 1996-1:2016[1]
$L_{evening}$	Equivalent continuous sound pressure level when the reference time interval is the evening[1]

[1] *Source*: ISO (2016).

L_{night}	Equivalent continuous sound pressure level when the reference time interval is the night[1]
$L_{peak,C}$	Level of peak sound pressure with C-weighting, within a specified time interval
$L_{peak,lin}$	Level of peak sound pressure with linear frequency weighting, within a specified time interval
Sound pressure level	the logarithm of the ratio of a given sound pressure to the reference sound pressure in dB is 20 times the logarithm to the base ten of the ratio.
SLOW	Slow response has a time constant of 10 000 milliseconds on a sound level meter

Executive summary

Environmental noise is an important public health issue, featuring among the top environmental risks to health. It has negative impacts on human health and well-being and is a growing concern among both the general public and policy-makers in Europe.

At the Fifth Ministerial Conference on Environment and Health in Parma, Italy, in 2010, WHO was requested by the Member States in the European Region to produce noise guidelines that included not only transportation noise sources but also personal electronic devices, toys and wind turbines, which had not yet been considered in existing guidelines. Furthermore, European Union Directive 2002/49/EC relating to the assessment and management of environmental noise (END) and related technical guidance from the European Environment Agency both elaborated on the issue of environmental noise and the importance of up-to-date noise guidelines.

The WHO Regional Office for Europe has therefore developed environmental noise guidelines for the European Region, proposing an updated set of public health recommendations on exposure to environmental noise.

Objectives

The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. Leisure noise in this context refers to all noise sources that people are exposed to due to leisure activities, such as attending nightclubs, pubs, fitness classes, live sporting events, concerts or live music venues and listening to loud music through personal listening devices. The guidelines focus on the WHO European Region and provide policy guidance to Member States that is compatible with the noise indicators used in the European Union's END.

The following two key questions identify the issues addressed by the guidelines.

- In the general population exposed to environmental noise, what is the exposure–response relationship between exposure to environmental noise (reported as various indicators) and the proportion of people with a validated measure of health outcome, when adjusted for confounders?
- In the general population exposed to environmental noise, are interventions effective in reducing exposure to and/or health outcomes from environmental noise?

In light of these questions, the guidelines set out to define recommended exposure levels for environmental noise in order to protect population health.

Methods used to develop the guidelines

The process of developing the WHO guidelines followed a rigorous methodology involving several groups with separate roles and responsibilities. Throughout the process, the Grading of

Recommendations Assessment, Development and Evaluation (GRADE) approach was followed. In particular, the different steps in the development of the guidelines included:

- formulation of the scope and key questions of the guidelines;
- review of the pertinent literature;
- selection of priority health outcome measures;
- a systematic review of the evidence;
- assessment of certainty of the bodies of evidence resulting from systematic reviews;
- identification of guideline exposure levels; and
- setting of the strength of recommendations.

Based on the defined scope and key questions, these guidelines reviewed the pertinent literature in order to incorporate significant research undertaken in the area of environmental noise and health since the community noise guidelines and night noise guidelines for Europe were issued (WHO, 1999; WHO Regional Office for Europe, 2009). In total, eight systematic reviews of evidence were conducted to assess the relationship between environmental noise and the following health outcomes: cardiovascular and metabolic effects; annoyance; effects on sleep; cognitive impairment; hearing impairment and tinnitus; adverse birth outcomes; and quality of life, mental health and well-being. A separate systematic review of evidence was conducted to assess the effectiveness of environmental noise interventions in reducing exposure and associated impacts on health.[2] Once identified and synthesized, the quality of the evidence of the systematic reviews was assessed by the Systematic Review Team. Subsequently, the Guideline Development Group (GDG) formulated recommendations, guided by the Systematic Review Team's assessment and informed by of a number of additional contextual parameters. To facilitate the formulation of recommendations, the GDG first defined priority health outcomes and then selected the most relevant health outcome measures for the outcomes. Consecutively, a process was developed to identify the guideline exposure levels with the help of the exposure–response functions provided by the systematic reviews. To reflect the nature of the research (observational studies) underpinning the relationship between environmental noise and health, the GRADE procedures were adapted to the requirements of environmental exposure studies where needed.

Noise indicators

From a scientific point of view, the best noise indicator is the one that performs best in predicting the effect of interest. There are, however, a number of additional criteria that may influence the choice of indicator. For example, various indicators might be suitable for different health end-points. Some considerations of a more political nature can be found in the European Commision's Position paper on EU noise indicators (EC, 2000).

[2] All systematic reviews are publicly available online in the *International Journal of Environmental Research and Public Health*. A detailed list of links to the individual reviews is provided in section 2.3.2 and in Annex 2 of these guidelines.

The current guidelines are intended to be suitable for policy-making in the WHO European Region. They therefore focus on the most used noise indicators L_{den} and/or L_{night} (see the glossary of acoustic terms for further details). They can be constructed using their components (L_{day}, $L_{evening}$, L_{night} and the duration in hours of L_{night}), and are provided for exposure at the most exposed façade, outdoors. The L_{den} and L_{night} indicators are those generally reported by authorities and are widely used for exposure assessment in health effect studies.

Recommendations

Specific recommendations have been formulated for road traffic noise, railway noise, aircraft noise, wind turbine noise and leisure noise. Recommendations are rated as either strong or conditional.

Strength of recommendation

- A **strong** recommendation can be adopted as policy in most situations. The guideline is based on the confidence that the desirable effects of adherence to the recommendation outweigh the undesirable consequences. The quality of evidence for a net benefit – combined with information about the values, preferences and resources – inform this recommendation, which should be implemented in most circumstances.
- A **conditional** recommendation requires a policy-making process with substantial debate and involvement of various stakeholders. There is less certainty of its efficacy owing to lower quality of evidence of a net benefit, opposing values and preferences of individuals and populations affected or the high resource implications of the recommendation, meaning there may be circumstances or settings in which it will not apply.

Alongside specific recommendations, several guiding principles were developed to provide generic advice and support for the incorporation of recommendations into a policy framework. They apply to the implementation of all of the specific recommendations.

Guiding principles: reduce, promote, coordinate and involve

- Reduce exposure to noise, while conserving quiet areas.
- Promote interventions to reduce exposure to noise and improve health.
- Coordinate approaches to control noise sources and other environmental health risks.
- Inform and involve communities potentially affected by a change in noise exposure.

The recommendations, source by source, are as follows.

Road traffic noise

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by road traffic below **53 decibels (dB)** L_{den}, as road traffic noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by road traffic during night time below **45 dB** L_{night}, as night-time road traffic noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from road traffic in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions, the GDG recommends reducing noise both at the source and on the route between the source and the affected population by changes in infrastructure.	Strong

Railway noise

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by railway traffic below **54 dB** L_{den}, as railway noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by railway traffic during night time below **44 dB** L_{night}, as night-time railway noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from railways in the population exposed to levels above the guideline values for average and night noise exposure. There is, however, insufficient evidence to recommend one type of intervention over another.	Strong

Aircraft noise

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft below **45 dB** L_{den}, as aircraft noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft during night time below **40 dB** L_{night}, as night-time aircraft noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from aircraft in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions the GDG recommends implementing suitable changes in infrastructure.	Strong

Wind turbine noise

Recommendation	Strength
For average noise exposure, the GDG conditionally recommends reducing noise levels produced by wind turbines below **45 dB** L_{den}, as wind turbine noise above this level is associated with adverse health effects.	Conditional
No recommendation is made for average night noise exposure L_{night} of wind turbines. The quality of evidence of night-time exposure to wind turbine noise is too low to allow a recommendation.	
To reduce health effects, the GDG conditionally recommends that policy-makers implement suitable measures to reduce noise exposure from wind turbines in the population exposed to levels above the guideline values for average noise exposure. No evidence is available, however, to facilitate the recommendation of one particular type of intervention over another.	Conditional

Leisure noise

Recommendation	Strength
For average noise exposure, the GDG conditionally recommends reducing the yearly average from all leisure noise sources combined to **70 dB** $L_{Aeq,24h}$ as leisure noise above this level is associated with adverse health effects. The equal energy principle[3] can be used to derive exposure limits for other time averages, which might be more practical in regulatory processes.	Conditional
For single-event and impulse noise exposures, the GDG conditionally recommends following existing guidelines and legal regulations to limit the risk of increases in hearing impairment from leisure noise in both children and adults.	Conditional
Following a precautionary approach, to reduce possible health effects, the GDG strongly recommends that policy-makers take action to prevent exposure above the guideline values for average noise and single-event and impulse noise exposures. This is particularly relevant as a large number of people may be exposed to and at risk of hearing impairment through the use of personal listening devices. There is insufficient evidence, however, to recommend one type of intervention over another.	Strong

Target audience

The guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience, as a large body of the evidence underpinning the recommendations was derived not only from European noise effect studies but also from research in other parts of the world – mainly in America, Asia and Australia.

[3] The equal energy principle states that the total effect of sound is proportional to the total amount of sound energy received by the ear, irrespective of the distribution of that energy in time (WHO, 1999).

1. Introduction

Environmental noise features among the top environmental risks to physical and mental health and well-being, with a substantial associated burden of disease in Europe (WHO Regional Office for Europe & JRC, 2011; Hänninen et al., 2014). It has negative impacts on human health and well-being and is a growing concern among both the general public and policy-makers in Europe.

WHO published community noise guidelines (CNG) and night noise guidelines (NNG) for Europe in 1999 and 2009, respectively (WHO, 1999; WHO Regional Office for Europe, 2009). Since then, significant new evidence has accumulated on the health effects of environmental noise.

The need for updated health-based guidelines originates in part from commitments made at the Fifth Ministerial Conference on Environment and Health in Parma, Italy, in 2010, where Member States asked WHO to produce appropriate noise guidelines that would include additional noise sources such as personal electronic devices, toys and wind turbines (WHO Regional Office for Europe, 2010). Furthermore, European Union (EU) Directive 2002/49/EC relating to the assessment and management of environmental noise (the END – EC, 2002a) and related technical guidance from the European Environment Agency (EEA) both elaborated on the issue of environmental noise and the importance of up-to-date noise guidelines (EEA, 2010).

The WHO Regional Office for Europe has therefore developed environmental noise guidelines for the European Region, proposing an updated set of public health recommendations on exposure to environmental noise. The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. The guidelines focus on the WHO European Region and provide policy guidance to Member States that is compatible with the noise indicators used in the EU's END.

The following two key questions identify the issues addressed by the guidelines.

- In the general population exposed to environmental noise, what is the exposure–response relationship between exposure to environmental noise (reported as various indicators) and the proportion of people with a validated measure of health outcome, when adjusted for confounders?
- In the general population exposed to environmental noise, are interventions effective in reducing exposure to and/or health outcomes from environmental noise?

1.1 The public health burden from environmental noise

Exposure to noise can lead to auditory and nonauditory effects on health. Through direct injury to the auditory system, noise leads to auditory effects such as hearing loss and tinnitus. Noise is also a nonspecific stressor that has been shown to have an adverse effect on human health, especially following long-term exposure. These effects are the result of psychological and physiological distress, as well as a disturbance of the organism's homeostasis and increasing allostatic load (Basner et al., 2014). This is further outlined in the WHO narrative review of the biological mechanisms of nonauditory effects (Eriksson et al., 2018).

The evidence of the association between noise exposure and health effects is based on experimental work regarding biological plausibility and, in observational studies, consistency among study results, presence of an exposure–response relationship and the magnitude of the effect. Environmental noise risk assessment and risk management relies on established exposure–response relationships (Babisch, 2014).

In 2011 the WHO Regional Office for Europe and the European Commission (EC) Joint Research Centre (JRC) published a report on the burden of disease from environmental noise that quantified the healthy years of life lost in western Europeam countries as a result of environmental noise (WHO Regional Office for Europe & JRC, 2011). The burden of disease is calculated, in a single measure of disability-adjusted life-years (DALYs), as the sum of the years of life lost from premature mortality and the years lived with disability for people living with the disease or health condition or its consequences in the general population (WHO, 2014a).

Sufficient information was deemed available to quantify the burden of disease from environmental noise for cardiovascular disease, cognitive impairment in children, sleep disturbance, tinnitus and annoyance. The report, based on a limited set of data, estimated that DALYs lost from environmental noise in western European countries are equivalent to 61 000 years for ischaemic heart disease (IHD), 45 000 years for cognitive impairment in children, 903 000 years for sleep disturbance, 22 000 years for tinnitus and 654 000 years for annoyance (WHO Regional Office for Europe & JRC, 2011). These results indicate that at least one million healthy years of life are lost every year from traffic-related environmental noise in western Europe. Sleep disturbance and annoyance, mostly related to road traffic noise, constitute the bulk of this burden. Available assessments place the burden of disease from environmental noise as the second highest after air pollution (WHO Regional Office for Europe & JRC, 2011; Hänninen et al., 2014; WHO 2014b). However, a lack of noise exposure data in the central and eastern parts of the WHO European Region means that it is not possible to assess the burden of disease from environmental noise for the whole Region.

1.2 The environmental noise policy context in the EU

The EU has been working to develop a harmonized noise policy for more than two decades. 1993 saw the start of the EC's Fifth Environment Action Programme, which stated that "no person should be exposed to noise levels which endanger health and quality of life" (EC, 1993). This was followed by a Green Paper on future noise policy (EC, 1996), which reinforced the importance of noise as one of the main environmental problems in Europe and proposed a new framework for noise policy development.

The Sixth Environment Action Programme had as one of its objectives: "to achieve a quality of environment where the levels of man-made contaminants do not give rise to significant impacts on, or risks to, human health" (EC, 2002b). This paved the way for the Commission to adopt and implement the END in 2002 (EC, 2002a). The main aim of the Directive is "to define a common approach intended to avoid, prevent or reduce on a prioritized basis the harmful effects, including annoyance, due to exposure to environmental noise".

The END obliges the EC to adapt its Annexes I–III (I on noise indicators in addition to L_{den}[4] and L_{night}[5], II on noise assessment methods and III on methods for assessing harmful effects of noise) to technical and scientific progress. While work on revising Annex II was finalized in 2015 and common noise assessment methods were introduced (EC, 2015), revisions of Annex III to establish methods to assess the harmful effects of noise only started in 2015. Annex III would primarily define what exposure–response relationships should be used to assess the effect of noise on populations. EU Member States have already expressed the view that the recommendations from these environmental noise guidelines for the WHO European Region will guide the revision of Annex III. Beside this main directive, few other legislative documents cover different noise sources and other related issues in the EU (EEA, 2014: Annex I).

The Seventh Environment Action Programme, which guides European environment policy until 2020 (EC, 2014a), is committed to safeguarding the EU's citizens from environment-related risks to health by ensuring that by 2020 "noise pollution in the Union has significantly decreased, moving closer to WHO-recommended levels". A particular requirement for achieving this is "implementing an updated EU noise policy aligned with the latest scientific knowledge, and measures to reduce noise at source, and including improvements in city design".

In addition to the EU's END, several national governments also have legislation and/or limit values that apply at national and/or regional levels (WHO Regional Office for Europe, 2012). The EEA, through its European Topic Centre on Land Use and Spatial Information, gathers noise exposure data and maintains the Noise Observation and Information Service for Europe, based on strategic noise maps provided by Member States (EEA, 2018). A total of 33 EEA countries, in addition to six cooperating countries in south-eastern Europe, report information on noise exposure to the EEA, following the requirements of the END. The quality and availability of noise exposure assessment differs between EU and non-EU Member States where, even if noise legislation has been harmonized with the Directive, noise mapping and action plans are still at the planning stage (EEA, 2014; 2017a; WHO Regional Office for Europe, 2012).

1.2.1 Definition of indicators in the END

The END specifies a number of noise indicators to be applied by Member States in noise mapping and action planning. The most important are L_{den} and L_{night}.

The L_{den} indicator is an average sound pressure level over all days, evenings and nights in a year (EEA, 2010). This compound indicator was adopted by the EU in the END (EC, 2002a). The L_{den} in decibels (dB) is defined by a specific formula, where:

- L_{day} is the A-weighted long-term average sound level as defined in ISO 1996-1: 2016, determined over all the day periods of a year;
- $L_{evening}$ is the A-weighted long-term average sound level as defined in ISO 1996-1: 2016, determined over all the evening periods of a year; and
- L_{night} is the A-weighted long-term average sound level as defined in ISO 1996-1: 2016, determined over all the night periods of a year (ISO, 2016).

[4] Day-evening-night-weighted sound pressure level as defined in section 3.6.4 of ISO 1996-1:20161 (ISO, 2016).
[5] Equivalent continuous sound pressure level when the reference time interval is the night.

The L_{night}, according to the definition in the END, is an equivalent outdoor sound pressure level, measured at the most exposed façade, associated with a particular type of noise source during night time (at least eight hours), calculated over a period of a year (WHO Regional Office for Europe, 2009).

Annex I of the END gives technical definitions for L_{den} and L_{night}, as well as supplementary noise indicators, which might be useful for monitoring special noise situations. For example, in the case of noisy but short-lived noise like shooting noise or noise emitted by trains, $L_{A,max}$ is often used. This is a measure of the maximum sound pressure reached during a defined measurement period. It is used to set noise limits and is sometimes considered in studies to determine certain health effects (such as awakening reactions).

1.3 Perceptions of environmental noise in the WHO European Region

1.3.1 Trends at the regional level

The general population greatly values the benefits of clean and quiet environments. In Europe, people perceive noise as an important issue that affects human health and well-being (EC, 2008; 2014b). In recent years, several Europe-wide surveys have examined the perception of noise as an issue among the population. Overall, these surveys ask about generic noise, referring to “neighbourhood noise” or “noise from the street”. This type of noise differs significantly in its definition from what is considered “environmental noise” in these guidelines. Nevertheless, in the absence of specific large surveys on perceptions of environmental noise as defined in these guidelines, the results provide insight into the public perception of this issue.

The European quality-of-life surveys, carried out every four years, are unique, pan-European surveys examining both the objective circumstances of lives of European citizens and how they feel about those circumstances and their lives in general. The last (fourth) survey was conducted in 2016–2017, involving nearly 37 000 citizens from all EU Member States and the five candidate countries (Albania, Montenegro, Serbia, the former Yugoslav Republic of Macedonia and Turkey). Respondents were asked whether they had major, moderate or no problems with noise in the immediate neighbourhood of their home. Almost one third (32%) reported problems with noise (ranging from 14% to 51% in individual countries), mainly in cities or city suburbs (49%) (Eurofound, 2017).

A 2010 survey of the then 27 countries in the EU, requested by the EC, showed that 80% of respondents (n = 26 602) believed that noise affects their health, either to some or to a great extent (EC, 2010).

A Eurobarometer report on attitudes of European citizens towards the environment (EC, 2014b) compiled opinions on various environmental risks from almost 28 000 respondents in 28 EU countries. Results showed that for 15% of respondents, noise pollution is one of the top five environmental issues they are worried about. Furthermore, 17% of respondents said that they lack information about noise pollution.

1.3.2 Trends at the national level

Data on perception of specific sources of environmental noise as a problem are not available for the entire WHO European Region. Nevertheless, some countries – including France, Germany, the Netherlands, Slovakia and the United Kingdom – conduct national surveys on noise annoyance, either regularly or on demand (Sobotova et al., 2006; Lambert & Philipps-Bertin, 2008; van Poll et al., 2011; Centraal Bureau voor de Statistiek, 2012; Notley et al., 2014; Umweltbundesamt, 2017).

According to these large-scale surveys, road traffic noise is the most important source of annoyance, generally followed closely by neighbour noise. Aircraft noise can also be a substantial source of annoyance. Railway noise and industrial noise are enumerated less frequently. Only limited data are available on the population's perception of newer sources of noise, such as wind turbines.

While perception surveys do not provide information on actual quantitative relationships between noise exposure and health outcomes, it is important to note that the results of such surveys represent people's preferences and values regarding environmental noise. Despite limitations and an incomplete picture, the available data on perception of environmental noise as a public health problem show concern in Europe. People are not always aware of the health impacts of noise, especially of those related to long-term noise exposure at lower levels. Greater awareness of the issue may further increase positive values and preferences.

1.4 Target audience

The environmental noise guidelines for the European Region serve as a reference for an audience made up of different groups, with varied areas of expertise including decision-making, research and advocacy. More specifically, this covers:

- various technical experts and decision-makers at the local, national or international levels, with responsibility for developing and implementing regulations and standards for noise control, urban planning and housing, and other relevant environment and health domains;
- health impact assessment and environmental impact assessment practitioners and researchers;
- national and local authorities responsible for developing and implementing relevant measures and for risk communication;
- nongovernmental organizations and other advocacy groups involved in risk communication and general awareness-raising.

These guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience, as a large body of the evidence underpinning the recommendations was derived not only from European noise effect studies but also from research in other parts of the world – mainly in America, Asia and Australia.

2. Development of the guidelines

2.1 Overview

The process of developing WHO guidelines follows a rigorous methodology and involves several groups with well defined roles and responsibilities (WHO, 2014c). These include: formulation of the scope and key questions of the guidelines; review of the pertinent literature; selection of priority health outcome measures; a systematic review of the evidence; an assessment of certainty of the bodies of evidence resulting from systematic reviews; identification of guideline exposure levels; and setting of the strength of recommendations. Throughout the process, the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach was followed (Morgan et al., 2016).

The development of environmental noise guidelines started in 2013. Following WHO's procedures, the WHO Regional Office for Europe, through its European Centre for Environment and Health in Bonn, Germany, obtained planning approval and established a Steering Group and a Guideline Development Group (GDG). The former was primarily involved in initiating, structuring and executing the guideline development process; the latter was composed of leading experts and end-users, responsible for the process of scoping the guidelines and developing the evidence-based recommendations. During the initiation meeting in October 2013 in Bonn, the GDG members defined the scope of the guidelines, decided on the key questions to be addressed, prioritized health outcomes and set a timeline for completion of the work. Furthermore, authors were appointed for background papers, systematic reviews and different guideline background chapters.

In October 2014 a main evidence review meeting was held between the GDG and the Systematic Review Team in Bern, Switzerland, to discuss the evidence review drafts. In October 2014 and May 2015 the GDG met in Bern and Bonn, respectively, to refine the scope and draft recommendations. The revision and finalization of the systematic reviews of evidence was completed in early 2017. Through a series of remote meetings and teleconferences, the GDG discussed and addressed the remaining outstanding issues and feedback from the peer review of the draft guidelines, and decided on the final formulation of the recommendations. The following sections describe the steps of the guideline development process in detail.

2.2 Scope of the guidelines

Defining the scope of the guidelines included the selection of noise sources to be considered, as well as situations in which people are exposed, and noise indicators used for the formulation of recommendations. These guidelines separately consider outdoor exposure to environmental noise from road traffic, railway traffic, aircraft, wind turbines as well as outdoor and indoor exposure during leisure activities (such as attending nightclubs, pubs, fitness classes, live sporting events, concerts or live music venues and listening to loud music through personal listening devices). The guidelines are source specific and not environment specific. They therefore cover all settings where people spend a significant portion of their time, such as residences, educational institutions, workplaces and public venues, although hospital noise is exempted from the list of public institutions owing to the unique characteristics of the population involved.

The GDG agreed not to develop specific recommendations for occupational and industrial noise. Industrial noise can affect both people working at an industrial site and those living in its vicinity. The guidelines do not consider workers' exposure to noise in industrial environments, as these are regulated by workplace standards and may, in some cases, require the wearing of protective equipment or application of other preventive and protective measures. Further, the guidelines do not explicitly consider industrial noise as an environmental noise source, affecting people living in the vicinities of industrial sites. This is mainly due to the large heterogeneity and specific features of industrial noise, and the fact that exposure to industrial noise has a very localized character in the urban population.

Likewise, the current guidelines do not provide specific recommendations for the prevention of health effects linked to neighbourhood noise. Neighbourhood noise may stem from various potential sources of noise (such as ventilation systems; church bells; animals; neighbours; commercial, recreational and occupational activities; or shooting/military). As the sources may be located in close proximity to where people live, they can cause considerable concern even at low levels (Omlin et al., 2011). Several of these sources can also produce low-frequency noise, and as such, require indoor measurements for proper exposure assessment. In general, little scientific research is available on exposure and health outcomes related to neighbourhood noise.

Moreover, the guidelines do not include recommendations about any kind of multiple exposures. In everyday life people are often exposed to noise from several sources at the same time. In Germany, for example, 44% of the population are annoyed by at least two and up to five sources of noise (Umweltbundesamt, 2015). For some health outcomes, such as obesity, new evidence indicates that combined exposure to noise from several means of transportation is particularly harmful (Pyko et al., 2015; 2017).

Research indicates that, alongside exposure to more than one source of noise, combined exposure to different factors – for example, noise and vibration or noise and air pollution – has gained increasing relevance in recent years (Sörensen et al., 2017). The EC estimates that the social cost of noise and air pollution is up to €1 trillion every year (EC, 2016a). WHO acknowledges the need to develop comprehensive models to quantify the effects of multiple exposures on human health. As the main body of evidence on environmental noise still focuses on source-specific impacts of noise on health outcomes and does not incorporate combined exposure effects of multiple noise sources or other pollutants, however, the current guidelines provide recommendations for each source of noise specifically. No attempt has been made to combine noise from multiple sources for any particular health outcome.

2.2.1 Key questions

The environmental noise guidelines for the WHO European Region seek to address two main questions, which define the issues addressed by the guideline recommendations.

- In the general population exposed to environmental noise, what is the exposure–response relationship between exposure to environmental noise (reported as various indicators) and the proportion of people with a validated measure of health outcome, when adjusted for confounders?
- In the general population exposed to environmental noise, are interventions effective in reducing exposure to and/or health outcomes from environmental noise?

2.2.2 Environmental noise indicators used in the guidelines

From a scientific point of view, the best noise indicator is the one that performs best in predicting the effect of interest. There are, however, a number of additional criteria that may influence the choice of indicator because, for example, various indicators might be suitable for different health end-points and some indicators are more practical to use or easier to calculate than others. Some of these considerations are of a more political nature, as mentioned in the EC's Position paper on EU noise indicators (EC, 2000).

The current guidelines are intended to be suitable for policy-making primarily in the WHO European Region. They are therefore based on the most frequently used average noise indicators in Europe: L_{den} and L_{night}. These are often reported by authorities and are used widely for exposure assessment in health effect studies and noise impact assessments in the Region. The L_{den} (also referred to as "DENL") indicator can be calculated as the A-weighted average sound pressure level, measured over a 24-hour period, with a 10 dB penalty added to the average level in the night (23:00–07:00 or 22:00–06:00), a 5 dB penalty added to the evening (19:00–23:00 or 18:00–22:00) and no penalty added to the daytime period (07:00–19:00 or 06:00–18:00). The penalties are introduced to indicate people's extra sensitivity to noise during the evening and night. The L_{night} indicator is the A-weighted average sound pressure level, measured over an eight-hour period during night time, usually between 23:00 and 07:00 (EC, 2002a).

In these guidelines, L_{den} and L_{night} refer to a measurement or calculation of noise exposure at the most exposed façade, outdoors, reflecting the long-term average exposure. Thus, L_{den} and L_{night} represent all the single noise events due to a specific noise source that occur over a longer period of time, such as during a year. Moreover, most health outcomes considered in these guidelines are expected to occur as a result of long-term exposure. It is generally accepted that the most relevant parts of the whole day or night, which especially account for the time when a person is at home, are correctly attributed when using average indicators like L_{den} or L_{night}.

The majority of studies that form the body of evidence for the recommendations in these guidelines – among them large-scale epidemiological studies and socioacoustic surveys on annoyance and self-reported sleep disturbance – refer to noise exposure measured outdoors, usually at the most exposed façade of dwellings. Virtually all noise exposure prediction models in use today estimate free-field exposure levels outdoors, and most noise abatement regulations refer to outdoor levels as well. These are the practical reasons why the GDG decided not to recommend any guideline values for noise indoors. Nevertheless, in certain cases it could be helpful to estimate indoor levels based on outdoor values. The differences between indoor and outdoor levels are usually estimated at around 10 dB for open, 15 dB for tilted or half-open and about 25 dB for closed windows. When considering more accurate estimation of indoor levels, using a range of different predictors, the relevant scientific literature can be consulted (Locher et al., 2018).

The GDG was aware of the fact that many countries outside the EU are not bound by the terms of the END (EC, 2002a) and/or use noise indicators other than L_{den} or L_{night} in their noise regulations. They still can make use of these guidelines, however, because energy-based average noise indicators are usually highly correlated and "rule of thumb" transformations from one indicator to another are possible with acceptable uncertainty, as long as the conversion accounts for the long-term average of populations, rather than individual exposure situations. Empirically derived generic conversion terms between a wide range of different noise indicators (including L_{den}, L_{dn}, L_{day}, L_{night} and $L_{Aeq,24h}$; see the glossary of acoustic terms for further details), with their uncertainty estimates, were published recently (Brink et al., 2018). The GDG encourages the use of these conversions, should the need arise.

In many situations, average noise levels like the L_{den} or L_{night} indicators may not be the best to explain a particular noise effect. Single-event noise indicators – such as the maximum sound pressure level ($L_{A,max}$)[6] and its frequency distribution – are warranted in specific situations, such as in the context of night-time railway or aircraft noise events that can clearly elicit awakenings and other physiological reactions that are mostly determined by $L_{A,max}$. Nevertheless, the assessment of the relationship between different types of single-event noise indicators and long-term health outcomes at the population level remains tentative. The guidelines therefore make no recommendations for single-event noise indicators.

Different noise sources – for example, road traffic noise and railway noise – can be characterized by different spectra, different noise level rise times of noise events, different temporal distributions of noise events and different frequency distributions of maximum levels. Because of the extensive differences in the characteristics of individual noise sources, these guidelines only consider source-specific exposure–response functions (ERFs) and, therefore, formulate only source-specific recommendations.

2.3 Evidence base

Based on the overall scope and key questions the current guidelines review the relevant literature in the area of environmental noise and health in order to incorporate significant research undertaken since the publication of previous guidelines. The process of evidence search and retrieval involved several steps. These include the identification, retrieval and synthesis of the evidence, followed by a systematic review and assessment (described in section 2.4).

2.3.1 Identification, retrieval and synthesis of evidence

As a first step, the GDG identified key health outcomes associated with environmental noise. Next, it rated the relevance of these health outcomes according to the following three categories:

- critical for assessing environmental noise issues
- important, but not critical for assessing environmental noise issues
- unimportant.

The GDG rated the relevance based on the seriousness and prevalence of the outcomes and the anticipated availability of evidence for an association with noise exposure. The following health outcomes were selected as either critical or important for developing recommendations on the health impacts of environmental noise.

[6] $L_{A,max}$ is the maximum time-weighted and A-weighted sound pressure level within a stated time interval starting at t1 and ending at t2, expressed in dB.

Critical health outcome	Important health outcome
Cardiovascular disease	Adverse birth outcomes
Annoyance[7]	Quality of life, well-being and mental health
Effects on sleep	Metabolic outcomes
Cognitive impairment	
Hearing impairment and tinnitus	

The GDG noted that research into the relationship between noise exposure and its effects on humans brings into focus several questions concerning the definition of health and the boundary between normal social reaction to noise and noise-induced ill health. As stated in WHO's Constitution: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 1946). Accordingly, documenting physical health does not present a complete picture of general health; and being undisturbed by noise in all activities, including sleep, constitutes an asset worthy of protection. Therefore, in accordance with the above definition, the GDG regarded (long-term) annoyance and impaired well-being, as well as self-reported sleep disturbance due to noise, as health outcomes.

Regarding sleep disturbance, the health outcome measures considered in these guidelines largely disregard "objective" indicators of sleep disturbance, such as the probability of awakening reactions or other polysomnography parameters. The main reason for this is the nature of the body of evidence on acute, objectively measured effects of noise during sleep. Studies of physiological effects of sleep and especially polysomnographic investigations are complex and resource-demanding; they therefore include only a small number of participants, who are often healthy young volunteers not representative of the general population. For these reasons, the majority of such studies do not meet the requirements for inclusion in the GRADE framework and full-scale meta-analysis, including adjustment for confounders. Furthermore, it is currently unclear how acute physiological reactions that affect the microstructure of sleep but are less well correlated with global sleep parameters, such as total sleep time, are related to long-term health impediments, especially considering the large interindividual differences in susceptibility to noise (Basner et al., 2011).

As sleeping satisfies a basic need and the absence of undisturbed sleep can have serious effects on human health (WHO Regional Office for Europe, 2009), the GDG set self-reported sleep disturbance, in line with the WHO definition of health, as a primary health outcome. Even though self-reported sleep disturbance might differ considerably from objectively measured parameters of sleep physiology, it constitutes a valid indicator in its own right, as it reflects the effects on sleep perceived by an individual over a longer period of time (WHO Regional Office for Europe & JRC, 2011). The importance of considering both annoyance and self-reported sleep disturbance as health outcomes is further supported by evidence indicating that they may be part of the causal pathway of noise-induced cardiovascular and metabolic diseases. This is further elaborated in the narrative review on biological mechanisms (Eriksson et al., 2018).

[7] Noise annoyance is defined as a feeling of displeasure, nuisance, disturbance or irritation caused by a specific sound (Ouis, 2001). In the current guidelines, "annoyance" refers to long-term noise annoyance.

The second step in the evidence retrieval process constituted formulation of the key questions for the critical and important health outcomes and identification of the areas of evidence to be reviewed, following the PICOS/PECCOS approach defined in the WHO handbook for guideline development (WHO, 2014c). PICOS/PECCOS is an evidence-based technique that frames health care-related questions to facilitate the search for suitable studies that can provide answers to the questions at hand (Huang et al., 2006). The PICOS approach divides intervention questions into five elements: population, intervention, comparator, outcome and study design. In exposure studies, PICOS becomes PECCOS, which stands for population, exposure, comparator, confounder, outcome and study design. The specification of the elements of PICOS/PECCOS serves to construct the body of evidence that underpins each recommendation. Due to the complex nature of environmental noise, several distinct areas of evidence were defined to address each of the scoping questions comprehensively.

For each of the critical and important health outcomes a systematic review was conducted (see also section 2.3.2). Health outcomes regarded as important were given less weight in the decision-making process than critical ones. Inclusion and exclusion criteria to be regarded in the systematic evidence reviews were defined in accordance with the PICOS/PECCOS framework for the evaluation of evidence (see Table 1). All evidence that met the inclusion criteria was included in the systematic reviewing process. A detailed description of the types of measure for each of the health outcomes under consideration is provided in the protocol for conducting the systematic reviews (Héroux & Verbeek, 2018a). See Annex 2 for details of all background documents and systematic reviews used in preparation of these guidelines.

Table 1. Inclusion and exclusion criteria for evidence reviews of health effects of environmental noise

Category	Inclusion criteria	Exclusion criteria
Populations	• Members of the general population • Specific segments of the population particularly at risk (children or vulnerable groups) • People exposed to noise in occupational settings (if relevant with combined exposure to environmental noise)	• Does not meet inclusion criteria
Exposure	• Noise exposure levels, either measured or calculated and expressed in dB values • Representative of the individual exposure of study participants (for most observational studies the dwelling location or home) • Calculated levels for transportation noise (road, rail, air) based on traffic data reflecting the use of roads, railway lines and in- and outbound flight routes at airports	• Does not meet inclusion criteria; in particular: - studies using hearing loss or hearing impairment as a proxy for (previous) noise exposure - surveys assessing noise exposure or number of listening hours based on subjective ratings given by subjects in a questionnaire
Confounders	• No inclusion criteria applied since the relationship between exposure to noise and a health outcome can be confounded by other risk factors; however, possible confounders taken into account were assessed for every study	• No exclusion criteria applied; however, possible confounders taken into account were assessed for every study

Table 1. contd.

Category	Inclusion criteria	Exclusion criteria
Outcomes	• Adverse birth outcomes • Annoyance • Cardiovascular disease • Cognitive impairment • Effects on sleep • Hearing impairment and tinnitus • Metabolic outcomes • Quality of life, mental health and well-being	• Does not meet inclusion criteria
Study types	• Cohort studies • Case-control studies • Cross-sectional studies • Ecological studies (only for cardiovascular disease)	• Does not meet inclusion criteria

Alongside the systematic reviews of the critical and important health outcomes, the GDG decided to review the evidence on health effects from noise mitigation measures and interventions to reduce noise levels in order to inform and complement the recommendations.

Interventions on environmental noise were defined according to five broad categories based on the available intervention literature and the experience of decades of environmental noise management (see Table 2 and Brown & van Kamp, 2017).

Table 2. Types of noise intervention

Intervention type	Intervention category	Intervention subcategory
A	Source intervention	• change in emission levels of sources • time restrictions on source operations
B	Path intervention	• change in the path between source and receiver • path control through insulation of receiver/receiver's dwelling
C	New/closed infrastructure	• opening of a new infrastructure noise source • closure of an existing one • planning controls between (new) receivers and sources
D	Other physical intervention	• change in other physical dimensions of dwelling/neighbourhood
E	Behaviour change intervention	• change in individual behaviour to reduce exposure • avoidance or duration of exposure • community education, communication

The GDG recognized that nonacoustic factors are an important possible confounder in both ERFs between noise levels and critical health effects and the effects of acoustic interventions on health outcomes. Whereas the inclusion criteria for confounders were not specified in PECCOS for the systematic reviews of evidence, they were considered at the stage of assessing the quality of evidence, using the GRADE approach. Depending on the health effect under investigation, possible nonacoustic factors may include:

- gender
- age
- education
- subjective noise sensitivity
- extroversion/introversion
- general stress score
- co-morbidity
- length of residence
- duration of stay at dwelling in the day
- window orientation of a bedroom or living room towards the street
- personal evaluation of the source
- attitudes towards the noise source
- coping capacity with respect to noise
- perception of malfeasance by the authorities responsible
- body mass index
- smoking habits.

In noise annoyance studies nonacoustic factors may explain up to 33% of the variance (Guski, 1999). The higher the quality of evidence, the lower confounding effects of nonacoustic factors may be expected. Nevertheless, as with measurement errors, confounding cannot be avoided.

Based on the retrieval and evaluation of the pertinent literature, the GDG decided to address the association of environmental noise from different sources and health outcomes separately and individually for each source of noise, and for critical and important health outcomes.

In addition to the systematic reviews of the health effects of environmental noise, a narrative review of biological mechanisms of nonauditory effects was conducted (Eriksson et al., 2018). This covers literature related to pathways for nonauditory effects and provides supporting evidence on the association between environmental noise and health outcomes in humans, especially related to cardiovascular and metabolic diseases.

2.3.2 Systematic reviewing process

After the retrieval of the evidence based on the PICOS/PECCOS approach, systematic reviews were conducted for all critical and important health outcomes. To meet the demands of the diverse and broad nature of the evidence, it was agreed that systematic reviews could vary in type. For some areas of evidence, a novel and fully fledged systematic reviewing process was needed to summarize the existing evidence; for others, the reviewing process could build upon existing (and mostly published) systematic reviews and summaries of evidence. Thus, the process consisted of two phases.

First, a comprehensive search was conducted for available systematic reviews and meta-analyses on environmental noise effects published after 2000. Each of the reviews was assessed for both relevance and quality. To be included in the evidence review process, studies from these reviews were required to meet a high quality standard, judged according to high scores of the AMSTAR checklist.[8] In cases where quality criteria were met but the review was older than two years (published before 2012), the search of the systematic review was updated to include new papers. If no good quality systematic reviews were available, a new search for original papers was conducted. The Systematic Review Team decided how the results would affect the search strategy for individual studies as part of the second phase. This was based on the assessment of the quality of the systematic reviews and on the coherence between the main research questions of the systematic reviews and the scope of the work of the guidelines.

In the second phase a search for individual papers was conducted, with the search strategy adapted according to the outcome of the first phase. As availability of systematic reviews and meta-analyses differed for the various health outcomes considered in the guidelines, this process varied for each evidence review. The search included cohort studies, case-control studies and cross-sectional studies of people exposed to environmental noise. Where relevant – for example, for the health outcome cardiovascular disease – the search also included ecological studies.

Due to the individualized retrieval of evidence for each of the systematic reviews, the time frames of the literature included varied. An indication of the temporal coverage of the studies included in different systematic review is provided in the relevant tables in Chapter 4.

A detailed description of the methodology used to conduct the systematic evidence reviews, including individual protocols for the reviews of health effects resulting from environmental noise and from noise interventions, is available (Héroux & Verbeek, 2018b). Furthermore, all systematic reviews conducted in the guideline development process are publicly available in the open-access journal *International Journal of Environmental Research and Public Health*:

- systematic review of transport noise interventions and their impacts on health (Brown & van Kamp, 2017);
- systematic review on environmental noise and adverse birth outcomes (Nieuwenhuijsen et al, 2017);
- systematic review on environmental noise and annoyance (Guski et al., 2017);
- systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018);
- systematic review on environmental noise and cognition (Clark & Paunovic, 2018);
- systematic review on environmental noise and effects on sleep (Basner & McGuire, 2018);
- systematic review on environmental noise and permanent hearing loss and tinnitus (Śliwińska-Kowalska & Zaborowski, 2017);
- systematic review on mental health and well-being (Clark & Paunovic, in press).

[8] AMSTAR is an instrument used to assess quality of evidence; it stands for "A MeaSurement Tool to Assess systematic Reviews" (Shea et al., 2007).

2.4 From evidence to recommendations

Once the evidence had been identified and synthesized, the Systematic Review Team assessed its quality. Subsequently, the GDG formulated recommendations, guided by this assessment and consideration of a number of other factors recognized as important. To facilitate the formulation of recommendations, it first prioritized the health outcome measures of the critical and important outcomes. A process was developed to identify the guideline exposure levels from each of the ERFs provided by the systematic reviews of evidence.

The following sections describe the assessment of the overall quality of the evidence based on the GRADE approach, selection of priority health outcome measurements, identification of guideline exposure levels and setting the strength of recommendations.

2.4.1 Assessment of overall quality of a body of evidence: the GRADE approach

As set out in the WHO handbook for guideline development (WHO, 2014c), the main framework for producing evidence-informed recommendations is the GRADE approach (Guyatt et al., 2008). This is used to assess the quality of a body of evidence synthesized in a systematic review. The assessment facilitates judgements about the certainty of effect estimates, which increases with the quality of the body of evidence. The quality can be rated high, moderate, low or very low (see Box 1).

Box 1 GRADE interpretations of quality of evidence

- **High quality:** further research is very unlikely to change the certainty of the effect estimate
- **Moderate quality:** further research is likely to have an important impact on the certainty of the effect estimate and may change the estimate
- **Low quality:** further research is very likely to have an important impact on the certainty of the effect estimate and is likely to change the estimate
- **Very low quality:** any effect estimate is uncertain

The original GRADE approach was developed specifically to rate the body of evidence resulting from a review of intervention studies. The initial quality level is set by study design: randomized control trials (RCTs) are considered high quality, whereas observational (nonrandomized) study designs are low quality. Then five factors are considered for downgrading the quality of the body of evidence resulting from RCTs or observational studies, and three factors are considered for upgrading the body of evidence resulting from observational studies alone.

The following five factors are used for downgrading the quality of evidence by one or two levels:

- study limitations or risk of bias in all studies that make up the body of evidence
- inconsistency of results between studies
- indirectness of evidence in the studies
- imprecision of the pooled effect estimate
- publication bias detected in a body of evidence.

The following three factors are used for upgrading the quality of evidence:

- high magnitude of the pooled effect
- direction of residual confounding and biases opposes an effect (i.e. when all plausible confounders are anticipated to reduce the estimated effect and there is still a significant effect)
- exposure–response gradient.

The GRADE approach was originally developed for application in the field of clinical medicine, where the majority of studies are randomized trials. However, to assess health effects resulting from an exposure such as environmental noise, randomized controlled trials are not applicable, as it would be unethical to expose participants deliberately to possibly harmful risk factors. The limitations of the application of GRADE to environmental health have been recognized and discussed in the literature (Morgan et al., 2016). Other types of study design dominate the evidence base in the domain of environmental noise research, so it was necessary to adapt the original GRADE approach to the subject of the current guidelines, as follows.

Instead of using the RCT study design as the starting-point for the quality rating, the study design most applicable and available for the field of research at hand was used. Thus, for evidence on the association between noise exposure and clinical health outcome measures, the rating of an evidence base consisting of cohort and case-control studies[9] was initially rated high quality. Cross-sectional studies and ecological studies were rated low quality and very low quality, respectively. This initial point of departure was only adapted for the evidence of the association between noise exposure and annoyance and sleep disturbance. Here, cross-sectional studies were rated high quality because annoyance and sleep disturbance are regarded as an immediate effect of exposure to environmental noise. Finally, in accordance with the original GRADE approach, the starting-point for evidence on the effect of interventions was rated low quality for observational studies. After determining the point of departure, the evidence base was rated down or up whenever one or more of the criteria for downgrading or upgrading (described above) were met. Each of the systematic reviews commissioned for these guidelines includes a detailed report on the assessment of the quality of the evidence.

A detailed discussion of the adaptations of GRADE is provided in the separate methodology publication (Héroux & Verbeek, 2018b).

2.4.2 Selection of priority health outcomes

In line with the WHO handbook for guideline development (WHO, 2014c), the GDG selected the key health outcomes associated with environmental noise at the beginning of the evidence retrieval process, and the systematic reviews were commissioned accordingly. The selection of health outcomes was based on the available evidence for the association between environmental noise and the specific outcome, as well as public concern about the health outcome resulting from noise exposure. The following health outcomes were rated critical: cardiovascular disease, annoyance,

[9] In the context of the current guidelines, "cohort studies" refer to longitudinal studies in which the occurrence of the outcome of interest in an exposed group is compared to the occurrence of that outcome in a reference group with no or lower exposure over time.

effects on sleep, cognitive impairment and hearing impairment and tinnitus. Adverse birth outcomes, quality of life, well-being and mental health, and metabolic outcomes were rated important (see also section 2.3.1).

Since all these health outcomes can be measured in various ways, the GDG evaluated each individually and prioritized different outcome measures for each in terms of their representativeness and validity. These measures were used to derive the guideline exposure levels; their prioritization was based on the impact of the disease and the disability weights (DWs) associated with the health outcome measure.[10]

The critical health outcomes, priority outcome measures identified and justifications for their selection are listed in Table 3.

Table 3. Critical health outcomes, outcome measures identified and justifications for selection

Critical health outcome	Critical health outcome measures (priority measures marked in bold)	Justification for selection
Cardiovascular disease (L_{den})	Self-reported or measured prevalence, **incidence**, hospital admission or mortality due to: • **ischaemic heart disease (IHD) (including angina pectoris and/or myocardial infarction)** • **hypertension** • stroke	Except for self-reports, these are objective measures of the outcome, affect a large proportion of the population, have important health consequences and can lead to more severe diseases and/or mortality. DW for IHD: 0.405. DW for hypertension: 0.117.
Effects on sleep (L_{night})	• **percentage of the population highly sleep-disturbed (%HSD)**, self-reported, assessed with a standardized scale • polysomnography measured outcomes (probability of additional awakenings) • cardiac and blood pressure outcome measures during sleep • motility measured sleep outcomes in adults • sleep disturbance in children	This is the most meaningful, policy-relevant measure of this health outcome. Self-reported sleep disturbances are a very common problem in the general population: they affect quality of life directly and may also lead to subsequent health impediments. Effects on sleep may be in the causal pathway to cardiovascular disease. This measure is not a proxy for physiological sleep quality parameters but is an important outcome in its own right. DW for %HSD: 0.07.
Annoyance (L_{den})	• **percentage of the population highly annoyed (%HA), assessed with standardized scale** • percentage annoyed, preferably assessed with standardized scale	This is the most objective measure of this health outcome. Large proportions of the population are affected by noise annoyance, even at relatively low exposure levels. Annoyance may be in the causal pathway to cardiovascular disease. DW for %HA: 0.02.

[10] DWs are ratings that vary between 0 and 1, in which 0 indicates no disability and 1 indicates the maximum amount of disability. The rates are derived from large population surveys in which people are asked to rank a specific disease for its impact on several abilities. The DWs have been proven useful in calculating the burden of disease.

Table 3. contd.

Critical health outcome	Critical health outcome measures (priority measures marked in bold)	Justification for selection
Cognitive impairment (L_{den})	• **reading and oral comprehension, assessed with tests** • impairment assessed with standardized tests • short and long-term memory deficit • attention deficit • executive function deficit (working memory capacity)	This outcome measure is the most meaningful: it can affect vulnerable individuals (children) and have a significant impact later in life. DW for impaired reading and oral comprehension: 0.006.
Hearing impairment and tinnitus (L_{Aeq}[11] and $L_{AF,max}$[12])	• **permanent hearing impairment, measured by audiometry** • permanent tinnitus	This outcome measure can affect vulnerable individuals (children) and have a significant impact later in life. It is the most objective measure for which there is an ISO standard (ISO, 2013), specifying how to estimate noise-induced hearing loss. DW for mild severity level (threshold at 25 dB) for childhood onset: 0.0150.

Table 4 provides a list of the important health outcomes along with the corresponding health outcome measures included in the systematic reviews. There was no prioritization of health outcome measures leading to justification of selection, since important health outcomes had less impact on the development of recommendations.

Table 4. Important health outcomes and health outcome measures reviewed

Important health outcome	Health outcome measures reviewed
Adverse birth outcomes (L_{den})	• pre-term delivery • low birth weight • congenital anomalies
Quality of life, well-being and mental health (L_{den})	• self-reported health and quality of life • medication intake for depression and anxiety • self-reported depression, anxiety and psychological distress • interviewer-assessed depressive and anxiety disorders • emotional and conduct disorders in children • children's hyperactivity • other mental health outcomes
Metabolic outcomes (L_{den})	prevalence, incidence, hospital admission or mortality due to: • type 2 diabetes • obesity

[11] L_{Aeq} is an A-weighted, equivalent continuous sound pressure level during a stated time interval starting at t1 and ending at t2, expressed in dB, of a noise at a given point in space.

[12] $L_{AF,max}$ is the maximum time-weighted and A-weighted sound pressure level with FAST time constant within a stated time interval starting at t1 and ending at t2, expressed in dB.

2.4.3 Identification of guideline exposure levels for each noise source

The GDG agreed to set guideline exposure levels based on the definition: "noise exposure levels above which the GDG is confident that there is an increased risk of adverse health effects". The identification of guideline values for each of the specific noise sources involved five distinct steps:

1. assessment of the validity of ERFs resulting from the systematic reviews of the effects of noise on each of the critical and important health outcomes;
2. assessment of the lowest noise level measured in the studies included in each of the corresponding systematic reviews;
3. assessment of the smallest risk or relative risk (RR) increase for each of the adverse health outcomes considered relevant;
4. determination of the guideline exposure level based on the ERF, starting from the lowest level measured (see step 2) and associated with the smallest relevant risk increase for adverse health outcomes (see step 3);
5. comparison of the guideline exposure levels calculated for each of the critical health outcomes of one source (for example, incidence of IHD, incidence of hypertension, %HA, permanent hearing impairment and reading and oral comprehension for road traffic noise): selection of the guideline exposure level for each noise source was based on the priority health outcome measure with the lowest exposure level for that source.

To define an "increased risk" to set the guideline exposure level, the GDG made a judgement about the smallest risk or RR of the adverse health effect it considered relevant for each of the priority health outcome measures. It is important to note that the relevant risk increases are benchmark values. The GDG agreed to set them in accordance with the guiding principles it had developed, to provide guideline values that illustrate an increased risk of adverse health effects. It used expert judgements for the determination of the benchmark values; these are elaborated further in section 2.4.3.2.

The guideline exposure levels presented are therefore not meant to identify effect thresholds (the lowest observed adverse effect levels for different health outcomes). This is a difference in approach from prior WHO guidelines, like the night noise guidelines for Europe (WHO Regional Office for Europe, 2009), which explicitly aimed to define levels indicating no adverse health effects. The approach to making choices about relevant risk increases is outlined below and summarized in Table 5.

For IHD and hypertension, RR increases were considered; for annoyance and sleep disturbance, absolute risks of %HA and %HSD were considered; and for reading and oral comprehension an average delay of reading age was defined. For the cardiovascular outcomes, incidence measures were prioritized, although much of the epidemiological evidence was based on prevalence data – particularly for hypertension – where almost no longitudinal studies were available. Prevalence data are generally derived from cross-sectional studies, where the temporal aspects are difficult to determine.

Table 5. Priority health outcomes and relevant risk increases for setting guideline levels

Priority health outcome measure (associated DW)	Relevant risk increase considered for setting of guideline level
Incidence of IHD (DW: 0.405)	5% RR increase
Incidence of hypertension (DW: 0.117)	10% RR increase
%HA (DW: 0.02)	10% absolute risk
%HSD (DW: 0.07)	3% absolute risk
Permanent hearing impairment (DW: 0.0150)	No risk increase due to environmental noise
Reading and oral comprehension (DW: 0.006)	One-month delay in terms of reading age

The DWs used to rank the priority critical health outcomes measures were retrieved from the relevant literature. For cardiovascular disease as a group and for hypertension, the burden of disease from environmental noise values (WHO Regional Office for Europe & JRC, 2011) were not considered applicable by the GDG for these guidelines. Thus, for cardiovascular disease, the DW value (DW: 0.405) specifically applied to acute myocardial infarction in the publication outlining the data sources, methods and results of the global burden of disease in 2002 (Mathers et al., 2003) was retained. Since hypertension is mainly viewed as an important risk factor and not as a health outcome, no general DW has been developed. The only other available DW value available is the DW of 0.117 for hypertensive episodes in pregnancy (Mathers et al., 1999). In the absence of any general DW, the GDG agreed on a conservative approach and decided to use this value.

The DWs for high sleep disturbance (DW: 0.07), high annoyance (DW: 0.02) and impaired reading and oral comprehension (DW: 0.006) were developed in the context of calculating the burden of disease from environmental noise (WHO Regional Office for Europe & JRC, 2011). The DW for hearing impairment was not included in that publication, but it was available from the technical paper on the burden of disease from environmental noise (WHO, 2013); the DW for permanent hearing impairment ranged from 0.0031 to 0.3342, depending on severity level. Environmental noise (leisure noise) contributes to the cumulative total noise exposure throughout the life-course, which may lead to permanent hearing impairment and cause more severe disability in the later years of life. As a result, the GDG selected a DW of 0.0150 for moderate severity level ("has difficulty following a conversation in a noisy environment, but no other hearing problems"). For cognitive impairment, the DW was derived from the estimates of the burden of disease from environmental noise (WHO Regional Office for Europe & JRC, 2011). This was at a very conservative value (DW: 0.006) for noise-related impairment of children's cognition, equivalent to a DW for contemporaneous cognitive deficit in the context of a range of cognitive impairments in children ranging from 0.468 for Japanese encephalitis to 0.024 for iron deficiency anaemia (Lopez et al., 2006).

2.4.3.1 Development of ERFs

The systematic reviews of evidence provided either an ERF or other noise exposure value/metric that could be related to a risk increase of the health outcome measure. These ERFs were used to develop guideline exposure levels; however, only those functions where noise exposure demonstrated a statistically significant effect were used.

To obtain the starting level of the ERFs derived in the systematic reviews, a weighted average of the lowest exposure values measured in the individual studies included in the meta-analyses was calculated. The weighting used the inverse of the variance of the effect estimate of the study. Thus, the lowest exposure value of studies with a small variance (usually with the largest sample size) contributed the most to the assumed onset of the ERF.

2.4.3.2 Relevant risk increase of adverse health effects

The following sections describe in detail the rationale for the selection of the relevant relative risk (RR) increase percentage for each of the priority health outcome measures considered.

Cardiovascular disease: IHD and hypertension

High-quality epidemiological evidence described in the systematic review on cardiovascular and metabolic effects of environmental noise indicates that exposure to road traffic noise increases the risk of IHD (van Kempen et al., 2018). The GDG was confident that health risks result from exposure at an RR increase in the order of 5–10% in the incidence of IHD. This is similar to the reasoning in the WHO air quality guidelines for fine particulate matter ($PM_{2.5}$) (WHO, 2006). To determine a relevant risk increase for IHD, the GDG took as a starting-point the RR increase of 5% measured in epidemiological studies of environmental noise or air pollution. Taking into account the incidence of IHD and the seriousness of the disease, it considered lowering the RR increase for IHD to 1%, as a 5% RR increase might imply a comparatively high absolute risk from a population perspective. To decide on the final benchmark value for IHD, several aspects were considered: the number of people in a population affected by IHD; whether health risks caused by noise would make up a large part of the incidence of the disease; other examples of health risks of similar magnitude leading to preventive action. For IHD, in an average EU country with 20 million inhabitants, an RR increase of 5% for IHD would lead to several thousand extra cases attributable to noise yearly. This corresponds to a proportion of cases of IHD attributable to noise exposure of less than 10%, which is still relatively small. After extensive discussion at the very end of the guideline development process, the GDG decided to adhere to 5% as the relevant risk increase.

Hypertension is a common condition and is an important risk indicator for IHD and other cardiovascular diseases. Thus, the hypertension risk increase can be transformed into a risk increase for cardiovascular disease. To derive a relevant risk increase, the GDG focused on the incidence of hypertension, owing to the nature and quality of epidemiological evidence. Since hypertension is less serious than IHD, and not all people with hypertension will progress to cardiovascular disease, the relevant risk increase in the incidence of hypertension needed to be higher than that for IHD. Therefore, the GDG agreed on an RR increase of 10% for hypertension.

Self-reported sleep disturbance and annoyance

The GDG initially considered 5%HSD and 10%HA due to noise as relevant absolute risks, not be exceeded at the guideline level. After discussion, however, members agreed that these absolute risks were too large, since a considerable proportion of the population would still be affected; they decided to lower the relevant risk from 5% being highly sleep-disturbed to 3%. In doing so, the GDG referred to the WHO night noise guidelines (WHO, 2009), which concluded that while there was insufficient evidence that physiological effects at noise levels below 40 dB L_{night} are harmful to health, there were observed adverse health effects at levels starting from 40 dB L_{night}. At 40 dB, about 3–4%

(depending on the noise source) of the population still reported being highly sleep-disturbed due to noise, which was considered relevant to health. The GDG considered it important that this level is consistent with the previous health-based approach adopted by the WHO night noise guidelines, and agreed that the absolute risk associated with the guideline value selected should not exceed 3%HSD to be health protective.

For annoyance, which is considered a less serious health effect than self-reported sleep disturbance (as indicated by the respective DWs), the relevant risk remained at 10%HA. This means the absolute risk associated with the guideline value selected should be closest to, but not above 10%HA, to be health protective.

Cognitive impairment: reading and oral comprehension

Acquiring skills in reading and oral comprehension at a young age is important for further development: a delay in acquiring these skills can have an impact later in life (Wilson & Lonigan, 2010). This impact cannot be predicted very accurately, but the GDG considered a delay of one month a relevant absolute risk.

Permanent hearing impairment

The literature on hearing impairment as a result of occupational noise exposure is extensive. A noise exposure level beyond 80 dB during 40 years of working a 40 hour work week can give rise to permanent hearing impairment. Given that environmental exposure to noise is much lower than these levels and that noise-related hearing impairments are not reversible, the GDG considered that there should be no risk of hearing impairment due to environmental noise and considered any increased risk of hearing impairment relevant.

2.4.4 Strength of the recommendations

Finally, having determined the guideline exposure levels based on the ranking of prioritized health outcome measures, setting the strength of the recommendation was set as the final step of the guideline development process. This was also guided by the GRADE methodology (Alonso-Coello et al., 2016a; 2016b). According to this approach, strength of recommendation can be set as either strong or conditional (WHO, 2014c).

- A **strong** recommendation can be adopted as policy in most situations. The guideline is based on the confidence that the desirable effects of adherence to the recommendation outweigh the undesirable consequences. The quality of evidence for a net benefit – combined with information about the values, preferences and resources – inform this recommendation, which should be implemented in most circumstances.
- A **conditional** recommendation requires a policy-making process with substantial debate and involvement of various stakeholders. There is less certainty of its efficacy owing to lower quality of evidence of a net benefit, opposing values and preferences of individuals and populations affected or the high resource implications of the recommendation, meaning there may be circumstances or settings in which it will not apply.

The GRADE approach defines a number of parameters that should be assessed to determine the strength of recommendations: quality of evidence, balance of benefits and harms, values and preference related to the outcomes of interventions to exposure, resources implications, priority of the problem, equity and human rights, acceptability and feasibility (Box 2; Morgan et al., 2016).

Box 2 Parameters determining the strength of a recommendation

Quality of evidence further represents the confidence in the estimates of effect of the evaluated evidence, across outcomes critical and important to decision-making. The higher the quality of evidence, the greater the likelihood of a strong recommendation.

Balance of benefits and harms requires an evaluation of the absolute effects of both benefits and harms (or downsides) of the intervention or exposure and their importance. The greater net benefit or net harm associated with an intervention or an exposure, the greater the likelihood of a strong recommendation in favour or against an intervention or exposure.

Values and preferences related to the outcomes of an intervention or exposure set out the relative importance assigned to health outcomes by those affected by them; how such importance varies within and across populations; and whether this importance or variability is surrounded by uncertainty. The less uncertainty or variability there is about the values and preferences of people experiencing the critical or important outcomes, the greater the likelihood of a strong recommendation.

Resource implications take into consideration how resource-intensive and how cost-effective and substantially beneficial an intervention or exposure is. The more advantageous or clearly disadvantageous the resource implications are, the greater the likelihood of a strong recommendation either for or against the intervention or exposure.

The priority of the problem is determined by its importance and frequency (the burden of disease, disease prevalence or baseline risk). The greater the importance of the problem, the greater the likelihood of a strong recommendation.

Equity and human rights considerations are an important aspect of the process. The greater the likelihood that the intervention will reduce inequities, improve equity or contribute to the realization of one or several human rights as defined under the international legal framework, the greater the likelihood of a strong recommendation.

Acceptability plays a prominent role: the greater the acceptability of an option to all or most stakeholders, the greater the likelihood of a strong recommendation.

Feasibility overlaps with values and preferences, resource considerations, existing infrastructures, equity, cultural norms, legal frameworks and many other considerations. The greater the feasibility of an option from the standpoint of all or most stakeholders, the greater the likelihood of a strong recommendation.

The GDG evaluated the strength of the recommendations based on these parameters, following a two-step procedure. Initially, the strength of each recommendation was set as strong or conditional based on an assessment of the quality of evidence. The GDG then identified and assessed contextual parameters that might have a contributory role (see Box 2 above). Based on this qualitative evaluation, the initial recommendation strength was either adapted or confirmed. It is important to note that while the initial parameter "quality of evidence" was informed by comprehensive systematic reviewing processes, the remaining contextual parameters were assessed by the informed qualitative expert judgement of the GDG.

Furthermore, the GDG agreed to decision-making rules, applied when formulating the recommendations. An evidence rating of low quality or very low quality would lead only to a conditional recommendation. Setting a strong recommendation was only considered if the evidence was at least moderate quality. The final recommendations were formulated based on the consideration of all the parameters and decision rules adopted by the GDG. A detailed exploration of all the recommendations is set out in Chapter 3.

2.5 Individuals and partners involved in the guideline development process

The process of WHO guideline development is conducted by several groups with clearly defined roles and responsibilities. Comprising WHO staff members, experts and stakeholders, these are the Steering Group, the GDG, the Systematic Review Team and the External Review Group.

The **Steering Group** includes WHO staff members with different affiliations but whose work experience is relevant to the topic of environmental noise and associated health outcomes. It is involved at all stages of planning, selecting members of the GDG and External Review Group, reviewing evidence and developing potential recommendations at the main expert meetings, as well as ongoing consultation on revisions following peer review. Details of the members of the Steering Group are listed in Table A1.1 in Annex 1.

The **GDG** consists of a group of content experts gathered to investigate all aspects of evidence contributing to the recommendations, including expertise in evidence-based guideline development. This Group defined the key questions and priorities of the research, chose and ranked outcomes and provided advice on any modifications of the scope as established by the Steering Group. The members also outlined the systematic review methods; appraised the evidence used to inform the guidelines; and advised on the interpretation of this evidence, with explicit consideration of the overall balance of benefits and harms. Ultimately the GDG formulated the final recommendations, taking into account the diverse values and preferences of individuals and populations affected. It also determined the strength of the results and responded to external peer reviews. The complete list of GDG members and their specific roles, affiliations and areas of expertise are listed in Table A1.2 in Annex 1.

The **Systematic Review Team** includes experts in the field of environmental health, commissioned by WHO staff to undertake systematic reviews of evidence. The GDG recommended a number of authors to conduct the evidence reviews and summary chapters, based on their expertise. Details of the members of the Systtematic Review Team are included in Table A1.3 in Annex 1.

The **External Review Group** is composed of technical content experts and end-users as well as stakeholders, and is balanced geographically and by gender. The experts and end-users were selected for their expertise in the field, and the Group also included representatives of professional groups and industry associations, who will be implementing the guidelines. Members were asked to review the material at different stages of the development process. The list of technical experts and stakeholders is provided in Tables A1.4 and A1.5, respectively, in Annex 1.

Management of conflict of interest is an integral part of WHO's guideline development procedure. All members of the GDG and authors of the evidence reviews completed WHO declaration of interest forms. These were reviewed by the WHO Secretariat for potential conflicts of interest. A number of conflicts of interest were declared in the forms, but following a standardized management review it was not found necessary to exclude any members of the GDG or authors from their respective roles. Members of the External Review Group (technical experts only) were also asked to complete the form when invited to participate.

In addition, at the start of the meeting of the GDG all members of the GDG received a briefing about the nature of all types of conflict of interest (financial, academic/intellectual and nonacademic) and were asked to declare to the meeting any conflicts they might have. No member of the GDG or the Systematic Review Team was excluded from his/her respective role. A summary of the conflict of interest management is presented in Annex 3.

The GDG set its own rules on how it would work and how contentious issues should be resolved – for instance, by means of a vote. The main decision-making mechanism involved reaching consensus; if a vote was required, the experts involved in developing the underlying evidence for the specific recommendation were excluded from voting, and an agreement was reached via a two thirds majority of the rest of the group.

2.6 Previously published WHO guidelines on environmental noise

Prior to this publication, WHO published community noise guidelines (CNG) in 1999 (WHO, 1999) and night noise guidelines for Europe (NNG) in 2009 (WHO Regional Office for Europe, 2009).

2.6.1 CNG

The scope of WHO's efforts to develop the CNG in 1999 was similar to that for the current guidelines. The objective was then formulated as: "to consolidate scientific knowledge of the time on the health impacts of community noise and to provide guidance to environmental health authorities and professionals trying to protect people from the harmful effects of noise in nonindustrial environments" (WHO, 1999). The guidelines were based on studies carried out up to 1995 and a few meta-analyses from some years later.

The health risk to humans from exposure to environmental noise was evaluated and guideline values derived. At that time WHO had not yet developed its guideline development process, on which the current guidelines are based (WHO, 2014c). The main differences in content are that the previous guidelines were expert-based and provided more global coverage and applicability, such as issues of noise assessment and control that were addressed in detail. They included a discussion on noise sources and measurement, including the basic aspects of source characteristics, sound propagation and transmission. Adverse health effects of noise were characterized, and combined noise sources and their effects were considered. Furthermore, the guidelines included discussions of strategies and priorities in the management of indoor noise levels, noise policies and legislation, environmental noise impact and enforcement of regulatory standards; although there were no chapters on wind turbine noise and leisure noise.

2.6.2 NNG

In 2009 the WHO Regional Office for Europe published the NNG to provide scientifically based advice to Member States for the development of future legislation and policy action in the area of assessment and control of night noise exposure.

The NNG complement the previous CNG, incorporating the advancement of research on noise and sleep disturbance up to 2006. The working group of experts reviewed available scientific evidence on the health effects of night noise and derived health-based guideline values. Again, WHO had not yet introduced its evidence-based recommendations policy and the NNG were mainly expert-based. They considered the scientific evidence on the threshold of night noise exposure indicated by L_{night} as defined in the END (EC, 2002a), and the experts concluded that a L_{night} value of 40 dB should be the target of the NNG (for all sources) to protect the public, including the most vulnerable groups such as children, chronically ill and elderly people. Further, an L_{night} value of 55 dB was recommended as an interim target for countries that could not follow the guidelines in the short term for various reasons or where policy-makers chose to adopt a stepwise approach.

2.6.3 Differences from the prior noise guidelines

The current guidelines differ from the older ones, recommending levels of exposure unlike those previously outlined (especially by the NNG). The following major differences between the previous and current guidelines explain the novel set of recommended values.

- The development process for the current guidelines adhered to a new, rigorous, evidence-based methodology, as outlined in the WHO handbook for guideline development (WHO, 2014c). WHO adopted these internationally recognized standards to ensure high methodological quality and a transparent, evidence-based decision-making process in the guideline development.
- The current guidelines consider cardiovascular disease a critical health outcome measure.
- They also consider a broader set of health outcomes, including adverse birth outcomes, diabetes, obesity and mental well-being. Wherever applicable, incidence, prevalence and mortality were considered separately.
- The current guidelines cover two new noise sources: wind turbines and leisure noise.
- Critical and important health outcomes are considered separately for each of the noise sources.
- The guideline development process included the health effects of intervention measures to mitigate noise exposure from different noise sources for the first time.
- The style of recommendations differs: the current guidelines include an exact exposure value for every health outcome regarded as critical, for each noise source. Guideline recommendation values were set for each of the noise sources separately, based on the exact exposure values and a prioritization scheme, developed with the help of DWs.
- The current guidelines apply a 1 dB increment scheme, whereas prior guidelines (CNG and NNG) formulated or presented recommendations in 5 dB steps.

- In comparison to the 1999 CNG, which defined environment-specific exposure levels, the current guidelines are source specific. They recommend values for outdoor exposure to road traffic, railway, aircraft and wind turbine noise, and indoor as well as outdoor exposure levels for leisure noise.
- Except for leisure noise, all exposure levels recommended in the current guidelines are average sound pressure levels for outdoor exposure.
- The current guidelines make use of the noise indices defined in the END: L_{den} and L_{night}.

The definition of "community noise" used in the CNG in 1999 was also adapted. The GDG agreed to use the term "environmental noise" instead, and offered an operational definition of: "noise emitted from all sources except sources of occupational noise exposure in workplaces".

The current environmental noise guidelines for the European Region supersede the CNG from 1999. Nevertheless, the GDG recommends that all CNG indoor guideline values and any values not covered by the current guidelines (such as industrial noise and shopping areas) should remain valid.

Furthermore, the current guidelines complement the NNG from 2009. Two main aspects of the NNG constitute this complementarity: the different guiding principles and the comprehensive investigation of the immediate physiological effects of environmental noise on sleep. As guiding principles the NNG defined effect thresholds or "lowest observed adverse health effect levels" for both immediate physiological reactions during sleep (i.e. awakening reactions or body movements during sleep) and long-term adverse health effects (i.e. self-reported sleep disturbance). These guideline exposure levels defined a level below which no effects were expected to occur (corresponding to 30 dB L_{night}) and proceeded to define the level where adverse effects start to occur (corresponding to 40 dB L_{night}), with the aim of protecting the whole population, including – to some extent – vulnerable groups. The development of the NNG values relied on evidence-based expert judgement. In contrast, the current guidelines formulate recommendations more strictly based on the available evidence and following the guiding principle to identify exposure values based on a relevant risk increase of adverse health effects. Thus, the recommended guideline values might not lead to full protection of the population, including all vulnerable groups. The GDG stresses that the aim of the current guidelines is to define an exposure level at which effects certainly begin.

Secondly, the NNG comprehensively investigate the immediate short-term effects of environmental noise during sleep, including physiological reactions such as awakening reactions and body movements. They also provided threshold information about single-event noise indicators (such as the $L_{A,max}$). In contrast, the current guideline values for the night time are only based on the prevalence of self-reported sleep disturbance and do not take physiological effects into account. The causal link between immediate physiological reactions and long-term adverse health effects is complex and difficult to prove. Thus, the current guidelines are restricted to long-term health effects during night time and therefore only include recommendations about average noise indicators: L_{night}. Nevertheless, the evidence review on noise and sleep (Basner & McGuire, 2018) includes an overview of single-event exposure–effect relationships.

3. Recommendations

This chapter presents specific recommendations on guideline exposure levels and/or interventions to reduce exposure and/or improve health for individual sources of noise: road traffic, railway, aircraft, wind turbines and leisure noise. The strength of each recommendation is provided (strong or conditional) and a short rationale for how each of the guideline levels was achieved is given.

The GDG discussed extensively the best way to present guideline exposure levels – either as the exact values or in 5 dB steps – and the approach to rounding the values to the nearest integer. The 5 dB increment, rounded down from the exact exposure value to the nearest 5 dB level, was initially chosen as being commonly applied in noise legislation and used in prior guidelines (WHO, 1999; EC, 2002a; WHO Regional Office for Europe, 2009). It was also used to meet the principle of precaution, since imprecision in the exposure assessment in the field of epidemiology tends to attenuate the actual effects in the population.

Use of 5 dB increments resulted in uneven magnitude of rounding down, however, raising concerns of arbitrariness. It became apparent that inclusion of both exact values and the 5 dB rounded-down values might be confusing and could affect the applicability of the guidelines. Hence, the GDG ultimately decided that formulating recommendations based on the exact calculated values, rounded only to the nearest integer, would ensure more clarity and transparency. Furthermore, it noted that adhering to a 5 dB roster might not reflect the progress in the precision of exposure assessment methods in recent decades, which would justify application of a 1 dB step.

The GDG acknowledged that the recommendations might be presented as the exact guideline exposure levels only, leaving the use of 5 dB bands to the potential policy decisions to formulate or revise noise legislation, which are beyond the scope of this publication. The WHO guideline values are public health-oriented recommendations, based on scientific evidence on health effects and on an assessment of achievable noise levels. They are strongly recommended and as such should serve as the basis for a policy-making process in which policy options are quantified and discussed. It should be recognized that in that process additional considerations of costs, feasibility, values and preferences should also feature in decision-making when choosing reference values such as noise limits for a possible standard or legislation.

In addition to the source-specific recommendations in the following sections, a short rationale for the decision-making process by the GDG for developing a particular recommendation is provided, as well as an overview of the evidence considered. This includes a recapitulation of the specific PICOS/PECCOS question (see section 2.3.1), along with a summary of evidence for each of the critical and important health effects from exposure to each of the noise sources, and for the effectiveness of interventions.

Furthermore, a description is provided of the other factors considered according to the GRADE dimensions for the assessment of the strength of recommendations (see section 2.4.4). While the quality of evidence is central to determining this, the process of moving from evidence to recommendations involves several other considerations. These include values and preferences, balance of benefits and harms, consideration of the priority of the problem, resource implications, equity and human rights aspects, acceptability and feasibility (WHO, 2014c).

3.1 Road traffic noise

Recommendations

For average noise exposure, the GDG **strongly** recommends reducing noise levels produced by road traffic below **53 dB** L_{den}, as road traffic noise above this level is associated with adverse health effects.

For night noise exposure, the GDG **strongly** recommends reducing noise levels produced by road traffic during night time below **45 dB** L_{night}, as road traffic noise above this level is associated with adverse effects on sleep.

To reduce health effects, the GDG **strongly** recommends that policy-makers implement suitable measures to reduce noise exposure from road traffic in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions, the GDG recommends reducing noise both at the source and on the route between the source and the affected population by changes in infrastructure.

3.1.1 Rationale for the guideline levels for road traffic noise

The exposure levels were derived in accordance with the prioritization process of critical health outcomes described in section 2.4.3. For each of the outcomes, the exposure level was identified by applying the benchmark, set as relevant risk increase to the corresponding ERF. In the case of exposure to road traffic noise, the process can be summarized as follows (Table 6).

Table 6. Average exposure levels (L_{den}) for priority health outcomes from road traffic noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Incidence of IHD The 5% relevant risk increase occurs at a noise exposure level of 59.3 dB L_{den}. The weighted average of the lowest noise levels measured in the studies was 53 dB L_{den} and the RR increase per 10 dB is 1.08.	5% increase of RR	High quality
Incidence of hypertension One study met the inclusion criteria. There was no significant increase of risk associated with increased noise exposure in this study.	10% increase of RR	Low quality
Prevalence of highly annoyed population There was an absolute risk of 10% at a noise exposure level of 53.3 dB L_{den}.	10% absolute risk	Moderate quality
Permanent hearing impairment	No increase	No studies met the inclusion criteria
Reading skills and oral comprehension in children	One-month delay	Very low quality

In accordance with the prioritization process (see section 2.4.3), the GDG set a guideline exposure level of 53.3 dB L_{den} for average exposure, based on the relevant increase of the absolute %HA. It was confident that there was an increased risk for annoyance below this noise exposure level, but probably no increased risk for other priority health outcomes. In accordance with the defined rounding procedure, the value was rounded to 53 dB L_{den}. As the evidence on the adverse effects of road traffic noise was rated moderate quality, the GDG made the recommendation strong.

Next, the GDG assessed the evidence for night noise exposure and its effect on sleep disturbance (Table 7).

Table 7. Night-time exposure levels (L_{night}) for priority health outcomes from road traffic noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Sleep disturbance 3% of the participants in studies were highly sleep-disturbed at a noise level of **45.4 dB** L_{night}	3% absolute risk	Moderate quality

Based on the evidence of the adverse effects of road traffic noise on sleep disturbance, the GDG defined a guideline exposure level of 45.4 dB L_{night}. The exact exposure value was rounded to 45 dB L_{night}. As the evidence was rated moderate quality, the GDG made the recommendation strong.

The GDG also considered the evidence for the effectiveness of interventions. The results showed that:

- addressing the source by improving the choice of appropriate tyres, road surface, truck restrictions or by lowering traffic flow can reduce noise exposure;
- path interventions such as insulation and barrier construction reduce noise exposure, annoyance and sleep disturbance;
- changes in infrastructure such as construction of road tunnels lower noise exposure, annoyance and sleep disturbance;
- other physical interventions such as the availability of a quiet side of the residence reduce noise exposure, annoyance and sleep disturbance.

Given that it is possible to reduce noise exposure and that best practices already exist for the management of noise from road traffic, the GDG made a strong recommendation.

3.1.1.1 Other factors influencing the strength of recommendations

Other factors considered in the context of recommendations on road traffic noise included those related to values and preferences, benefits and harms, resource implications, equity, acceptability and feasibility; moreover, nonpriority health outcomes (the incidence of stroke and diabetes) were considered. Ultimately, the assessment of all these factors did not lead to a change in the strength of the recommendations. Further details are provided in section 3.1.2.3.

3.1.2 Detailed overview of the evidence

The following sections provide a detailed overview of the evidence constituting the basis for setting the recommendations on road traffic noise. It is presented and summarized separately for each of the critical health outcomes, and the GDG's judgement of the quality of evidence is indicated (for a detailed overview of the evidence on important health outcomes, see Annex 4). Research into health outcomes and effectiveness of interventions is addressed consecutively.

A comprehensive summary of all evidence considered for each of the critical and important health outcomes can be found in the eight systematic reviews published in the *International Journal of Environmental Research and Public Health* (see section 2.3.2 and Annex 2).

3.1.2.1 Evidence on health outcomes

The key question posed was: in the general population exposed to road traffic noise, what is the exposure–response relationship between exposure to road traffic noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied (see section 2.3.1) and the main findings is set out in Tables 8 and 9.

Table 8. PICOS/PECCOS scheme of critical health outcomes for exposure to road traffic noise

PECO	Description	
Population	General population	
Exposure	Exposure to high levels of noise produced by road traffic (average/night time)	
Comparison	Exposure to lower levels of noise produced by road traffic (average/night time)	
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes	For night noise exposure: 1. effects on sleep

Table 9. Summary of findings for health effects from exposure to road traffic noise (L_{den})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)	Quality of evidence
Cardiovascular disease					
L_{den}	Incidence of IHD	RR = 1.08 (95% confidence interval (CI): 1.01–1.15) per 10 dB increase	53 dB	67 224 (7)	High (upgraded for dose-response)
L_{den}	Incidence of hypertension	RR = 0.97 (95% CI: 0.90–1.05) per 10 dB increase	N/A	32 635 (1)	Low (downgraded for risk of bias and because only one study was available)
Annoyance					
L_{den}	%HA	Odds ratio (OR) = 3.03 (95% CI: 2.59–3.55) per 10 dB increase	40 dB	34 112 (25)	Moderate (downgraded for inconsistency)
Cognitive impairment					
L_{den}	Reading and oral comprehension	Not estimated	N/A	Over 2844 (1)	Very low (downgraded for inconsistency)
Hearing impairment and tinnitus					
L_{den}	Permanent hearing impairment	–	–	–	–

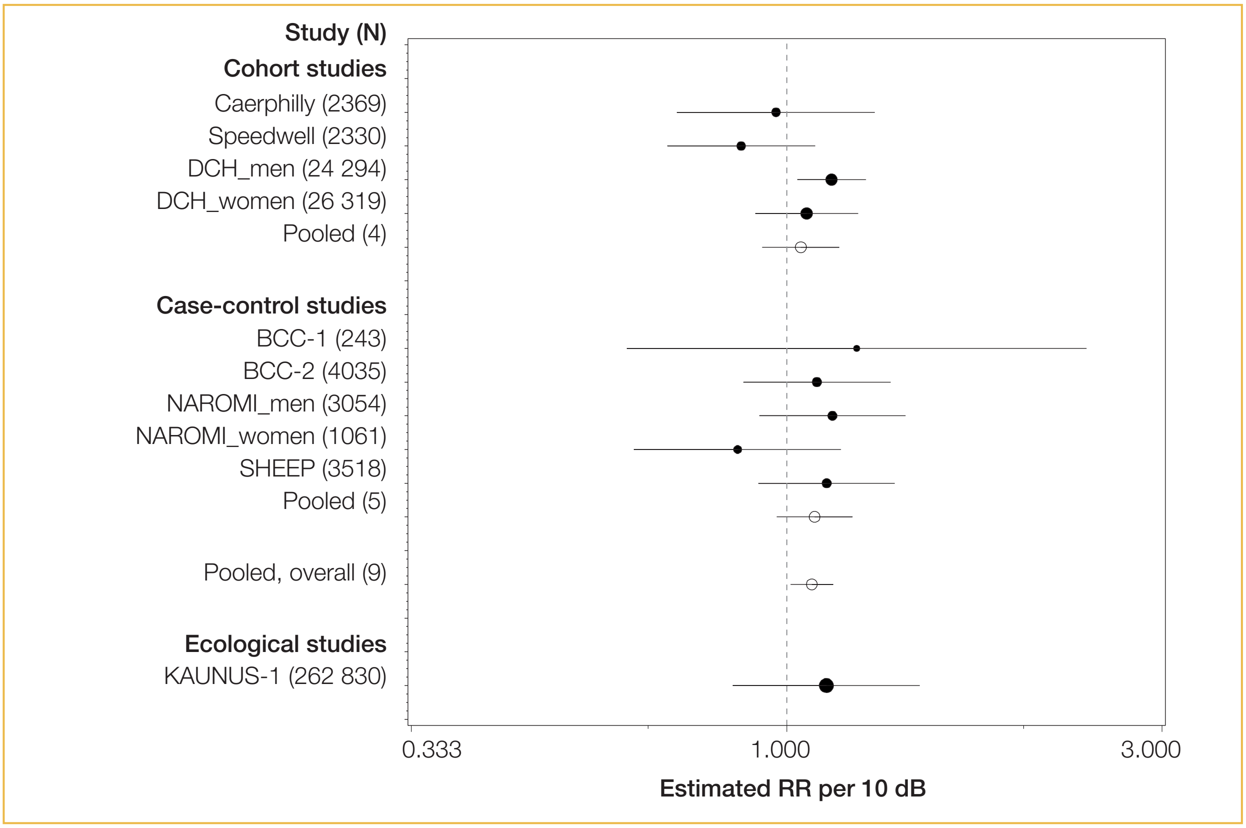
Cardiovascular disease

IHD

A total of three cohort (Babisch & Gallacher, 1990; Babisch et al., 1988; 1993a; 1993b; 1999; 2003; Caerphilly and Speedwell Collaborative Group, 1984; Sörensen et al., 2012a; 2012c) and four case-control studies (Babisch, 2004; Babisch et al., 1992; 1994; 2005a; Selander et al., 2009; Wiens, 1995) investigated the relationship between road traffic noise and the incidence of IHD. These involved a total of 67 224 participants, including 7033 cases. As identified in Fig. 1, the overall RR derived from the meta-analysis was 1.08 (95% CI: 1.01–1.15) per 10 dB L_{den} increase in noise levels, across a noise range of 40 dB to 80 dB. This evidence was rated high quality.

The data were supported by one ecological study conducted with 262 830 participants, including 418 cases, which also reported a statistically significant estimate (Grazuleviciene et al., 2004; Lekaviciute, 2007). In this study, a positive but nonsignificant association was found: RR of 1.12 (95% CI: 0.85–1.48) per 10 dB L_{den} increase in noise. This evidence was rated very low quality.

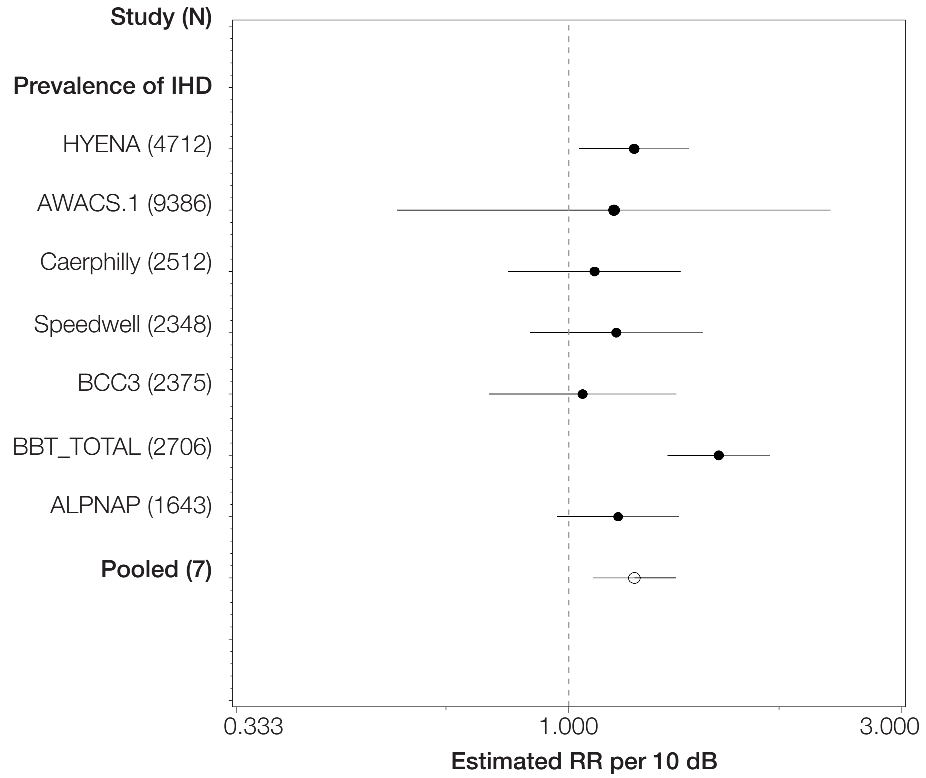
Fig. 1. The association between exposure to road traffic noise (L_{den}) and incidence of IHD



Notes: The dotted vertical line corresponds to no effect of exposure to road traffic noise. The black circles correspond to the estimated RR per 10 dB and 95% CI. The white circles represent the pooled random effect estimates and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Furthermore, additional evidence was available from eight cross-sectional studies that investigated the relationship between road traffic noise and prevalence of IHD (Babisch & Gallacher, 1990; Babisch et al., 1988; 1992; 1993a; 1993b; 1994; 1999; 2003; 2005a; 2008; 2012a; 2012b; Caerphilly and Speedwell Collaborative Group, 1984; Floud et al., 2011; 2013a; 2013b; Heimann et al., 2007; Jarup et al., 2005; 2008; Lercher et al., 2008; 2011; van Poll et al., 2014; Wiens, 1995). These studies involved a total of 25 682 participants, including 1614 cases. The overall RR was 1.24 (95% CI: 1.08–1.42) per 10 dB L_{den} increase in road traffic noise levels. The range in noise levels in the studies under evaluation was 30–80 dB. The results of the meta-analysis are presented in Fig. 2. This evidence was rated low quality.

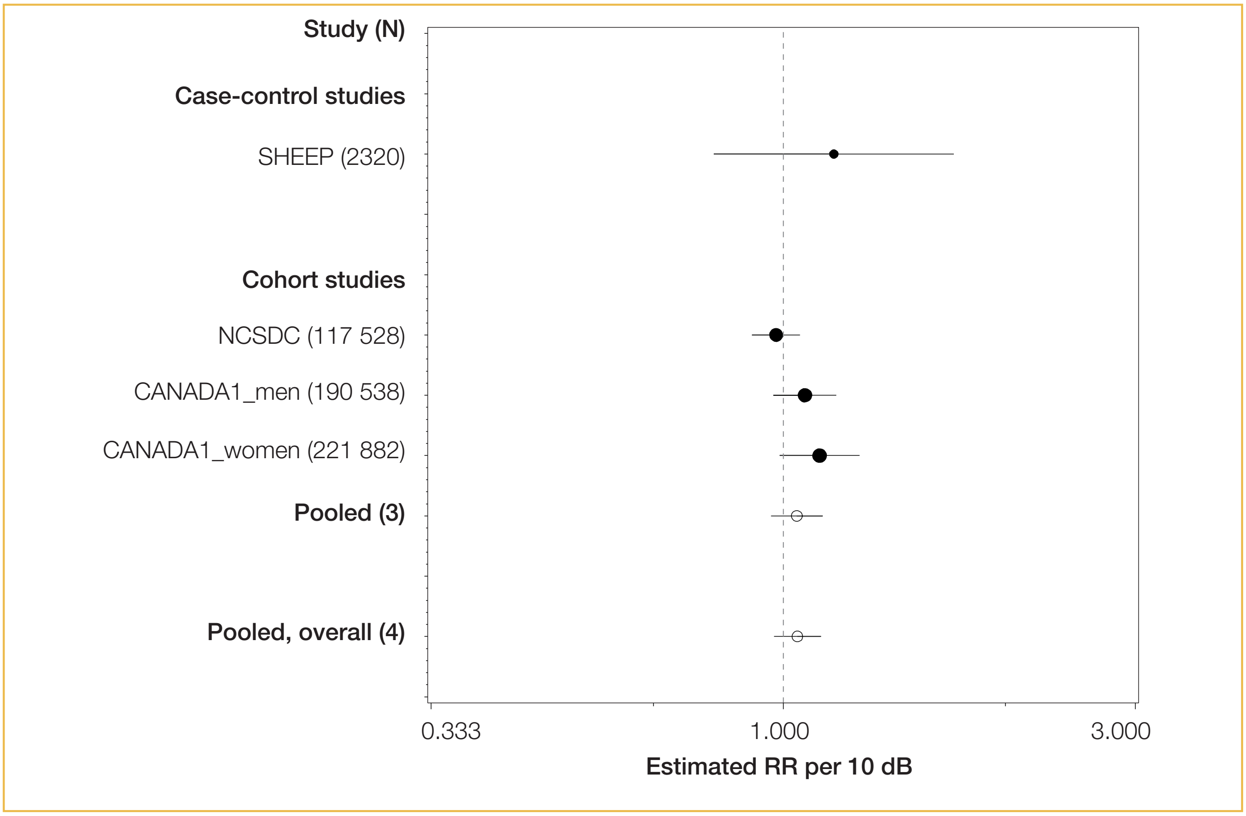
Fig. 2. The association between exposure to road traffic noise (L_{den}) and prevalence of IHD



Notes: The dotted vertical line corresponds to no effect of exposure to road traffic noise. The black circles correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the pooled random effect estimates and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Mortality from IHD was also investigated in one case-control (Selander et al., 2009) and two cohort studies (Beelen et al., 2009; Gan et al., 2012), which involved 532 268 participants, including 6884 cases. The quantitative relationship between road traffic noise and mortality from IHD was RR = 1.05 (95% CI: 0.97–1.13) per 10 dB L_{den} increase in noise levels (see Fig. 3). This evidence was rated moderate quality.

Fig. 3. The association between exposure to road traffic noise (L_{den}) and mortality from IHD



Notes: The dotted vertical line corresponds to no effect of exposure to road traffic noise. The black circles correspond to the estimated RR per 10 dB and 95% CI. The white circles represent the pooled random effect estimates and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

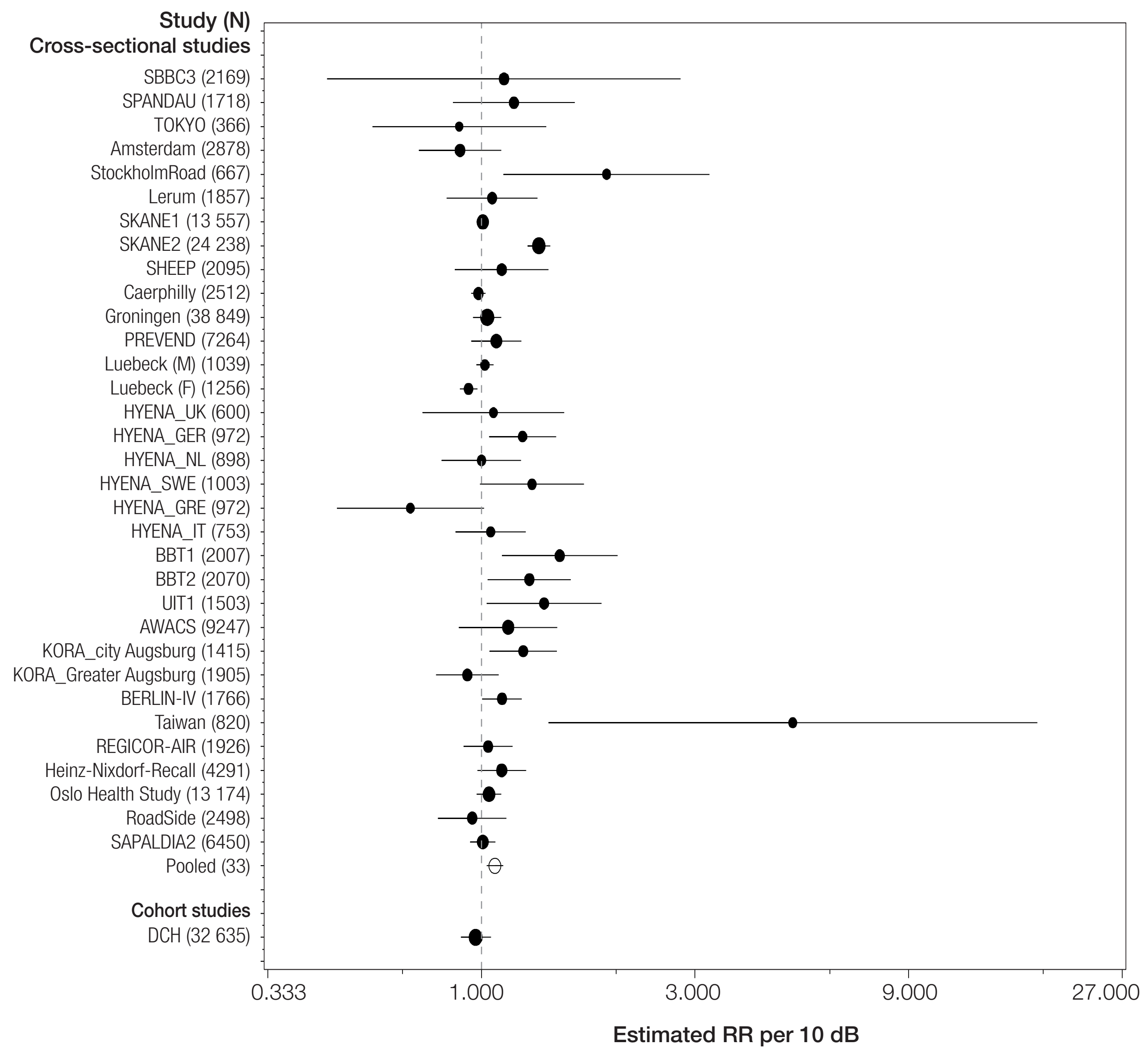
Hypertension

One cohort study into the relationship between road traffic noise and incidence of hypertension was identified; it involved 32 635 participants, including 3145 cases (Sörensen et al., 2011; 2012c). The study found a nonsignificant effect size of 0.97 (95% CI: 0.90–1.05) per 10 dB L_{den} increase in noise levels, which does not support an increased risk of hypertension due to exposure to road traffic noise. Because of the risk of bias and the availability of only one study, this evidence was rated low quality.

In addition, 26 cross-sectional studies were identified that looked at the association between road traffic noise and prevalence of hypertension (Babisch et al., 1988; 1992; 1994; 2005a; 2008; 2012a; 2012b; 2013a; 2013b; 2014b; 2014c; Barregard et al., 2009; Bjork et al., 2006; Bluhm et al., 2007; Bodin et al., 2009; Caerphilly and Speedwell Collaborative Group, 1984; Chang et al., 2011; 2014; de Kluizenaar et al., 2007a; 2007b; Dratva et al., 2012; Eriksson et al., 2012; Foraster et al., 2011; 2012; 2013; 2014a; 2014b; Fuks et al., 2011; Hense et al., 1989; Herbold et al., 1989; Jarup et al., 2005; 2008; Knipschild et al., 1984; Lercher et al., 2008; 2011; Maschke, 2003; Maschke & Hecht, 2005; Maschke et al., 2003; Oftedal et al., 2011; 2014; Selander et al., 2009; van Poll et al., 2014; Wiens, 1995; Yoshida et al., 1997). In total, these studies involved 154 398 participants, including 18 957 cases. The overall RR for prevalence of hypertension was 1.05 (95% CI: 1.02–1.08) per 10 dB L_{den} increase in noise levels. The noise range of the studies under evaluation was 20–85 dB. The overall evidence was rated very low quality.

Fig. 4 shows the association between road traffic noise and incidence and prevalence of hypertension.

Fig. 4. The association between exposure to road traffic noise (L_{den}) and hypertension



Notes: The dotted vertical line corresponds to no effect of exposure to road traffic noise. The black dots correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the summary estimate and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Stroke

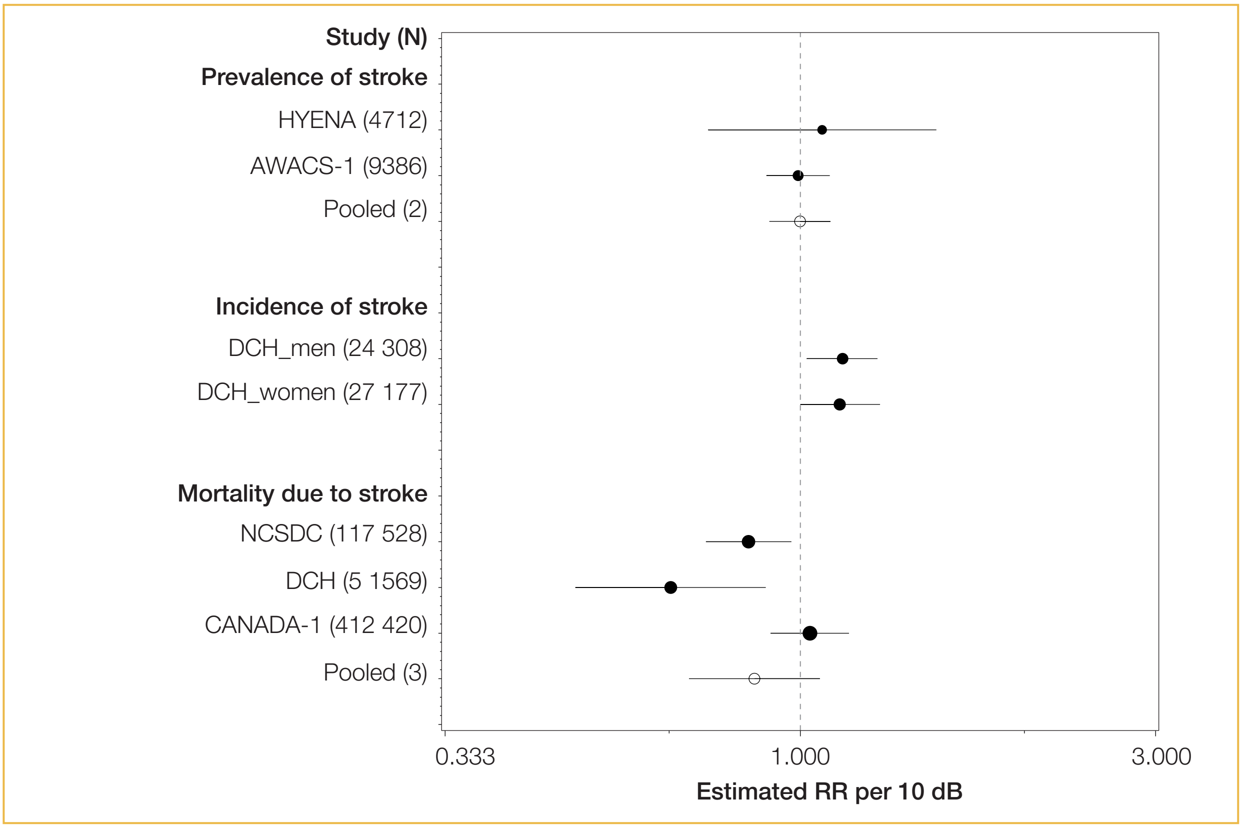
One cohort study into the relationship between road traffic noise and incidence of stroke was identified (Sörensen et al., 2011; 2012b; 2014). It involved 51 485 participants, including 1881 cases, and found an RR of 1.14 (95% CI: 1.03–1.25) per 10 dB L_{den} increase in noise levels, across a range of around 50–70 dB. The evidence was rated moderate quality.

Two cross-sectional studies on road traffic noise and prevalence of stroke involved 14 098 participants, including 151 cases (Babisch et al., 2005a; 2008; 2012a; 2012b; 2013a; Floud et al., 2011; 2013a; 2013b; Jarup et al., 2005; 2008; van Poll et al., 2014) yielded an estimated RR of 1.00 (95% CI: 0.91–1.10) per 10 dB L_{den} increase in noise levels. This evidence was rated very low quality.

Furthermore, three cohort studies investigated the relationship between road traffic noise and mortality due to stroke (Beelen et al., 2009; Gan et al., 2012; Sörensen et al., 2011; 2012b; 2014). These involved 581 517 participants, including 2634 cases, and their pooled estimate was a statistically nonsignificant RR = 0.87 (95% CI: 0.71–1.06) per 10 dB L_{den} increase in road traffic noise levels. This evidence was rated moderate quality.

Fig. 5 presents the results of the meta-analysis for road traffic noise and measures of stroke.

Fig. 5. The association between exposure to road traffic noise (L_{den}) and stroke



Notes: The dotted vertical line corresponds to no effect of exposure to road traffic noise. The black dots correspond to the estimated RR per 10 dB and 95% CI. The white circles represent the summary estimate and 95% CI.
For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Children's blood pressure

Six cross-sectional studies investigated the change in systolic and diastolic blood pressure in children exposed to road traffic noise in residential settings (Belojevic & Evans, 2011; 2012; Bilenko et al., 2013; Liu et al., 2013; 2014; Regecova & Kellerova, 1995; van Kempen et al., 2006). In total, 4197 children were included in these studies; the number of cases was not reported. For each increase in 10 dB L_{den} in noise levels, there was a statistically nonsignificant increase in systolic and in diastolic blood pressure of 0.08 mmHg (95% CI: –0.48–0.64) and 0.47 mmHg (95% CI: –0.30–1.24), respectively. The overall evidence was rated very low quality.

Furthermore, five cross-sectional studies investigated the association between systolic and diastolic blood pressure in children and exposure to road traffic noise in educational settings (Belojevic & Evans, 2011; 2012; Bilenko et al., 2013; Clark et al., 2012; Paunovic et al., 2013; Regecova & Kellerova, 1995; van Kempen et al., 2006). In total, 4520 children were included in these studies; the number of cases was not reported. Systolic blood pressure decreased statistically nonsignificantly, at –0.60 mm (95% CI: –1.51–0.30) per 10 dB L_{den} increase in road traffic noise levels. Diastolic blood pressure increased statistically nonsignificantly, at 0.46 mm (95% CI: –0.60–1.53) per 10 dB L_{den} increase in road traffic noise levels. For both relationships, the evidence was rated very low quality.

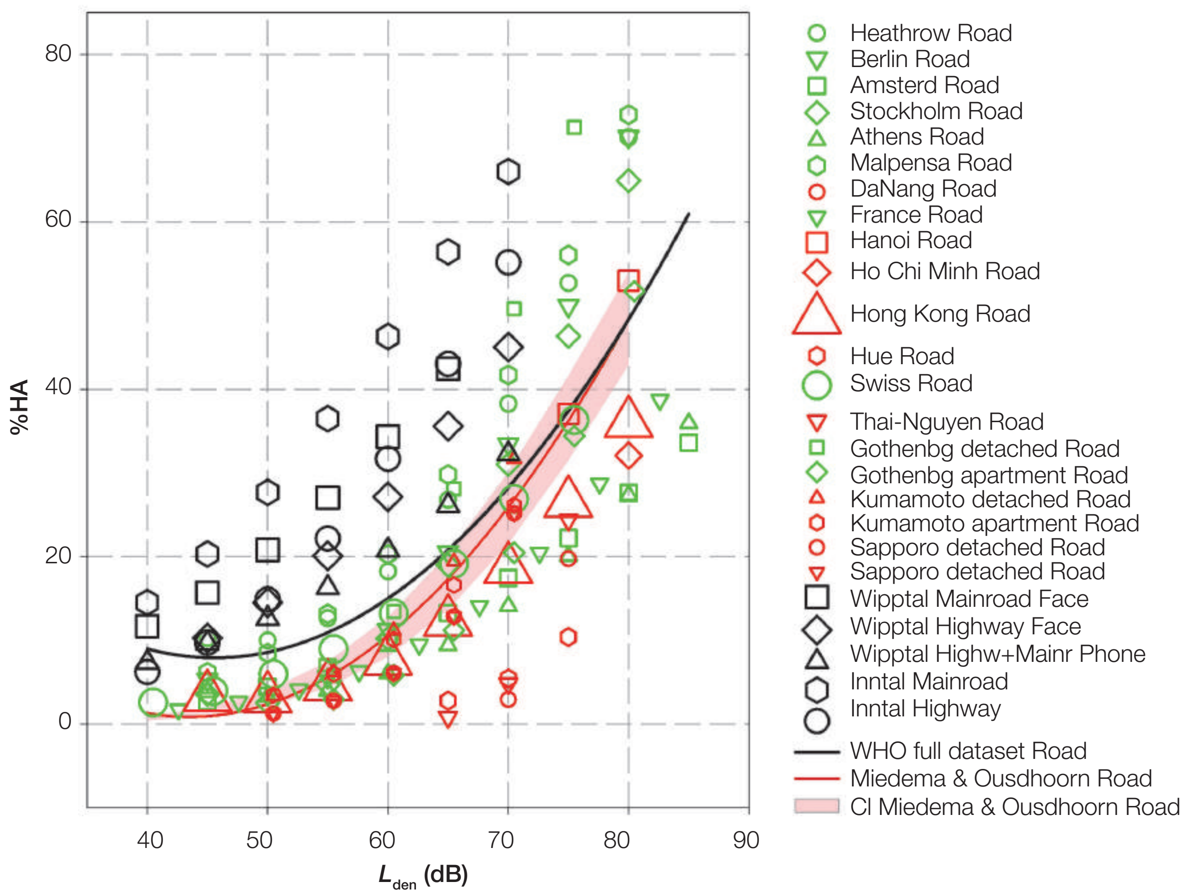
Annoyance

A vast amount of research proves the association between road traffic noise and annoyance. In total, 17 road traffic noise studies were identified that were used to model ERFs of the relationship between L_{den} and %HA (Babisch et al., 2009; Brink, 2013; Brink et al., 2016; Brown et al., 2014; 2015; Champelovier et al., 2003; Heimann et al., 2007; Lercher et al., 2007; Medizinische Universitaet Innsbruck, 2008; Nguyen et al., 2012a; Pierette et al., 2012; Sato et al., 2002; Shimoyama et al., 2014). These incorporated data from 34 112 study participants. The estimated data points of each of the studies are plotted in Fig. 6, alongside an aggregated ERF including the data from all the individual studies (see the black line for "WHO full dataset"). The lowest category of noise exposure considered in any of the studies, and hence included in the systematic review, is 40 dB, corresponding to approximately 9%HA. The benchmark level of 10%HA is reached at 53.3 dB L_{den} (see Fig 6).

Table 10 shows the %HA in relation to exposure to road traffic noise. The calculations are based on the regression equation $\%HA = 78.9270–3.1162 \times L_{den} + 0.0342 \times L_{den}^{2}$ derived from the systematic review (Guski et al., 2017). Even though there is a large evidence base substantiating the association of average road traffic noise and noise annoyance, the overall evidence had to be rated low quality. The main reasons for downgrading included limitations regarding the acoustical data provided, the nature of study design (most of the studies in the realm of annoyance research follow a cross-sectional approach), the inconsistency of results and the variety in the questions asked.

Nevertheless, the general quality of the evidence was substantiated with the help of additional statistical analyses that apply classic health outcome measures to estimate noise annoyance. When comparing road traffic noise exposure at 50 dB and 60 dB, the analyses revealed evidence rated moderate quality for an association between road traffic noise and %HA for an increase per 10 dB (OR = 2.74; 95% CI: 1.88–4.00). Moreover, there was evidence rated high quality for the increase of %HA per 10 dB increase in sound exposure, when data on all sound classes were included (OR = 3.03; 95% CI: 2.59–3.55).

Fig. 6.Scatterplot and quadratic regression of the relationship between road traffic noise (L_{den}) and annoyance (%HA)



Notes: The ERF by Miedema & Oudshoorn (2001) is added in red for comparison.
The size of the data points corresponds to the number of participants in the respective study (size = SQRT(N)/10).
If two results from different studies fall on the same data point, the last point plotted may mask the former one.
The black curve is derived from aggregated secondary data, while the red one is derived from individual data.
There is no indication of 95% CIs of the WHO full dataset, as a weighting based on the total number of participants for each 5 dB L_{den} sound class could not be calculated; weighting based on all participants of all sound classes proved to be unsuitable. The range of data included is illustrated by the distribution of data points.
For further details on the studies included in the figure please refer to the systematic review on environmental noise and annoyance (Guski et al., 2017).

Table 10. The association between exposure to road traffic noise (L_{den}) and annoyance (%HA)

L_{den} (dB)	%HA
40	9.0
45	8.0
50	8.6
55	11.0
60	15.1
65	20.9
70	28.4
75	37.6
80	48.5

Cognitive impairment

Evidence rated very low quality was available for the association between road traffic noise and reading and oral comprehension, assessed by tests. The review identified two papers that reported the results of the cross-sectional road traffic and aircraft noise exposure and children's cognition and health (RANCH) study, which examined exposure–effect relationships (Clark et al., 2006; Stansfeld et al., 2005). The study of over 2000 children aged 9–10 years, attending 89 schools around three major airports in the Netherlands, Spain and the United Kingdom did not find an exposure–effect relationship between road traffic noise exposure at primary school, which ranged from 31 to 71 dB $L_{Aeq,16h}$, and children's reading comprehension.

Few studies have investigated other health outcome measures related to cognition. Evidence rated low quality was available for an association between road traffic noise and cognitive impairment assessed through standardized tests (Cohen et al., 1973; Lukas et al., 1981; Pujol et al., 2014; Shield & Dockrell, 2008). There was evidence rated very low quality for an association between road traffic noise and long-term memory (Matheson et al., 2010; Stansfeld et al., 2005). No studies examined effects on short-term memory.

There was evidence rated very low quality, however, that road traffic noise does not have a considerable effect on children's attention (Cohen et al., 1973; Stansfeld et al., 2005). Further, there was evidence rated low quality that road traffic noise does not have a substantial effect on executive function (working memory), with studies consistently reporting no association (Clark et al., 2012; Matheson et al., 2010; Stansfeld et al., 2005; van Kempen et al., 2010; 2012).

Hearing impairment and tinnitus

No studies were found, and therefore no evidence was available for the association between road traffic noise and hearing impairment and tinnitus.

Sleep disturbance

For road traffic noise and self-reported sleep outcomes (awakenings from sleep, the process of falling asleep and sleep disturbance), 12 studies were identified that included a total of 20 120 participants (Bodin et al., 2015; Brown et al., 2015; Hong et al., 2010; Phan et al., 2010; Ristovska et al., 2009; Sato et al., 2002; Shimoyama et al., 2014); these were cross-sectional studies, conducted in healthy adults. The health outcome was measured by self-reporting via general health and noise surveys that included questions about sleep in general, and other questions about how noise affects sleep (see Table 11).

Table 11. Summary of findings for health effects from exposure to road traffic noise (L_{night})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)	Quality of evidence
Effects on sleep					
L_{night}	%HSD	OR: 2.13 (95% CI: 1.82–2.48) per 10 dB increase	43 dB	20 120 (12)	Moderate (downgraded for study limitations, inconsistency; upgraded for dose-response, magnitude of effect)

The model in the systematic review (Basner & McGuire, 2018) was based on outdoor L_{night} levels between 40 dB and 65 dB only; 40 dB was chosen as the lower limit because of possible inaccuracies of predicting lower noise levels. The range of noise exposure reported in the studies reviewed was 37.5–77.5 dB L_{night}. About 2% (95% CI: 0.90–3.15) of the population was characterized as highly sleep-disturbed at L_{night} levels of 40 dB. The %HSD at other, higher levels of road traffic noise is presented in Table 12. The association between road traffic noise and the probability of being highly sleep-disturbed was OR: 2.13 (95% CI: 1.82–2.48) per 10 dB increase in noise. This evidence was rated moderate quality.

Table 12. The association between exposure to road traffic noise (L_{night}) and sleep disturbance (%HSD)

L_{night} (dB)	%HSD	95% CI
40	2.0	0.9–3.15
45	2.9	1.40–4.44
50	4.2	2.14–6.27
55	6.0	3.19–8.84
60	8.5	4.64–12.43
65	12.0	6.59–17.36

Additional analyses were conducted for other health outcome measures related to sleep, which provided supporting evidence on the overall relationship between road traffic noise and sleep disturbance. When the noise source was not specified in the question, the relationship between road traffic noise and self-reported sleep outcomes was still positive but no longer statistically significant, with an OR of 1.09 (95% CI: 0.94–1.27) per 10 dB increase (Bodin et al., 2015; Brink, 2011; Frei et al., 2014; Halonen et al., 2012). This evidence was rated very low quality.

There was evidence rated moderate quality for an association between road traffic noise and sleep outcomes measured with polysomnography (probability of additional awakenings) with an OR of 1.36 (95% CI: 1.19–1.55) per 10 dB increase in indoor $L_{AS,max}$ [13] (Basner et al., 2006; Elmenhorst et al., 2012). Further, evidence rated low quality showed an association between road traffic noise and sleep outcomes measured as motility in adults (Frei et al., 2014; Griefahn et al., 2000; Oehrstroem et al., 2006a; Passchier-Vermeer et al., 2007; Pirrera et al., 2014). Finally, there was evidence rated very low quality for an association between road traffic noise and both self-reported and motility-measured sleep disturbance in children (Ising & Ising, 2002; Lercher et al., 2013; Oehrstroem et al., 2006a; Tiesler et al., 2013).

3.1.2.2 Evidence on interventions

This section summarizes the evidence underlying the recommendation on the effectiveness of interventions for road traffic noise exposure. The key question posed was: in the general population exposed to road traffic noise, are interventions effective in reducing exposure to and/or health outcomes from road traffic noise? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 13 and 14.

Table 13. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to road traffic noise

PICO	Description	
Population	**General population**	
Intervention(s)	The interventions can be defined as: (a) a measures that aim to change noise exposure and associated health effects; (b) a measures that aim to change noise exposure, with no particular evaluation of the impact on health; or (c) a measures designed to reduce health effects, but that may not include a reduction in noise exposure.	
Comparison	**No intervention**	
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes	For night noise exposure: 1. effects on sleep

[13] $L_{AS,max}$ is the maximum time-weighted and A-weighted sound pressure level with SLOW time constant within a stated time interval starting at t1 and ending at t2, expressed in dB.

Table 14. Summary of findings for road traffic noise interventions by health outcome

Type of intervention	Number of participants (studies)	Effect of intervention	Quality of evidence
Annoyance			
Type A – source interventions (change in traffic flow rate, improved road resurfacing, truck restriction strategy, complex set of barriers, road surfaces and other measures)	6096[a] (9)	• Changes in noise level ranged from around –15 dB to +15.5 dB (various noise metrics). • Most studies found that the intervention resulted in a change in annoyance.	Moderate (downgraded for study limitations; upgraded for dose-response)
Type B – path interventions (dwelling insulation, barrier construction, building intervention)	2970 (7)	• Changes in noise level ranged from –3 dB to –13 dB (various noise metrics). • All studies found that the intervention resulted in a change in annoyance, as estimated by an ERF.	Moderate (downgraded for study limitations; upgraded for dose-response)
Type C – changes in infrastructure (new road tunnel infrastructure)	1211 (2)	• Noise levels reduced by an average of –12 dB ($L_{Aeq,24h}$). • Both studies found lower annoyance responses post intervention, with no change in the controls.	Moderate (downgraded for study limitations; upgraded for dose-response)
Type D – other physical interventions (availability of quiet side to the dwelling, existence of nearby green space)	26 786 (6)	• Because of large variability in noise levels between most and least exposed façade (quiet side), access to quiet side and/or green space resulted in less annoyance.	Very low (downgraded for study limitations)
Sleep disturbance			
Type B – path interventions (1: façade insulation; 2: enlargement of motorway lanes but with dwelling insulation, barriers and quiet pavement)	1158 (2)	• 1: façade insulation resulted in a reduction of 7 dB for indoor noise level. • 2: enlargement led to reduction in the extent of population exposure at higher noise levels (55–65 dB) with an increase in lower levels (45–55 dB) • Both path interventions resulted in changes in sleep outcomes	Moderate (downgraded for study limitations)
Type C – changes in infrastructure (new road tunnel infrastructure)	166 (2)	• Noise levels reduced by an average of –12 dB ($L_{Aeq,24h}$). • Both studies found lower sleep disturbance indicators/ improvement in sleep post intervention, with no change in the controls.	Moderate (downgraded for study limitations)
Type D – other physical interventions (availability of quiet side to the dwelling)	100 (1)	• An absence of quiet façade resulted in increased reporting of difficulty in falling asleep.	Very low (downgraded for study limitations, inconsistency)
Cardiovascular disease			
Type D – other physical interventions (availability of quiet side to the dwelling)	9203 (4)	• Three studies found changes (including in self-reported hypertension) with and without a quiet side. One study found no change.	Very low (downgraded for study limitations)

Note: [a] This figure does not include number of participants from the studies by Langdon & Griffiths (1982) and Baughan & Huddart (1993), as the exact number of respondents was not reported.

Type A – source interventions

Most of the nine source intervention studies – Baughan & Huddart (1993), Brown (1987; 2015), Brown et al. (1985), Griffiths & Raw (1987; 1989), Kastka (1981), Langdon & Griffiths (1982), Pedersen et al. (2013; 2014), Stansfeld et al. (2009b) – showed an effect in annoyance due to changes in road traffic flow rates. In some cases these were combined with other measures like improved road resurfacing, truck restrictions or complex control measures, including barriers or road surfaces. A majority of the changes resulted in reductions of noise levels.

Regarding the strength of association between exposure and annoyance outcome, all intervention studies demonstrated that the response was of at least the magnitude estimated by a steady-state ERF. The limited available evidence on long-term effects shows that this excess response undergoes some attenuation but is largely maintained over several years. In spite of the high risk of bias in all studies, the evidence in the systematic review was initially assessed as high quality, due to an upgrade because of the dose-response effect. However, the GDG decided to downgrade this assessment in an effort to maximize consistency with the grading approach of the remaining systematic reviews. It was therefore rated moderate quality.

Type B – path interventions

Seven path intervention studies – Amundsen et al. (2011; 2013), Bendtsen et al. (2011), Gidloef-Gunnarsson et al. (2010), Kastka et al. (1995), Nilsson & Berglund (2006), Vincent & Champelovier (1993) – explored the effects on annoyance by interventions related to dwelling insulation, barrier constructions and a combination of both, as well as a full-scale building intervention. With the help of pre/post designs, the studies assessed changes in noise exposure achieved by the interventions over different periods of time. In six studies the path intervention was associated with a change in annoyance outcomes. Four of these showed that the annoyance response to the change was in the same direction and of at least the same magnitude estimated by the ERF. In spite of the high risk of bias in all studies, the evidence in the systematic review was initially assessed as high quality, due to an upgrade because of the dose-response effect. However, the GDG decided to downgrade this assessment in an effort to maximize consistency with the grading approach of the remaining systematic reviews. The evidence was therefore rated moderate quality.

Two of the studies (Amundsen et al., 2013; Bendtsen et al., 2011) assessed path interventions and sleep disturbance. The results showed a reduction in the %HSD after the interventions were conducted. One of the studies included a two-year follow-up, revealing the persistence of the effect. Risk of bias was assessed as high in both studies. The evidence was rated moderate quality.

Type C – new/closed infrastructure interventions

Two infrastructural intervention studies (Gidloef-Gunnarsson et al., 2013; Oehrstroem, 2004; Oehrstroem & Skanberg, 2000) evaluated the impact on annoyance of major reductions in road traffic flows, combined with other environmental improvements. One was a new road tunnel infrastructure, resulting in substantial traffic and noise levels reductions for residents near the previously heavy-traffic road. Both studies were pre/post designs using repeated measures of annoyance outcomes. Following the reduction in noise levels (around –12 dB $L_{Aeq,24h}$), both studies demonstrated a statistically significant lower degree of annoyance, while there was no change in the control group. Both also reported that the after-scores in the studies matched those estimated by the ERF, but both reported excess response, meaning that the response to change was in the direction estimated by the ERF but much steeper. In spite of the high risk of bias in all studies, the quality of the evidence in the systematic review was initially assessed as high, due to an upgrade because of the dose-response effect. However, the GDG decided to downgrade this assessment in an effort to maximize consistency with the grading approach of the remaining systematic reviews. The evidence was therefore rated moderate quality.

Two studies investigated the impact of new tunnels that removed traffic flow from surface roads on sleep disturbance (Oehrstroem, 2004; Oehrstroem & Skanberg, 2000; 2004). Subjective and objective measures of sleep quality were assessed before and after the intervention. Both studies demonstrated a statistically significant lower reporting of various sleep disturbance indicators post intervention. One study reported statistically significantly reduced time spent in bed after the intervention, which, according to the authors, could suggest increased sleep efficiency. Risk of bias was assessed as high, so this evidence was rated moderate quality.

Type D – other physical infrastructure interventions

No intervention studies were available to assess impacts on annoyance of other physical interventions. The only relevant studies (Babisch et al., 2012; de Kluizenaar et al, 2011; 2013; Gidloef-Gunnarsson & Oehrstroem 2007; van Renterghem & Botteldooren, 2012; 2010) did not provide direct evidence of an intervention. Instead, they provided indirect evidence on the magnitude of the likely effect of certain interventions (e.g. using the quiet side of the dwelling, green space in the neighbourhood) by comparing responses from groups with and without the intervention/feature of interest. All studies found an effect of the presence of the dimension investigated; in all but one, the effect was statistically significant. Risk of bias was assessed as high in all studies, so the evidence was rated very low quality.

One study investigated a subjective assessment of difficulty in falling asleep (van Renterghem & Botteldooren, 2012), before and after the intervention. The difference in the proportion of participants reporting difficulty falling asleep "at least sometimes" between homes with and without a quiet side was statistically significant. Absence of a quiet façade resulted in increased reporting of this sleep parameter. Confounding was adjusted for in the analyses of the ERFs, including noise sensitivity, window-closing behaviour and front-façade L_{den}. Risk of bias was assessed as high, so the evidence was rated very low quality.

Four studies that assessed the effect of other physical interventions on cardiovascular disease were identified (Babisch et al., 2012; 2014a; Bluhm et al., 2007; Lercher et al., 2011). Three of these found changes, including self-reported hypertension, with and without a quiet side of the dwelling; in two the difference was statistically significant. The risk of bias in these studies was generally high, so the evidence was rated very low quality.

3.1.2.3 Consideration of additional contextual factors

As the foregoing overview has shown, ample evidence about the adverse health effects of long-term exposure to road traffic noise exists. Based on the quality of the available evidence, the GDG set the strength of the recommendation on road traffic noise at strong. As a second step, it qualitatively assessed contextual factors to explore whether other considerations could have a relevant impact on the recommendation strength. These considerations mainly concerned the balance of harms and benefits, values and preferences, equity, and resource use and implementation.

When assessing the balance of harms and benefits of interventions to reduce exposure to road traffic noise, the GDG initially noted that road traffic is the most widespread source of noise pollution, measured in terms of the number of affected people both within and outside urban areas. The EEA estimates that more than 100 million people in Europe are exposed to L_{den} levels above 55 dB; for night-time road traffic noise, over 72 million Europeans are exposed to L_{night} levels above 50 dB (Blanes et al., 2017).[14] The amount of road traffic noise emitted is unlikely to decrease significantly: both transport demand, including for passenger cars (EC, 2016b), and the number of city inhabitants (Eurostat, 2016) are expected to increase. Considering the significant burden of disease attributable to exposure to road traffic noise (WHO Regional Office for Europe & JRC, 2011), the GDG expects substantial health benefits to evolve from implementing the recommendations to reduce population exposure to road traffic noise. Depending on the intervention measures used (such as restrictions of traffic), possible harms could include effects on the transportation of goods and on individual mobility of the population. Both can have impacts on local, national and international economies. Overall, the GDG estimated that the benefits gained from minimizing adverse health effects due to road traffic noise exposure outweigh the possible (economic) harms.

Considering values and preferences, it has been established that people appreciate quiet areas as beneficial for their health and well-being, especially in urban areas (Shepherd et al., 2013; Gidloef-Gunnarsson & Oehrstroem, 2007; Oehrstroem et al., 2006b). Nevertheless, the GDG recognized that the convenience of individual mobility with the help of passenger cars is valued overall by large parts of the population in the EU, as illustrated by the sustained high volume of passenger kilometres driven in Europe (EEA, 2016a; 2017a). In general, values and preferences are expected to vary throughout society, as exposure to environmental noise and continuous road traffic noise is not equally distributed: those of individuals directly affected by long-term road traffic exposure are likely to differ from those that are not affected. Individuals with a higher average sound pressure level of road traffic noise are, for example, more willing to pay to reduce their noise exposure (Bristow et al., 2014).

In light of the dimension of equity, the GDG highlighted the fact that the risk of exposure to road traffic noise is not equally distributed throughout society. People with lower socioeconomic status and other disadvantaged groups often live in more polluted and louder areas, including in proximity to busy roads (EC, 2016a). Moreover, socioeconomic factors are not only related to differences in exposure to environmental factors such as noise but are also associated with increased vulnerability and poorer coping capacities (Karpati et al., 2002).

With resource use and implementation considerations, the GDG recognized that no comprehensive cost–benefit analysis for the WHO European Region yet exists, so this assessment is based on informed expert judgement regarding the feasibility of implementing the recommendation for the majority of the population. As the systematic review of environmental noise interventions and their

[14] These are gap-filled figures based on the reported data and including the situation both within and outside cities, as defined by the END.

associated impact on health shows, various effective measures exist to reduce noise exposure from road traffic and improve health (Brown & van Kamp, 2017). The resources needed to implement these measures vary as they rely on the type of intervention and the context. The GDG pointed out the following four major solutions, which are known to be cost-effective: choice of appropriate tyres, use of low-noise road surfaces, building of noise barriers and installation of soundproof windows (CSES et al., 2016). Other types of intervention include limitations of speed or type of traffic allowed on roads.

Regarding feasibility of implementation, the GDG was convinced that many of the solutions can be planned as part of regular maintenance processes and accelerated fleet and road modernization. In particular, appropriate tyres and road surfaces are only slightly more expensive than existing products, and various countries have already considered or adopted similar interventions to reduce noise levels (Ohiduzzaman et al., 2016; Sirin, 2016). This indicates that solutions to achieve recommended noise levels can be implemented and carry a reasonable cost on a societal level. The GDG noted, however, that the feasibility of implementing measures can be hindered by the fact that costs and benefits are not evenly distributed. In most cases, the health benefits gained by interventions that reduce long-term road traffic exposure accrue to citizens, whereas the costs are borne by road users, private companies and public authorities. Furthermore, the GDG expects challenges in the implementation of all long-term measures that include changes in behaviour of the population, such as increased use of car-sharing or public transport. Even though the overall costs are expected to be significant, because of the large number of people affected, the benefit of implementation of the recommendation to minimize the risk of adverse health effects due to road traffic noise for a majority of the population exceeds the resources needed.

In light of the assessment of the contextual factors in addition to the quality of evidence, the recommendation remains strong.

Other nonpriority adverse health outcomes

As an additional consideration, although not priority health outcomes and coming from a single study, the GDG noted the evidence rated moderate quality for an association between road traffic noise and the prevalence of diabetes (van Kempen et al., 2018). The noise levels in the study identified ranged from around 50 dB to 70 dB L_{den}, so the recommendation proposed is thought to be protective enough for this health outcome. Thus, it did not lead to a change in the recommendation.

Additional considerations or uncertainties

Individual noise annoyance judgements of residents are to a large extent moderated by personal variables (such as noise sensitivity and coping capacity). However, further situational factors that apply to many residents should be taken into account when analysing noise annoyance from road traffic noise, as they may moderate the relationship. These include the type(s) of road being considered (highways, urban main roads, secondary roads and so on) and the related traffic composition (share of cars, motorcycles and heavy and loud trucks) and pattern (fluctuation, frequency, intermittency). Moreover, the location of settlements and/or individual dwellings, proximity to the road, and location and availability of a quiet façade can also influence the relationship when predicting health outcomes such as annoyance.

3.1.3 Summary of the assessment of the strength of the recommendations

Table 15 provides a comprehensive summary of the different dimensions for the assessment of the strength of the road traffic noise recommendations.

Table 15. Summary of the assessment of the strength of the road traffic noise recommendation

Factors influencing the strength of recommendation	Decision
Quality of evidence	**Average exposure** (L_{den}) *Health effects* • Evidence for a relevant RR increase for incidence of IHD at **59 dB** L_{den} was rated **high quality**. • Evidence for the incidence of hypertension was rated **low quality**. • Evidence for a relevant absolute risk of annoyance at **53 dB** L_{den} was rated **moderate quality**. • Evidence for a relevant RR increase for reading and oral comprehension was rated **very low quality**. *Interventions* • Evidence on effectiveness of interventions to reduce noise exposure and/or health outcomes from road traffic noise is of varying quality. **Night-time exposure** (L_{night}) *Health effects* • Evidence for a relevant absolute risk of sleep disturbance related to night noise exposure from road traffic at **45 dB** L_{night} was rated **moderate quality**. *Interventions* • Evidence on effectiveness of interventions to reduce noise exposure and/or sleep disturbance from road traffic noise is of varying quality.
Balance of benefits versus harms and burdens	Health benefits can be gained from markedly reducing exposure of the population to road traffic noise; benefits outweigh the harms of interventions to reduce continuous road traffic noise.
Values and preferences	Quiet areas are valued by the population, especially by those affected by continuous noise exposure. Some variability is possible between those who benefit from interventions to reduce road traffic noise and those who finance the interventions.
Equity	Risk of exposure to road traffic noise is not equally distributed.
Resource use and implications	No comprehensive cost–effectiveness analysis data are available; nevertheless, a wide range of solutions exists and several are being implemented, showing that effective interventions are both feasible and economically reasonable.
Decisions on recommendation strength	• **Strong** for guideline level for average noise exposure (L_{den}) • **Strong** for guideline value for average night noise exposure (L_{night}) • **Strong** for specific interventions to reduce noise exposure

3.2 Railway noise

Recommendations

For average noise exposure, the GDG **strongly** recommends reducing noise levels produced by railway traffic below **54 dB** L_{den}, as railway noise above this level is associated with adverse health effects.

For night noise exposure, the GDG **strongly** recommends reducing noise levels produced by railway traffic during night time below **44 dB** L_{night}, as railway noise above this level is associated with adverse effects on sleep.

To reduce health effects, the GDG **strongly** recommends that policy-makers implement suitable measures to reduce noise exposure from railways in the population exposed to levels above the guideline values for average and night noise exposure. There is, however, insufficient evidence to recommend one type of intervention over another.

3.2.1 Rationale for the guideline levels for railway noise

The exposure levels were derived in accordance with the prioritizing process of critical health outcomes described in section 2.4.3. For each of the outcomes, the exposure level was identified by applying the benchmark, set as relevant risk increase to the corresponding ERF. In the case of exposure to railway noise, the process can be summarized as follows (Table 16).

Table 16. Average exposure levels (L_{den}) for priority health outcomes from railway noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Incidence of IHD No studies were available and therefore incidence of IHD could not be used to assess the exposure level.	5% increase of RR	No studies met the inclusion criteria/no studies available
Incidence of hypertension One study met the inclusion criteria. There was no significant increase of risk associated with increased noise exposure in this study.	10% increase of RR	Low quality
Prevalence of highly annoyed population There was an absolute risk of 10% at a noise exposure level of 53.7 dB L_{den}.	10% absolute risk	Moderate quality
Permanent hearing impairment	No increase	No studies met the inclusion criteria/no studies available
Reading skills and oral comprehension in children	One-month delay	No studies met the inclusion criteria/no studies available

In accordance with the prioritization process (see section 2.4.3), the GDG set a guideline exposure level of 53.7 dB L_{den} for average exposure, based on the relevant increase of the absolute %HA. In accordance with the defined rounding procedure, the value was rounded to 54 dB L_{den}. As the evidence on the adverse effects of railway noise was rated moderate quality, the GDG made the recommendation strong.

Next, the GDG assessed the evidence for night noise exposure and its effect on sleep disturbance (Table 17).

Table 17. Night-time exposure levels (L_{night}) for priority health outcomes from railway noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Sleep disturbance 3% of the participants in studies were highly sleep-disturbed at a noise level of **43.7 dB** L_{night}	3% absolute risk	Moderate quality

Based on the evidence of the adverse effects of railway noise on sleep disturbance, the GDG defined a guideline exposure level of 43.7 dB L_{night}. The exact exposure value was rounded to 44 dB L_{night}. As the evidence was rated moderate quality, the GDG made the recommendation strong.

The GDG also considered the evidence for the effectiveness of interventions. The results showed that:

- intervening at the source by applying rail grinding procedures can reduce noise annoyance;
- behavioural interventions such as informing the community about noise interventions can reduce noise annoyance.

In light of the strong evidence about the adverse health effects, the GDG followed a precautionary approach and made a strong recommendation for interventions on railway noise, as it was confident that interventions are realizable and that best practices already exist for the management of noise from railways. Since the empirical evidence on the effectiveness of different types of intervention was rated either low or very low quality, the GDG felt that no recommendation could be made on the preferred type of intervention, and agreed not to recommend any specific type of intervention over another.

3.2.1.1 Other factors influencing the strength of recommendations

Other factors considered in the context of recommendations on railway noise included those related to values and preferences, benefits and harms, resource implications, equity, acceptability and feasibility; moreover, nonpriority health outcomes were considered. The assessment of all these factors – especially the values and preferences involved in railway noise – did not lead to a change in the strength of the recommendations. Further details are provided in Section 3.2.2.3.

3.2.2 Detailed overview of the evidence

The following sections provide a detailed overview of the evidence constituting the basis for setting the recommendations on railway noise. It is presented and summarized separately for each of the critical health outcomes, and the GDG's judgement of the quality of evidence is indicated (for a detailed overview of the evidence on important health outcomes, see Annex 4). Research into health outcomes and effectiveness of interventions is addressed consecutively.

A comprehensive summary of all evidence considered for each of the critical and important health outcomes can be found in the eight systematic reviews published in the *International Journal of Environmental Research and Public Health* (see section 2.3.2 and Annex 2).

3.2.2.1 Evidence on health outcomes

The key question posed was: in the general population exposed to railway noise, what is the exposure–response relationship between exposure to railway noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 18 and 19.

Table 18. PICOS/PECCOS scheme of critical health outcomes for exposure to railway noise

PECO	Description	
Population	General population	
Exposure	Exposure to high levels of noise produced by railway traffic (average/night time)	
Comparison	Exposure to lower levels of noise produced by railway traffic (average/night time)	
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes	For night noise exposure: 1. effects on sleep

Table 19. Summary of findings for health effects from exposure to railway noise (L_{den})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)[a]	Quality of evidence
Cardiovascular disease					
L_{den}	Incidence of IHD	–	–	–	–
L_{den}	Incidence of hypertension	RR = 0.96 (95% CI: 0.88–1.04) per 10 dB increase	N/A	7249 (1)	Low (downgraded for risk of bias and availability of only one study)
Annoyance					
L_{den}	%HA	OR = 3.53 (95% CI: 2.83–4.39) per 10 dB increase	34	10 970 (10)	Moderate (downgraded for inconsistency, directness; upgraded for dose-response)
Cognitive impairment					
L_{den}	Reading and oral comprehension	–	–	–	–
Hearing impairment and tinnitus					
L_{den}	Permanent hearing impairment	–	–	–	–

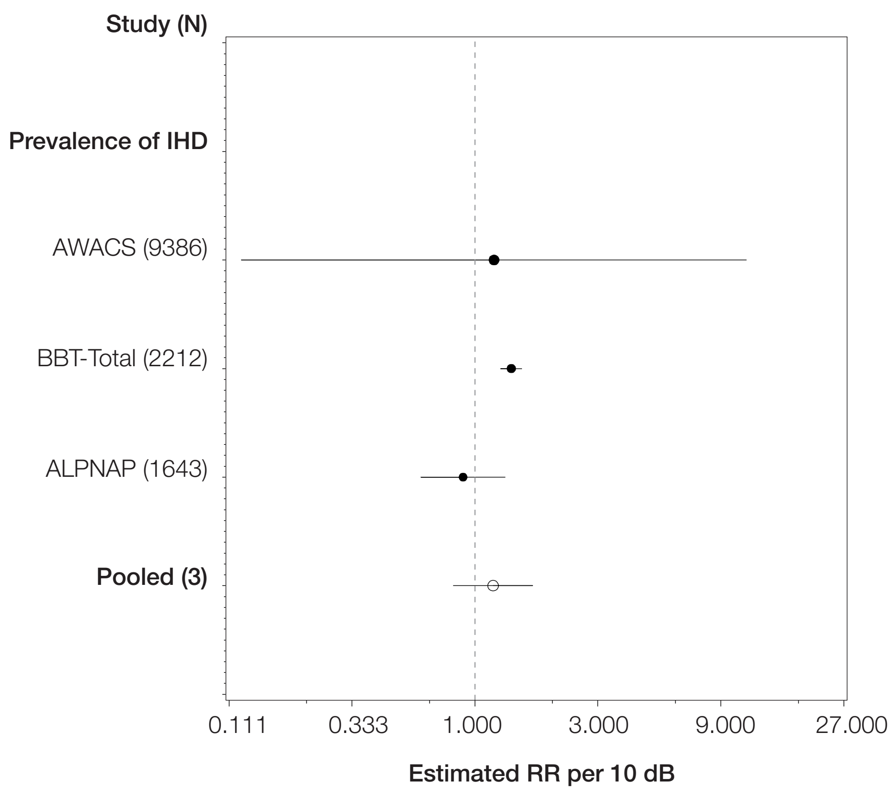
Note: [a] Results are partly derived from population-based studies.

Cardiovascular disease

IHD

No evidence was available on the relationship between railway noise and the incidence of or mortality from IHD. Four cross-sectional studies were identified, however, that assessed the prevalence of IHD in a total of 13 241 participants, including 283 cases (Heimann et al., 2007; Lercher et al., 2008; 2011; van Poll et al., 2014). The overall risk was not statistically significantly increased: the RR was 1.18 (95% CI: 0.82–1.68) per 10 dB L_{den} increase, with inconsistency across studies (see Fig. 7). The evidence was rated very low quality.

Fig. 7. The association between exposure to railway noise (L_{den}) and prevalence of IHD



Notes: The dotted vertical line corresponds to no effect of exposure to railway noise. The black circles correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the pooled random effect estimates and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

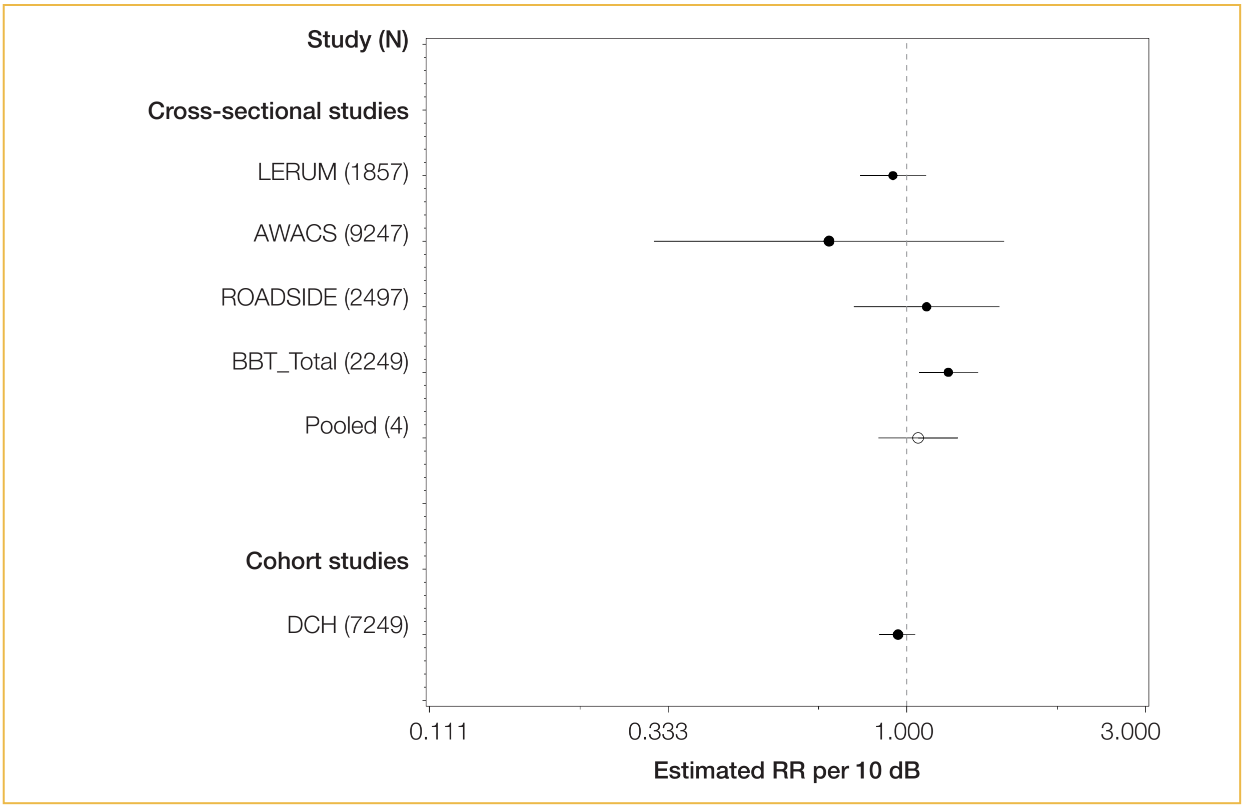
Hypertension

One cohort study on the relationship between railway noise and hypertension was identified; it assessed the incidence among people living in Denmark (Sörensen et al., 2011; 2012a). The study involved 7249 participants, including 3145 cases. The authors did not find an association between railway noise exposure and incidence of hypertension, with RR = 0.96 (95% CI: 0.88–1.04) per 10 dB L_{den} increase. This evidence was rated low quality.

In addition, five cross-sectional studies assessed the prevalence of hypertension in 15 850 participants, including 2059 cases (Barregard et al., 2009; Eriksson et al., 2012; Lercher et al., 2008; 2011; van Poll et al., 2014). The overall RR increase was not statistically significant, at 1.05 (95% CI: 0.88–1.26) per 10 dB L_{den} increase. Moreover, there was inconsistency among the results across studies. The evidence was rated very low quality.

Fig. 8 presents the studies investigating the relationship between railway noise and different measures of hypertension.

Fig. 8. The association between exposure to railway noise (L_{den}) and hypertension



Notes: The dotted vertical line corresponds to no effect of exposure to railway noise. The black dots correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the summary estimate and 95% CI.
For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Stroke

As for IHD, no evidence was available on the relationship between railway noise and incidence of or mortality from stroke. However, one cross-sectional study was identified that assessed the prevalence of stroke in 9365 participants, including 89 cases (van Poll et al., 2014). The overall risk was not statistically significantly increased, with RR = 1.07 (95% CI: 0.92–1.25) per 10 dB L_{den} increase. The evidence was rated very low quality.

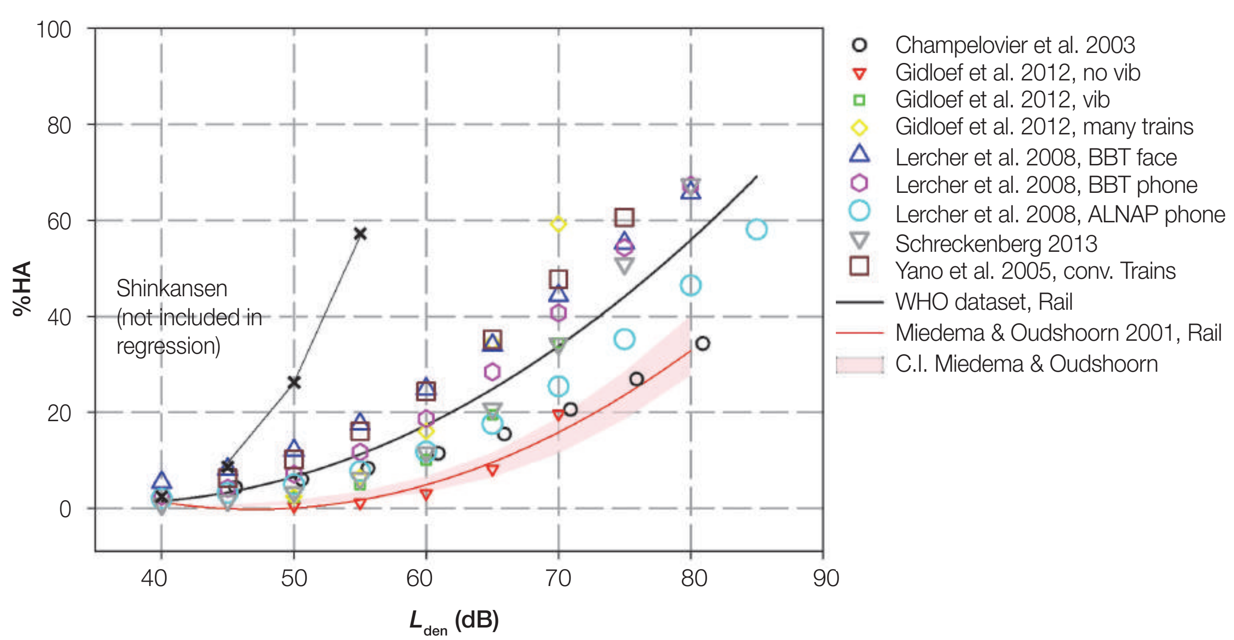
Children's blood pressure

No evidence was available for the association between railway noise and the systolic and/or diastolic blood pressure of children in residential and/or educational settings.

Annoyance

In total, 10 studies with ERFs on the association between railway noise and annoyance were included in analyses (Champelovier et al., 2003; Gidloef-Gunnarsson et al., 2012; Lercher et al., 2007; 2008; Sato et al., 2004; Schreckenberg, 2013; Yano et al., 2005; Yokoshima et al., 2008). The studies incorporated individual data from 10 970 participants. The estimated data points of each of these studies are plotted in Fig. 9, alongside an aggregated ERF including the data from all the individual studies (see the black line for "WHO dataset, Rail"). The lowest category of noise exposure considered in any of the studies, and hence included in the systematic review is 40 dB, corresponding to approximately 1.5%HA. The 10% benchmark for %HA is reached at 53.7 dB L_{den} (see Fig. 9).

Fig. 9. Scatterplot and quadratic regression of the relationship between railway noise (L_{den}) and annoyance (%HA)



Notes: The ERF by Miedema & Oudshoorn (2001) is added in red for comparison.
There is no indication of 95% CIs of the WHO dataset curve, as a weighting based on the total number of participants for each 5 dB L_{den} sound class could not be calculated; weighting based on all participants of all sound classes proved to be unsuitable. The range of data included is illustrated by the distribution of data points.
For further details on the studies included in the figure please refer to the systematic review on environmental noise and annoyance (Guski et al., 2017).

Table 20 shows the %HA for railway noise exposure. The calculations are based on the regression equation %HA = 38.1596–2.05538 × L_{den} + 0.0285 × L_{den}^2 derived from the systematic review (Guski et al., 2017). The overall evidence was rated moderate quality. Additional statistical analyses of annoyance outcomes supported these findings. When comparing railway noise exposure at 50 dB and 60 dB, the analyses revealed evidence rated moderate quality for an association between railway noise and %HA for an increase per 10 dB (OR = 3.40; 95% CI: 2.05–5.62). Moreover, evidence rated high quality was available for the increase in %HA per 10 dB increase in sound exposure, when data on all sound classes were included (OR = 3.53; 95% CI: 2.83–4.39).

Table 20. The association between exposure to railway noise (L_{den}) and annoyance (%HA)

L_{den} (dB)	%HA
40	1.5
45	3.4
50	6.6
55	11.3
60	17.4
65	25.0
70	33.9
75	44.3
80	56.1

Cognitive impairment

Studies of railway noise on children's reading and oral comprehension were lacking. Nevertheless, other measures of cognition yielded evidence rated very low quality for an association between railway noise and children with poorer performance on standardized assessment tests (Bronzaft, 1981; Bronzaft & McCarthy, 1975). Evidence for the association between railway noise and children having poorer long-term memory (Lercher et al., 2003) was rated very low quality. No studies examined effects on short-term memory.

There was no clear relation between railway noise and attention in children (Lercher et al., 2003), and this evidence was rated very low quality.

Hearing impairment and tinnitus

No studies were found, and therefore no evidence was available on the association between railway noise and hearing impairment and tinnitus.

Sleep disturbance

For railway noise and self-reported sleep outcomes (awakenings from sleep, the process of falling asleep and sleep disturbance), five studies were identified that included a total of 7133 participants (Bodin et al., 2015; Hong et al., 2010; Sato et al., 2004; Schreckenberg, 2013). The studies were cross-sectional and conducted on healthy adults. The health outcome was measured by self-reporting via general health surveys and noise surveys that included questions about sleep in general, and other questions about how noise affects sleep (Table 21).

Table 21. Summary of findings for health effects from exposure to railway noise (L_{night})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)	Quality of evidence
Effects on sleep					
L_{night}	%HSD	OR: 3.06 (95% CI: 2.38–3.93) per 10 dB increase	33 dB	7133 (5)	Moderate (downgraded for study limitations, inconsistency; upgraded for dose-response, magnitude of effect)

The model in the systematic review (Basner & McGuire, 2018) was based on outdoor L_{night} levels between 40 dB and 65 dB only; 40 dB was chosen as the lower limit because of possible inaccuracies in predicting lower noise levels. The range of noise exposure reported in the studies was 27.5–82.5 dB L_{night}. About 2% (95% CI: 0.79–3.48) of the population was characterized as highly sleep-disturbed for L_{night} levels of 40 dB. The %HSD at other, higher levels of railway noise is presented in Table 17. The association between railway noise and the probability of being sleep-disturbed was OR: 3.1 (95% CI: 2.4–3.9) per 10 dB increase in noise. This evidence was rated moderate quality.

Table 22. The association between exposure to railway noise (L_{night}) and sleep disturbance (%HSD)

L_{night} (dB)	%HSD	95% CI
40	2.1	0.79–3.48
45	3.7	1.63–5.71
50	6.3	3.12–9.37
55	10.4	5.61–15.26
60	17.0	9.48–24.37
65	26.3	15.20–37.33

Additional analyses were conducted for sleep quality measures, which provided supporting evidence on the overall relationship between railway noise and sleep. When the noise source was not specified in the question, the relationship between railway noise and self-reported sleep outcomes was still positive but no longer statistically significant, with an OR of 1.27 (95% CI: 0.89–1.81) per 10 dB increase (Bodin et al., 2015; Brink, 2011; Frei et al., 2014). This evidence was rated very low quality.

There was evidence rated moderate quality for an association between railway noise and the probability of additional awakenings, measured with polysomnography, with an OR of 1.35 (95% CI: 1.21–1.52) per 10 dB increase in indoor $L_{AS,max}$ (Elmenhorst et al., 2012). Finally, evidence rated low quality was available for an association between railway noise and sleep outcomes measured as motility in adults (Griefahn et al., 2000; Hong et al., 2006; Lercher et al., 2010; Passchier-Vermeer et al., 2007), and rated very low quality for an association between railway noise and both self-reported and motility-measured sleep disturbance in children (Ising & Ising, 2002; Lercher et al., 2013; Tiesler et al., 2013).

3.2.2.2 Evidence on interventions

This section summarizes the evidence underlying the recommendation on the effectiveness of interventions for railway noise exposure (Tables 23 and 24). The key question posed was: in the general population exposed to railway noise, are interventions effective in reducing exposure to and/or health outcomes from railway noise? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 23 and 24.

Table 23. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to railway noise

PICO	Description	
Population	**General population**	
Intervention(s)	The interventions can be defined as: (a) a measure that aims to change noise exposure and associated health effects; (b) a measure that aims to change noise exposure, with no particular evaluation of the impact on health; or (c) a measure designed to reduce health effects, but that may not include a reduction in noise exposure.	
Comparison	**No intervention**	
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes	For night noise exposure: 1. effects on sleep

Table 24. Summary of findings for railway noise interventions by health outcome

Type of intervention	Number of participants (studies)	Effect of intervention	Quality of evidence
Annoyance			
Type A – source interventions (rail grinding)	81 (1)	• Changes in noise level as a consequence of the intervention ranged from around –7dB to –8 dB. • Most studies found changes in annoyance outcomes, persisting more than 12 months after the intervention.	Very low (downgraded for study limitations, inconsistency, imprecision)
Type C – changes in infrastructure (new rail infrastructure)	6000[a] (1)	• A very small increase in total noise exposure was found (most had <+1 dB change; some had +2–4 dB change). • Original noise from road traffic overwhelmed the train noise for effectively all participants.	Very low (downgraded for study limitations, inconsistency, imprecision)
Type E – behaviour change interventions (informing the community about a noise intervention)	411 (1)	• Exposure levels were not reported; emission levels reduced by 1–2 dB. • A reduction in annoyance of the community as a result of the intervention was reported.	Very low (downgraded for study limitations, inconsistency, imprecision)

Note: [a] According to Lam & Au (2008), this records the number of invitation letters sent; the response rate was not reported.

Three studies on railway noise interventions met the criteria to be included in the evidence base. All studies consisted of a pre/post design and reported annoyance outcomes at people's dwellings (Lam & Au, 2008; Moehler et al., 1997; Schreckenberg et al., 2013). They could be categorized as a source intervention, a new/closed infrastructure intervention and a communication intervention. In two of the studies, the changes in exposure after the intervention were only small, although there were significant effects on noise annoyance. The study on source interventions and annoyance revealed that a change of –10 dB in noise exposure led to a significant reduction in annoyance, which persisted over a period of 12 months after the intervention. As confounding was not addressed, and railway noise was not the dominant sound source in the studies, the evidence was rated very low quality.

3.2.2.3 Consideration of additional contextual factors

As the foregoing overview has shown, sufficient evidence about the adverse health effects of long-term exposure to railway noise exists. Based on the quality of the available evidence, the GDG set the strength of recommendation on railway noise at strong. As a second step, it qualitatively assessed contextual factors to explore whether other considerations could have a relevant impact on the recommendation strength. These contextual considerations mainly concerned the balance of harms and benefits, values and preferences, and resource use and implementation.

When assessing the balance of harms and benefits of interventions to reduce exposure to railway noise and minimize noise-associated adverse health effects, the GDG recognized that railway transportation is the second most dominant source of environmental noise in Europe. Based on EEA estimates, the number of people exposed to L_{den} above 55 dB and L_{night} above 50 dB from railway noise is 17 million and 15 million, respectively (Blanes et al., 2017).[15] In light of the burden of disease from environmental noise, and railway noise in particular, the GDG agreed that the health benefits from a reduction of long-term railway noise exposure (especially during night time) to the recommended values would be significant. Considering possible harms related to adaptation of the recommended values, the GDG noted that reliance on railway transportation has increased in recent years in Europe and is expected to increase further, as an important component of the shift towards a greener economy. At a societal level, an environmental and economic benefit from the use of rail transportation is expected: trains contribute to lower environmental pollution and carbon emission than road transportation. Therefore, there is a need to balance the expected health benefits from reduced continuous railway noise exposure and the overall positive effects on the health of the population from increased reliance on the comparatively environmentally friendly mode of railway transportation. Overall, the GDG agreed that even though fewer people are exposed to railway noise than road traffic noise, it remains a major source of localized noise pollution; therefore, considerable benefits are gained by reducing exposure to railway noise.

When exploring values and preferences, the GDG acknowledged that, in general, people value rail as an alternative and more sustainable transportation method than air or road traffic (EEA, 2016a; 2016b; 2017b). Furthermore, the values and preferences in relation to implementation of the recommendation are expected to vary: those of individuals living in the vicinity of railway tracks are expected to differ from those of the rest of the population not exposed to railway noise on a long-term basis. Economic depreciation of housing and fear of adverse health effects were assumed

[15] These are gap-filled figures based on the reported data and including the situation both within and outside cities, as defined by the END.

to be two main aspects influencing the evaluation of affected individuals. This especially applies to areas where new railway tracks are being built, as this results in considerable change for local inhabitants. Moreover, the GDG acknowledged that preferences might also vary in the policy-making domain across different countries as the implementation of the recommendations would mean a renunciation of the so-called "railway bonus".[16]

On resource use and implementation considerations, the GDG pointed out that no comprehensive cost–benefit analysis for the WHO European Region has yet been conducted, so this assessment is based on informed qualitative expert judgement regarding the feasibility of implementing the recommendation for the majority of the population. The systematic review of environmental noise interventions and their associated impact on health shows that various measures to reduce continuous noise from railway traffic exist, although knowledge about their effectiveness remains limited (Brown & van Kamp, 2017). The GDG noted that the resources needed to implement different measures may vary considerably, as they depend on the situation and the type of intervention required. Implementation of some measures is expected to be most feasible during the development of new railway tracks; such as rail pads, bi-bloc sleepers, small noise barriers and – in extreme cases – tunnels, cuttings or earthwork barriers. Other interventions include acoustic rail grinding, noise barriers built alongside the tracks, construction of quieter locomotives and wagons and replacement of brakes on freight trains. The GDG assumed that most of these solutions could be planned as part of regular maintenance or, for instance, by speeding up fleet modernization and track modernization. Even though not broadly implemented, the solutions mentioned above have already been considered or adopted to reduce noise levels from railway noise exposure. Some EU countries (such as Germany), have programmes to replace old brake blocks from freight trains with newer, quieter ones and to ban all freight trains with old brake blocks from 2020 (Umweltbundesamt, 2017). This illustrates that solutions to achieve recommended noise levels can be implemented at a reasonable cost. Overall, the GDG agreed that the benefit of implementation of the recommendation to minimize the risk of adverse health effects due to railway noise for a majority of the population exceeds the (monetary) resources needed.

In light of the assessment of the contextual factors in addition to the quality of evidence, the recommendation remains strong.

Additional considerations or uncertainties

The GDG acknowledged that the main body of evidence for the recommendations on railway noise for average exposure was based on annoyance studies, conducted mainly in Asia and Europe. Studies are few for other priority health outcomes, and the evidence was generally rated low/very low quality. There is therefore uncertainty about the effects on health outcomes. Nevertheless, as a precautionary approach, a strong recommendation is made for average exposure to L_{den}, as a broad evidence base exists for health effects from exposure to other sources of transportation noise. However, the GDG stressed the importance of further research into health effects due to long-term exposure to railway noise.

Moreover, situational factors should be taken into account when analysing annoyance from railway noise. In particular, ground-borne vibrations are sometimes an additional exposure variable in railway

[16] The "railway bonus" is a correction factor commonly applied in the noise abatement policy domain in recent decades. It subsidizes the noise rating level for railway transportation by a predefined factor (Schuemer & Schuemer-Kohrs, 1991).

noise situations – especially in the case of annoyance – which may be difficult to separate from noise effects. In the set of 11 studies included in the systematic review on railway noise and annoyance, only two explicitly mentioned ground-borne vibrations as an additional source of annoyance.

Overall, the low-carbon, low-polluting nature of railway transport, especially using electric trains, means that rail is favoured over road and air traffic. However, night-time railway traffic on busy lines, including freight traffic, can be a significant source of sleep disturbance. Thus, guideline values should be set to encourage the development of rail traffic in Europe while at the same time giving adequate protection to residents from sleep disturbance.

3.2.3 Summary of the assessment of the strength of the recommendations

Table 25 provides a comprehensive summary of the different dimensions for the assessment of the strength of the railway noise recommendations.

Table 25. Summary of the assessment of the strength of the recommendation

Factors influencing the strength of recommendation	Decision
Quality of evidence	**Average exposure** (L_{den}) *Health effects* • Evidence for a relevant absolute risk of annoyance at **54 dB** L_{den} was rated **moderate quality.** • Evidence for a relevant RR increase of the incidence of hypertension was rated **low quality**. One study met the inclusion criteria but did not find a significant increase. *Interventions* • Evidence that different types of intervention reduce noise annoyance from railways was rated **very low quality**. **Night-time exposure** (L_{night}) *Health effects* • Evidence for a relevant absolute risk of sleep disturbance related to night noise exposure from railways at **44 dB** L_{night} was rated **moderate quality**. *Interventions* • No evidence was available on the effectiveness of interventions to reduce noise exposure and/or sleep disturbance from railway noise.
Balance of benefits versus harms and burdens	Railway noise is a major source of localized pollution. The health benefits of adapting the recommendation outweigh the harms. Nevertheless, it is important to consider the relevance of railways as an environmentally friendly mode of transportation.
Values and preferences	Quiet areas are valued by the population; especially by those affected by continuous noise exposure. Some variability is expected among those directly affected by railway noise and those not affected.
Resource implications	No comprehensive cost–effectiveness-analysis data are available, although a wide range of interventions exists, indicating that measures are both feasible and economically reasonable.
Decisions on recommendation strength	• **Strong** for guideline value for average noise exposure (L_{den}). • **Strong** for guideline value for night noise exposure (L_{night}). • **Strong** for specific interventions to reduce noise exposure.

3.3 Aircraft noise

Recommendations

For average noise exposure, the GDG **strongly** recommends reducing noise levels produced by aircraft below **45 dB** L_{den}, as aircraft noise above this level is associated with adverse health effects.

For night noise exposure, the GDG **strongly** recommends reducing noise levels produced by aircraft during night time below **40 dB** L_{night}, as aircraft noise above this level is associated with adverse effects on sleep.

To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from aircraft in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions the GDG recommends implementing suitable changes in infrastructure.

3.3.1 Rationale for the guideline levels for aircraft noise

The exposure levels were derived in accordance with the prioritization process of critical health outcomes described in section 2.4.3. For each of the outcomes, the exposure level was identified by applying the benchmark, set as relevant risk increase to the corresponding ERF. In the case of exposure to aircraft noise, the process can be summarized as follows (Table 26).

Table 26. Average exposure levels (L_{den}) for priority health outcomes from aircraft noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Incidence of IHD A relevant risk increase from exposure to aircraft noise occurs at 52.6 dB L_{den}. The weighted average of the lowest noise levels measured in the studies was 47 dB L_{den} and the corresponding RR in the meta-analysis was 1.09 per 10 dB.	5% increase of RR	Very low quality
Incidence of hypertension One study met the inclusion criteria. There was no significant increase of risk associated with increased noise exposure in this study.	10% increase of RR	Low quality
Prevalence of highly annoyed population There was an absolute risk of 10% at a noise exposure level of 45.4 dB L_{den}.	10% absolute risk	Moderate quality
Permanent hearing impairment	No increase	No studies met the inclusion criteria
Reading skills and oral comprehension in children A relevant risk increase was found at 55 dB L_{den}.	One-month delay	Moderate quality

Based on the evaluation of evidence on relevant risk increases from the prioritized health outcomes, the GDG set a guideline exposure level of 45.4 dB L_{den} for average exposure to aircraft noise, based on the absolute %HA. It was confident that there was an increased risk for annoyance below this exposure level, but probably no relevant risk increase for other priority health outcomes. In accordance with the defined rounding procedure, the value was rounded to 45 dB L_{den}. As the evidence on the adverse effects of aircraft noise was rated moderate quality, the GDG made the recommendation strong.

Next, the GDG considered the evidence for night noise exposure and its effect on sleep disturbance (Table 27).

Table 27. Night-time exposure levels (L_{night}) for priority health outcomes from aircraft noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Sleep disturbance 11% of participants were highly sleep-disturbed at a noise level of 40 dB L_{night}.	3% absolute risk	Moderate quality

Based on the evidence of the adverse effects of aircraft noise on sleep disturbance, the GDG defined a guideline exposure level of 40.0 dB L_{night}. It should be stressed that this recommendation for average aircraft noise levels at night far exceeds the benchmark of 3%HSD defined as relevant risk increase, but since no reliable acoustic data below this level were available, the GDG decided not to lower the guideline exposure level further, as an extrapolation of the exposure–response relationship to achieve these values would have been unavoidable. As the evidence was rated moderate quality, the GDG made the recommendation strong.

The GDG also considered the evidence for the effectiveness of interventions. The results showed that changes in infrastructure (opening and/or closing of runways, or flight path rearrangements) can lead to a reduction in aircraft noise exposure, as well as a decline in cognitive impairment in children and a reduction in annoyance. Moreover, examples of best practice already exist for the management of noise from aircraft, so the GDG made a strong recommendation.

3.3.1.1 Other factors influencing the strength of recommendations

Other factors considered in the context of recommendations on aircraft traffic noise included those related to values and preferences, benefits and harms, resource implications, equity, acceptability and feasibility; moreover, nonpriority health outcomes were considered. Ultimately, the assessment of all these factors did not lead to a change in the strength of the recommendations. Further details are provided in section 3.3.2.3.

3.3.2 Detailed overview of the evidence

The following sections provide a detailed overview of the evidence constituting the basis for setting the recommendations on aircraft noise. It is presented and summarized separately for each of the critical health outcomes, and the GDG's judgement of the quality of evidence is indicated (for a detailed overview of the evidence on important health outcomes, see Annex 4). Research into health outcomes and effectiveness of interventions is addressed consecutively.

A comprehensive summary of all evidence considered for each of the critical and important health outcomes can be found in the eight systematic reviews published in the *International Journal of Environmental Research and Public Health* (see section 2.3.2 and Annex 2).

3.3.2.1 Evidence on health outcomes

The key question posed was: in the general population exposed to aircraft noise, what is the exposure–response relationship between exposure to aircraft noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 28 and 29.

Table 28. PICOS/PECCOS scheme of critical health outcomes for exposure to aircraft noise

PECO	Description	
Population	General population	
Exposure	Exposure to high levels of noise produced by aircraft traffic (average/night time)	
Comparison	Exposure to lower levels of noise produced by aircraft traffic (average/night time)	
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes	For night noise exposure: 1. effects on sleep

Table 29 .Summary of findings for health effects from exposure to aircraft noise (L_{den})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)[a]	Quality of evidence
Cardiovascular disease					
L_{den}	Incidence of IHD	RR = 1.09 (95% CI: 1.04–1.15) per 10 dB increase	47 dB	9 619 082[a] (2)	Very low (downgraded for risk of bias; upgraded for dose-response)
L_{den}	Incidence of hypertension	RR = 1.00 (95% CI: 0.77–1.30) per 10 dB increase	N/A	4712 (1)	Low (downgraded for risk of bias and because only one study available)
Annoyance					
L_{den}	%HA	OR = 4.78 (95% CI: 2.27–10.05) per 10 dB increase	33 dB	17 094 (12)	Moderate (downgraded for inconsistency)
Cognitive impairment					
L_{den}	Reading and oral comprehension	1–2-month delay per 5 dB increase	Around 55 dB	(4)	Moderate (downgraded for inconsistency)
Hearing impairment and tinnitus					
L_{den}	Permanent hearing impairment	–	–	–	–

Note: [a] Results are partly derived from population-based studies.

Cardiovascular disease

IHD

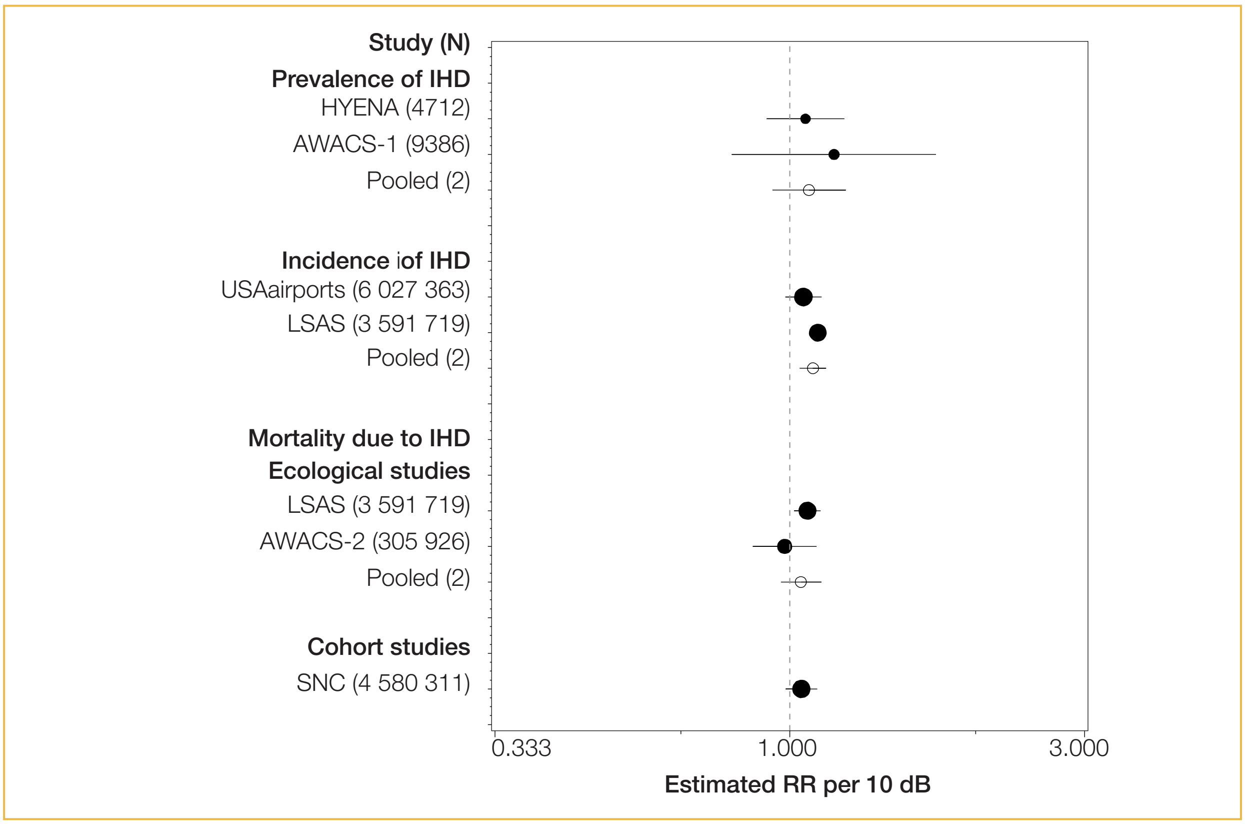
No cohort or case-control studies on the relationship between aircraft noise and IHD are available. However, two ecological studies were identified that provide information on the relationship between aircraft noise and incidence (hospital admission) of IHD (Correia et al., 2013; Hansell et al., 2013). These involved a total of 9 619 082 participants, including 158 977 cases. The RR was 1.09 (95% CI: 1.04–1.15) per 10 dB L_{den} increase, and the lowest exposure range was ≤51 dB and <45 dB. Given the weights in the meta-analysis of these two studies, the weighted average starting level was calculated as 47 dB. The evidence was rated very low quality.

Two cross-sectional studies were identified that assessed the prevalence of IHD in people living in cities located around airports in Europe. The studies involved 14 098 participants, including 340 cases (Babisch et al., 2005b; 2008; 2012a; 2012b; 2013a; Floud et al., 2011; 2013a; 2013b; Jarup et al., 2005; 2008; van Poll et al., 2014). The overall risk was RR = 1.07 (95% CI: 0.94–1.23) per 10 dB L_{den} increase. The evidence was rated low quality.

With regard to the relationship between aircraft noise and mortality due to IHD, one cohort study (Huss et al., 2010) and two ecological studies (Hansell et al., 2013; van Poll et al., 2014) were identified. The cohort study identified 4 580 311 participants, including 15 532 cases, living in Switzerland, and the authors found an RR of 1.04 (95% CI: 0.98–1.11) per 10 dB L_{den} increase in noise. The evidence was rated low quality. The two ecological studies identified a total of 3 897 645 participants, including 26 066 cases in the Netherlands and the United Kingdom. The overall RR was 1.04 (95% CI: 0.97–1.12) per 10 dB L_{den} increase in noise, and the evidence was rated very low quality.

Fig. 10 summarizes the results for the relationship between aircraft noise and different measures of IHD.

Fig. 10. The association between exposure to aircraft noise (L_{den}) and IHD



Notes: The dotted vertical line corresponds to no effect of exposure to aircraft noise. The black circles correspond to the estimated RR per 10 dB and 95% CI. The white circles represent the pooled random effect estimates and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

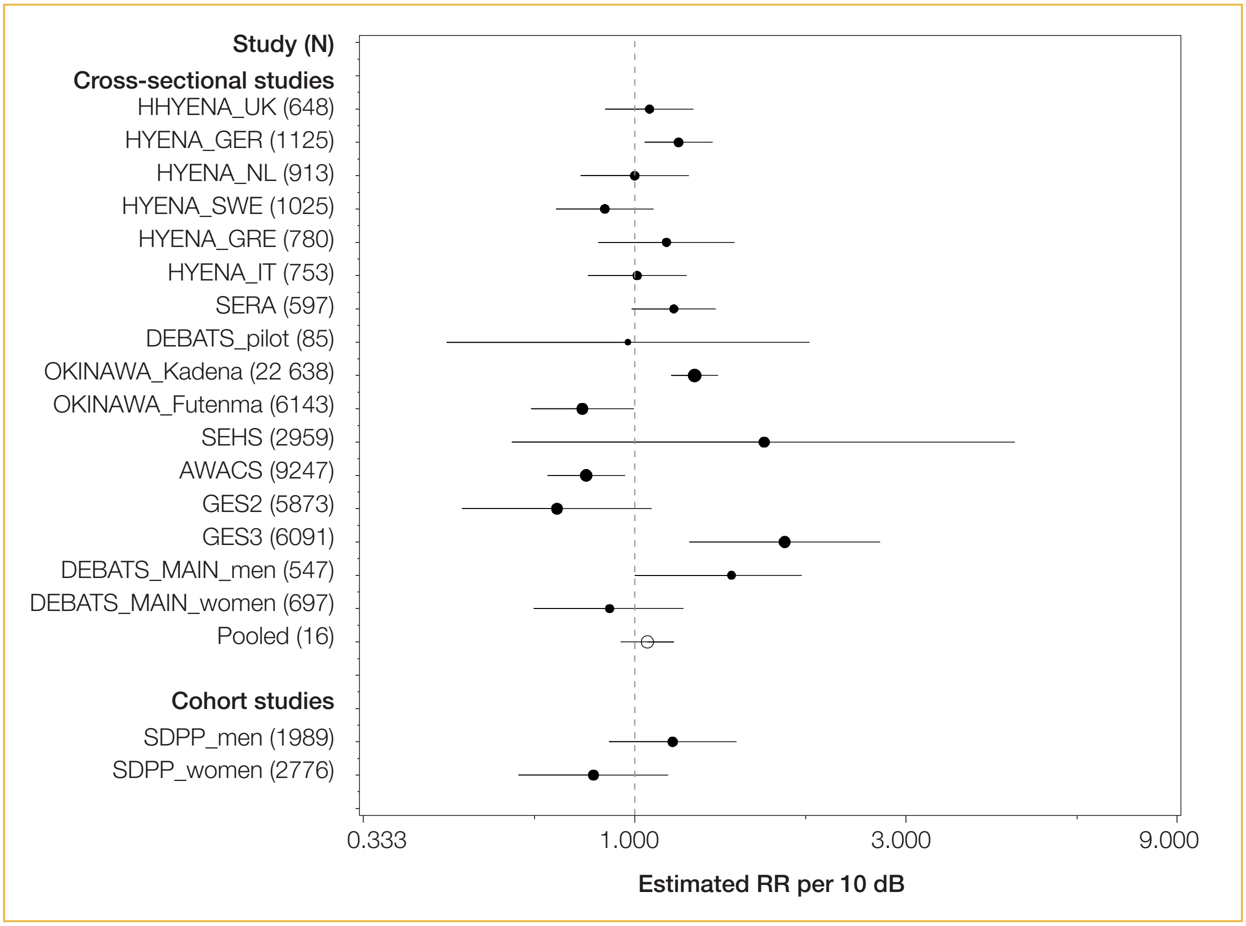
Hypertension

One cohort study was identified that assessed the relationship between aircraft noise and hypertension in people living in Sweden (Bluhm et al., 2004; 2009; Eriksson et al., 2007; 2010). The study involved 4712 participants, including 1346 cases. The authors found a nonstatistically significant effect size of RR = 1.00 (95% CI: 0.77–1.30) per 10 dB L_{den} increase. This evidence was rated moderate quality.

Furthermore, nine cross-sectional studies assessed the prevalence of hypertension in 60 121 participants, including 9487 cases (Ancona et al., 2010; Babisch et al., 2005b; 2008; 2012a; 2012b; 2013a; Breugelmans et al., 2004; Evrard et al., 2013; 2015; Houthuijs & van Wiechen, 2006; Jarup et al., 2005; 2008; Matsui, 2013; Matsui et al., 2001; 2004; Rosenlund et al., 2001; van Kamp et al., 2006; van Poll et al., 2014). The overall RR was 1.05 (95% CI: 0.95–1.17) per 10 dB L_{den} increase, with inconsistency across studies. The evidence was rated low quality.

Fig. 11 summarizes the results for both prevalence and incidence of hypertension.

Fig. 11. The association between exposure to aircraft noise (L_{den}) and hypertension in cross-sectional and cohort studies



Notes: The dotted vertical line corresponds to no effect of aircraft noise exposure. The black dots correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the pooled summary estimate and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Stroke

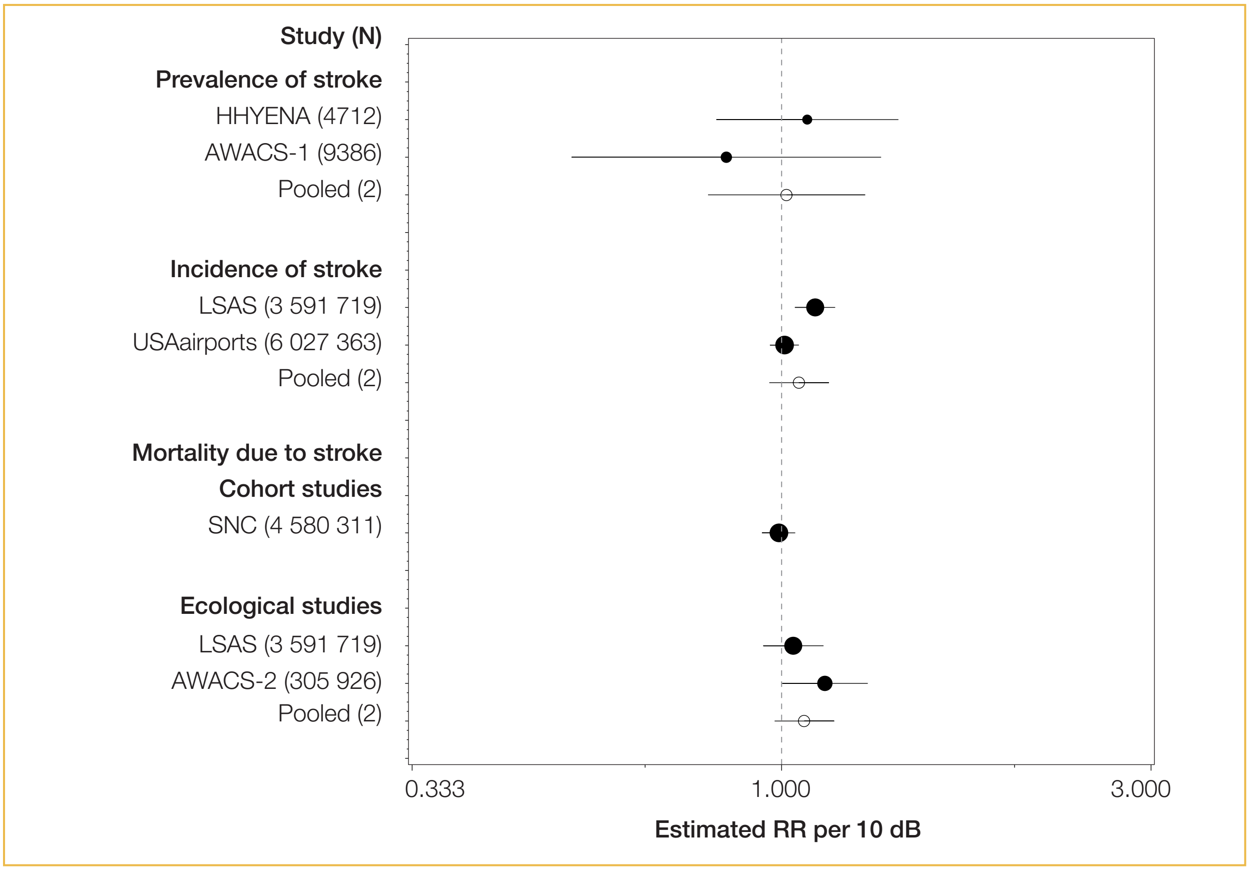
No cohort or case-control studies on the relationship between aircraft noise and incidence (hospital admission) of stroke were available, but two ecological studies were conducted in cities around airports in the United Kingdom and United States of America, involving 9 619 082 participants, including 97 949 cases (Correia et al., 2013; Hansell et al., 2013). An overall RR of 1.05 (95% CI: 0.96–1.15) per 10 dB L_{den} increase in noise was found. The evidence was rated very low quality.

Two cross-sectional studies were identified that assessed the prevalence of stroke in 14 098 participants, including 151 cases (Babisch et al., 2005b; 2008; 2012a; 2012b; 2013a; Floud et al., 2011; 2013a; 2013b; Jarup et al., 2005; 2008; van Poll et al., 2014). The overall RR was 1.02 (95% CI: 0.80–1.28) per 10 dB L_{den} increase. The evidence was rated very low quality.

On the relationship between aircraft noise and mortality due to stroke, one cohort study (Huss et al., 2010) and two ecological studies (Hansell et al., 2013; van Poll et al., 2014) were identified. The cohort study identified 4 580 311 participants, including 25 231 cases, living in Switzerland; the authors found an RR of 0.99 (95% CI: 0.94–1.04) per 10 dB L_{den} increase in noise. The overall evidence was rated moderate quality. The two ecological studies identified a total of 3 897 645 participants, including 12 086 cases, in the Netherlands and the United Kingdom. The overall RR was 1.07 (95% CI: 0.98–1.17) per 10 dB L_{den} increase in noise. The evidence was rated very low quality.

Fig. 12 summarizes the results for the relationship between aircraft noise and different measures of stroke.

Fig. 12. The association between exposure to aircraft noise (L_{den}) and stroke



Notes: The dotted vertical line corresponds to no effect of exposure to aircraft noise. The black dots correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the summary estimate and 95% CI.
For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

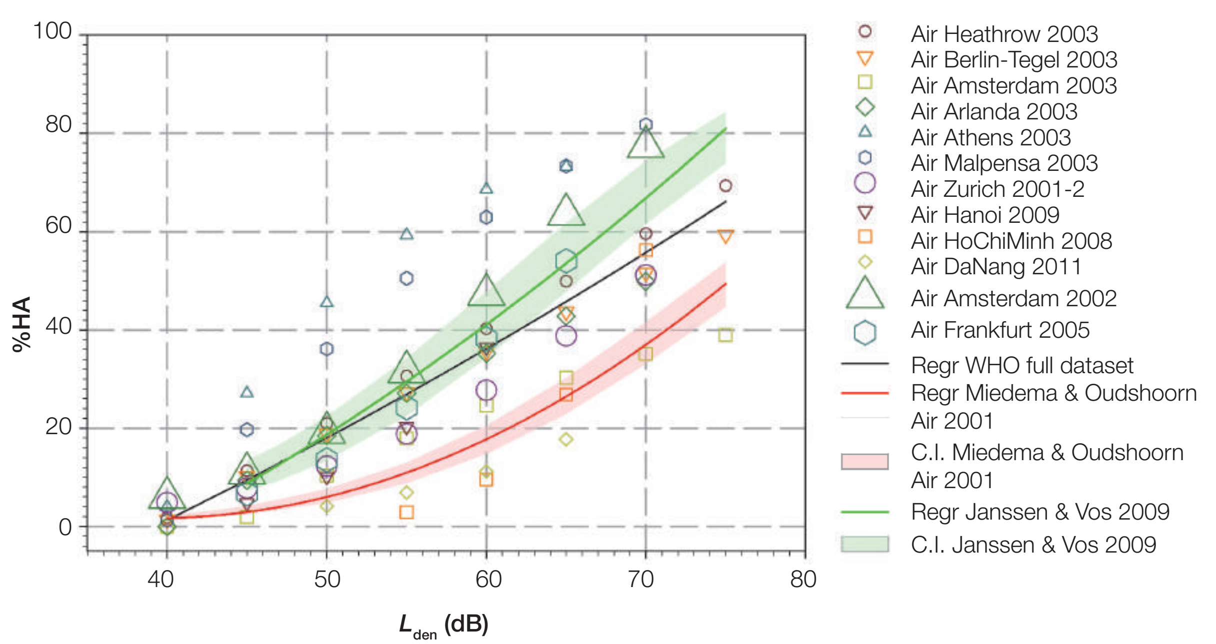
Children's blood pressure

For the association between aircraft noise and blood pressure in children, two cross-sectional studies were conducted in Australia, the Netherlands and the United Kingdom, including a total of 2013 participants (Clark et al., 2012; Morrell et al., 1998; 2000; van Kempen et al., 2006). The change in both systolic and diastolic blood pressure was assessed, in residential and/or educational settings. There was serious inconsistency in the results and therefore no overall estimate of the effect was developed. The evidence was rated very low quality.

Annoyance

A vast amount of evidence proves the association between aircraft noise and annoyance. In total, 12 aircraft noise studies were identified that were used to model ERFs of the relationship between L_{den} and %HA (Babisch et al., 2009; Bartels et al., 2013; Breugelmans et al., 2004; Brink et al., 2008; Gelderblom et al., 2014; Nguyen et al., 2011; 2012a; 2012b; Sato & Yano, 2011; Schreckenberg & Meis, 2007). These include data from 17 094 study participants. The estimated data points of each of the studies are plotted in Fig. 13, alongside an aggregated ERF including the data from all the individual studies (see the black line for "Regr WHO full dataset"). The lowest category of noise exposure considered in any of the studies, and hence included in the systematic review, is 40 dB, corresponding to approximately 1.2%HA. The benchmark level of 10%HA is reached at approximately 45 dB L_{den} (see Fig. 13).

Fig. 13. Scatterplot and quadratic regression of the relationship between aircraft noise (L_{den}) and annoyance (%HA)



Notes: ERFs by Miedema & Oudshoorn (2001, red), and Janssen & Vos (2009, green) are added for comparison. There is no indication of 95% CIs of the WHO dataset curve, as a weighting based on the total number of participants for each 5 dB L_{den} sound class could not be calculated; weighting based on all participants of all sound classes proved to be unsuitable. The range of data included is illustrated by the distribution of data points. For further details on the studies included in the figure please refer to the systematic review on environmental noise and annoyance (Guski et al., 2017).

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Table 30 shows the %HA in relation to exposure to aircraft traffic noise. It is based on the regression equation %HA = −50.9693 + 1.0168 × L_{den} + 0.0072 × L_{den}^{2} derived from the systematic review (Guski et al., 2017). As the majority of the studies are cross-sectional, the evidence was rated moderate quality.

The general quality of the evidence was further substantiated with the help of additional statistical analyses that apply classical health outcome measures to estimate noise annoyance. When comparing aircraft noise exposure at 50 dB and 60 dB, the analyses revealed evidence rated high quality for an association between aircraft noise and %HA for an increase per 10 dB (OR = 3.40; 95% CI: 2.42–4.80). Moreover, there was evidence rated high quality for the increase of %HA per 10 dB increase in sound exposure, when data on all sound classes were included (OR = 4.78; 95% CI: 2.27–10.05).

Table 30. The association between exposure to aircraft noise (L_{den}) and annoyance (%HA)

L_{den} (dB)	%HA
40	1.2
45	9.4
50	17.9
55	26.7
60	36.0
65	45.5
70	55.5

Cognitive impairment

Evidence rated moderate quality was available for an association between aircraft noise and reading and oral comprehension, assessed by standardized tests. This is based on a narrative review of 14 studies that examined aircraft noise exposure effects on reading and oral comprehension (Clark et al., 2006; 2012; 2013; Evans & Maxwell, 1997; Haines et al., 2001a; 2001b; 2001c; Hygge et al., 2002; Klatte et al., 2014; Matsui et al., 2004; Seabi et al., 2012; 2013; Stansfeld et al., 2005; 2010). Of these studies, 10 were cross-sectional, and only four had a longitudinal and/or intervention design (Clark et al., 2013; Haines et al., 2001c; Hygge et al., 2002; Seabi et al., 2013). Most of the studies (10 of 14) demonstrated a statistically significant association or at least demonstrated a trend between higher aircraft noise exposure and poorer reading comprehension.

This relationship is supported by evidence on other health outcome measures related to cognition. Evidence rated moderate quality was available for an association between aircraft noise and children with poorer performance on standardized assessment tests (Eagan et al., 2004; FICAN, 2007; Green et al., 1982; Sharp et al., 2014). There was also evidence rated moderate quality on aircraft noise being associated with children having poorer long-term memory (Haines et al., 2001b). No studies examined the effects on short-term memory.

However, there was no substantial effect (evidence rated low quality) of aircraft noise on children's attention (Haines et al., 2001a; Hygge et al., 2002; Matsui et al., 2004; Stansfeld et al., 2005; 2010), or on executive function (working memory) (evidence rated very low quality), with studies consistently suggesting no association for aircraft noise (Clark et al., 2012; Haines et al., 2001a;

Haines et al., 2001b; Klatte et al., 2014; Matheson et al., 2010; Stansfeld et al., 2005; 2010; van Kempen et al., 2010; 2012).

Hearing impairment and tinnitus

No studies were found, and therefore no evidence was available on the association between aircraft noise and hearing impairment and tinnitus.

Sleep disturbance

For aircraft noise and self-reported sleep outcomes, six studies were identified that included a total of 6371 participants (Nguyen et al., 2009; 2010; 2011; 2012c; 2015; Schreckenberg et al., 2009; Yano et al., 2015). The majority of studies were cross-sectional by design and were conducted in otherwise healthy adults. The model was based on outdoor L_{night} levels between 40 dB and 65 dB only; the lower limit of 40 dB was set because of inaccuracies in predicting lower noise levels (Table 31).

Table 31. Summary of findings for health effects from exposure to aircraft noise (L_{night})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)	Quality of evidence
Effects on sleep					
L_{night}	%HSD	OR: 1.94 (95% CI: 1.61–2.33) per 10 dB increase	35 dB	6371 (6)	Moderate (downgraded for study limitations, inconsistency; upgraded for dose-response, magnitude of effect)

The range of noise exposure reported in studies was 37.5–62.5 dB. Over 11% (95% CI: 4.72–17.81) of the population was characterized as highly sleep-disturbed at L_{night} levels of 40 dB. The %HSD at other, higher levels of aircraft noise is presented in Table 27. The table is derived from the regression model in the systematic review specified as %HSD = 16.79–0.9293 × L_{night} + 0.0198 × L_{night}^2. The health outcome was measured in the studies by self-reporting, focusing on questions asking about awakenings from sleep, the process of falling asleep and/or sleep disturbance, where the question referred specifically to how noise affects sleep. The same relationship between aircraft noise and reporting being sleep-disturbed (all questions combined) can also be expressed as an OR of 1.94 (95% CI: 1.61–2.33) per 10 dB increase in noise. This evidence was rated moderate quality.

Table 32. The association between exposure to aircraft noise (L_{night}) and sleep disturbance (%HSD)

L_{night}	%HSD	95% CI
40	11.3	4.72–17.81
45	15.0	6.95–23.08
50	19.7	9.87–29.60
55	25.5	13.57–37.41
60	32.3	18.15–46.36
65	40.0	23.65–56.05

Additional analyses were included in the systematic review and provided supporting evidence on the association between aircraft noise and sleep. When the noise source was not specified in the survey question, the relationship between aircraft noise and self-reported sleep outcomes was still positive, although no longer statistically significant (OR: 1.17 (95% CI: 0.54–2.53) per 10 dB increase) (Brink, 2011). This evidence was rated very low quality.

Further, there was evidence rated moderate quality for an association between aircraft noise and polysomnography-measured outcomes (probability of additional awakenings), with an OR of 1.35 (95% CI: 1.22–1.50) per 10 dB increase in indoor $L_{AS,max}$ (Basner et al., 2006). Evidence rated low quality was also available for an association between aircraft noise and motility-measured sleep outcomes in adults (Passchier-Vermeer et al., 2002).

3.3.2.2 Evidence on interventions

The following section summarizes the evidence underlying the recommendation on the effectiveness of interventions for aircraft noise exposure. The key question posed was: in the general population exposed to aircraft noise, are interventions effective in reducing exposure to and/or health outcomes from aircraft noise? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 33 and 34.

Seven studies examining different types of interventions on aircraft noise met the inclusion criteria to become part of the evidence base of the systematic review. Six of these investigated infrastructure interventions (Breugelmans et al., 2007; Brink et al., 2008; Fidell et al., 2002; Hygge et al., 2002), and one assessed a path intervention (Asensio et al., 2014). The majority of studies focused on annoyance as a health outcome, but two also included effects on sleep and one investigated the effects of path interventions on cognitive development in children.

Table 33. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to aircraft noise

PICO	Description	
Population	**General population**	
Intervention(s)	The interventions can be defined as: (a) a measure that aims to change noise exposure and associated health effects; (b) a measure that aims to change noise exposure, with no particular evaluation of the impact on health; or (c) a measure designed to reduce health effects, but that may not include a reduction in noise exposure.	
Comparison	**No intervention**	
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes	For night noise exposure: 1. effects on sleep

Table 34. Summary of findings for aircraft noise interventions by health outcome

Type of intervention	Number of participants (studies)	Effect of intervention	Quality of evidence
Annoyance			
Type B – path interventions (retrofitting dwellings close to airports with acoustic insulation)	689 (1)	• Change in noise levels was not reported. • The study found a drop in annoyance following the insulation intervention	Very low (downgraded for study limitations, inconsistency, precision)
Type C – changes in infrastructure (opening and/or closing of runways, or flight path rearrangements)	2101 (3)	• There was a wide range of changes in noise levels (from –12 dB to +13.7 dB; most between ±1 dB and 2 dB; different noise indicators used). • All studies found changes in annoyance outcomes as a result of the intervention.	Moderate (downgraded for study limitations; upgraded for dose-response)
Sleep disturbance			
Type C – changes in infrastructure (flight path changes)	1707 (2)	• Changes in noise levels were mostly between ±1 dB and 2 dB. • Both studies found changes in sleep disturbance outcomes as a result of the intervention.	Low (downgraded for study limitations)
Cognitive development of children			
Type C – changes in infrastructure (opening and/or closing of runways, or flight path rearrangements)	326 (1)	• Changes in noise levels of +9 dB at the new airport and of –14 dB at the old airport were reported. • The study found various cognitive effects on children (for both the reduction and the increase in exposure). Effects disappeared when the old airport closed, emerging after the new airport opened.	Moderate (downgraded for inconsistency)

The largest body of research concentrated on the opening and closing of runways, leading to subsequent changes in flight paths (Breugelmans et al., 2007; Brink et al., 2008; Fidell et al., 2002). It showed that changes in noise exposure as a consequence of rearrangement of flight paths, step changes or increase or removal of over-flights resulted in statistically significant changes of the annoyance ratings of residents living in the vicinity of airports. The studies investigated both increases and reductions in exposure. Moreover, all the studies provided evidence that the change in response to noise exposure was an excess response to the intervention. As all the studies either adjusted for confounding or ruled out confounding by design, and the risk of bias was high in two studies but low in one, the evidence was rated moderate quality.

Two of these studies also investigated the effects of interventions on sleep disturbance. The results indicated that the percentage of sleep disturbance changed in association with the change in noise exposure caused by flight path adaptations (Breugelmans et al., 2007; Fidell et al., 2002). Both studies adjusted for confounding, but the risk of bias was assessed as high. Thus, the evidence was rated low quality.

One study examined the impact of rearranging flight paths on the cognitive effects on children (Hygge et al., 2002), showing various effects (for both the reduction and the increase in exposure).

The study ruled out confounding by study design and the risk of bias was assessed as low. The evidence was therefore rated moderate quality.

Alongside infrastructure interventions, a Spanish study presented evidence on path interventions (Asensio et al., 2014), showing a drop in annoyance following an insulation intervention. The study did not control for confounding and the risk of bias was assessed as high. The evidence was therefore rated very low quality.

3.3.2.3 Consideration of additional contextual factors

As the foregoing overview has shown, substantial evidence about the adverse health effects of long-term exposure to aircraft noise exists. Based on the quality of the available evidence, the GDG set the strength of the recommendation of aircraft noise at strong. As a second step, it qualitatively assessed contextual factors to explore whether other considerations could have a relevant impact on the recommendation strength. These considerations mainly concerned the balance of harms and benefits, values and preferences, equity, and resource use and implementation.

When assessing the balance of harms and benefits from implementing the recommendations on aircraft exposure, the GDG acknowledged that the number of people affected was lower than for road traffic or railway noise, since aircraft noise only affects the areas surrounding airports and under flight paths. Data from the EEA show that the estimated number of people in Europe exposed to L_{den} levels above 55 dB and L_{night} levels above 50 dB is 3 million and 1.2 million, respectively (Blanes et al., 2017).[17] Nevertheless, it remains a major source of localized noise pollution and has been predicted to increase (EASA et al., 2016). Furthermore, aircraft noise is regarded as more annoying than the other sources of transportation noise (Schreckenberg et al., 2015; Miedema & Oudshoorn, 2001); it is therefore associated with a significant burden on public health, and the GDG expects substantial health benefits for the population to evolve from implementing the recommendations to reduce exposure to aircraft traffic noise. Furthermore, the GDG noted that, depending on the intervention measure implemented (such as a night flight ban), additional health benefits could evolve, resulting from a simultaneous reduction in air pollution (EC, 2016a). The GDG also acknowledged that intervention measures like night flight bans might also reduce carbon emission, thereby positively influencing the shift towards a greener and more sustainable economy. Possible harms in relation to the applied noise abatement strategy, on the other hand, could include effects on the transportation of goods, as well as individual mobility of the population. Both could have impacts on local, national and international economies. Overall, the GDG estimated that the benefits gained from minimizing adverse health effects due to aircraft noise exposure outweigh the possible (economic) harms.

Considering values and preferences, the GDG noted that negative attitudes towards aircraft noise are especially prevalent in affected individuals who can see and hear aircraft from their house, or who fear that living in proximity of airports will have an impact on their health (Schreckenberg et al., 2015) or property value (economic loss) (Bristow et al., 2014). A lack of trust in the airport and government authorities can enhance these negative attitudes towards airports and aircraft noise (Borsky, 1979; Schreckenberg, 2017). Furthermore, the GDG recognized that values and preferences of individuals living in the vicinity of different airports may vary, as the infrastructural characteristics

[17] These are gap-filled figures based on the reported data and including the situation both within and outside cities, as defined by the END.

of airports have a significant effect on the evaluation of residents. Airports with a stable number of aircraft movements in the near past and no intention to change the number in the future can give rise to a different evaluation of values and preferences than airports with relatively sustained increases in the number of aircraft movements. This can result from the fact that opening new runways or increasing the number of flights usually means considerable change in the environment for inhabitants of the affected area. It has been postulated that the change of exposure itself may be an annoying factor, and this may explain why aircraft noise annoyance is generally higher than that for other sources of transportation noise at a comparable noise level (Brown & van Kamp, 2009). The GDG acknowledged that, in general, air travel is an important means of transportation relevant for businesses, the public and the economy. In Europe, aviation is projected to be the fastest-growing sector from passenger transport demand, by 2050 (EEA, 2016a). The general population tends to value the convenience of travel by air. Moreover, the GDG pointed out that exposure to aircraft noise is not equally distributed throughout society. The preferences of people living in the vicinity of airports are expected to differ from those of the general population that does not experience the same noise burden. This might facilitate variance in the values and preference of the population, as those benefiting from the services and revenues generated by an airport may regard noise reduction measures as an additional, unnecessary extra cost, while those living around an airport and affected by aircraft noise may be in favour of noise reductions, since this concerns their health and well-being. Despite these differences, however, the GDG was confident that a majority of the population would value the minimization of adverse health effects and therefor welcome the implementation of the recommendations.

Regarding the dimension of equity, the GDG highlighted that the risk of exposure to aircraft noise is not equally distributed throughout society. Members of society with a lower socioeconomic status and other disadvantaged groups often live in more polluted and louder areas, including in close proximity to airports (EC, 2016a). In addition to the increased risk of exposure to environmental noise, socioeconomic factors are also associated with increased vulnerability and poorer coping capacities (Karpati et al., 2002).

With resource use and implementation considerations, the GDG acknowledged that the economic evaluation of the health impacts of environmental noise is most elaborate and extensive for aircraft noise (Berry & Sanchez, 2014). Nevertheless, no comprehensive cost–benefit analysis for the WHO European Region yet exists, so this assessment is based on informed qualitative expert judgement regarding the feasibility of implementing the recommendation for the majority of the population. The systematic review of interventions and their associated impact on environmental noise and health shows that various measures to reduce continuous noise from aircraft exist. Moreover, the quality of the evidence was judged to be moderate (Brown & van Kamp, 2017). The GDG noted that the resources needed to implement different intervention measures may vary considerably, because they depend on the situation and the type of intervention required. The distribution of costs also differs from that for other modes of transportation, since exposure to aircraft noise is localized in a more agglomerated way, and overall the population affected is smaller compared to other modes of transportation. The GDG furthermore recognized that multiple cost-effective intervention strategies exist (EC, 2016b). Prohibition or discouragement strategies against citizens moving to the direct proximity of airports, for example, can be implemented in the context of urban planning. Likewise, diverting flight paths above less-populated areas can lead to a reduction in exposure. In principle, such intervention measures do not involve any direct costs, although safety concerns may limit the feasibility of these strategies. Passive noise abatement measures like the installation of soundproof windows at the dwelling were also regarded as feasible and economically reasonable by the GDG, as these are implemented at several airports already. In relation to active abatement measures, the GDG acknowledged the "balanced approach" elaborated by International Civil Aviation Organization, which states that noise reduction should take place first at the source. As indicated by the Clean Sky Programme, this could, for example, entail shifting towards the introduction of new aircraft. This broad European research programme estimates that, depending on type, the shift to newly produced aircraft could lead to a reduction of approximately 55–79% of the area affected by aircraft noise, and consequently the population exposed. As this solution has been put forward by the aviation sector, it is considered feasible. Overall, this indicates that solutions to achieve recommended noise levels can be implemented and at reasonable costs. The GDG agreed that implementation of the recommendation to minimize the risk of adverse health effects due to aircraft noise for a majority of the population would require a reasonable amount of (monetary) resources. It noted, however, that the feasibility of implementing the measures could be hindered by the fact that costs and benefits are not equally distributed. In most cases, the health benefits citizens gain from interventions that reduce aircraft exposure are borne by private companies and public authorities.

In light of the assessment of the contextual factors in addition to the quality of evidence, the recommendation remains strong.

Other nonpriority adverse health outcomes

Although not a priority health outcome and coming from a single study, the GDG noted the evidence rated moderate quality for the statistically significant association between aircraft noise and the change in waist circumference (Eriksson et al., 2014). The range of noise levels in the study identified was 48 to 65 dB L_{den}, and therefore the recommendation would also be protective enough for this health outcome.

In the context of aircraft noise, when considering the impacts of exposure on cognitive impairment in children, these guideline recommendations also apply particularly to the school setting. Noise exposure at primary school and at home is often highly correlated; however, the evidence base considered comes mainly from studies designed around sampling at school and not residences.

Additional considerations or uncertainties

There is additional uncertainty when characterizing exposure using the acoustical description of aircraft noise by means of L_{den} or L_{night}. Use of these average noise indicators may limit the ability to observe associations between exposure to aircraft noise and some health outcomes (such as awakening reactions); as such, noise indicators based on the number of events (such as the frequency distribution of $L_{A,max}$) may be better suited. However, such indicators are not widely used.

The GDG acknowledged that the guideline recommendation for L_{night} may not be fully protective of health, as it implies that around 11% (95% CI: 4.72–17.81) of the population may be characterized as highly sleep-disturbed at the recommended L_{night} level. This is higher than the 3% absolute risk considered for setting the guideline level. However, the high calculation uncertainty in predicting noise levels lower than 40 dB prevented the GDG from recommending a lower level. Furthermore, lower levels would probably require a ban on night or early morning flights altogether, which is not feasible in many situations, given that the general population tends to value the convenience of air travel.

3.3.3 Summary of the assessment of the strength of recommendation

Table 35 provides a comprehensive summary of the different dimensions for the assessment of the strength of the aircraft noise recommendations.

Table 35. Summary of the assessment of the strength of the recommendation

Factors influencing the strength of recommendation	Decision
Quality of evidence	**Average exposure (L_{den})** *Health effects* • Evidence for a relevant RR increase of the incidence of IHD at **52 dB** L_{den} was rated **very low quality.** • Evidence for a relevant RR increase of the incidence of hypertension was rated **low quality**. • Evidence for a relevant absolute risk of annoyance at **45 dB** L_{den} was rated **moderate quality**. • Evidence for a relevant RR increase of impaired reading and oral comprehension at **55 dB** L_{den} was rated **moderate quality**. *Interventions* • Evidence on effectiveness of interventions to reduce noise exposure and/or health outcomes from aircraft noise was of varying quality. **Night-time exposure (L_{night})** *Health effects* • Evidence for a relevant absolute risk of sleep disturbance related to night noise exposure from aircraft at **40 dB** L_{night} was rated **moderate quality**. *Interventions* • Evidence on effectiveness of changes in infrastructure (flight path changes) to reduce sleep disturbance from aircraft noise was rated **low quality**.
Balance of benefits versus harms and burdens	Aircraft noise is a major source of localized noise pollution. The health benefits of adapting the recommendations are expected to outweigh the harms.
Values and preferences	Quiet areas are valued by the population, especially by those affected by continuous aircraft noise exposure. Some variability is expected among those directly affected by aircraft noise and those not affected.
Equity	Risk of exposure to aircraft noise is not equally distributed.
Resource implications	No comprehensive cost–effectiveness analysis data are available; nevertheless, a wide variety of interventions exist (some at very low cost), indicating that measures are both feasible and economically reasonable.
Decisions on recommendation strength	• **Strong** for guideline value for average noise exposure (L_{den}) • **Strong** for guideline value for night noise exposure (L_{night}) • **Strong** for specific interventions to reduce noise exposure

3.4 Wind turbine noise

Recommendations

For average noise exposure, the GDG **conditionally** recommends reducing noise levels produced by wind turbines below **45 dB** L_{den}, as wind turbine noise above this level is associated with adverse health effects.

To reduce health effects, the GDG **conditionally** recommends that policy-makers implement suitable measures to reduce noise exposure from wind turbines in the population exposed to levels above the guideline values for average noise exposure. No evidence is available, however, to facilitate the recommendation of one particular type of intervention over another.

3.4.1 Rationale for the guideline levels for wind turbine noise

The exposure levels were derived in accordance with the prioritizing process of critical health outcomes described in section 2.4.3. For each of the outcomes, the exposure level was identified by applying the benchmark, set as relevant risk increase to the corresponding ERF. In the case of exposure to wind turbine noise, the process can be summarized as follows (Table 36).

Table 36. Average exposure levels (L_{den}) for priority health outcomes from wind turbine noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Incidence of IHD Incidence of IHD could not be used to assess the exposure level.	5% increase of RR	No studies were available
Incidence of hypertension Incidence of hypertension could not be used to assess the exposure level.	10% increase of RR	No studies were available
Prevalence of highly annoyed population Four studies were available. An exposure–response curve of the four studies revealed an absolute risk of 10%HA (outdoors) at a noise exposure level of 45 dB L_{den}.	10% absolute risk	Low quality
Permanent hearing impairment	No increase	No studies were available
Reading skills and oral comprehension in children	One-month delay	No studies were available

In accordance with the prioritization process, the GDG set a guideline exposure level of 45.0 dB L_{den} for average exposure, based on the relevant increase of the absolute %HA. The GDG stressed that there might be an increased risk for annoyance below this noise exposure level, but it could not state whether there was an increased risk for the other health outcomes below this level owing to a lack of evidence. As the evidence on the adverse effects of wind turbine noise was rated low quality, the GDG made the recommendation conditional.

Next, the GDG considered the evidence for night noise exposure to wind turbine noise and its effect on sleep disturbance (Table 37).

Table 37. Night-time exposure levels (L_{night}) for priority health outcomes from wind turbine noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Sleep disturbance Six studies were available; they did not reveal consistent results about effects of wind turbine noise on sleep.	3% absolute risk	Low quality

Based on the low quantity and heterogeneous nature of the evidence, the GDG was not able to formulate a recommendation addressing sleep disturbance due to wind turbine noise at night time.

The GDG also looked for evidence about the effectiveness of interventions for wind turbine noise exposure. Owing to a lack of research, however, no studies were available on existing interventions and associated costs to reduce wind turbine noise.

Based on this assessment, the GDG therefore provided a conditional recommendation for average noise exposure (L_{den}) to wind turbines and a conditional recommendation for the implementation of suitable measures to reduce noise exposure. No recommendation about a preferred type of intervention could be formulated; nor could a recommendation be made for an exposure level for night noise exposure (L_{night}), as studies were not consistent and in general did not provide evidence for an effect on sleep.

3.4.1.1 Other factors influencing the strength of recommendation

Other factors considered in the context of recommendations on wind turbine noise included those related to values and preferences, benefits and harms, resource implications, equity, acceptability and feasibility. Ultimately, the assessment of all these factors did not lead to a change in the strength of recommendation, although it informed the development of a conditional recommendation on the intervention measures. Further details are provided in section 3.4.2.3.

3.4.2 Detailed overview of the evidence

The following sections provide a detailed overview of the evidence constituting the basis for setting the recommendations on wind turbine noise. It is presented and summarized separately for each of the critical health outcomes, and the GDG's judgement of the quality of evidence is indicated (for a detailed overview of the evidence on important health outcomes, see Annex 4). Research into health outcomes and effectiveness of intervention is addressed consecutively.

A comprehensive summary of all evidence considered for each of the critical and important health outcomes can be found in the eight systematic reviews published in the *International Journal of Environmental Research and Public Health* (see section 2.3.2 and Annex 2).

It should be noted that, due to the time stamp of the systematic reviews, some more recent studies were not included in the analysis. This relates in particular to several findings of the Wind Turbine Noise and Health Study conducted by Health Canada (Michaud, 2015). Further, some studies were omitted, as they did not meet the inclusion criteria, including, for instance, studies using distance to the wind turbine instead of noise exposure to investigate health effects. The justification for including and excluding studies is given in the systematic reviews (Basner & McGuire, 2018; Brown et al., 2017; Clark & Paunovic, 2018; in press; Guski et al., 2017; Niewenhuijsen et al.,2017; Śliwińska-Kowalska & Zaborowski, 2017; van Kempen et al., 2018; see Annex 2 for further details).

3.4.2.1 Evidence on health outcomes

The key question posed was: in the general population exposed to wind turbine noise, what is the exposure–response relationship between exposure to wind turbine noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 38 and 39.

Table 38. PICOS/PECCOS scheme of critical health outcomes for exposure to wind turbine noise

PECO	Description	
Population	General population	
Exposure	Exposure to high levels of noise produced by wind turbines (average/night time)	
Comparison	Exposure to lower levels of noise produced by wind turbines (average/night time)	
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes	For night noise exposure: 1. effects on sleep

Table 39. Summary of findings for health effects from exposure to wind turbine noise (L_{den})

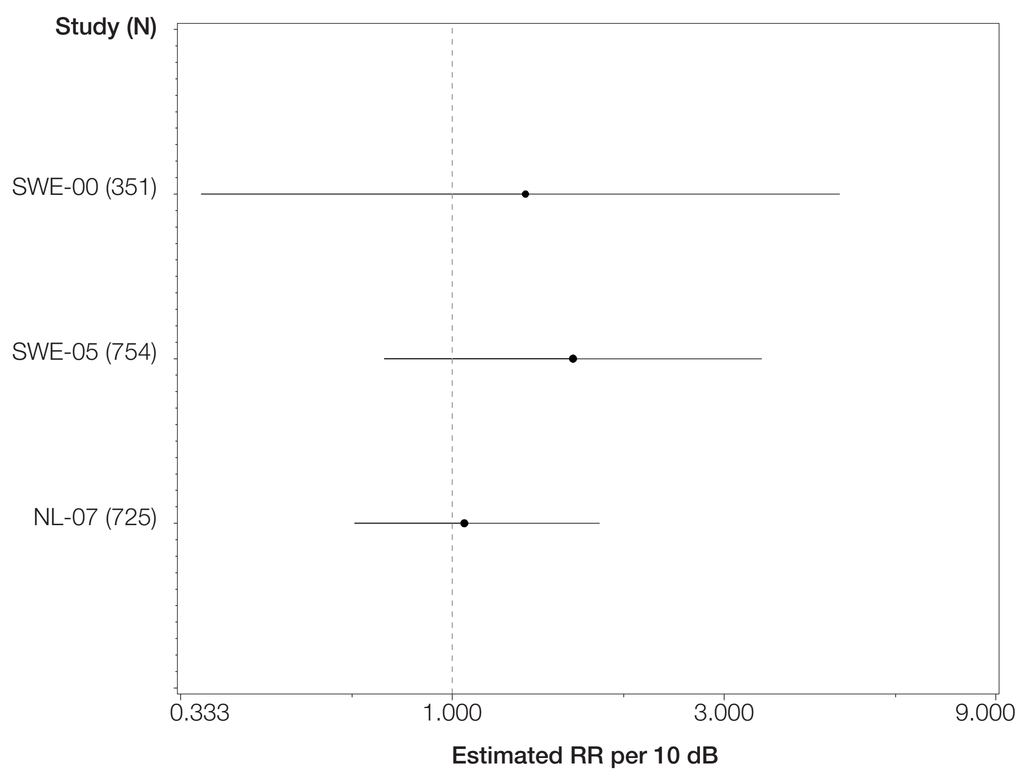
Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)	Quality of evidence
Cardiovascular disease					
L_{den}	Incidence of IHD	–	–	–	–
L_{den}	Incidence of hypertension	–	–	–	–
Annoyance					
L_{den}	%HA	Not able to pool because of heterogeneity	30 dB	2481 (4)	Low (downgraded for inconsistency and imprecision)
Cognitive impairment					
L_{den}	Reading and oral comprehension	–	–	–	–
Hearing impairment and tinnitus					
L_{den}	Permanent hearing impairment	–	–	–	–

Cardiovascular disease

For the relationship between wind turbine noise and prevalence of hypertension, three cross-sectional studies were identified, with a total of 1830 participants (van den Berg et al., 2008; Pedersen, 2011; Pedersen & Larsman, 2008; Pedersen & Persson Waye, 2004; 2007). The number of cases was not reported. All studies found a positive association between exposure to wind turbine noise and the prevalence of hypertension, but none was statistically significant. The lowest levels in studies were either <30 or <32.5 L_{den}. No meta-analysis was performed, since too many parameters were unknown and/or unclear. Due to very serious risk of bias and imprecision in the results, this evidence was rated very low quality (see Fig. 14).

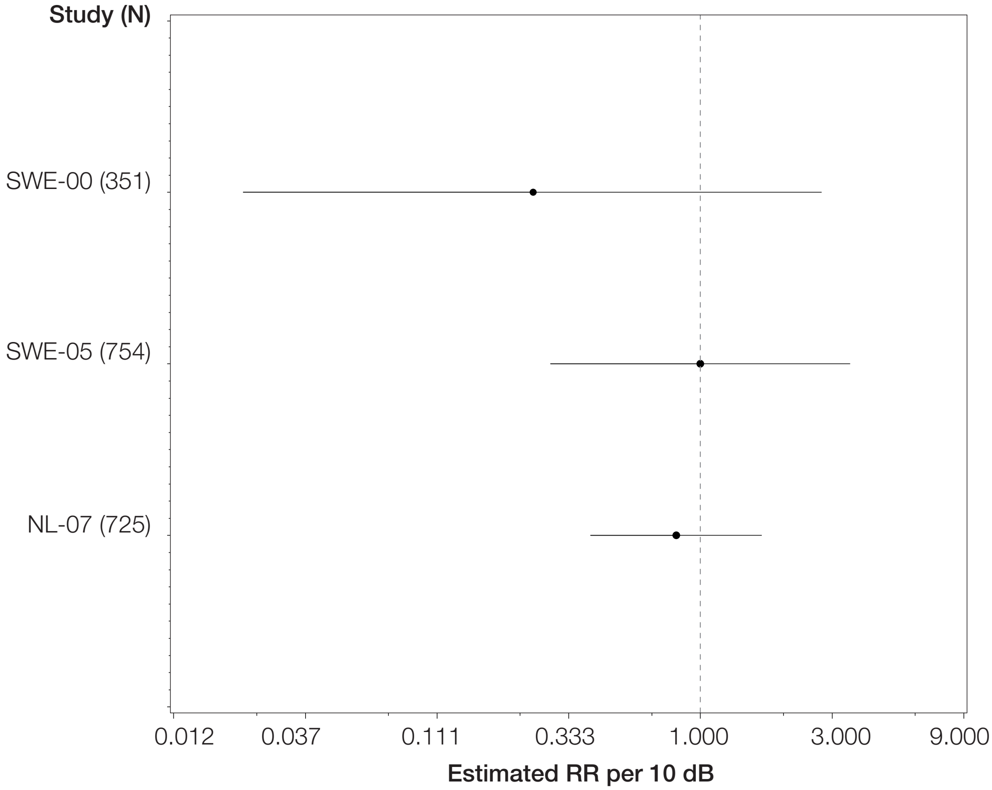
The same studies also looked at exposure to wind turbine noise and self-reported cardiovascular disease, but none found an association. No evidence was available for other measures of cardiovascular disease. As a result, only evidence rated very low quality was available for no considerable effect of audible noise (greater than 20 Hz) from wind turbines or wind farms on self-reported cardiovascular disease (see Fig. 15).

Fig. 14. The association between exposure to wind turbine noise (sound pressure level in dB) and hypertension



Notes: The dotted vertical line corresponds to no effect of exposure to wind turbine noise. The black dots correspond to the estimated RR per 10 dB and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Fig. 15. The association between exposure to wind turbine noise (sound pressure level) and self-reported cardiovascular disease



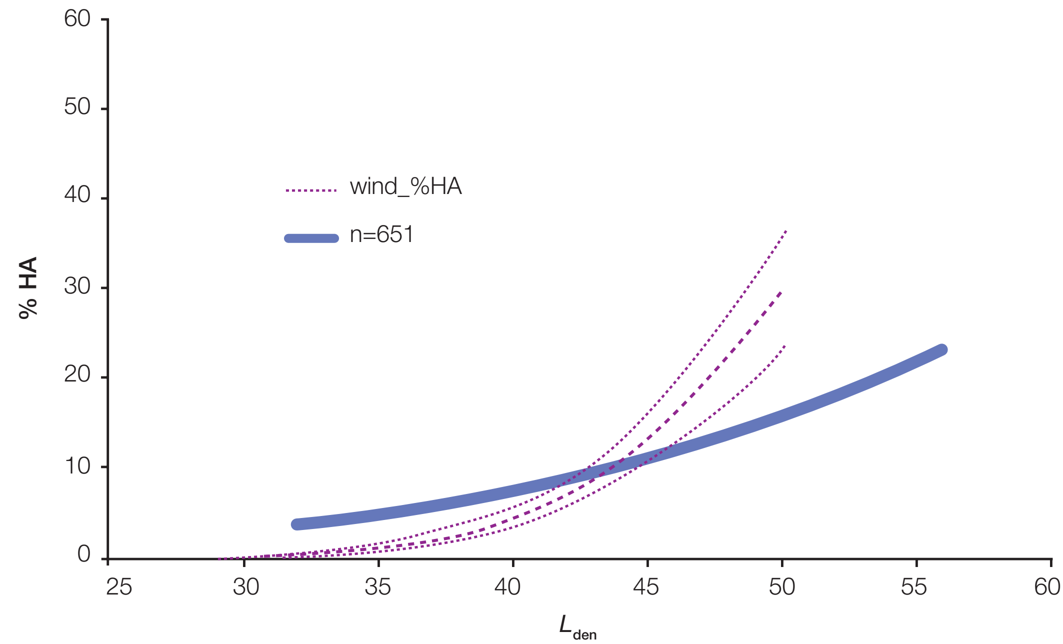
Notes: The dotted vertical line corresponds to no effect of exposure to wind turbine noise.The black circles correspond to the estimated RR per 10 dB (sound pressure level) and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Annoyance

Two publications containing descriptions of four individual studies were retrieved (Janssen et al., 2011; Kuwano et al., 2014). All four studies used measurements in the vicinity of the respondents' addresses; the noise exposure metrics used in the three original studies (Pedersen, 2011; Pedersen & Persson Waye, 2004; 2007) included in Janssen et al. (2011) were recalculated into L_{den}. The noise levels in the studies ranged from 29 dB to 56 dB. Different scales were used to assess annoyance, with slightly different definitions of "highly annoyed" and explicit reference to outdoor annoyance in the data used for the Janssen et al. (2011) curve. Construction of the ERFs provided in the two publications differed and they were therefore not further combined in a meta-analysis. Fig. 16 shows the %HA from the two publications. The 10% criterion for %HA is reached at around 45 dB L_{den} (where the two curves coincide). There was a wide variability in %HA between studies, with a range of 3–13%HA at 42.5 dB and 0–32%HA at 47.5 dB. The %HA in the sample is comparatively high, given the relatively low noise levels. There is evidence rated low quality for an association between wind turbine noise and annoyance, but this mainly applies to the association between wind turbine noise and annoyance and not to the shape of the quantitative relationship.

Further statistical analyses of annoyance yield evidence rated low quality for an association between wind turbine noise and %HA when comparing an exposure at 42.5 dB and 47.5 dB, with a mean difference in %HA of 4.5 (indoors) and 6.4 (outdoors). There is also evidence rated moderate quality for a correlation between individual noise exposure and annoyance raw scores (r = 0.28).

Fig. 16. Overlay of the two wind turbine annoyance graphs



Notes: Overlay of the two wind turbine outdoor annoyance graphs adapted from Janssen et al. (2011, red) and Kuwano et al. (2014, blue). The Kuwano et al. curve is based on L_{dn}; no correction for L_{den} has been applied.[18]
For further details on the studies included in the figure please refer to the systematic review on environmental noise and annoyance (Guski et al., 2017).

Cognitive impairment, hearing impairment and tinnitus, adverse birth outcomes

No studies were found, and therefore no evidence was available on the relationship between wind turbine noise and measures of cognitive impairment; hearing impairment and tinnitus; and adverse birth outcomes.

Sleep disturbance

Six cross-sectional studies on wind turbine noise and self-reported sleep disturbance were identified (Bakker et al., 2012; Kuwano et al., 2014; Michaud, 2015; Pawlaczyk-Luszczynska et al., 2014; Pedersen & Persson Waye, 2004; 2007). Noise levels were calculated using different methods, and different noise metrics were reported. Three of the studies asked how noise affects sleep; the other three evaluated the effect of wind turbine noise on sleep using questions that explicitly referred to noise (Table 40).

[18] L_{dn} is the day-night-weighted sound pressure level as defined in section 3.6.4 of ISO 1996-1:2016.

Table 40. Summary of findings for health effects from exposure to wind turbine noise (L_{night})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of effects in studies	Number of participants (studies)	Quality of evidence
Effects on sleep					
L_{night}	%HSD	1.60 (95% CI: 0.86–2.94) per 10 dB increase	31 dB	3971 (6)	Low (downgraded for study limitations, inconsistency, precision)

The risk of bias was assessed as high for all six studies, as effects on sleep were measured by self-reported data. There were a limited number of subjects at higher exposure levels. A meta-analysis was conducted for five of the six studies, based on the OR for high sleep disturbance for a 10 dB increase in outdoor predicted sound pressure level. The pooled OR was 1.60 (95% CI: 0.86–2.94). The evidence was rated low quality.

3.4.2.2 Evidence on interventions

This section summarizes the evidence underlying the recommendation on the effectiveness of interventions for wind turbine noise exposure. The key question posed was: in the general population exposed to wind turbine noise, are interventions effective in reducing exposure to and/or health outcomes from wind turbine noise? A summary of the PICOS/PECCOS scheme applied is set out in Table 41.

Table 41. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to wind turbine noise

PICO	Description	
Population	**General population**	
Intervention(s)	The interventions can be defined as: (a) a measure that aims to change noise exposure and associated health effects; (b) a measure that aims to change noise exposure, with no particular evaluation of the impact on health; or (c) a measure designed to reduce health effects, but that may not include a reduction in noise exposure.	
Comparison	**No intervention**	
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes	For night noise exposure: 1. effects on sleep

No studies were found, and therefore no evidence was available on the effectiveness of interventions to reduce noise exposure from wind turbines.

3.4.2.3 Consideration of additional contextual factors

As the foregoing overview has shown, very little evidence is available about the adverse health effects of continuous exposure to wind turbine noise. Based on the quality of evidence available, the GDG set the strength of the recommendation on wind turbine noise to conditional. As a second step, it qualitatively assessed contextual factors to explore whether other considerations could have a relevant impact on the recommendation strength. These considerations mainly concerned the balance of harms and benefits, values and preferences, and resource use and implementation.

Regarding the balance of harms and benefits, the GDG would expect a general health benefit from a marked reduction in any kind of long-term environmental noise exposure. Health effects of individuals living in the vicinity of wind turbines can theoretically be related not only to long-term noise exposure from the wind turbines but also to disruption caused during the construction phase. The GDG pointed out, however, that evidence on health effects from wind turbine noise (apart from annoyance) is either absent or rated low/very low quality (McCunney et al., 2014). Moreover, effects related to attitudes towards wind turbines are hard to discern from those related to noise and may be partly responsible for the associations (Knopper & Ollson, 2011). Furthermore, the number of people exposed is far lower than for many other sources of noise (such as road traffic). Therefore, the GDG estimated the burden on health from exposure to wind turbine noise at the population level to be low, concluding that any benefit from specifically reducing population exposure to wind turbine noise in all situations remains unclear. Nevertheless, proper public involvement, communication and consultation of affected citizens living in the vicinity of wind turbines during the planning stage of future installations is expected to be beneficial as part of health and environmental impact assessments. In relation to possible harms associated with the implementation of the recommendation, the GDG underlined the importance of wind energy for the development of renewable energy policies.

The GDG noticed that the values and preferences of the population towards reducing long-term noise exposure to wind turbine noise vary. Whereas the general population tends to value wind energy as an alternative, environmentally sustainable and low-carbon energy source, people living in the vicinity of wind turbines may evaluate them negatively. Wind turbines are not a recent phenomenon, but their quantity, size and type have increased significantly over recent years. As they are often built in the middle of otherwise quiet and natural areas, they can adversely affect the integrity of a site. Furthermore, residents living in these areas may have greater expectations of the quietness of their surroundings and therefore be more aware of noise disturbance. Negative attitudes especially occur in individuals who can see wind turbines from their houses but do not gain economically from the installations (Kuwano et al., 2014; Pedersen & Persson Waye, 2007; van den Berg et al., 2008). These situational variables and the values and preferences of the population may differ between wind turbines and other noise sources, as well as between wind turbine installations, which makes assessment of the relationship between wind turbine noise exposure and health outcomes particularly challenging.

Assessing resource use and implementation considerations, the GDG noted that reduction of noise exposure from environmental sources is generally possible through simple measures like insulating windows or building barriers. With wind turbines, however, noise reduction interventions are more complicated than for other noise sources due to the height of the source and because outdoor disturbance is a particularly large factor. As generally fewer people are affected (compared to transportation noise), the expected costs are lower than for other environmental sources of noise. The GDG was not aware of any existing interventions (and associated costs) to reduce harms from wind turbine noise, or specific consequences of having regulations on wind turbine noise. Therefore, it could not assess feasibility, or discern whether any beneficial effects of noise reduction would outweigh the costs of intervention. In particular, there is no clear evidence on an acceptable and uniform distance between wind turbines and residential areas, as the sound propagation depends on many aspects of the wind turbine construction and installation.

In light of the assessment of the contextual factors in addition to the quality of evidence, the recommendation for wind turbine noise exposure remains conditional.

Additional considerations or uncertainties

Assessment of population exposure to noise from a particular source is essential for setting health-based guideline values. Wind turbine noise is characterized by a variety of potential moderators, which can be challenging to assess and have not necessarily been addressed in detail in health studies. As a result, there are serious issues with noise exposure assessment related to wind turbines.

Noise levels from outdoor sources are generally lower indoors because of noise attenuation from the building structure, closing of windows and similar. Nevertheless, noise exposure is generally estimated outside, at the most exposed façade. As levels of wind turbine noise are generally much lower than those of transportation noise, the audibility of wind turbines in bedrooms, particularly when windows are closed, is unknown.

In many instances, the distance from a wind farm has been used as a proxy to determine audible noise exposure. However, in addition to the distance, other variables – such as type, size and number of wind turbines, wind direction and speed, location of the residence up- or downwind from wind farms and so on – can contribute to the resulting noise level assessed at a residence. Thus, using distance to a wind farm as a proxy for noise from wind turbines in health studies is associated with high uncertainty.

Wind turbines can generate infrasound or lower frequencies of sound than traffic sources. However, few studies relating exposure to such noise from wind turbines to health effects are available. It is also unknown whether lower frequencies of sound generated outdoors are audible indoors, particularly when windows are closed.

The noise emitted from wind turbines has other characteristics, including the repetitive nature of the sound of the rotating blades and atmospheric influence leading to a variability of amplitude modulation, which can be a source of above average annoyance (Schäffer et al., 2016). This differentiates it from noise from other sources and has not always been properly characterized. Standard methods of measuring sound, most commonly including A-weighting, may not capture the low-frequency sound and amplitude modulation characteristic of wind turbine noise (Council of Canadian Academies, 2015).

Even though correlations between noise indicators tend to be high (especially between L_{Aeq}-like indicators) and conversions between indicators do not normally influence the correlations between the noise indicator and a particular health effect, important assumptions remain when exposure to wind turbine noise in L_{den} is converted from original sound pressure level values. The conversion requires, as variable, the statistical distribution of annual wind speed at a particular height, which depends on the type of wind turbine and meteorological conditions at a particular geographical location. Such input variables may not be directly applicable for use in other sites. They are sometimes used without specific validation for a particular area, however, because of practical limitations or lack of data and resources. This can lead to increased uncertainty in the assessment of the relationship between wind turbine noise exposure and health outcomes.

Based on all these factors, it may be concluded that the acoustical description of wind turbine noise by means of L_{den} or L_{night} may be a poor characterization of wind turbine noise and may limit the ability to observe associations between wind turbine noise and health outcomes.

3.4.3 Summary of the assessment of the strength of recommendations

Table 42 provides a comprehensive summary of the different dimensions for the assessment of the strength of the wind turbine recommendations.

Table 42. Summary of the assessment of the strength of the recommendation

Factors influencing the strength of recommendation	Decision
Quality of evidence	**Average exposure (L_{den})** *Health effects* • Evidence for a relevant absolute risk of annoyance at **45 dB L_{den}** was rated **low quality.** *Interventions* • No evidence was available on the effectiveness of interventions to reduce noise exposure and/or health outcomes from wind turbines. **Night-time exposure (L_{night})** *Health effects* • No statistically significant evidence was available for sleep disturbance related to exposure from wind turbine noise at night. *Interventions* • No evidence was available on the effectiveness of interventions to reduce noise exposure and/or sleep disturbance from wind turbines.
Balance of benefits versus harms and burdens	Further work is required to assess fully the benefits and harms of exposure to environmental noise from wind turbines and to clarify whether the potential benefits associated with reducing exposure to environmental noise for individuals living in the vicinity of wind turbines outweigh the impact on the development of renewable energy policies in the WHO European Region.
Values and preferences	There is wide variability in the values and preferences of the population, with particularly strong negative attitudes in populations living in the vicinity of wind turbines.
Resource implications	Information on existing interventions (and associated costs) to reduce harms from wind turbine noise is not available.
Additional considerations or uncertainties	There are serious issues with noise exposure assessment related to wind turbines.
Decisions on recommendation strength	• **Conditional** for guideline value for average noise exposure (L_{den}) • **Conditional** for the effectiveness of interventions (L_{night})

3.5 Leisure noise

Recommendations

For average noise exposure, the GDG **conditionally** recommends reducing the yearly average from all leisure noise sources combined to **70 dB** $L_{Aeq,24h}$, as leisure noise above this level is associated with adverse health effects. The equal energy principle[19] can be used to derive exposure limits for other time averages, which might be more practical in regulatory processes.

For single-event and impulse noise exposures, the GDG **conditionally** recommends following existing guidelines and legal regulations to limit the risk of increases in hearing impairment from leisure noise in both children and adults.

Following a precautionary approach, to reduce possible health effects, the GDG **strongly** recommends that policy-makers take action to prevent exposure above the guideline values for average noise and single-event and impulse noise exposures. This is particularly relevant as a large number of people may be exposed to and at risk of hearing impairment through the use of personal listening devices (PLDs). There is insufficient evidence, however, to recommend one type of intervention over another.

3.5.1 Rationale for the guideline levels for leisure noise

As specific evidence for the relationship between leisure noise and hearing loss is of insufficient quality, the GDG decided to follow a different approach for this noise source, based on knowledge regarding prevention of hearing loss in the workplace and on the CNG (WHO, 1999). There is sufficient evidence that the nature of the noise matters little in causing hearing loss, so using the existing guidelines is a justified step to prevent permanent hearing loss from leisure noise.

In accordance with the procedures for the other noise sources, the GDG would have considered evidence on exposure–response relationships for the prioritized health outcomes. However, no such ERFs could be established in the systematic reviews for any of the health outcomes (Table 43).

Table 43. Average exposure levels ($L_{Aeq,24h}$) for priority health outcomes from leisure noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Incidence of IHD **Incidence of hypertension** **Prevalence of highly annoyed population** **Reading skills and oral comprehension in children**		No evidence was available
Permanent hearing impairment There is an indication that PLDs have an effect on hearing impairment and tinnitus. There was no evidence (because no studies were found) for an effect of other sources of leisure noise on hearing impairment or tinnitus. The results of the studies could not be synthesized because of heterogeneity of outcome measurement.	No increase	Very low quality/no evidence

[19] The equal energy principle states that the total effect of sound is proportional to the total amount of sound energy received by the ear, irrespective of the distribution of that energy in time (WHO, 1999).

In accordance with the evidence on the effects of PLDs on permanent hearing loss from leisure noise, the GDG recommended a guideline exposure level of 70 dB $L_{Aeq,24h}$ yearly average from all leisure noise sources combined. It was confident that there was no relevant risk increase for permanent hearing impairment below this exposure level of average leisure noise. The GDG recognized that a conversion to alternative time averages for exposure to leisure noise might be helpful for regulatory purposes; thus, a detailed table converting hourly and weekly exposure into yearly averages is provided in the subsection on additional considerations or uncertainties in section 3.5.2.3, Table 49. Furthermore, the GDG recommended sticking to the CNG recommendations for single events to limit the risk of hearing impairment from leisure noise increases for both children and adults (WHO, 1999).[20] Due to the nature and limited amount of available evidence, the GDG made the recommendation conditional.

Next, the GDG assessed the evidence for night noise exposure and its effect on sleep disturbance (Table 44).

Table 44. Night-time exposure levels (L_{night}) for priority health outcomes from leisure noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Sleep disturbance	3% absolute risk	No evidence was available

Because of a lack of evidence, the GDG was not able to formulate a recommendation addressing sleep disturbance due to leisure noise at night time.

The GDG also looked for evidence about the effectiveness of interventions for leisure noise exposure. Owing to a lack of research, however, no studies were available on existing interventions and associated costs to reduce leisure noise. As no evidence was available, it was not possible to develop a recommendation on any specific type of intervention measure. However, following a precautionary approach, to reduce possible health effects, the GDG made a strong recommendation that policy-makers take action to prevent exposures above the guideline values for average noise and single-event and impulse noise exposures. This is particularly relevant as a large number of people may be exposed to and at risk of hearing impairment through the use of PLDs. There is insufficient evidence, however, to recommend one type of intervention over another.

3.5. 1.1 Other factors influencing the strength of recommendations

Other factors considered in the context of recommendations on leisure noise included those related to values and preferences, benefits and harms, resource implications, equity, acceptability and feasibility; moreover, nonpriority health outcomes were considered. Ultimately, the assessment of all these factors did not lead to a change in the strength of recommendation. Further details are provided in section 3.5.2.3.

[20] The GDG acknowledged the scarcity of cohort study-based evidence to define a threshold for hearing damage due to single loud exposures. It initially decided to propose $L_{AF,max}$ = 110, but after much discussion it appeared that the conversion of relevant standing limits (expressed in $L_{peak,C}$ and others) lacked sufficient basis.

3.5.2 Detailed overview of the evidence

The following sections provide a detailed overview of the evidence constituting the basis for setting the recommendations on leisure noise. As noted above, however, only limited evidence was available for several of the prioritized health outcomes, so it is presented and summarized for all critical and important health outcomes where possible, along with indications of the GDG's judgement of the quality of evidence. Research into health outcomes and effectiveness of interventions is addressed consecutively.

A comprehensive summary of all evidence considered for each of the critical and important health outcomes can be found in the eight systematic reviews published in the *International Journal of Environmental Research and Public Health* (see section 2.3.2 and Annex 2).

3.5.2.1 Evidence on health outcomes

The key question posed was: in the general population exposed to leisure noise, what is the exposure–response relationship between exposure to leisure noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 45 and 46.

Table 45. PICOS/PECCOS scheme of critical health outcomes for exposure to leisure noise

PECO	Description	
Population	General population	
Exposure	Exposure to high levels of noise produced by leisure activities (average/night time)	
Comparison	Exposure to lower levels of noise produced by leisure activities (average/night time)	
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes	For night noise exposure: 1. effects on sleep

Table 46. Summary of findings for health effects from exposure to leisure noise ($L_{Aeq,24h}$)

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies[a]	Number of participants (studies)	Quality of evidence
Cardiovascular disease					
$L_{Aeq,24}$	Incidence of IHD	–	–	–	–
$L_{Aeq,24}$	Incidence of hypertension	–	–	–	–
Annoyance					
$L_{Aeq,24}$	%HA	–	–	–	–
Cognitive impairment					
$L_{Aeq,24}$	Reading and oral comprehension	–	–	–	–
Hearing impairment and tinnitus					
$L_{Aeq,24}$	Permanent hearing impairment	Not estimated	–	484 (3)	Very low (downgraded for study limitations, precision)

Hearing impairment and tinnitus

Several types of leisure activity are accompanied by loud sounds, such as attending nightclubs, pubs and fitness classes; live sporting events; concerts or live music venues; listening to loud music through PLDs. This recommendation is informed by a systematic review that assessed the evidence on permanent hearing loss and tinnitus due to exposure to leisure noise (Śliwińska-Kowalska & Zaborowski, 2017). The review identified two existing systematic reviews that summarized recent estimates of the risk of developing permanent hearing loss from the use of PLDs. It did not identify any studies with objective measurement of exposure to any other type of leisure noise.

The Scientific Committee on Emerging and Newly Identified Hazards and Risk (SCENIHR) (EC, 2008b) report concluded that prolonged exposure to sounds from PLDs may result in temporary hearing threshold shift, permanent hearing threshold shift and tinnitus, as well as poor speech communication in noisy conditions. However, based on the data available, there was no direct evidence for an effect of repeated, regular daily exposure to music through PLDs on development of permanent noise-induced hearing loss. Data on tinnitus were inadequate and therefore inconclusive. No meta-analysis was provided for any of the hearing effects; nor were the exposure–effect curves reported. The SCENIHR report was based on a narrative review of 30 original papers with over 2000 participants and exposure to music sounds that covered a range of 60–120 dB. Studies included in the review were carried out between 1982 and 2007.

In 2014 a second systematic review was published by Vasconcellos et al. (2014). Although the objective of this publication was to determine threshold levels of personally modifiable risk factors for hearing loss in the paediatric population, specific thresholds analyses were limited. Based on the descriptive overview of original papers, the authors identified exposure to loud music (including use of PLDs) and working on a mechanized farm as the main risk factors for hearing loss in children and teenagers. Thresholds of exposure to music, significantly associated with hearing loss in youth, were:

- more than four hours per week or more than five years of personal headphone usage;
- more than four visits per month to a discotheque.

The evidence review identified five new cross-sectional studies on noise from PLDs since the publication of the SCENIHR report (Feder et al., 2013; Levesque et al., 2010; Sulaiman et al., 2013; 2014; Vogel et al., 2014). Direct measurement of hearing thresholds with pure tone audiometry was performed only in three studies – by Feder et al. (2013) and Sulaiman et al. (2013 and 2014). In total, audiometric data from 484 subjects were analysed; among them, 449 were exposed and 35 were not exposed to PLD music. Two other studies by Levesque et al. (2010) and Vogel et al. (2014) did not perform audiometric measurement but reported on tinnitus in a total of 1067 participants.

Noise from PLDs was estimated based on direct measurement of equivalent sound pressure levels (in dB) in four studies (Feder, 2013; Levesque et al., 2010; Sulaiman et al., 2013; 2014) and based on converting volume-control setting levels of PLD into dB levels in one study (Vogel et al., 2014). The resulting exposure levels (L_{Aeq} values) had a mean of between 72 dB and 91 dB, although in two studies these data were not provided. In all studies, individual $L_{Aeq,8h}$ value was calculated based on an estimated level of music and the number of hours a day listening to the music through the PLD declared by an individual in the questionnaire. Resulting $L_{Aeq,8h}$ mean values were between 62 dB and 83 dB when provided.

Potential confounding was controlled by excluding the subjects with exposure to other sources of high-level noise or prior ear problems (Sulaiman et al., 2013), by excluding those with these factors and ototoxic drug intake (Sulaiman et al., 2014) or by controlling for these confounders by accounting for them in the statistical models. The confounders comprised socioeconomic status, demographic factors, tubes in the ear and leisure exposures in one study (Feder, 2013), and age and sex in one study (Vogel et al., 2014). One of the studies did not adjust for confounding factors (Levesque et al., 2010).

Data on permanent hearing loss were taken from audiometric measurements (Feder, 2013; Sulaiman et al., 2013; 2014), while data about permanent tinnitus were taken from self-reported responses to questionnaires (Levesque et al., 2010; Vogel et al., 2014). In one case, the outcome was defined as "permanent hearing-related symptoms", but it is not clear what proportion of subjects experienced permanent tinnitus (Vogel et al., 2014).

For permanent hearing loss, there is no pooled effect size, because the authors of the original studies either did not report data or reported in different formats. However, these studies indicate a harmful effect of listening to PLDs. For permanent tinnitus, there is no pooled effect size because the effects of noise from PLDs on permanent tinnitus were contradictory. These results are generally consistent with previous reviews by SCENIHR (EC, 2008b) and Vasconcellos et al. (2014).

The risk of bias was assessed as high for all five studies. The overall evidence for an effect of PLDs on hearing impairment and tinnitus was rated very low quality.

3.5.2.2 Evidence on interventions

The following section summarizes the evidence underlying the recommendation on the effectiveness of interventions for leisure noise exposure. The key question posed was: in the general population exposed to leisure noise, are interventions effective in reducing exposure to and/or health outcomes from leisure noise? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 47 and 48.

Table 47. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to leisure noise

PICO	Description	
Population	General population	
Intervention(s)	The interventions can be defined as: (a) a measure that aims to change noise exposure and associated health effects; (b) a measure that aims to change noise exposure, with no particular evaluation of the impact on health; or (c) a measure designed to reduce health effects, but that may not include a reduction in noise exposure.	
Comparison	No intervention	
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes	For night noise exposure: 1. effects on sleep

Table 48. Summary of findings for interventions for leisure noise

Type of intervention	Number of participants (studies)	Effect of intervention	Quality of evidence
Hearing impairment			
Type E – behaviour change interventions (education programme/campaign)	4151 (7)	None of the studies involved measurement or estimation of exposure levels or health outcomes. Most studies found a significant effect of change in knowledge or behaviour.	–

Seven individual studies on PLDs, attendance at music venues and participation in other recreational activities where there was risk of hearing damage and/or tinnitus were included in the systematic review (Dell & Holmes, 2012; Gilles & Van de Heyning, 2014; Kotowski et al., 2011; Martin et al., 2013; Taljaard et al., 2013; Weichbold & Zorowka, 2003; 2007). All studies examined interventions directed at changes in knowledge or behaviour and hearing impairment.

The studies all sought evidence on the effectiveness of some form of educational programme or campaign aimed at children, adolescents or college students. These addressed perceptions and knowledge of the risk of high levels of noise – generally, but not exclusively, from PLD sources or from attendance at music events – and actual or intended changes to hearing damage risk behaviours, including avoidance, frequency or duration of exposure, regeneration periods when in high noise, or playback levels.

The outcome assessed in all intervention studies was the change in knowledge and behaviours towards hearing damage risk. The health outcome measures varied widely and included measurements on the youth attitude towards noise scale, participants' knowledge about hearing damage, participants' PLD usage patterns, participants' attitudes to wearing hearing protection (some in general; some at discotheques) and frequency of discotheque attendance. A majority of the studies found a significant effect of change in knowledge or behaviour. No indication on the persistence of knowledge and behavioural change was given, though.

None of the studies included objectively measured outcomes or a measured change in noise level exposure; thus, the effectiveness of the interventions could not be assessed, and the quality of the evidence was not rated according to GRADE.

3.5.2.3 Consideration of additional contextual factors

Based on the quality of the available evidence discussed in the foregoing overview, the GDG set the strength of recommendation of leisure noise to conditional. As a second step, it qualitatively assessed contextual factors to explore whether other considerations could have a relevant impact on the recommendation strength. These considerations mainly concerned the balance of harms and benefits, values and preferences, and resource use and implementation.

When assessing the balance of benefits and harms, the GDG recognized that exposure to leisure noise is widespread and frequent. In particular, as many as 88–90% of teenagers and young adults report listening to music through PLDs earphones (Pellegrino et al., 2013; Vogel et al., 2011). In 2015 WHO estimated that 1.1 billion young people worldwide could be at risk of hearing loss due to unsafe listening practices (WHO, 2015a). Furthermore, among young people aged 12–35 years in middle- and high-income countries, nearly 50% listen to unsafe levels of sound through personal audio devices (mp3 players, smartphones and others), and around 40% are exposed to potentially damaging levels of sound at nightclubs, bars and sporting events. Noise-induced hearing loss can be prevented by following safe listening practices, so the GDG concluded that health benefits can be gained from markedly reducing population exposure to leisure noise, including through actions to promote safe listening practices. A reduction of leisure noise is also assumed to reduce nuisance that can be caused to other people than those who enjoy leisure activities, such as neighbours. Furthermore, specifically for PLDs, it can reasonably be expected that a reduction of noise exposure could also lead to a reduction in accidents, injuries and other potential safety risks. In relation to possible harms and burdens, the GDG could not identify any harms (except economic costs, which are addressed in the paragraph on resource use and implementation) arising from implementation of the recommended guideline values.

Considering values and preferences, the GDG recognized that listening to music with the help of a PLD, going to concerts and attending sport events are activities regarded as enjoyable and therefore assumed to be valued by the overall population. Furthermore, it is expected that values and preferences might vary in particular with respect to the use of PLDs and embracing leisure activities involving loud noise, like concerts, and that some population groups – especially younger individuals – might voluntarily expose themselves to high levels of sound during these activities. Despite this, the GDG was confident that recommendations to lower noise levels for the prevention of hearing damage from leisure noise would be welcome by a majority of the population. Recommendations are expected to be particularly welcome when it comes to protecting the hearing of young children and teenagers, as these vulnerable groups often do not have control over their environment and the noise levels to which they are exposed, such as from noisy toys or at school.

With resource use and implementation, the GDG noted that interventions exist to reduce exposure to leisure noise from PLDs, attendance at music venues and participation in recreational activities, as aggregated by the systematic review on environmental noise interventions and their associated impacts (Brown & van Kamp, 2017). As most of these relate to implementation of a behaviour change, the reduction of exposure to leisure noise is expected to be technically feasible and cheap. None of the empirical investigations objectively measured outcomes or a measured change in noise level exposure, so the effectiveness of such measures cannot be assessed. Nevertheless, it is important to note that there is ample evidence from the occupational health field that high noise levels cause hearing damage, and that occupational interventions to reduce noise exposure are effective at lowering the risk of hearing problems or hearing damage (EC, 2003; Garcia et al., 2018; ISO, 2013; Maassen et al., 2001). In conclusion, resources needed to reduce exposure to leisure noise are not expected to be intensive, but implementation and long-term success of measures might be challenging, owing to cultural factors, as changes in behaviour are expected to be tricky to implement.

In light of the assessment of the contextual factors in addition to the quality of evidence, the recommendation remains conditional.

Additional considerations or uncertainties

The GDG considers the noise levels selected for this recommendation to be reasonable precautionary measures, in view of the rating of very low quality for the available evidence on an effect of leisure noise on permanent hearing impairment and tinnitus identified in the systematic review.

Extensive literature shows hearing impairment in populations exposed to specific types of nonoccupational environments, although these exposures are generally not well characterized. There are no studies with objective measurement of exposure to any other type of leisure noise (except PLDs) and permanent hearing impairment or tinnitus. Nevertheless, this recommendation generally applies to all leisure noise exposures, such as events in public venues (concerts halls, sports events, bars and discotheques) and educational facilities, and use of PLDs. The recommendation also applies to exposure to impulse sounds, such as those in shooting facilities or from the use of toys and firecrackers.

Hearing loss is the resultant value of combined exposures to different sources of leisure noise including, but not limited to, PLDs. Therefore, the recommendations apply to the combined noise levels from all sources.

Noise-induced hearing loss develops very slowly over years of exposure, giving rise to challenges in the assessment of the health impacts from prolonged use of PLDs and exposure to leisure noise. The induction period for the development of hearing impairment and tinnitus is long, and varying exposure conditions and changing lifestyle habits (including confounding noise sources), particularly among young people, will have an impact. Therefore, recommendations regarding leisure noise have often been inferred from the occupational field, where exposure conditions are more stable over time.

Indeed, long-term exposure to noise, objectively assessed and at levels measured in occupational settings for various professions, can lead to permanent hearing loss and tinnitus. This evidence, while not reviewed systematically as part of the work related to these guidelines, can be used as supportive evidence and justification for the need to develop a recommendation for leisure noise, given that many people could be at risk of developing hearing loss and/or tinnitus from exposure to lower levels of environmental noise. Similar otobiological mechanisms must also be considered for environmental noise.

To date, no commonly accepted method for assessing the risk of hearing loss due to environmental exposure to noise has been developed. One of the main challenges is to conduct a long-term objective exposure assessment of environmental noise and relate this to the development of permanent hearing impairment and tinnitus. The GDG underlined the strong need for research to develop a comprehensive methodology. In the absence of a method, and as long as no other tools are available, the equal energy principle outlined in the ISO standard for the estimation of noise-induced hearing loss (WHO, 1999) can be used as a practical tool for protecting public health from exposure to leisure noise. As a result, the relationship between leisure noise exposure and auditory effects can be quantified for a variety of exposure levels, duration and frequency.

Several organizations have established regulations for the protection of workers from risks to their health and safety arising from exposure to noise, and in particular risk to hearing. Of particular relevance is EU Directive 2003/10/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (EC, 2003). Based on the ISO 1999 standard (ISO, 2013), the Directive sets limits of exposure depending on equivalent noise level for an eight-hour working day and obliges the employer to take suitable steps if the limits are exceeded. It recommends three action levels for occupational settings, setting the lowest, most conservative value at $L_{ex,8hr}$ = 80 dB. According to the Directive, no consequences of exposure to occupational noise are expected at this level. While exposure patterns and certain characteristics of occupational and leisure noise exist, knowledge of the hearing impairment risks and preventive interventions can be used to assess health risks associated with leisure noise (Neitzel & Fligor, 2017).

The CNG recommend a limit of $L_{Aeq,24h}$ = 70 dB(A) for preventing hearing loss from industrial, commercial shopping and traffic areas, indoors and outdoors (WHO, 1999). Health and safety regulations are usually based on an exposure profile of a typical worker (eight hours per day, five days per week). Using the existing knowledge from the ISO standard and established health and safety regulations, it is possible to use the equal energy principle to derive the resulting noise exposure level for an exposure profile more appropriately suited for leisure noise. Converting 40 hours at 80 dB to a continuous exposure to noise (24 hours per day, seven days per week), this leads to a yearly average exposure of 71 dB for lifelong exposure.[21] This is the same value as the WHO recommendation of

[21] 71 dB = 80 dB (derived from ISO standard) – 6.2 dB (conversion of yearly average of 40 working hours divided by continuous exposure to noise: (10 log (2080hrs/8760 hrs)) – 3 dB (extrapolation of 40 working years to lifelong exposure).

70 dB (WHO, 1999). Table 49 presents the noise levels per hour for various time averages in order to keep within the recommended yearly average exposure, and assuming that exposure to other noise sources generally does not contribute significantly. For example, for specific events taking place for one-, two- or four-hour averages, once a week (such as visiting a discotheque or watching a loud movie), an hourly noise level of 85 dB would lead to an average yearly exposure of 63 dB, 66 dB and 69 dB, respectively. However, the same hourly exposure of 85 dB for an activity taking place for 14 hours per week (two hours per day, seven days a week) would lead to a yearly exposure of 74 dB, which exceeds the recommendations.

Table 49. Combination of hourly exposure and number of hours per week to arrive at a yearly average L_{Aeq}

Hours of exposure per week	One-hour exposure level (L_{Aeq})						
	70	**75**	**80**	**85**	**90**	**95**	**100**
1	48	53	58	63	68	73	78
2	51	56	61	66	71	76	81
4	54	59	64	69	74	79	84
14 (2 hours per day, 7 days per week)	59	64	69	74	79	84	89
28 (4 hours per day, 7 days per week)	62	67	72	77	82	87	92
40 (8 hours per day, 5 days per week)	64	69	74	79	84	89	94
168 (24 hours per day, 7 days per week)	70	75	80	85	90	95	100

Note: green = combinations of exposure/duration below current guideline level; red = combinations of exposure/duration above current guideline level; blue = input parameters.

The equal energy principle cannot be used to derive single-event limits because at high levels the ear starts to respond with nonlinear behaviour. The CNG provides several values, in different units: $L_{AF,max}$ = 110 dB for industrial noises (no distance stated), $L_{peak,lin}$ = 140 dB for adults and $L_{peak,lin}$ = 120 dB for children (measured at 100 mm) (WHO, 1999). EU Directive 2003/10/EC on the minimum health and safety requirements regarding the exposure of workers recommends a lower action level of $L_{peak,C}$ = 135 dB (at 100 mm). In a recent overview Hohmann (2015) provided an ERF for hearing damage caused by shooting noise, from which it appears that a safe level of L_E = 120 dB can be derived.

Although it is clear that high noise levels cause acute hearing damage, there is no agreement on a safe level. Further research is highly recommended. In the mean time, existing guidelines should be applied.

3.5.3 Summary of the assessment of the strength of recommendation

Table 50 provides a comprehensive summary of the different dimensions for the assessment of the strength of the leisure noise recommendations.

Table 50. Summary of the assessment of the strength of the recommendation

Factors influencing the strength of recommendation	Decision
Quality of evidence	**Average exposure ($L_{Aeq,24h}$)** *Health effects* • Evidence of an effect from PLDs on hearing impairment and tinnitus, in the absence of evidence for other health outcomes and absence of evidence on hearing impairment and tinnitus from other types of leisure noise besides PLDs, was rated **very low quality.** *Interventions* • No evidence was available on the effectiveness of interventions to reduce noise exposure and/or health outcomes from leisure noise.
Balance of benefits versus harms and burdens	The general benefit from reduction of leisure noise outweighs any potential harms.
Values and preferences	There is variability in the values and preferences of the general population.
Resource implications	The resources needed to reduce exposure to leisure noise are not expected to be intensive, but implementation and the long-term success of measures may be challenging, mainly due to cultural factors.
Decision on strength of recommendation	• **Conditional** for guideline level for average noise exposure ($L_{Aeq,24h}$) • **Conditional** for single-event and impulse noise • **Strong** for interventions to reduce noise exposure

3.6 Interim targets

An interim target was proposed in the NNG (WHO Regional Office for Europe, 2009), "recommended in situations where the achievement of NNG is not feasible in the short run for various reasons". The NNG emphasized that an interim target is "not a health-based limit value by itself. Vulnerable groups cannot be protected at this level".

The GDG discussed whether to propose interim targets as part of the current guidelines, and if so, what process would be needed to derive those values. The current recommendations are health-based and already provide guideline values per noise source (for both L_{den} and L_{night}). They also include information on exposure–response relationships for various health outcomes, which can be used by policy-makers or other stakeholders to inform the selection of different values, if needed. Further, interim targets may work differently in different countries and for different noise sources, and it may not be optimal to propose them Europe-wide. As a result, there was consensus among members of the GDG not to provide interim targets.

4. Implications for research

The development of these environmental noise guidelines for the WHO European Region has made evident some key knowledge gaps and research needs. The main ones specific to the guideline recommendations are presented as implications for research in the sections that follow.

4.1 Implications for research on health impacts from transportation noise

For the assessment of health effects from the main sources of transportation noise (road traffic, railways and aircraft), the various evidence reviews show the following knowledge gap: there is a need for longitudinal studies on the health impacts from exposure to environmental noise, to inform future recommendations properly (Table 51).

Table 51. Implications for research on health impacts from transportation noise (air, rail, road)

Current state of the evidence	Limited evidence is available on health impacts from transportation noise from large-scale cohort and case-control studies, with objective measurement of both noise exposure and health outcomes.
Population of interest	Research is needed into effects of exposure on children and adults exposed to environmental noise from transportation sources.
Exposure of interest	Objective measurement or calculation of transportation noise exposure is required; in particular, from studies of health effects related to combined exposure to different noise sources.
Comparison of interest	The data should be compared to the effects of lower levels of transportation noise.
Outcomes of interest	Measures of the following health outcomes is required, assessed objectively and harmonized where possible – for example, according to common protocols: • annoyance • effects on sleep • cardiovascular and metabolic effects • adverse birth outcomes • cognitive impairment • mental health, quality of life and well-being • hearing impairment and tinnitus • any other relevant health outcome.
Time stamp	The systematic review included studies between October 2014 and December 2016.

4.1.1 Specific implications for annoyance

To predict absolute %HA at the full range of levels (and the corresponding CIs), an integrated analysis of the original raw data from all of individual studies would be necessary. The evidence review conducted as part of the guidelines focused only on secondary data handling and therefore does not replace a full meta-analysis of all individual data. The development of a generic exposure–response relationship (from a full meta-analysis based on all individual data) is suggested as a priority research recommendation (see Table 52).

Table 52. Recommendation for research addressing the exposure–response relationship

Current state of the evidence	The evidence review on annoyance conducted as part of the guidelines does not provide a generalized ERF but points to significant differences compared to the curves used in the past. It shows that the available generalized ERFs are in need of adjustment, preferably as a result of undertaking a full meta-analysis. This is especially the case for the sources aircraft and railway noise, which new data show are more annoying than previously documented.
Population of interest	Research is needed into effects of exposure on children and adults exposed to air, rail and/or road traffic noise.
Exposure of interest	Objective measurement of transportation noise exposure is required.
Comparison of interest	The data should be compared to the effects of lower levels of transportation noise.
Outcomes of interest	Measures of health outcomes are required, assessed objectively according to common protocols (such as the International Commission on Biological Effects of Noise (ICBEN) scale for annoyance).
Time stamp	The systematic review included studies up to October 2014.

4.2 Implications for research on health impacts from wind turbine noise

Further research into the health impacts from wind turbine noise is needed so that better-quality evidence can inform any future public health recommendations properly. For the assessment of health effects from wind turbines, the evidence was either unavailable or rated low/very low quality. Recommendations for research addressing this priority are proposed in Table 53.

Table 53. Implications for research on health impacts from wind turbine noise

Current state of the evidence	The current evidence on health outcomes related to wind turbine noise is unavailable or of low/very low quality and mainly comes from cross-sectional studies. Methodologically robust longitudinal studies with large samples investigating the quantitative relationship between noise from wind turbines and health effects are needed.
Population of interest	Research is needed into effects of exposure on children and adults exposed and living near sources of wind turbine noise. Studies should assess subgroup differences in effects for vulnerable groups such as children, elderly people and those with existing poor physical and mental health.
Exposure of interest	Exposure to noise at a wide range of levels and frequencies (including low-frequency noise), with information on noise levels measured outdoors and indoors (particularly relevant for effects on sleep) at the residence is needed. The noise exposure should be measured objectively and common protocols for exposure to wind turbine noise should be established, considering a variety of noise characteristics specific to wind turbine noise.
Comparison of interest	The data should be compared to the effects in similar areas without wind turbines. Pre/post studies of new wind turbine installations are needed, especially if "before measures" unbiased by the stress and knowledge of potential wind turbine farm development need to be developed.
Outcomes of interest	Measures of health outcomes are required, assessed objectively – for example, according to common protocols (ICBEN scale for annoyance and self-reported sleep disturbance). The studies should include the most important situational and personal confounding variables, such as negative attitudes towards wind turbines, visual impact, economic gain and other socioeconomic factors.
Time stamp	The systematic review included studies between October 2014 (review on annoyance) and December 2016 (review on cardiovascular disease).

Alongside the defined needs for research on wind turbine noise it should be noted that research regarding industrial noise in general is required. More specifically, there is a need to investigate stationary sources (including heat, ventilation and acclimatization devices) and their impacts on health. Studies on hearing disorders from impulse and/or intermittent sounds are also needed; these would enable assessment of adverse effects created by one or several sounds of short duration with a high maximum sound level or impulse sound level.

4.3 Implications for research on health impacts from leisure noise

For the assessment of effects from leisure noise, the evidence to make a recommendation on the ERF to use for health risk assessment, or of a threshold for effects, was either unavailable or rated very low quality. This is a research gap: longitudinal studies with longer follow-up are needed; these should measure noise objectively, not only from PLDs but also from other types of leisure noise.

There is uncertainty in the measurement of early hearing disorders among young people using the tonal audiometry commonly applied. Precise methods to identify early hearing impairment and other hearing disorders are needed. Owing to long induction periods, however, adequate research may be difficult to perform, particularly among young people who change their exposure in terms of sound level and frequency as they age (for example, changing their music listening habits and venue visits). As a result, the recommendations refer to the results derived from stationary noise sources in the occupational field, in conjunction with the equal energy principle (see Table 54).

Table 54. Implications for research on health impacts from leisure noise

Current state of the evidence	Currently, no evidence is available on hearing impairment and tinnitus from large-scale cohort and case-control studies, with objective measurement of noise exposure and using a suitable method to assess hearing impairment in young people.
Population of interest	Research is needed into effects of exposure on children and adults exposed to environmental noise from different sources and in different settings.
Exposure of interest	Objective measurement of leisure noise exposure is required.
Comparison of interest	The data should be compared to the effects of no leisure noise exposure from these sources.
Outcomes of interest	The primary outcomes identified are: • hearing loss measured by audiometry; • specific threshold analyses focused on stratifying the risk of permanent hearing loss according to clearly defined levels of exposure to leisure noise, such as music through PLDs; • concise methods to identify early hearing impairment and other hearing disorders; • temporary threshold shift after exposure to leisure noise, as it may be reasonably predictive of future permanent threshold shift; • age-related hearing loss progression depending on early-age exposure to leisure noise, such as to loud music; and • tinnitus, measured objectively and subjectively.
Time stamp	The systematic review included studies up to June 2015.

4.4 Implications for research on effectiveness of interventions to reduce exposure and/or improve public health

The quality of the evidence on the effectiveness of interventions to reduce exposure to and health outcomes from environmental noise was variable. Further studies directly linking noise interventions to health outcomes are required, particularly for sources other than road traffic noise, and for human health outcomes other than annoyance.

Most studies involved road traffic noise (63%), followed by aircraft noise (13%) and railway noise (6%). The remaining interventions were for leisure noise (13%) and noise in hospital settings (4%). No interventions were identified that either addressed wind turbine noise or focused on educational settings.

Exposure-related interventions were mainly associated with a reduction in environmental noise exposure. However, in five studies (four road traffic noise studies and one aircraft noise study) some or all of the participants experienced noise exposure increases.

There is no clear evidence with respect to thresholds, which are defined as:

- the smallest change in exposure levels that results in a change in outcome; and
- the minimum before-level, regarding changes in health outcomes as a result of interventions.

The limited evidence base on the health effects of environmental noise interventions is thinly spread across different noise source types, outcomes and intervention types. Diversity exists between studies even within intervention types in terms of study designs, methods of analysis, exposure levels and changes in exposure experienced as a result of the interventions. For these reasons, carrying out a meta-analysis across studies examining the association between changes in level and changes in outcome was not possible.

To remedy this main research gap, longitudinal studies assessing noise exposure and health outcomes objectively should be developed, taking into account the most relevant confounders. The establishment of common protocols for future research is warranted (see Table 55).

Authorities should include significant funding for the design and implementation of studies to evaluate the effectiveness of interventions to reduce noise and their impact on health.

Table 55. Implications for research on effectiveness of interventions to reduce exposure and/or improve public health

Current state of the evidence	The current evidence on effectiveness of interventions to reduce health outcomes is limited and of varying quality. Few longitudinal studies have been done that take into account the most relevant confounders and measure the noise exposure and the outcomes objectively.
Population of interest	Research is needed into effects of interventions on defined populations exposed to and/or living near sources of environmental noise.
Intervention of interest	Research into any noise intervention at various points along the system pathway between source and outcome, for a variety of noise sources, is required.
Comparison of interest	The data should be compared to: • a steady-state control group, in similar areas with various exposure gradients from environmental noise sources; • the noise exposure in the same population, through a series of sequential measurements assessing the change before and after the intervention, preferably with multiple after measurements.
Outcomes of interest	Future intervention studies should use validated and, where possible, harmonized measures of exposure and outcome, as well as of moderators and confounders. The studies should use measures of exposure including noise exposure at a wide range of levels and frequencies (including low-frequency noise), with information on noise levels outdoors and indoors (particularly relevant for effects on sleep). They should also use measures of health outcomes, including the following outcomes assessed objectively – for example, according to common protocols (ICBEN scale for annoyance) – with consideration that the change in human response for some health outcomes from a step change in exposure may have a different time course to that of the change in exposure: • annoyance • effects on sleep • cardiovascular and metabolic diseases • adverse birth outcomes • cognitive impairment • mental health, quality of life and well-being • hearing impairment and tinnitus • any other relevant health outcome. Further, they should use measures of moderators and confounders, including repeated measurements of situational and personal variables such as activity interference, potential confounders such as noise sensitivity, coping strategies and a range of other attitudinal variables.
Time stamp	The systematic review included studies up to October 2014.

5. Implementation of the guidelines

5.1 Introduction

These guidelines focus on the WHO European Region and provide guidance to Member States that is compatible with the noise indicators used in the EU's END (EC, 2002a). They provide information on the exposure–response relationships between exposure to environmental noise from different noise sources and the proportion of people affected by certain health outcomes, as well as interventions that are considered efficient in reducing exposure to environmental noise and related health outcomes.

The WHO guideline values are evidence-based public health-oriented recommendations. As such, they are recommended to serve as the basis for a policy-making process in which policy options are considered. In the policy decisions on reference values, such as noise limits for a possible standard or legislation, additional considerations – such as feasibility, costs, preferences and so on – feature in and can influence the ultimate value chosen as a noise limit. WHO acknowledges that implementing the guideline recommendations will require coordinated effort from ministries, public and private sectors and nongovernmental organizations, as well as possible input from international development and finance organizations. WHO will work with Member States and support the implementation process through its regional and country offices.

5.2 Guiding principles

Four guiding principles provide generic advice and support when incorporating the recommendations into a policy framework, and apply to the implementation of all the recommendations.

The **first principle** is to reduce exposure to noise, while conserving quiet areas. The recommendations focus on reduction of population exposure to environmental noise from a variety of sources, in different settings. The general population can be exposed regularly to more than one source of noise simultaneously (including, in some cases, occupational noise), as well as to other nonacoustic factors that can modify the response to noise (such as vibration from railways, air pollution from traffic or visual aspects of wind turbines). Thus, overall reduction of exposure from all sources should be promoted. Furthermore, noise exposure reduction in one area should not come at the expense of an increase in noise elsewhere; existing large quiet outdoor areas should be preserved.

The **second principle** is to promote interventions to reduce exposure to noise and improve health. The evidence from epidemiological studies on adverse health effects at certain noise levels, used as a basis to derive the guideline values proposed in the recommendations, supports the promotion of noise interventions. The potential health impacts from environmental noise are significant, especially when considering the widespread exposure to environmental noise across the population and the high baseline rates for various health outcomes associated with environmental noise.

There are challenges in assessment of the effectiveness of interventions to reduce noise exposure and/or improve health, as there is often a significant time lag between the intervention and a measurable change in exposure and related health benefits. The lack of – or limited direct evidence for – quantifiable health benefits of some specific interventions does not imply that measures to achieve population exposure according to the proposed guidelines should be ignored.

Given the different factors that determine noise exposure, a single measure alone may not be sufficient to reduce exposure and/or improve health significantly, and a combination of methods may be warranted. Nevertheless, it is widely acknowledged that the most effective actions to reduce exposure tend to be those that reduce noise at the source. Such actions have the biggest potential, whereas other measures can be less effective or sustained over time, especially when they depend on behaviour change or noise reductions inside houses.

The **third principle** is to coordinate approaches to control noise sources and other environmental health risks. Considering the common transport-related sources of environmental noise and air pollution, and in particular the evidence of independent effects on the cardiovascular system, a coordinated approach to policy development in the sectors related to urban planning, transport, climate and energy should be adopted for policies with an impact on environmental noise, air quality and/or climate. Such an approach should yield multiple benefits through increased commitment and financial resources; increased attention to securing health considerations in all policies; and use of policy to control noise and other environmental risks such as air pollutants, including short-lived climate pollutants. There is wide consensus on the value of pursuing coordinated policies that can deliver health and other benefits, such as those associated with the local environment and economic development. Furthermore, coordinated policy-making is potentially cost-saving.

The **fourth principle** is to inform and involve communities that may be affected by a change in noise exposure. In planning new urban and/or rural developments (transport schemes, new infrastructures in less densely populated areas, noise abatement and mitigation strategies), bringing together planners, environmental professionals and public health experts with policy-makers and citizens is key to public acceptability and involvement and to the successful guidance of the decision-making proces. Potential health effects from environmental noise should be included as part of health impact assessments of future policies, plans and projects, and the communities potentially affected by a positive or negative change in noise exposure should be well informed and engaged from the outset to maximize potential benefits to health. Introducing measures incrementally may help with acceptance.

5.3 Assessment of national needs and capacity-building

National needs, including the need for capacity-building, differ between Member States in the WHO European Region. They depend on the existence and level of implementation of national and/or European and international noise policies; these are more likely to be implemented fully in EU countries thanks to the legally binding provisions of the EU's END (EC, 2002a). In most countries in the Region noise is perceived as a major and growing environmental health and public health problem. Noise mapping and action plans are carried out in accordance with the END in EU Member States, and in south-eastern European countries noise legislation has mainly been harmonized with the END. Nevertheless, significant differences still exist in the completeness and regular updating of noise exposure assessment between countries. Noise exposure assessment is a required input for noise health impact assessments, along with exposure–response relationships and population baseline data.

WHO has identified some common needs for knowledge transfer and capacity-building for health risk assessment of environment noise in the Member States that joined the EU after 2003, the newly independent states and south-eastern European countries (WHO Regional Office for Europe, 2012):

- implementation of the END and its annexes, especially in the preparation of strategic noise mapping and action plans;
- human resources development through education and training in health risk assessment and burden of diseases stemming from environmental noise;
- methodological guidance for health risk assessment of environmental noise.

These guidelines mostly recommend exposure–response relationships related to the exposure indicators L_{den} and L_{night}. They are therefore of particular relevance to EU countries and those applying the END. In countries that do not use these indicators, users of the guidelines need to convert their noise indicators into L_{den} and L_{night} before being able to apply the recommendations. Conversion between indicators is possible, using a certain set of assumptions (Brink et al., 2018).

5.4 Usefulness of guidelines for target audiences

The provision of guideline values as a practical tool for guiding exposure reduction and the design of effective measures and policies is widely seen as useful. The WHO guidelines equip policy-makers and other end-users with a range of different needs with the necessary evidence base to inform their decisions. As indicated in section 1.4, these guidelines serve as a reference for several target audiences, and for each group they can be useful in different ways.

- For technical experts and decision-makers, the guidelines can be used to provide exposure–response relationships that give insight into the consequences of certain regulations or standards on the associated health effects. They also can be useful at the national and international level when developing noise limits or standards, as they provide the scientific basis to identify the levels at which environmental noise causes a significant health impact. Based on these recommendations, national governments and international organizations can be better informed when introducing noise limits, to ensure protection of people's health.
- For health impact assessment and environmental impact assessment practitioners and researchers, these guidelines provide exposure–response relationships that give insight into the expected health effects at observed or expected noise exposure levels. They offer recommendations on the maximum admissible noise levels for some sources and provide important input to assit in deriving the health burden from noise; in that sense, they can be used when producing studies such as noise maps and action plans to obtain an evaluation of the magnitude of the health problem. The systematic reviews developed in support of these guidelines allow practitioners to raise awareness of the credibility of the issue of noise as a public health problem and to use the recommended exposure–response relationships uniformly. Researchers will also benefit from the guidelines as they clearly identify critical data gaps that need to be filled in the future to better protect the population from the harmful effects of noise.
- The guideline recommendations provide a useful tool for national and local authorities when deciding about noise reduction measures, as they provide data to estimate the health burden on the population and therefore allow comparison among different policy options. These options

can include measures to reduce the noise emitted by the sources, measures aimed at impeding the transmission of noise from the sources to people and measures aimed at better planning the location of houses (urban planning).

- The guideline recommendations can also be used by civil society, patients and other advocacy groups to raise awareness and encourage actions to protect the population, including vulnerable groups, from exposure to noise.

Regarding noise abatement and mitigation of noise sources, practical exposure–response relationships for various noise sources are useful quantitative input to determine the impact of noise on health. They can be valuable information to use in cost–effectiveness and cost–benefit analyses of various policies for noise abatement. In this respect, the guideline recommendations can be an integral part of the policy process for noise reduction by various institutions; they are of great value for communicating the health risks and potential cost-effective solutions to reduce noise.

National and local authorities and nongovernmental organizations responsible for risk communication and general awareness-raising can use these guidelines for promotion campaigns and appropriate risk communication. The guidelines provide scientific evidence on a range of health effects associated with noise and facilitate appropriate risk communication to specific vulnerable groups. They therefore need to be promoted broadly to citizens, national and local authorities and nongovernmental organizations responsible for risk communication.

5.5 Methodological guidance for health risk assessment of environmental noise

A health risk assessment is the scientific evaluation of potential adverse health effects resulting from human exposure to a particular hazard – in this case, environmental noise. The main purpose of the assessment is to estimate and communicate the health impact of exposure to noise or changes in noise in different socioeconomic, environmental and policy circumstances.

The guideline recommendations, along with the detailed information contained in the systematic evidence reviews, can be used to assess health impacts in order to answer a variety of policy questions on:

- the public health burden associated with current or projected levels of noise;
- the human health benefits associated with changing a noise policy or applying a more stringent noise standard;
- the impacts on human health of emissions from specific sources of noise for selected economic sectors (and the benefits of policies related to them); and
- the human health impacts of current policy or implemented action.

The results from a health risk assessment are usually reported as the number of attributable deaths, number of cases, years of life lost, years lost due to disability or DALYs.

The quantification of the impacts for one combination of noise source, noise exposure indicator and health outcome may to some extent include effects attributable to another. Consequently, for any particular set of combinations, consideration should be given to potential double counting.

It is also important to note the uncertainties in quantification of the health impacts. One set of uncertainties relates to the CIs associated with the recommended ERFs; these quantify the random error and variability attributed to heterogeneity in the epidemiological studies used for health risk assessment. Other types of uncertainty include modelling/calculation of noise exposure, estimates of population background rates for morbidity and mortality, and transferability of ERFs from locations where studies were carried out or data were otherwise gathered to another location. This is especially true for noise annoyance, for which there is often considerable heterogeneity in effect sizes of studies because estimates vary between noise sources and are to some degree dependent on the situation and context. Furthermore, cultural differences around what is considered annoying are significant, even within Europe. It is therefore not possible to determine the "exact value" of %HA for each exposure level in any generalized situation. Instead, data and exposure–response curves derived in a local context should be applied whenever possible to assess the specific relationship between noise and annoyance in a given situation. If, however, local data are not available, general exposure–response relationships can be applied, assuming that the local annoyance follows the generalized average annoyance. Despite the challenges in applying a "generalized" ERF to specific local situations, the GDG believes that the percentage of high annoyance defined in section 2.4.3 is an acceptable estimate of the "average" %HA at a certain noise level – for example, in Europe.

When performing a health risk assessment of environmental noise, it is important to note several considerations. The selection of particular noise source(s), noise exposure indicator(s) and health outcome combinations to be used for estimation of the health impacts depends on the particular policies and/or measures being assessed. These guidelines propose recommendations for four types of noise source using noise indicators L_{den} and/or L_{night} (road traffic, railway noise, aircraft noise and wind turbine noise) and one recommendation using $L_{Aeq,24h}$ (leisure noise). Any population may be exposed to different noise sources associated with the same health outcome. Estimated impacts should not be added together without recognizing that addition will, in most practical circumstances, lead to some overestimation of the true impact. Impacts estimated for only one combination will, on the other hand, underestimate the true impact of the noise mixture, if other sources of noise also affect that same health outcome.

The scientific evidence reviewed and summarized in these guidelines implies that the following health outcomes can be quantified in a health risk assessment, and that their effects are cumulative:

- from road traffic noise – incidence of IHD, annoyance and sleep disturbance, and potentially incidence of stroke and diabetes;
- from railway noise – annoyance and sleep disturbance;
- from aircraft noise – annoyance, reading and oral comprehension in children, sleep disturbance and potentially change in waist circumference and incidence of IHD;
- from wind turbine noise: annoyance.

The DWs suggested in section 2.4.3 can be used to calculate DALYs.

Data on incidence and prevalence of some health outcomes related to noise (mainly cardiovascular disease) can be found at a national level in online databases available on the WHO Regional Office for Europe website (WHO Regional Office for Europe, 2017).

General principles of relevance for environmental factors when conducting health risk assessments and quantifying the burden of disease can be found elsewhere (European Centre for Health Policy, 1999; Murray, 1994; Murray & Acharya, 1997; Murray & Lopez, 2013; Quigley et al., 2006; WHO, 2014a; 2014b; WHO Regional Office for Europe, 2016). In particular, the WHO Regional Office for Europe and JRC jointly published the first estimates of the burden of disease from environmental noise in 2011 (WHO Regional Office for Europe & JRC, 2011). The publication includes guidance on the procedure for the health risk assessment of environmental noise, exemplary estimates of the burden of the health impacts of environmental noise and a discussion of the uncertainties and limitations of the procedure to calculate the environmental burden of disease. The reader is referred to this publication for more detailed explanations on quantitative risk assessment methods for environmental noise.

5.6 Route to implementation: policy, collaboration and the role of the health sector

Preventing noise and related health impacts relies on effective action across different sectors: health, environment, transport, urban planning and so on. The health sector needs to be engaged effectively in different sectors' policy processes at national, regional and international levels. It needs to provide authoritative advice about the health impacts of noise and policy options that will bring the greatest benefits to health.

In most countries in the WHO European Region, the commitment of the health sector to engage in action to address environmental noise issues needs to be improved and better coordinated. A more coherent overall response is needed, taking into account relevant linkages with existing health priorities and concerns. Thus, some actions can be seen as aspects of the role of the health sector:

- engaging in proper communication with relevant sectors about noise exposure from different sectors and sources (environmental, urban development, transport and so on) to ensure that health issues are adequately addressed as part of international, regional, national and/or local efforts to address environmental noise – the implementation approach may differ across sectors, depending on the level of awareness of noise as a public health problem;
- promoting the guideline recommendations to policy-makers from different sectors and organizing information campaigns and awareness-raising activities in collaboration with national health authorities and WHO country offices to inform citizens and health practitioners about the health risks of environmental noise;
- using decision support instruments such as health impact and health risk assessments to quantify health risks and potential benefits associated with policies and interventions aimed at addressing environmental noise, including presenting information about the severity of the health effects (for example, with cardiovascular disease) to convey the serious impacts of noise and to try to change attitudes and behaviours of policy-makers and the general public;
- promoting the guidelines to health practitioners and physicians, especially at the community level (through associations of physicians, cardiologists and so on as part of the stakeholder group);
- supporting the establishment of national health institutions capable of initiating and developing health promotion measures, and conducting research, monitoring and reporting on health impacts from environmental noise and its different sources;

- organizing capacity-building workshops and training to increase knowledge of the guidelines as well as creating tools, skills and resources for health risk assessment and developing intersectoral collaboration, particularly in non-EU countries;
- promoting relevant research initiatives and shaping the research agenda, in part based on critical research recommendations and gaps identified in the guidelines, as well as on the impact and effectiveness of interventions and experience with their implementation;
- developing and updating guidelines and policies that influence national, regional and international benchmarks and targets related to environmental noise, as well as advocating the inclusion of the guidelines in development and shaping of national, regional and international noise policies and standards;
- working with other sectors to strengthen noise level monitoring and evaluation, particularly in non-EU countries, to ensure proper conducting of health risk assessments of environmental noise.

5.7 Monitoring and evaluation: assessing the impact of the guidelines

Exposure–response relationships and other recommendations provided by these guidelines should be incorporated into national health policies and the main related policy documents. They should be used for health impact and health risk assessments to identify health risks and potential benefits associated with policies and interventions related to environmental noise.

Population noise exposure should be monitored and assessed at a national scale, at least in urban areas. Furthermore, information on trends in occurrence of noise-related health outcomes considered in these guidelines, such as annoyance or sleep disturbance, should be gathered. These monitoring activities should be performed on a regular basis to ensure proper health risk assessments of noise.

5.8 Updating the guidelines

The progress and pace of noise and health research has intensified over the last 10 years, including new studies published after the completion of the systematic reviews done for these guidelines. This is partly related to the growing car fleet and resulting traffic, the density of urbanization, demographic changes and shifts towards renewable energy, including wind turbines, which have caused an increase in public perception and political awareness of the environmental noise problem. Noise exposure assessment has also improved, due partly to European legislation, and this has provided useful data for epidemiological studies on the health effects of environmental noise. Considering this, the recommendations proposed in these guidelines are expected to remain valid for a period of about 10 years. WHO will monitor the development of the scientific advancements on noise and health research in order to inform any updated guidance on environmental noise.

References

Alonso-Coello P, Oxman AD, Moberg J, Brignardello-Petersen R, Akl EA, Davoli M et al. (2016a). GRADE Evidence to Decision (EtD) frameworks: a systematic and transparent approach to making well informed healthcare choices. 2: Clinical practice guidelines. BMJ. 353:i2089. doi: 10.1136/bmj.i2089.

Alonso-Coello P, Schünemann HJ, Moberg J, Brignardello-Petersen R, Akl EA, Davoli M et al. (2016b). GRADE Evidence to Decision (EtD) frameworks: a systematic and transparent approach to making well informed healthcare choices. 1: Introduction. BMJ. 353: i2016. doi: 10.1136/bmj.i2016.

Amundsen AH, Klaeboe R, Aasvang GM (2011). The Norwegian facade insulation study: the efficacy of facade insulation in reducing noise annoyance due to road traffic. J Acoust Soc Am. 129(3):1381–9.

Amundsen AH, Klaeboe R, Aasvang GM (2013). Long-term effects of noise reduction measures on noise annoyance and sleep disturbance: the Norwegian facade insulation study. J Acoust Soc Am. 133(6):3921–8.

Ancona C, Forastiere F, Mataloni F, Badaloni C, Fabozzi T, Perucci CA, on behalf of the SERA Study Team (2010). Aircraft noise exposure and blood pressure among people living near Ciampino airport in Rome. In: Proceedings. 39th International Congress on Noise Control Engineering 2010 (INTER-NOISE 2010), Lisbon, Portugal, 13–16 June 2010. Lisbon: Sociedade Portuguesa de Acustica.

Asensio C, Recuero M, Pavón I (2014). Citizens' perception of the efficacy of airport noise insulation programmes in Spain. Appl Acoust. 84:107–15.

Babisch W (2004). The NaRoMI-Study: executive summary – traffic noise. In: Federal Environmental Agency, editor. Chronic noise as a risk factor for myocardial infarction, The NaRoMI study. Berlin: Umweltbundesamt:1–16.

Babisch W (2014). Updated exposure–response relationship between road traffic noise and coronary heart diseases: a meta-analysis. Noise Health. 16(68):1–9.

Babisch W, Beule B, Schust M, Kersten N, Ising H (2005a). Traffic noise and risk of myocardial infarction. Epidemiology. 16(1):33–40.

Babisch W, Gallacher JE (1990). Traffic noise, blood pressure and other risk factors: the Caerphilly and Speedwell Collaborative Heart Disease Studies. In: Proceedings. 5th International Congress on Noise as a Public Health Problem, Stockholm, Sweden, 21–28 August 1988. Stockholm: Swedish Council for Building Research.

Babisch W, Gallacher JE, Elwood PC, Ising H (1988). Traffic noise and cardiovascular risk. The Caerphilly Study, first phase. Outdoor noise levels and risk factors. Arch Environ Health. 43(6):407–14.

Babisch W, Houthuijs D, Kwekkeboom J, Swart W, Pershagen G, Bluhm G et al. (2005b). HYENA – hypertension and exposure to noise near airports: a European study on health effects of aircraft noise. In: Proceedings. 34th International Congress on Noise Control Engineering 2005 (INTER-NOISE 2005), Rio de Janeiro, Brazil, 7–10 August 2005. Washington DC: Institute of Noise Control Engineering of the USA.

Babisch W, Houthuijs D, Pershagen G, Cadum E, Katsouyanni K, Velonakis M et al. (2009). Annoyance due to aircraft noise has increased over the years – results of the HYENA study. Environ Int. 35:1169–76.

Babisch W, Houthuijs D, Pershagen G, Katsouyanni K, Velonakis M, Cadum E et al. (2008). Associations between road traffic noise level, road traffic noise annoyance and high blood pressure in the HYENA study. J Acoust Soc Am. 123:3448. doi: 10.1121/1.2934267.

Babisch W, Ising H, Elwood PC, Sharp DS, Bainton D (1993a). Traffic noise and cardiovascular risk: the Caerphilly and Speedwell studies, second phase. Risk estimation, prevalence, and incidence of ischemic heart disease. Arch Environ Health. 48(6):406–13.

Babisch W, Ising H, Gallacher JE (2003). Health status as a potential effect modifier of the relation between noise annoyance and incidence of ischaemic heart disease. Occup Environ Med. 60(10):739–45.

Babisch W, Ising H, Gallacher JE, Sharp DS, Baker I (1993b). Traffic noise and cardiovascular risk: the Speedwell study, first phase. Outdoor noise level and risk factors. Arch Environ Health. 48(6):401–5.

Babisch W, Ising H, Gallacher JEJ, Sweetnam PM, Elwood PC (1999). Traffic noise and cardiovascular risk: the Caerphilly and Speedwell studies, third phase – 10-year follow up. Arch Environ Health. 54(3):210–16.

Babisch W, Ising H, Kruppa B, Wiens D (1992). Verkehrslärm und Herzinfarkt, Ergebnisse zweier Fall-Kontroll-Studien in Berlin [Transport noise and myocardial infarction. Results of two case studies from Berlin]. In WoBoLu-Hefte 2/92. Insitut für Wasser, Boden und Lufthygiene. Berlin: Umweltbundeamt].

Babisch W, Ising H, Kruppa B, Wiens D (1994). The incidence of myocardial infarction and its relation to road traffic noise – the Berlin case-control studies. Environ Int. 20(4):469–74.

Babisch W, Pershagen G, Selander J, Houthuijs D, Breugelmans O, Cadum E et al. (2013a). Noise annoyance – a modifier of the association between noise level and cardiovascular health? Sci Total Environ. 452–53:50–7.

Babisch W, Swart W, Houthuijs D, Selander J, Bluhm G, Pershagen G et al. (2012). Exposure modifiers of the relationships of transportation noise with high blood pressure and noise annoyance. J Acoust Soc Am. 132(6):3788–808.

Babisch W, Wolf K, Petz M, Heinrich J, Cyrys J, Peters A (2013b). Road traffic noise, air pollution and (isolated systolic) hypertension: cross-sectional results from the KORA study. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Babisch W, Wolf K, Petz M, Heinrich J, Cyrys J, Peters A (2014c). Associations between traffic noise, particulat air pollution, hypertension, and isolated systolic hypertension in adults: the KORA study. Environ Health Perspect. 122(5):492–8.

Babisch W, Wolke G, Heinrich J, Straff W (2014a). Road traffic noise and hypertension – accounting for the location of rooms. Environ Res. 133:380–7.

Babisch W, Wolke G, Heinrich J, Straff W (2014b). Road traffic, location of rooms and hypertension. J Civil Environ Eng. 4(5):162.

Bakker RH, Pedersen E, van den Berg GP, Stewart RE, Lok W, Bouma J (2012). Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. Sci Total Environ. 425:42–51.

Barregard L, Bonde E, Ohrstrom E (2009). Risk of hypertension from exposure to road traffic noise in a population-based sample. Occup Environ Med. 66(6):410–15.

Bartels S, Müller U, Vogt J (2013). Predictors of aircraft noise annoyance: results of a telephone study. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S et al. (2014). Auditory and non-auditory effects of noise on health. Lancet. 383(9925): 1325–32.

Basner M, Isermann U, Samel A (2006). Aircraft noise effects on sleep: application of the results of a large polysomnographic field study. J Acoust Soc Am. 119(5):2772–84.

Basner M, McGuire S (2018). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and effects on sleep. Int J Environ Res Public Health. 15(3):pii: E519 (http://www.mdpi.com/1660-4601/15/3/519/htm, accessed 27 June 2018).

Basner M, Müller U, Elmenhorst EM (2011). Single and combined effects of air, road, and rail traffic noise on sleep and recuperation. Sleep. 34(1):11–23.

Baughan C, Huddart L (1993). Effects of traffic noise changes on residents' nuisance ratings. In: Proceedings. 6th International Congress on Noise as a Public Health Problem. Nice, France, 5–9 July 1993. Lyon: Institut National de Recherche sur les Transports et leur Sécurité.

Beelen R, Hoek G, Houthuijs D, van den Brandt PA, Goldbohm RA, Fischer Pet al. (2009). The joint association of air pollution and noise from road traffic with cardiovascular mortality in a cohort study. Occup Environ Med. 66(4):243–50.

Belojevic G, Evans GW (2011). Traffic noise and blood pressure in North-American urban schoolchildren C3. In: Proceedings. 10th International Congress on Noise as a Public Health Problem 2011 (ICBEN 2011), London, United Kingdom, 24–28 July 2011. London: Institute of Acoustics.

Belojevic G, Evans GW (2012). Traffic noise and blood pressure in low-socioeconomic status, African-American urban schoolchildren. J Acoust Soc Am. 132(3):1403–6.

Bendtsen H, Michelsen L, Christensen EC (2011). Noise annoyance before and after enlarging Danish highway. In: Proceedings. Forum Acusticum: 6th European Congress on Acoustics, Aalborg, Denmark, 27 June – 1 July 2011. Stuttgart: Hirzel.

Berry B, Sanchez D (2014). The economic and social value of aircraft noise effects: A critical review of the state of the art. In: Proceedings. 11th International Congress on Noise as a Public Health Problem 2014 (ICBEN 2014), Nara, Japan, 1–5 June 2014. Tokyo: Institute of Noise Control Engineering of Japan.

Bilenko N, van Rossem L, Brunekreef B, Beelen R, Eeftens M, Hoek G et al. (2013). Traffic-related air pollution and noise and children's blood pressure: results from the PIAMA birth cohort study. Eur J Prev Cardiol. 22(1):4–12.

Bjork J, Ardo J, Stroh E, Lovkvist H, Ostergren PO, Albin M (2006). Road traffic noise in southern Sweden and its relation to annoyance, disturbance of daily activities and health. Scand J Work Environ Health. 32:392–401.

Blanes N, Fons J, Houthuijs D, Swart W, Sáinzde la Maza M, Ramos MJ et al. (2017). Noise in Europe 2017: updated assessment. Bilthoven: European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM Technical Paper 2016/13; http://acm.eionet.europa.eu/reports/ETCACM_TP_2016_13_NoiseInEurope2017, accessed 17 June 2017).

Bluhm G, Berglind N, Nordling E, Rosenlund M (2007). Road traffic noise and hypertension. Occup Environ Med. 64(2):122–6.

Bluhm G, Eriksson C, Hilding A, Ostenson CG (2004). Aircraft noise exposure and cardiovascular risk on men. First results from a study around Stockholm Arlanda airport. In: Proceedings. 33rd International Congress and Exhibition on Noise Control Engineering, Prague, Czechia, 22–25 August 2004. Prague: Czech Acoustical Society.

Bluhm G, Eriksson C, Pershagen G, Hilding A, Östenson CG (2009). Aircraft noise and incidence of hypertension: a study around Stockholm Arlanda airport. In: Proceedings. 8th European Conference on Noise Control 2009 (EURONOISE 2009), Edinburgh, United Kingdom, 26–28 October 2009. Edinburgh: Institute of Acoustics.

Bodin T, Albin M, Ardo J, Stroh E, Ostergren PO, Bjork E (2009). Road traffic noise and hypertension: results from a cross-sectional public health survey in southern Sweden. Environ Health. 8(38).

Bodin T, Björk J, Ardö J, Albin M (2015). Annoyance, sleep and concentration problems due to combined traffic noise and the benefit of quiet side. Int J Environ Res Public Health. 12(2): 1612–28.

Borsky, PN (1979). Sociopsychological factors affecting the human response to noise exposure. Otolaryngol Clin North Am. 12(3):521–35.

Breugelmans O, Houthuijs D, van Kamp I, Stellato R, van Wiechen C, Doornbos G (2007). Longitudinal effects of a sudden change in aircraft noise exposure on annoyance and sleep disturbance around Amsterdam airport. In: Proceedings. 19th International Congress on Acoustics (ICA 2007), Madrid, Spain, 2–7 September 2007. Madrid: Sociedad Espanola de Acustica.

Breugelmans ORP, van Wiechen CMAG, van Kamp I, Heisterkamp SH, Houthuijs DJM (2004). Gezondheid en beleving van de omgevingskwaliteit in de regio Schiphol 2002 [Health and quality of life near Amsterdam Schiphol airport: 2002]. Interim report 630100001 [in Dutch]. Bilthoven: National Institute for Public Health and the Environment.

Brink M (2011). Parameters of well-being and subjective health and their relationship with residential traffic noise exposure – a representative evaluation in Switzerland. Environ Int. 37:723–33.

Brink M (2013). Annoyance assessment in postal surveys using the 5-point and 11-point ICBEN scales: effects of sale and question arrangement. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Brink M, Schäffer B Pieren, R, Wunderli JM (2018). Conversion between noise exposure indicators L_{eq24h}, L_{Day}, $L_{Evening}$, L_{Night}, L_{dn} and L_{den}: principles and practical guidance. Int J Hyg Environ Health. 221(1):54–63. doi: 10.1016/j.ijheh.2017.10.003.

Brink M, Schreckenberg D, Vienneau D, Cajochen C, Wunderli JM, Probst-Hensch N et al. (2016). Effects of scale, question location, order of response alternatives, and season on self-reported noise annoyance using ICBEN scales: a field experiment. Int J Environ Res Public Health. 13(11). doi: 10.3390/ijerph13111163.

Brink M, Wirth KE, Schierz C, Thomann G, Bauer G (2008). Annoyance responses to stable and changing aircraft noise exposure. J Acoust Soc Am. 124(5):2930–41.

Bristow AL, Wardman M, Chintakayala VPK (2014). International meta-analysis of stated preference studies of transportation noise nuisance. Transportation. 42(1):71–100.

Bronzaft AL (1981). The effect of a noise abatement program on reading ability. J Environ Psychol. 1:215–22.

Bronzaft AL, McCarthy DP (1975). The effects of elevated train noise on reading ability. Environ Behav. 7(4):517–27.

Brown AL (1987). Responses to an increase in road traffic noise. J Sound Vib. 117(1):69–79.

Brown AL (2015). Longitudinal annoyance responses to a road traffic noise management strategy that reduced heavy vehicles at night. J Acoust Soc Am. 137(1):165–76.

Brown AL, Hall A, Kyle-Little J (1985). Response to a reduction in traffic noise exposure. J Sound Vib. 98(2):235–46.

Brown AL, Lam KC, van Kamp I (2015). Quantification of the exposure and effects of road traffic noise in a dense Asian city: a comparison with Western cities. Environ Health. 14–22. doi: 10.1186/s12940-015-0009-8.

Brown AL, Lam KC, van Kamp I, Yeung MKL (2014). Urban road traffic noise: exposure and human response in a dense, high-rise city in Asia. In: Proceedings. 11th International Congress on Noise as a Public Health Problem 2014 (ICBEN 2014), Nara, Japan, 1–5 June 2014. Tokyo: Institute of Noise Control Engineering of Japan.

Brown AL, van Kamp I (2009). Response to a change in transport noise exposure: a review of evidence of a change effect. J Acoust Soc Am. 125(5):3018–29.

Brown AL, van Kamp I (2017). WHO environmental noise guidelines for the European Region: a systematic review of transport noise interventions and their impacts on health. Int J Environ Res Public Health. 14(8). pii: E873 (http://www.mdpi.com/1660-4601/14/8/873/htm, accessed 27 June 2018).

Caerphilly and Speedwell Collaborative Group (1984). Caerphilly and Speedwell collaborative heart disease studies. J Epidemiol Community Health. 38:259–62.

Centraal Bureau voor de Statistiek (2012). Milieuhinder, milieugedrag en milieubesef van personen [Environmental nuisance, environmental behaviour and environmental awareness of indivuals] [in Dutch]. The Hague: Centraal Bureau voor de Statistiek (http://statline.cbs.nl/Statweb/publication/?VW=T&DM=SLNL&PA=03783&D1=18-26&D2=0&D3=a&HD=161128-0938&HDR=T&STB=G1,G2, accessed 27 November 2016).

Champelovier P, Cremezi-Charlet C, Lambert J (2003). Evaluation de la gêne due à l'exposition combinée aux bruits routier et ferroviaire [Assessement of annoyance from combined exposure to road and rail traffic noises] (Research Report 242). Lyon: Institut National de Recherche sur les Transports et leur Sécurité.

Chang TY, Beelen R, Li SF, Chen TI, Lin YJ, Bao BY et al. (2014). Road traffic noise frequency and prevalent hypertension in Taichung, Taiwan: a cross-sectional study. Environ Health. 13(1):37.

Chang TY, Liu CS, Bao BY, Li SF, Chen TI, Lin YJ (2011). Characterization of road traffic noise exposure and prevalence of hypertension in central Taiwan. Sci Total Environ. 409(6):1053–7.

Clark C, Crombie R, Head J, van Kamp I, van Kempen E, Stansfeld SA (2012). Does traffic-related air pollution explain associations of aircraft and road traffic noise exposure on children's health and cognition? A secondary analysis of the United Kingdom sample from the RANCH project. Am J Epidemiol. 176:327–37.

Clark C, Head J, Stansfeld SA (2013). Longitudinal effects of aircraft noise exposure on children's health and cognition: a six-year follow-up of the United Kingdom RANCH cohort. J Environ Psychol. 35:1–9.

Clark C, Martin R, van Kempen E, Alfred T, Head J, Davies HW et al. (2006). Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension – the RANCH project. Am J Epidemiol. 163:27–37.

Clark C, Paunovic K (2018). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and cognition. Int J Environ Res Public Health. 15(2). pii: E285 (http://www.mdpi.com/1660-4601/15/2/285/htm, accessed 27 June 2018).

Clark C, Paunovic K (in press). WHO Environmental noise guidelines for the European Region: a systematic review on environmental noise and quality of life, wellbeing and mental health. Int J Environ Res Public Health.

Cohen S, Glass DC, Singer JE (1973). Apartment noise, auditory discrimination, and reading ability in children. J Exp Soc Psychol. 9(5):407–22.

Correia AW, Peters JL, Levy JI, Melly S, Dominici F (2013). Residential exposure to aircraft noise and hospital admissions for cardiovascular diseases: multi-airport retrospective study. BMJ. 347:f5561.

Council of Canadian Academies (2015). Understanding the evidence: wind turbine noise. Ottawa: Council of Canadian Academies (http://www.scienceadvice.ca/en/assessments/completed/wind-turbine-noise.aspx, accessed 6 July 2018).

CSES, Accon, AECOM (2016). Evaluation of Directive 2002/49/EC relating to the assessment and management of environmental noise. Luxembourg: Publications Office of the European Union (https://publications.europa.eu/en/publication-detail/-/publication/7febde6d-9a89-11e6-9bca-01aa75ed71a1/language-en, accessed 10 July 2018).

de Kluizenaar Y, Gansevoort RT, Jong PE de, Miedema HME (2007a). Cardiovascular effects of road traffic noise with adjustment for air pollution. In: Proceedings. 36th International Congress and Exhibition on Noise Control Engineering 2007 (INTER-NOISE 2007), Istanbul, Turkey, 28–31 August 2007. Istanbul: Turkish Acoustical Society.

de Kluizenaar Y, Gansevoort RT, Miedema HM, Jong PE de (2007b). Hypertension and road traffic noise exposure. Occup Environ Med. 49(5):484–92.

de Kluizenaar Y, Janssen SA, Vos H, Salomons EM, Zhou H, van den Berg F (2013). Road traffic noise and annoyance: a quantification of the effect of quiet side exposure at dwellings. Int J Environ Res Public Health. 10(6):2258–70.

de Kluizenaar Y, Salomons EM, Janssen SA, van Lenthe FJ, Vos H, Zhou H et al. (2011). Urban road traffic noise and annoyance: the effect of a quiet facade. J Acoust Soc Am. 130(4):1936–42.

Dell SM, Holmes AE (2012). The effect of a hearing conservation program on adolescents' attitudes towards noise. Noise Health. 14(56):39–44.

Dratva J, Phuleria HC, Foraster M, Gaspoz JM, Keidel D, Kunzli N et al. (2012). Transportation noise and blood pressure in a population-based sample of adults. Environ Health Perspect. 120(1):50–5.

Eagan ME, Anderson G, Nicholas B, Horonjeff R, Tivnan T (2004). Relation between aircraft noise reduction in schools and standardized test scores. In: Proceedings. 9th International Congress on Noise as a Public Health Problem 2008 (ICBEN 2008), Foxwoods, USA, 21–25 July 2008. Zurich: International Commission on Biological Effects of Noise.

EASA, EEA, Eurocontrol (2016). European Aviation Environmental Report 2016. Cologne: European Aviation Safety Agency (https://ec.europa.eu/transport/sites/transport/files/european-aviation-environmental-report-2016-72dpi.pdf, accessed 24 January 2018).

EC (1993). Towards sustainability: a European Community programme of policy and action in relation to the environment and sustainable development. OJ C 138/10, 17.5.93 (http://ec.europa.eu/environment/archives/action-programme/5th.htm, accessed 27 November 2016).

EC (1996). Future noise policy: European Commission Green Paper. Luxembourg: Office for Official Publications of the European Communities (COM(96) 540 final; https://publications.europa.eu/en/publication-detail/-/publication/8d243fb5-ec92-4eee-aac0-0ab194b9d4f3/language-en, accessed 28 November 2016).

EC (2000). Position paper on EU noise indicators. Luxembourg: Office for Official Publications of the European Communities (https://publications.europa.eu/en/publication-detail/-/publication/10d75ba4-7279-4df2-aa50-3ed7fdf656a8/language-en, accessed 27 November 2016).

EC (2002a). Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. OJ L 189, 18.7.2002:12–25 (https://eur-lex.europa.eu/eli/dir/2002/49/oj, accessed 13 December 2016).

EC (2002b). Decision No 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme. OJ L 242, 6th EAP, 1–15 (http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002D1600&from=EN, accessed 28 November 2016).

EC (2003). Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (Seventeenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). OJ L 42, 15.2.2003:38–44 (https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32003L0010, accessed 24 January 2018).

EC (2008a). Attitudes of European citizens towards the environment. Luxembourg: Office for Official Publications of the European Communities (Special Eurobarometer 295; http://ec.europa.eu/environment/eurobarometers_en.htm, accessed 28 November 2016).

EC (2008b). Potential health risks of exposure to noise from personal music players and mobile phones including a music playing function. Luxembourg: Office for Official Publications of the European Communities (http://ec.europa.eu/health/scientific_committees/emerging/opinions/scenihr_opinions_en.htm, accessed 28 November 2016).

EC (2010). Electromagnetic Fields. Luxembourg: Publications Office of the European Union (Special Eurobarometer 347; http://ec.europa.eu/commfrontoffice/publicopinion/archives/eb_special_359_340_en.htm, accessed 27 November 2016).

EC (2014). Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 "Living well, within the limits of our planet". OJ L 354, 28.12.2013:171–200 (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32013D1386, accessed 28 November 2016).

EC (2014b). Attitudes of European citizens towards the environment. Luxembourg: Publications Office of the European Union (Special Eurobarometer 416; http://ec.europa.eu/environment/eurobarometers_en.htm, accessed 28 November 2016).

EC (2015). Commission Directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council. OJ L 168/1, 1.7.2015: 1–823 (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:JOL_2015_168_R_0001, accessed 28 November 2016).

EC (2016a). Links between noise and air pollution and socioeconomic status. Luxembourg: Publications Office of the European Union (Science for Environmenta Policy In-depth Report 13; http://ec.europa.eu/science-environment-policy, accessed 24 January 2018).

EC (2016b). EU reference scenario 2016 — Energy, transport and GHG emissions: trends to 2050. Luxembourg: Publications Office of the European Union (https://publications.europa.eu/en/publication-detail/-/publication/aed45f8e-63e3-47fb-9440-a0a14370f243/language-en, accessed 4 July 2018).

EEA (2010). Good practice guide on noise exposure and potential health effects. Copenhagen: European Environment Agency (Technical report No 11/2010; http://www.eea.europa.eu/publications/good-practice-guide-on-noise, accessed 27 November 2016).

EEA (2014). Noise in Europe 2014. Copenhagen: European Environment Agency (EEA Report No 10/2014; http://www.eea.europa.eu/publications/noise-in-europe-2014, accessed 28 November 2016).

EEA (2016a). Transitions towards a more sustainable mobility system. TERM 2016: Transport indicators tracking progress towards environmental targets in Europe. Luxembourg: Publications Office of the European Union (EEA Report No 34/2016; https://publications.europa.eu/en/publication-detail/-/publication/c276880f-9c1a-11e7-b92d-01aa75ed71a1/language-en, accessed 4 July 2018).

EEA (2016b). Environmental indicator report 2016. Luxembourg: Publications Office of the European Union (EEA Report No 30/2016; https://www.eea.europa.eu/publications/environmental-indicator-report-2016, accessed 15 March 2017).

EEA (2017a). Managing exposure to noise in Europe. Copenhagen: European Environment Agency (Briefing No 1/2017; https://www.eea.europa.eu/publications/managing-exposure-to-noise-in-europe/, accessed 24 January 2018).

EEA (2017b). TERM 12 — passenger transport volume and modal split. In: European Environment Agency: Indicators [website]. Copenhagen: European Environment Agency (https://www.eea.europa.eu/data-and-maps/indicators/passenger-transport-demand-version-2/assessment-9, accessed 30 January 2018).

EEA (2018). Noise Observation and Information Service for Europe [website]. Copenhagen: European Environment Agency (http://noise.eionet.europa.eu/, accessed 28 November 2016).

Elmenhorst EM, Pennig S, Rolny V, Quehl J, Mueller U, Maaß H et al. (2012). Examining nocturnal railway noise and aircraft noise in the field: sleep, psychomotor performance, and annoyance. Sci Total Environ. 424:48–56.

Eriksson C, Bluhm G, Hilding A, Ostenson CG, Pershagen G (2010). Aircraft noise and incidence of hypertension: gender specific effects. Environ Res. 110(8):764–72.

Eriksson C, Hilding A, Pyko A, Bluhm G, Pershagen G, Östenson CG (2014). Long-term aircraft noise exposure and body mass index, waist circumference, and type 2 diabetes: a prospective study. Environ Health Perspect. 122:687–94.

Eriksson C, Nilsson ME, Willers SM, Gidhagen L, Bellander T, Pershagen G (2012). Traffic noise and cardiovascular health in Sweden: the roadside study. Noise Health. 14(59):140–7.

Eriksson C, Pershagen G, Nilsson M (2018). Biological mechanisms related to cardiovascular and metabolic effects by environmental noise. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/biological-mechanisms-related-to-cardiovascular-and-metabolic-effects-by-environmental-noise, accessed 8 August 2018).

Eriksson C, Rosenlund M, Pershagen G, Hilding A, Ostenson CG, Bluhm G (2007). Aircraft noise and incidence of hypertension. Epidemiology. 18(6):716–21.

Eurofound (2017). European Quality of Life Survey 2016: quality of life, quality of public services, and quality of society. Luxembourg: Publications Office of the European Union.

European Centre for Health Policy (1999). Health impact assessment: main concepts and suggested approach. Brussels: WHO Regional Office for Europe (Gothenburg consensus paper; http://www.healthedpartners.org/ceu/hia/hia01/01_02_gothenburg_paper_on_hia_1999.pdf).

Eurostat (2016). Urban Europe—Statistics on cities, towns and suburbs. Luxembourg: Eurostat (http://ec.europa.eu/eurostat/statistics-explained/index.php/Urban_Europe_%E2%80%94_statistics_on_cities,_towns_and_suburbs, accessed 13 March 2017).

Evans G, Maxwell L (1997). Chronic noise exposure and reading deficits: The mediating effects of language acquisition. Environ Behav. 29:638–56.

Evrard AS, Bouaoun L, Champelovier P, Lambert J, Laumon B (2015). Does exposure to aircraft noise increase the mortality from cardiovascular disease in the population living in the vicinity of airports? Results of an ecological study in France. Noise Health. 17:328–36.

Evrard AS, Khati I, Champelovier P, Lambert J, Laumon B (2013). Cardiovascular effects of aircraft noise near Paris-Charles de Gaulle airport: results from the pilot study of the DEBATS research program. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Feder K, Marro L, Keith SE, Michaud DS (2013). Audiometric thresholds and portable digital audio player user listening habits. Int J Audiol. 52(9):606–16.

FICAN (2007). Findings of the FICAN pilot study on the relationship between aircraft noise reduction and changes in standardised test scores. Washington DC: Federal Interagency Committee on Aviation Noise.

Fidell S, Silvati L, Haboly E (2002). Social survey of community response to a step change in aircraft noise exposure. J Acoust Soc Am. 111(1 Pt 1):200–9.

Floud S, Blangiardo M, Clark C, Hoogh K de, Babisch W, Houthuijs D, et al. (2013a). Exposure to aircraft and road traffic noise and associations with heart disease and stroke in six European countries: a cross-sectional study. Environ Health. 12:89.

Floud S, Blangiardo M, Clark C, Hoogh K de, Babisch W, Houthuijs D, et al. (2013b). Heart disease and stroke in relation to aircraft noise and road traffic noise – The HYENA study. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Floud S, Vigna-Taglianti F, Hansell A, Blangiardo M, Houthuijs D, Breugelmans O et al. (2011). Medication use in relation to noise from aircraft and road traffic in six European countries: results of the HYENA study. Occup Environ Med. 68:518–24.

Foraster M, Basagaña X, Aguilera I, Agis D, Bouso L, Phuleria H et al. (2012). Transportation noise (in particular railway noise) and blood pressure in REGICOR compared to SAPALDIA. In: Proceedings. 41st International Congress and Exposition on Noise Control Engineering 2012 (INTER-NOISE 2012), New York, USA, 19–22 August 2012. Washington DC: Institute of Noise Control Engineering of the USA.

Foraster M, Basagaña X, Aguilera I, Rivera M, Agis D, Bouso L et al. (2011). Cross-sectional association between road traffic noise and hypertension in a population-based sample in Girona, Spain (REGICOR-AIR project). In: Proceedings. 10th International Congress on Noise as a Public Health Problem 2011 (ICBEN 2011), London, United Kingdom, 24–28 July 2011. London: Institute of Acoustics.

Foraster M, Basagaña X, Aguilera I, Rivera M, Agis D, Bouso L et al. (2013). Disentangling the effects of traffic-related noise and air pollution on blood pressure: Indoor noise levels and protections. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Foraster M, Basagaña X, Aguilera I, Rivera M, Agis D, Bouso L et al. (2014a). Association of long-term exposure to traffic-related air pollution with blood pressure and hypertension in an adult population-based cohort in Spain (the REGICOR study). Environ Health Perspect. 122(4):404–11.

Foraster M, Kunzli N, Aguilera I, Rivera M, Agis D, Vila J et al. (2014b). High blood pressure and long-term exposure to indoor noise and air pollution from road traffic. Environ Health Perspect. 122(11):1193–200.

Frei P, Mohler E, Roeoesli M (2014). Effect of nocturnal road traffic noise exposure and annoyance on objective and subjective sleep quality. Int J Hyg Environ Health. 217(2–3):188–95.

Fuks K, Moebus S, Hertel S, Viehmann A, Nonnemacher M, Dragano N et al. (2011). Long-term urban particulate air pollution, traffic noise, and arterial blood pressure. Environ Health Perspect. 119(12):1706–11.

Gan WQ, Davies HW, Koehoorn M, Brauer M (2012). Association of long-term exposure to community noise and traffic-related air pollution with coronary heart disease mortality. Am J Epidemiol. 175(9):898–906.

Garcia SL, Smith KJ, Palmer C. (2018). Cost–effectiveness analysis of a military hearing conservation program. Mil Med. doi: 10.1093/milmed/usx112.

Gelderblom FB, Gjestland TT, Granoien ILN, Taraldsen G (2014). The impact of civil versus military aircraft noise on noise annoyance. In: Proceedings. 43rd International Congress on Noise Control Engineering 2014 (INTER-NOISE 2014), Melbourne, Australia, 16–19 November 2014. Melbourne: Australian Acoustical Society.

Gidloef-Gunnarsson A, Oegren M, Jerson T, Oehrstroem E (2012). Railway noise annoyance and the importance of number of trains, ground vibration, and building situational factors. Noise Health. 14(59):190–201.

Gidloef-Gunnarsson A, Oehrstroem E (2010). Attractive "quiet" courtyards: a potential modifier of urban residents' responses to road traffic noise? Int J Environ Res Public Health. 7(9):3359–75.

Gidloef-Gunnarsson A, Oehrstroem E (2007). Noise and well-being in urban residential environments: the potential role of perceived availability to nearby green areas. Landsc Urban Plan. 83(2–3):115–26.

Gidloef-Gunnarsson A, Oehrstroem E, Kihlman T (2010). A full-scale intervention example of the "quiet side concept" in a residential area exposed to road traffic noise: effects on the perceived sound environment and general noise annoyance. In: Proceedings. 39th International Congress on Noise Control Engineering 2010 (INTER-NOISE 2010), Lisbon, Portugal, 13–16 June 2010. Lisbon: Sociedade Portuguesa de Acustica.

Gidloef-Gunnarsson A, Svensson H, Oehrstroem E (2013). Noise reduction by traffic diversion and a tunnel construction: effects on health and well-being after opening of the Southern Link. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Gilles A, Van de Heyning P (2014). Effectiveness of a preventive campaign for noise-induced hearing damage in adolescents. Int J Pediatr Otorhinolaryngol. 78(4):604–9.

Grazuleviciene R, Lekaviciute J, Mozgeris G, Merkevicius S, Deikus J (2004). Traffic noise emissions and myocardial infarction risk. Pol J Enviro Stud. 13:737–41.

Green KB, Pasternack BS, Shore RE (1982). Effects of aircraft noise on reading ability of school-age children. Arch Environ Health. 37(1): 24–31.

Griefahn B, Schuemer-Kohrs A, Schuemer R, Mohler U, Mehnert P (2000). Physiological, subjective, and behavioural responses to noise from rail and road traffic. Noise Health. 3(9):59–71.

Griffiths ID, Raw GJ (1987). Community and individual response to changes in traffic noise exposure. Dev Toxicol Environ Sci. 15:333–43.

Griffiths ID, Raw GJ (1989). Adaptation to changes in traffic noise exposure. J Sound Vib. 132(2):331–6.

Guski R (1999). Personal and social variables as co-determinants of noise annoyance. Noise Health. 3:45–56.

Guski R, Schreckenberg D, Schuemer R (2017). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and annoyance. Int J Environ Res Public Health. 14(12). pii:1539 (http://www.mdpi.com/1660-4601/14/12/1539/htm, accessed 27 June 2018).

Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P et al. (2008). GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 336(7650):924–6.

Hänninen O, Knol AB, Jantunen M, Lim TA, Conrad A, Rappolder M et al. (2014). Environmental burden of disease in Europe: assessing nine risk factors in six countries. Environ Health Perspect. 122(5):439–46.

Haines MM, Stansfeld SA, Brentnall S, Head J, Berry B, Jiggins M et al. (2001a). The West London Schools Study: the effects of chronic aircraft noise exposure on child health. Psychol Med. 31:1385–96.

Haines MM, Stansfeld SA, Job RF, Berglund B, Head J (2001b). Chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school children. Psychol Med. 31:265–77.

Haines MM, Stansfeld SA, Job RF, Berglund B, Head J (2001c). A follow-up study of effects of chronic aircraft noise exposure on child stress responses and cognition. Int J Epidemiol. 30:839–45.

Halonen JI, Vahtera J, Stansfeld S, Yli-Tuomi T, Salo P, Pentti J et al. (2012). Associations between nighttime traffic noise and sleep: the Finnish public sector study. Environ Health Perspect. 120(10): 1391–6.

Hansell AL, Blangiardo M, Fortunato L, Floud S, Hoogh K de, Fecht D et al. (2013). Aircraft noise and cardiovascular disease near Heathrow airport in London: small area study. BMJ. 347:f5432.

Heimann D, de Franceschi M, Emeis S, Lercher P, Seibert P, editors (2007). Air pollution, traffic noise and related health effects in the Alpine space: a guide for authorities and consulters. ALPNAP comprehensive report. Trento: Universita degli Studi di Trento, Dipartimento di Ingegneria Civile e Ambientale.

Hense HW, Herbold M, Honig K (1989). Risikofaktor Lärm in Felderhebungen zu Herz-Kreislauferkrankungen [Noise as a risk factor in field studies on cardiovascular disease]. Berlin: Umweltforschungsplan des Bundesministers für Umwelt, Naturschutz und Reaktorsicherheit.

Herbold M, Hense HW, Keil U (1989). Effects of road traffic noise on prevalence of hypertension in men: results of the Lübeck blood pressure study. Soz Praeventivmed. 34:19–23.

Héroux ME, Verbeek J (2018a). Results from the search for available systematic reviews and meta-analyses on environmental noise. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/results-search-for-available-systematic-reviews-environmental-noise, accessed 8 August 2018).

Héroux ME, Verbeek J (2018b). Methodology for systematic evidence reviews for the WHO environmental noise guidelines for the European Region. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/methodology-systematic-evidence-reviews-who-environmental-guidelines-for-the-european-region, accessed 8 August 2018).

Hohmann B (2015). Assessment of impulse noise regarding harmfulness to hearing. In: Proceedings. 10th European Conference on Noise Control 2015 (EURONOISE 2015), Maastricht, Netherlands, 31 May–3 June 2015. Maastricht: Institute of Acoustics.

Hong J, Kim J, Lim C, Kim K, Lee S (2010). The effects of long-term exposure to railway and road traffic noise on subjective sleep disturbance. J Acoust Soc Am. 128(5):2829–35.

Hong J, Lim C, Kim J, Lee S (2006). Assessment of sleep disturbance on night-time railway noise from the field survey. In: Proceedings. 35th International Congress and Exposition on Noise Control Engineering 2006 (INTER-NOISE 2006), Honolulu, USA, 3–6 December 2006. Washington DC: Institute of Noise Control Engineering of the USA.

Houthuijs DJM, van Wiechen CMAG (2006). Monitoring of health and perceptions around Schiphol Airport [in Dutch]. Bilthoven: National Institute for Public Health and the Environment.

Huang X, Lin J, Demner-Fushman D (2006). Evaluation of PICO as a knowledge representation for clinical questions. AMIA Annu Symp Proc. 359–63.

Huss A, Spoerri A, Egger M, Roeoesli M, for the Swiss National Cohort Study Group (2010). Aircraft noise, air pollution, and mortality from myocardial infarction. Epidemiology. 21(6):829–36.

Hygge S, Evans GW, Bullinger M (2002). A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren. Psychol Sci. 13(5):469–74.

ISO (2013). ISO 1999:2013. Acoustics – estimation of noise-induced hearing loss. Geneva: International Organization for Standardization (https://www.iso.org/standard/45103.html, accessed 28 November 2016).

ISO (2016). ISO 1996-1:2016: Acoustics – Description, measurement and assessment of environmental noise – Part 1: basic quantities and assessment. Geneva: International Organization for Standardization (https://www.iso.org/standard/59765.html, accessed 15 March 2017).

Ising H, Ising M (2002). Chronic cortisol increases in the first half of the night caused by road traffic noise. Noise Health. 4(16):13–21.

Janssen SA, Vos H (2009). A comparison of recent surveys to aircraft noise exposure–response relationships. Delft: TNO (Report No: 034-DTM-2009-01799).

Janssen SA, Vos H, Eisses AR, Pedersen E (2011). A comparison between exposure–response relationships for wind turbine annoyance and annoyance due to other noise sources. J Acoust Soc Am. 130(6):3746–53.

Jarup L, Babisch W, Houthuijs D, Pershagen G, Katsouyannie K, Cadum E et al. (2008). Hypertension and exposure to noise near airports: the HYENA study. Environ Health Perspect. 116(3):329–33.

Jarup L, Dudley ML, Babisch W, Houthuijs D, Swart W, Pershagen G et al. (2005). Hypertension and exposure to noise near airports (HYENA): study design and noise exposure assessment. Environ Health Perspect. 113(11):1473–8.

Karpati A, Galea S, Awerbuch T, Levins R (2002). Variability and vulnerability at the ecological level: implications for understanding the social determinants of health. Am J Public Health. 92(11):1768–72.

Kastka J (1981). Effects of traffic-silencing measures on noise nuisance. Zeitschrift fur Larmbekampfung. 28(1):25–30.

Kastka J, Buchta E, Ritterstaedt U, Paulsen R, Mau U (1995). The long-term effect of noise protection barriers on the annoyance response of residents. J Sound Vib. 184(5):823–52.

Klatte M, Bergström K, Spilski M, Mayerl J, Meis M (2014). NORAH Noise-related annoyance, cognition, and health: Wirkungen chronischer Fluglärmbelastung auf kognitive Leistungen und Lebensqualität bei Grundschulkindern [Effects of long-term aircraft exposure on the cognitive performance of elementary school children]. Kaiserslautern: Technische Universität Kaiserslautern.

Knipschild P, Meijer H, Salle H (1984). Transportation noise, psychological issues and hypertension. Results of a survey of Amsterdam residents [in Dutch]. Tijdsc Soc Gezondheid. 62:758–65.

Knopper L, Ollson C (2011). Health effects and wind turbines: a review of the literature. Environ Health. 10:78–87

Kotowski MR, Smith SW, Johnstone PM, Pritt E (2011). Using the Extended Parallel Process Model to create and evaluate the effectiveness of brochures to reduce the risk for noise-induced hearing loss in college students. Noise Health. 13(53):261–71.

Kuwano S, Yano T, Kageyama T, Sueoka S, Tachibanae H (2014). Social survey on wind turbine noise in Japan. Noise Control Eng J. 62(6):503–20.

Lam KC, Au WH (2008). Human annoyance response to a step change in noise exposure following the opening of a new railway extension in Hong Kong. In: Proceedings. 9th International Congress on Noise as a Public Health Problem 2008 (ICBEN 2008), Foxwoods, USA, 21–25 July 2008. Zurich: International Commission on Biological Effects of Noise.

Lambert J, Philipps-Bertin C (2008). Perception and attitudes to transportation noise in France: a national survey. In: Proceedings. 9th International Congress on Noise as a Public Health Problem 2008 (ICBEN 2008), Foxwoods, USA, 21–25 July 2008. Zurich: International Commission on Biological Effects of Noise.

Langdon FJ, Griffiths ID (1982). Subjective effects of traffic noise exposure. II: Comparisons of noise indices, response scales, and the effects of changes in noise levels. J Sound Vib. 83(2):171–80.

Lekaviciute J (2007). Traffic noise in Kaunas city and its influence on myocardial infarction risk [PhD thesis]. Kaunus: Vytautas Magnus University.

Lercher P, Botteldooren D, de Greve B, Dekoninck L, Ruedisser J (2007). The effects of noise from combined traffic sources on annoyance: the case of interactions between rail and road noise. In: Proceedings. 36th International Congress and Exhibition on Noise Control Engineering 2007 (INTER-NOISE 2007), Istanbul, Turkey, 28–31 August 2007. Istanbul: Turkish Acoustical Society.

Lercher P, Botteldooren D, Widmann U, Uhrner U, Kammeringer E (2011). Cardiovascular effects of environmental noise: research in Austria. Noise Health. 13(52):234–50.

Lercher P, Brink M, Rudisser J, et al. (2010). The effects of railway noise on sleep medication intake: results from the ALPNAP-study. Noise Health. 12(47):110–19.

Lercher P, Greve B de, Botteldooren D, Dekoninck L, Oettl D, Uhrner U et al. (2008). Health effects and major co-determinants associated with rail and road noise exposure along transalpine traffic corridors. In: Proceedings. 9th International Congress on Noise as a Public Health Problem 2008 (ICBEN 2008), Foxwoods, USA, 21–25 July 2008. Zurich: International Commission on Biological Effects of Noise.

Lercher P, Eisenmann A, Dekonick L, Botteldooren D (2013). The relation between disturbed sleep in children and traffic noise exposure in alpine valleys. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Lercher P, Evans GW, Meis M (2003). Ambient noise and cognitive processes among primary school children. Environ Behav. 35:725–35.

Levesque B, Fiset R, Isabelle L, Gauvin D, Baril J, Larocque R et al. (2010). Exposure of high school students to noise from personal music players in Québec City, Canada. Int J Child Adolescent Health. 3(30):413–20.

Lopez AD, Mathers CD, Ezzati M, Jamison DT, Murray CJ, editors (2006). Global burden of disease and risk factors. Washington DC: World Bank and New York: Oxford University Press.

Liu C, Fuertes E, Tiesler CM, Birk M, Babisch W, Bauer CP et al. (2014). The associations between traffic-related air pollution and noise with blood pressure in children: results from the GINIplus and LISAplus studies. Int J Hyg Environ Health. 217(4–5):499–505.

Liu C, Fuertes E, Tiesler CM, Birk M, Babisch W, Bauer CP et al. (2013). The association between road traffic noise exposure and blood pressure among children in Germany: the GINIplus and LISAplus studies. Noise Health. 15(64):165–72.

Locher B, Piquerez A, Habermacher M, Ragettli M, Röösli M, Brink M et al. (2018). Differences between outdoor and indoor sound levels for open, tilted, and closed windows. Int J Environ Res Public Health. 15(1): 149.

Lukas JS, DuPreeRB, Swing JW (1981). Report of a study on the effects of freeway noise on academic achievement of elementary school children, and a recommendation for a criterion level for a school noise abatement program. Sacramento, CA: California Department of Health Services.

Maassen M, Babisch W, Bachmann K D, Ising H, Lehnert G, Plath P et al. (2001). Ear damage caused by leisure noise. Noise Health. 4:1–16.

Martin WH, Griest SE, Sobel JL, Howarth LC (2013). Randomized trial of four noise-induced hearing loss and tinnitus prevention interventions for children. Int J Audiol. 52(Suppl 1):S41–9.

Maschke C (2003). Epidemiological research on stress caused by traffic noise and its effects on high blood pressure and psychic disturbances. In: Proceedings. 8th International Congress on Noise as a Public Health Problem 2003 (ICBEN 2003), Rotterdam, Netherlands, 29 June – 3 July 2003. Zurich: International Commission on Biological Effects of Noise.

Maschke C, Hecht K (2005). Pathogenesis mechanism by noise-induced clinical pictures – Lessons from the Spandau Health-Survey. Umweltmedizin in Forschung und Praxis. 10(2):77–88.

Maschke C, Wolf U, Leitmann T (2003). Epidemiological examinations of the influence of noise stress on the immune system and the emergence of arteriosclerosis [in German]. Berlin: Umweltbundesambt.

Mathers CD, Bernard C, Iburg KM, Inoue M, Fat DM, Shibuya K et al. (2003). Global burden of disease in 2002: data sources, methods and results. Geneva: World Health Organization (Global Programme on Evidence for Health Policy Discussion Paper No. 54; http://www.portal.pmnch.org/healthinfo/global_burden_disease/data_sources_methods/en/index1.html, accessed 2 July 2018).

Mathers C, Vos T, Stevenson C (1999). The burden of disease and injury in Australia. Canberra: Australian Institute of Health and Welfare cat. no. PHE 17. (https://www.aihw.gov.au/reports/burden-of-disease/the-burden-of-disease-injury-in-australia-1996/contents/table-of-contents, accessed 28 November 2016).

Matheson M, Clark C, Martin R, van Kempen E, Haines M, Barrio IL et al. (2010). The effects of road traffic and aircraft noise exposure on children's episodic memory: the RANCH project. Noise Health. 12:244–54.

Matsui T (2013). Psychosomatic disorder due to aircraft noise and its causal pathway. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Matsui T, Stansfeld S, Haines M, Head J (2004). Children's cognition and aircraft noise exposure at home – the West London Schools Study. Noise Health. 7:49–58.

Matsui T, Uehara T, Miyakita T, Hiramatsu K, Osada Y, Yamamoto T (2001). Association between blood pressure and aircraft noise exposure around Kadena airfield in Okinawa. In: Proceedings. 30th International Congress and Exhibition on Noise Control Engineering 2001 (INTER-NOISE 2001), The Hague, Netherlands, 27–30 August 2001. The Hague: Nederlands Akoestisch Genootschap.

Matsui T, Uehara T, Miyakita T, Hiramatsu K, Osada Y, Yamamoto T (2004). The Okinawa study: effects of chronic aircraft noise on blood pressure and some other psychological indices. J Sound Vib. 277(3):469–70.

McCunney R J, Mundt KA, Colby WD, Dobie R, Kaliski K, Blais M (2014). Wind turbines and health: a critical review of the scientific literature. J Occup Environ Med. 56(11):e108–30.

Medizinische Universitaet Innsbruck (2008). Galleria di Base del Brennero – Brenner Baistunnel – Sozioökonomie (public health) – Zusammenfassender Bericht [Social economics (public health) – final report]. Innsbruck: Medizinische Universität Innsbruck.

Michaud D (2015). Self-reported and objectively measured outcomes assessed in the Health Canada Wind Turbine Noise and Health Study: results support an increase in community annoyance. In: Proceedings. 44th International Congress and Exposition on Noise Control Engineering 2015 (INTER-NOISE 2015), San Francisco, USA, 9–12 August 2015. Washington DC: Institute of Noise Control Engineering of the USA.

Miedema HM, Oudshoorn CG (2001). Annoyance from transportation noise: relationships with exposure Metrics DNL and DENL and their CIs. Environ Health Perspect. 109:409–16.

Moehler U, Hegner A, Schuemer R, Schuemer-Kohrs A (1997). Effects of railway-noise reduction on annoyance after rail-grinding. In: Proceedings. 26th International Congress and Exposition on Noise Control Engineering (INTER-NOISE 1997), Budapest, Hungary, 25–27 August 1997. Budapest: OPAKFI.

Morgan RL, Thayer KA, Bero L, Bruce N, Falck-Ytter Y, Ghersi D et al. (2016). GRADE: Assessing the quality of evidence in environmental and occupational health. Environ Int. 2016;92-93:611–6. doi:10.1016/j.envint.2016.01.004.

Morrell S, Taylor R, Carter N, Job S, Peploe P (1998). Cross-sectional relationship between blood pressure of schoolchildren and aircraft noise. In: Proceedings. 7th International Congress on Noise as a Public Health Problem 1998 (ICBEN 1998), Sydney, Australia, 22–26 November 1998. Sydney: National Capital Printing ACT.

Morrell S, Taylor R, Carter N, Peploe P, Job S (2000). Cross-sectional and longitudinal results of a follow-up examination of child blood pressure and aircraft noise: the inner Sydney child blood pressure study. In: Proceedings. 29th International Congress on Noise Control Engineering 2000 (INTER-NOISE 2000), Nice, France, 27–31 August 2000. Paris: Societe Francaise D'acoustique.

Murray CJ (1994). Quantifying the burden of disease: the technical basis for disability-adjusted life-years. Bull World Health Organ. 72(3):429–45.

Murray CJ, Acharya AK (1997). Understanding DALYs (disability-adjusted life-years). J Health Econ. 16:703–30.

Murray CJ, Lopez AD (2013) Measuring the global burden of disease. N Engl J Med. 369(5): 448–57.

Neitzel R, Fligor B (2017). Determination of risk of noise-induced hearing loss due to recreational sound: review. Geneva: World Health Organization (http://www.who.int/pbd/deafness/Monograph_on_determination_of_risk_of_HL_due_to_exposure_to_recreational_sounds.pdf, accessed 30 January 2018).

Nguyen LT, Nguyen TL, Yano T, et al. (2015). Social surveys around Noi Bai Airport before and after the opening of a new terminal building. In: Proceedings. 44th International Congress and Exposition on Noise Control Engineering 2015 (INTER-NOISE 2015), San Francisco, USA, 9–12 August 2015. Washington DC: Institute of Noise Control Engineering of the USA.

Nguyen TL, Nguyen HQ, Yano T, Nishimura T, Sato T, Morihara T, Hashimoto Y (2012a). Comparison of models to predict annoyance from combined noise in Ho Chi Minh City and Hanoi. Appl Acoust. 73(9):952–59.

Nguyen TL, Yano T, Nguyen HQ, et al. (2010). Community response to aircraft and combined noises in Hanoi. In: Proceedings. 39th International Congress on Noise Control Engineering 2010 (INTER-NOISE 2010), Lisbon, Portugal, 13–16 June 2010. Lisbon: Sociedade Portuguesa de Acustica.

Nguyen TL, Yano T, Nguyen HQ, Nishimura T, Fukushima H, Sato T et al. (2011). Community response to aircraft noise in Ho Chi Minh City and Hanoi. Appl Acoust. 72(11):814–22.

Nguyen T, Yano T, Nguyen H, Nishimura T, Sato T, Morihara T (2012b). Community response to aircraft noise around three airports in Vietnam. In: Proceedings. Acoustics 2012 Hong Kong Conference, 13–18 May 2012. Hong Kong: Institute of Acoustics.

Nguyen TL, Yano T, Nguyen HQ, et al. (2012c). Aircraft and road traffic noise annoyance in Da Nang City, Vietnam. In: Proceedings. 41st International Congress and Exposition on Noise Control Engineering 2012 (INTER-NOISE 2012), New York, USA, 19–22 August 2012. Washington DC: Institute of Noise Control Engineering of the USA.

Nguyen TL, Yano T, Nishimura T, Sato T (2009). Social survey on community response to aircraft noise in Ho Chi Minh City. In: Proceedings. 38th International Congress and Exposition on Noise Control Engineering 2009 (INTER-NOISE 2009), Ottawa, Canada, 23–26 August 2009. Washington DC: Institute of Noise Control Engineering of the USA.

Nieuwenhuijsen MJ, Ristovska G, Dadvand P (2017). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and adverse birth outcomes. Int J Environ Res Public Health. 14(10). pii: E1252 (http://www.mdpi.com/1660-4601/14/10/1252/htm, accessed 27 June 2018).

Nilsson ME, Berglund B (2006). Noise annoyance and activity disturbance before and after the erection of a roadside noise barrier. J Acoust Soc Am. 119(4):2178–88.

Notley H, Grimwood C, Raw G, Clark C, Zepidou G, Van de Kerchhove R et al. (2014). National Noise Attitude Survey 2012 (NNAS2012): summary report. London: Department for Environment and Rural Affairs (http://randd.defra.gov.uk/Document.aspx?Document=12378_SummaryReportV1.0.pdf,

Oehrstroem E (2004). Longitudinal surveys on effects of changes in road traffic noise-annoyance, activity disturbances, and psycho-social well-being. J Acoust Soc Am. 115(2):719–29.

Oehrstroem E, Hadzibajramovic E, Holmes M, Svensson H (2006a). Effects of road traffic noise on sleep: studies on children and adults. J Environ Psychol. 26(2):116–26.

Oehrstroem E, Skanberg A (2000). Adverse health effects in relation to noise mitigation – a longitudinal study in the city of Göteborg. In: Proceedings. 29th International Congress on Noise Control Engineering 2000 (INTER-NOISE 2000), Nice, France, 27–31 August 2000. Paris: Societe Francaise D'acoustique.

Oehrstroem E, Skanberg A (2004). Longitudinal surveys on effects of road traffic noise substudy on sleep assessed by wrist actigraphs and sleep logs. J Sound Vib. 272:1097–109.

Oehrstroem E, Skanberg A, Svensson H, Gidloef-Gunnarsson A (2006b). Effects of road traffic noise and the benefit of access to quietness. J Sound Vib. 295:40–59.

Oftedal B, Krog NH, Graff-Iversen S, Haugen M, Schwarze P, Aasvang GM (2014). Traffic noise and markers of obesity: a population-based study. In: Proceedings. 11th International Congress on Noise as a Public Health Problem 2014 (ICBEN 2014), Nara, Japan, 1–5 June 2014. Tokyo: Institute of Noise Control Engineering of Japan.

Oftedal B, Nafstad P, Schwarze P, Aasvang GM (2011). Road traffic noise, air pollution and blood pressure in Oslo, Norway. In: Proceedings. 10th International Congress on Noise as a Public Health Problem 2011 (ICBEN 2011), London, United Kingdom, 24–28 July 2011. London: Institute of Acoustics.

Ohiduzzaman M, Sirin O, Kassem E, Rochat JL (2016). State-of-the-art review on sustainable design and construction of quieter pavements—Part 1: traffic noise measurement and abatement techniques. Sustainability. 8(8):742.

Omlin S, Bauer GF, Brink M. (2011). Effects of noise from non-traffic-related ambient sources on sleep: Review of the literature of 1999–2010. Noise Health. 13(53):299–309.

Ouis D (2001). Annoyance from road traffic noise: a review. J Environ Psychol. 21:101–20.

Passchier-Vermeer W, Vos H, Janssen SA, Miedema HM (2007). Sleep and traffic noise, summary report. Delft: TNO (Report No: 2007-D-R0012/A; https://www.tno.nl/en/focus-areas/circular-economy-environment/roadmaps/environment-sustainability/noise/field-study-of-sleep-and-traffic/, accessed 4 July 2018).

Passchier-Vermeer W, Vos H, Steenbekkers J, van der Ploeg F, Groothuis-Oudshoorn K (2002). Sleep disturbance and aircraft noise exposure: exposure-effect relationships. Delft: TNO (Report No: 2002.027; http://www2.vlieghinder.nl/knipsels_pmach/pdfs/0110xx_TNO_Sleep_disturbance_and_aircraft_noise_exposure_effect_rapport3.pdf, accessed 28 November 2016).

Paunovic K, Belojevic G, Jakovljevic B (2013). Blood pressure of urban school children in relation to road-traffic noise, traffic density and presence of public transport. Noise Health. 15(65):253–60.

Pawlaczyk-Luszczynska M, Dudarewicz A, Zaborowski K, Zamojska-Daniszewska M, Waszkowska M (2014). Evaluation of annoyance from the wind turbine noise: a pilot study. Int J Occup Med Environ Health. 27(3):364–88.

Pedersen E (2011). Health aspects associated with wind turbine noise: results from three field studies. Noise Control Eng J. 59(1):47–53.

Pedersen E, Larsman P (2008). The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines. J Environ Psychol. 28(4):379–89.

Pedersen E, Perrson Waye K (2004). Perception and annoyance due to wind turbine noise – a dose-response relationship. J Acoust Soc Am. 116(6):3460–70.

Pedersen E, Persson Waye K (2007). Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup Environ Med. 64(7):480–6.

Pedersen T, Le Ray G, Bendtsen H, Kragh J (2013). Community response to noise reducing road pavements. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Pedersen T, Le Ray G, DELTA SenseLab, Bendtsen H, Kragh J, Danish Road Directorate (2014). Community response to noise reducing road pavements. Copenhagen: Vejdirektoratet. (http://vejdirektoratet.dk/DA/viden_og_data/publikationer/sider/publikation.aspx?pubid=1182366409, accessed 28 November 2016).

Pellegrino E, Lorini C, Allodi G, Buonamici C, Garofalo G, Bonaccorsi G (2013). Music-listening habits with MP3 player in a group of adolescents: a descriptive survey. Ann Ig. 25(5):367–76.

Phan HYT, Yano T, Phan HAT, Nishimura T, Sato T, Hashimoto Y (2010). Community responses to road traffic noise in Hanoi and Ho Chi Minh City. Appl Acoust. 71(2):107–14.

Pierette M, Marquis-Favre C, Morel J, Rioux L, Vallet M, Viollon S et al. (2012). Noise annoyance from industrial and road traffic combined noises: a survey and a total annoyance model comparison. J Environ Psychol. 32(2):178–86.

Pirrera S, De Valck E, Cluydts R (2014). Field study on the impact of nocturnal road traffic noise on sleep: the importance of in- and outdoor noise assessment, the bedroom location and nighttime noise disturbances. Sci Total Environ. 500–1:84–90.

Pujol S, Levain JP, Houot H, Petit R, Berthillier M, Defrance J et al. (2014). Association between ambient noise exposure and school performance of children living in an urban area: a cross-sectional population-based study. J Urban Health. 91(2):256–71.

Pyko A, Eriksson C, Lind T, Mitkovskaya N, Wallas A, Ögren M et al. (2017). Long-term exposure to transportation noise in relation to development of obesity – a cohort study Environ Health Perspect. 125(11):117 005.

Pyko A, Eriksson C, Oftedal B, Hilding A, Östenson CG, Krog NH et al. (2015). Exposure to traffic noise and markers of obesity. Occup Environ Med. 72(8):594–601.

Quigley R, den Broeder L, Furu P, Bond A, Cave B, Bos R (2006). Health impact assessment: international best practice principles. Fargo, ND: International Association for Impact Assessment (Special Publication Series No. 5; http://www.iaia.org/best-practice.php, accessed 10 July 2018).

Regecova V, Kellerova E (1995). Effects of urban noise pollution on blood pressure and heart rate in preschool children. J Hypertens. 13(4):405–12.

Ristovska G, Gjorgjev D, Stikova E, Petrova V, Cakar MD (2009). Noise-induced sleep disturbance in adult population: cross-sectional study in Skopje urban centre. Maced J Med Sci. 2(3):255–60.

Rosenlund M, Berglind N, Pershagen G, Jarup L, Bluhm G (2001). Increased prevalence of hypertension in a population exposed to aircraft noise. Occup Environ Med. 58(12):769–73.

Sato T, Yano T (2011). Effects of airplane and helicopter noise on people living around a small airport in Sapporo, Japan. In: Proceedings. 10th International Congress on Noise as a Public Health Problem 2011 (ICBEN 2011), London, United Kingdom, 24–28 July 2011. London: Institute of Acoustics.

Sato T, Yano T, Björkman M, Rylander R (2002). Comparison of community response to road traffic noise in Japan and Sweden – Part I: outline of surveys and dose-response relationships. J Sound Vib. 250:161–7.

Sato T, Yano T, Morihara T (2004). Community response to noise from Shinkansen in comparison with ordinary railways: a survey in Kyushu, Japan. In: Proceedings. 18th International Congress on Acoustics (ICA 2004), Kyoto, Japan, 4–9 April. Kyoto: Acoustical Society of Japan.

Schäffer B, Schlittmeier SJ, Pieren R, Heutschi K, Brink M, Graf R et al. (2016). Short-term annoyance reactions to stationary and time-varying wind turbine and road traffic noise: a laboratory study. J Acoust Soc Am. 139(5):2949–63.

Schreckenberg D (2013). Exposure-response relationship for railway noise annoyance in the Middle Rhine Valley. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Schreckenberg D, Faulbaum F, Guski R, Ninke L, Peschel C, Spilski J et al. (2015). Wirkungen von Verkehrslärm auf die Belästigung und Lebensqualität [Effects of transportation noise on noise annoyance and quality of life]. In: Gemeinütziges Umwelthaus gGmbH, editor, NORAH (Noise related annoyance cognition and health): Verkehrslärmwirkungen im Flughafenumfeld [Effect of transportation noise in the area of an airport] (vol. 3). Kelsterbach: Umwelthaus gGmbH (https://www.norah-studie.de//en/publications.html, accessed 4 July 2018).

Schreckenberg D, Heudorf U, Eikmann T, Meis M (2009). Aircraft noise and health of residents living in the vicinity of Frankfurt airport. In: Proceedings. 8th European Conference on Noise Control 2009 (EURONOISE 2009), Edinburgh, United Kingdom, 26–28 October 2009. Edinburgh: Institute of Acoustics.

Schreckenberg D, Meis M (2007). Lärmbelästigung und Lebensqualität in der Bevölkerung am Frankfurter Flughafen [Noise annoyance and quality of life of the residents around Frankfurt Airport]. Lärmbekämpfung [Noise Abatement]. 2(6):225–33.

Schreckenberg D, Benz S, Belke C, Möhler U, Guski R (2017). The relationship between aircraft sound levels, noise annoyance and mental well-being: an analysis of moderated mediation. In: Proceedings. 12th International Congress on Noise as a Public Health Problem 2017 (ICBEN 2017), Zurich, Switzerland, 18–22 June 2017. Zurich: International Commission on Biological Effects of Noise.

Schreckenberg D, Moehler U, Liepert M, Schuemer R (2013). The impact of railway grinding on noise levels and residents' noise responses – Part II: the role of information. In: Proceedings. 42nd International Congress and Exposition on Noise Control Engineering 2013 (INTER-NOISE 2013), Innsbruck, Austria, 15–18 September 2013. Innsbruck: Austrian Noise Abatement Association.

Schuemer R, Schuemer-Kohrs A (1991). The nuisance of rail traffic noise in comparison with other sources of noise, comments on research results. Zeitschrift für Lärmbekämpfung [Magazine for Combating Noise]. 38:1–9.

Seabi J, Cockcroft K, Goldschagg P, GreylingM (2012). The impact of aircraft noise exposure on South African children's reading comprehension: the moderating effect of home language. Noise Health. 14:244–52.

Seabi J, Cockcroft K, Goldschagg P, Greyling M (2013). A prospective follow-up study of the effects of chronic aircraft noise exposure on learners' reading comprehension in South Africa. J Expo Sci Environ Epidemiol. 25(1):84–8.

Selander J, Nilsson ME, Bluhm G, Rosenlund M, Lindqvist M, Nise G et al. (2009). Long-term exposure to road traffic noise and myocardial infarction. Epidemiology. 20(2):272–9.

Shea BJ, Grimshaw JM, Wells GA, Boers M, Andersson N, Hamel C et al. (2007). Development of AMSTAR: a measurement tool to assess the methodological quality of systematic reviews. BMC Med Res Methodol. 7:10. PMID: 17302989.

Sharp B, Connor TL, McLaughlin D, Clark C, Stansfeld SA, Hervey J (2014). Assessing aircraft noise conditions affecting student learning, volume 1: final report. Washingtdon DC: Transportation Research Board of the National Academies of Sciences, Engineering, and Medicine (http://www.trb.org/Publications/Blurbs/170328.aspx, accessed 5 July 2018).

Shepherd D, Welch D, Dirks KN, McBride D (2013). Do quiet areas afford greater health related quality of life than noisy areas? Int J Environ Res Public Health. 10(4):1284–303.

Shield BM, Dockrell JE (2008). The effects of environmental and classroom noise on the academic attainments of primary schoolchildren. J Acoust Soc Am. 123:133–44.

Shimoyama K, Nguyen TL, Yano T, Morihara T (2014). Social surveys on community response to road traffic in five cities in Vietnam. In: Proceedings. In: Proceedings. 43rd International Congress on Noise Control Engineering 2014 (INTER-NOISE 2014), Melbourne, Australia, 16–19 November 2014. Melbourne: Australian Acoustical Society.

Sirin O (2016). State-of-the-art review on sustainable design and construction of quieter pavements—Part 2: factors affecting tyre-pavement noise and prediction models. Sustainability. 8(7):692.

Śliwińska-Kowalska M, Zaborowski K (2017). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and permanent hearing loss and tinnitus. Int J Environ Res Public Health. 14(10). pii: E1139 (http://www.mdpi.com/1660-4601/14/10/1139/htm, accessed 27 June 2018).

Sobotova L, Jurkovicova J, Stefanikova Z, Sevcikova L, Aghova L (2006). Community noise annoyance assessment in an urban agglomeration. Bratisl Lek Listy. 107(5):214–16.

Sörensen M, Andersen ZJ, Nordsborg RB, Jensen SS, Lillelund KG, Beelen R et al. (2012a). Road traffic noise and incident myocardial infarction: a prospective cohort study. PLoS One. 7(6):e39283.

Sörensen M, Andersen ZJ, Nordsborg RB, Tjonneland A, Raaschou-Nielsen O, Lillelund KG et al. (2012b). Road traffic noise and risk for stroke and myocardial infarction. In: Proceedings. 41st International Congress and Exposition on Noise Control Engineering 2012 (INTER-NOISE 2012), New York, USA, 19–22 August 2012. Washington DC: Institute of Noise Control Engineering of the USA.

Sörensen M, Hoffmann B, Hvidberg M, Ketzel M, Jensen SS, Andersen ZJ et al. (2012c). Long-term exposure to traffic-related air pollution associated with blood pressure and self-reported hypertension in a Danish cohort. Environ Health Perspect. 120(3):418–24.

Sörensen M, Hvidberg M, Hoffmann B, Andersen ZJ, Nordsborg RB, Lillelund KG et al. (2011). Exposure to road traffic and railway noise and associations with blood pressure and self-reported hypertension: a cohort study. Environ Health. 10(92).

Sörensen M, Luhdorf P, Ketzel M, Andersen ZJ, Tjonneland A, Overvad K, Raaschou-Nielsen O (2014). Combined effects of road traffic noise and ambient air pollution in relation to risk for stroke? Environ Res. 133:49–55.

Sörensen M, Wendelboe Nielsen O, Sajadieh A, Ketzel M, Tjonneland A, Overvad K et al. (2017). Long-Term Exposure to Road Traffic Noise and Nitrogen Dioxide and Risk of Heart Failure: A Cohort Study. Environ Health Perspect. 125(9):097021.

Stansfeld SA, Berglund B, Clark C, Lopez-Barrio I, Fischer P, Ohrstrom E, et al. (2005). Aircraft and road traffic noise and children's cognition and health: a cross-national study. Lancet. 365:1942–9.

Stansfeld SA, Haines MM, Berry B, Burr M (2009b). Reduction of road traffic noise and mental health: an intervention study. Noise Health. 11(44):169–75.

Stansfeld SA, Hygge S, Clark C, Alfred T (2010). Night-time aircraft noise exposure and children's cognitive performance. Noise Health. 12:255–62.

Sulaiman AH, Husain R, Seluakumaran K (2014). Evaluation of early hearing damage in personal listening device users using extended high-frequency audiometry and otoacoustic emissions. Eur Arch Otorhinolaryngol. 271(6):1463–70.

Sulaiman AH, Seluakumaran K, Husain R (2013). Hearing risk associated with the usage of personal listening devices among urban high school students in Malaysia. Public Health. 127(8):710–15.

Taljaard DS, Leishman NF, Eikelboom RH (2013). Personal listening devices and the prevention of noise-induced hearing loss in children: the Cheers for Ears Pilot Program. Noise Health. 15(65):261–8.

Tiesler CM, Birk M, Thiering E, Kohlbock G, Koletzko S, Bauer CP et al. (2013). Exposure to road traffic noise and children's behavioural problems and sleep disturbance: results from the GINIplus and LISAplus studies. Environ Res. 123:1–8.

Umweltbundesamt (2015). Umweltbewusstsein in Deutchland 2014: Ergebnisse einer repräsentativen Bevölkerungsumfrage [Environmental Consciousness in Germany in 2014: results of a representative survey of the population] [in German]. Berlin: Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/umweltbewusstsein_in_deutschland_2014.pdf, accessed 24 January 2018).

Umweltbundesamt (2017). Umweltbewusstsein in Deutchland 2016: Ergebnisse einer repräsentativen Bevölkerungsumfrage [Environmental Consciousness in Germany in 2016: results of a representative survey of the population] [in German]. Berlin: Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/umweltbewusstsein_deutschland_2016_bf.pdf, accessed 5 July 2018).

van den Berg F, Pedersen E, Bouma J, Bakker R (2008). Project WINDFARMperception. Visual and acoustic impact of wind turbine farms on residents. Groningen: University of Groningen (FP6-2005-Science-and-Society-20 Specific Support Action Project no. 044628; https://www.rug.nl/research/portal/publications/project-windfarmperception-visual-and-acoustic-impact-of-wind-turbine-farms-on-residents(b8745281-02e7-4761-bd06-86363e2be78b).html, accessed 27 November 2016).

van Kamp I, Houthuijs D, Van Wiechen C, Breugelmans O (2006). Environmental noise and cardiovascular diseases: results from a monitoring programme on aircraft noise C3 – Institute of Noise Control Engineering of the USA. In: Proceedings. 35th International Congress and Exposition on Noise Control Engineering 2006 (INTER-NOISE 2006), Honolulu, USA, 3–6 December 2006.Washington DC: Institute of Noise Control Engineering of the USA.

van Kempen E, Casas M, Pershagen G, Foraster M (2018). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and cardiovascular and metabolic effects: a summary. Int J Environ Res Public Health. 15(2). pii: E379 (http://www.mdpi.com/1660-4601/15/2/379/htm, accessed 27 June 2018).

van Kempen E, Fischer P, Janssen N, Houthuijs D, van Kamp I, Stansfeld S et al. (2012). Neurobehavioral effects of exposure to traffic-related air pollution and transportation noise in primary schoolchildren. Environ Res. 115:18–25.

van Kempen E, van Kamp I, Fischer P, Davies H, Houthuijs D, Stellato R et al. (2006). Noise exposure and children's blood pressure and heart rate: The RANCH project. Occup Environ Med. 63(9):632–9.

van Kempen E, van Kamp I, Lebret E, Lammers J, Emmen H, Stansfeld S (2010). Neurobehavioral effects of transportation noise in primary schoolchildren: a cross-sectional study. Environ Health. 9: 25.

van Poll H, Breugelmans O, Devilee J (2011). Hinder, bezorgdheid en woontevredenheid in Nederland: inventarisatie verstoringen 2008 [Annoyance, concern and residential satisfaction in the Netherlands: Annoyance inventory 2008]. Bilthoven: Rijksinstituut voor Volksgezondheid en Milieu (RIVM Rapport 630741001/2011; http://www.rivm.nl/dsresource?objectid=50e5cd0f-3de8-40ca-b3e5-7b31dbfaa93b&type=org&disposition=inline, accessed 27 November 2016).

van Poll R, Ameling C, Breugelmans O, Houthuis D, van Kempen E, Marra M et al. (2014). Gezondheidsonderzoek Vliegbasis Geilenkirchen (Desk Research) I. Hoofdrapportage: samenvatting, conclusies en aanbevelingen Gezondheidsonderzoek Vliegbasis Geilenkirchen [Health study at the military airport Geilenkirchen (desk research) I. Main report: summary, conclusions and recommendations of the health study at the military airport Geilenkirchen]. Bilthoven: National Institute for Public Health and the Environment (https://zoek.officielebekendmakingen.nl/blg-378125.pdf, accessed 15 March 2017).

van Renterghem T, Botteldooren D (2012). Focused study on the quiet side effect in dwellings highly exposed to road traffic noise. Int J Environ Res Public Health. 9(12):4292–310.

Vasconcellos AP, Kyle ME, Gilani S, Shin JJ (2014). Personally modifiable risk factors associated with pediatric hearing loss: a systematic review. Otolaryngol Head Neck Surg. 151(1):14–28.

Vincent B, Champelovier P (1993). Changes in the acoustic environment: need for an extensive evaluation of annoyance. In: Proceedings. 6th International Congress on Noise as a Public Health Problem 1993 (ICBEN 1993). Nice, France, 5–9 July 1993. Lyon: Institut National de Recherche sur les Transports et leur Sécurité.

Vogel I, Brug J, van der Ploeg CP, Raat H (2011). Adolescents risky MP3-player listening and its psychosocial correlates. Health Educ Res. 26(2):254–64.

Vogel I, van de Looij-Jansen PM, Mieloo CL, Burdorf A, de Waart F (2014). Risky music listening, permanent tinnitus and depression, anxiety, thoughts about suicide and adverse general health. PloS One. 9(6): e98912.

Weichbold V, Zorowka P (2003). Effects of a hearing protection campaign on the discotheque attendance habits of high-school students. Int J Audiol. 42(8):489–93.

Weichbold V, Zorowka P (2007). Can a hearing education campaign for adolescents change their music listening behavior? Int J Audiol. 46(3):128–33.

WHO (1946). Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19–22 June 1946; signed on 22 July 1946 by the representatives of 61 States and entered into force on 7 April 1948. Geneva: World Health Organization (http://www.who.int/about/mission/en/, accessed 27 June 2018).

WHO (1999). Guidelines for community noise. Geneva: World Health Organization (http://apps.who.int/iris/handle/10665/66217?show=full, accessed 28 November 2016).

WHO (2006). Air quality guidelines – global update 2005. Geneva: World Health Organization (http://www.who.int/phe/health_topics/outdoorair/outdoorair_aqg/en/, accessed 27 July 2018).

WHO (2013). WHO methods and data sources for global burden of disease estimates 2000–2011. Geneva: World Health Organization (Global Health Estimates Technical Paper WHO/HIS/HSI/GHE/2013.4; http://www.who.int/healthinfo/global_burden_disease/data_sources_methods/en/, accessed 28 November 2016).

WHO (2014a). Metrics: disability-adjusted life-year (DALY). In: World Health Organization: Health statistics and information systems [website]. Geneva: World Health Organization (http://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/, accessed 27 June 2018).

WHO (2014b). Burden of disease from ambient air pollution for 2012. Geneva: World Health Organization (http://www.who.int/phe/health_topics/outdoorair/databases/AAP_BoD_results_March2014.pdf, accessed 27 June 2018).

WHO (2014c). WHO handbook for guideline development, second edition. Geneva: World Health Organization (http://apps.who.int/iris/handle/10665/145714, accessed 27 June 2018).

WHO (2015a). Hearing loss due to recreational exposure to loud sounds: a review. Geneva: World Health Organization (http://apps.who.int/iris/handle/10665/154589, accessed 27 November 2016).

WHO Regional Office for Europe (2009). Night noise guidelines for Europe. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2009/night-noise-guidelines-for-europe, accessed 28 November 2016).

WHO Regional Office for Europe (2010). Parma Declaration on Environment and Health. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/publications/policy-documents/parma-declaration-on-environment-and-health, accessed 28 November 2016).

WHO Regional Office for Europe (2012). Assessment of need for capacity-building for health risk assessment for environmental noise: case studies. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2012/assessment-of-needs-for-capacity-building-for-health-risk-assessment-of-environmental-noise-case-studies, accessed 28 November 2016).

WHO Regional Office for Europe (2016). Health risk assessment of air pollution: general principles. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/publications/abstracts/health-risk-assessment-of-air-pollution.-general-principles-2016, accessed 12 January 2017).

WHO Regional Office for Europe (2017). Databases. In: WHO Regional Office for Europe: Data and evidence [website]. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/data-and-evidence/databases, accessed 13 March 2017).

WHO Regional Office for Europe, JRC (2011). Burden of disease from environmental noise: quantification of healthy life years lost in Europe. Copenhagen: WHO Regional Office for Europe (http://www.who.int/quantifying_ehimpacts/publications/e94888/en/, accessed 27 November 2016).

Wiens D (1995). Verkehrslärm und kardiovaskuläres Risiko. Eine Fall-Kontroll-Studie in Berlin (West) [Transportation noise and risk for cardiovascular disease. A case study in (West) Berlin] In: Dissertation aus dem Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes [Doctoral thesis for the Institute for Water, Ground and Air hygiene of the Federal Ministry of Health]. Berlin: Bundesgesundheitsamt.

Wilson SB, Lonigan, CJ (2010). Identifying preschool children at risk of later reading difficulties: evaluation of two emergent literacy screening tools. J Lern Disabil. 43(1):62–76.

Yano T, Morihara T, Sato T (2005). Community response to Shinkansen noise and vibration: a survey in areas along the Sanyo Shinkansen Line. In: Proceedings. Forum Acusticum: 4th European Congress on Acoustics, Budapest, Hungary, 29 August – 2 September 2005. Stuttgart: Hirzel.

Yano T, Nguyen TL, Nguyen TL, Takata M, Yamadal., Morinaga M et al. (2015). Community response to a step change in aircraft noise exposure: the first socio-acoustic survey around Noi Bai Airport in Hanoi. In: Proceedings. 22nd International Congress on Sound and Vibration (ICSV22) 2015, Florence, Italy, 12–16 July 2015. Ferrara: Acoustical Society of Italy.

Yokoshima S, Morihara T, Ota A, Tamura A (2008). Reanalysis of response curves of Shinkansen railway noise. In: Proceedings. 9th International Congress on Noise as a Public Health Problem 2008 (ICBEN 2008), Foxwoods, USA, 21–25 July 2008. Zurich: International Commission on Biological Effects of Noise.

Yoshida T, Kawaguchi T, Hoshiyama Y, Yoshida K, Yamamoto K (1997). Effects of road traffic noise on inhabitants of Tokyo. J Sound Vib. 205(4):517–22.

Annexes

Annex 1. Steering, advisory and external review groups

Tables A1.1–A1.5 give details of the various teams involved in the development of the WHO environmental noise guidelines for the European Region.

Table A1.1 WHO Steering Group

Name	Role	Affiliation
Shelly Chadha	Technical Officer, Office for Hearing Impairment	WHO headquarters, Geneva, Switzerland
Carlos Dora	Coordinator	WHO headquarters, Department of Public Health and Environment, Geneva, Switzerland
Marie-Eve Héroux	Technical Officer, Air Quality and Noise	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Dorota Jarosinska	Programme Manager, Living and Working Environments	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Rokho Kim	Environmental Health Specialist, Team Leader	WHO Regional Office for the Western Pacific, Division of Noncommunicable Diseases and Health through the Life-Course, Manila, Philippines
Jurgita Lekaviciute	Consultant, Noise	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Srdan Matic	Coordinator, Environment and Health	WHO Regional Office for Europe, Copenhagen, Denmark
Julia Nowacki	Technical Officer, Health Impact Assessment	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Elizabet Paunovic	Head of Office	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Poonum Wilkhu	Consultant, Noise	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Jördis Wothge	Consultant, Noise	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany

Table A1.2. Guideline Development Group

Area of expertise	Reference	Area of expertise	Reference
Noise sources and their measurement	1	Annoyance	6
Biological mechanisms of effects	2	Cognitive impairment, quality of life, mental health and well-being	7
Cardiovascular and metabolic diseases	3	Adverse birth outcomes	8
Sleep disturbance	4	Environmental noise interventions	9
Hearing impairment/tinnitus	5	Methodology and guideline development	10

Name	Position and affiliation	Area of expertise sought for guideline development (see reference numbers above)									
		1	2	3	4	5	6	7	8	9	10
Wolfgang Babisch	Senior Scientific Officer (retired) Federal Environment Agency Germany		X	X		X					
Goran Belojevic	Professor Institute of Hygiene and Medical Ecology Faculty of Medicine University of Belgrade Serbia			X			X				
Mark Brink	Senior Scientist Federal Office for the Environment Switzerland	X			X		X				
Sabine Janssen	Senior Scientist Department of Sustainable Urban Mobility and Safety Netherlands Organisation for Applied Scientific Research (TNO) Netherlands				X		X				
Peter Lercher (2013–2014)	Professor Medical University of Innsbruck Austria							X	X		
Marco Paviotti	Policy Officer Directorate-General for Environment European Commission Belgium	X								X	
Göran Pershagen	Professor Institute of Environmental Medicine Karolinska Institute Sweden		X	X					X		

Table A1.2. contd

Area of expertise	Reference	Area of expertise	Reference
Noise sources and their measurement	1	Annoyance	6
Biological mechanisms of effects	2	Cognitive impairment, quality of life, mental health and well-being	7
Cardiovascular and metabolic diseases	3	Adverse birth outcomes	8
Sleep disturbance	4	Environmental noise interventions	9
Hearing impairment/tinnitus	5	Methodology and guideline development	10

Name	Position and affiliation	Area of expertise sought for guideline development (see reference numbers above)									
		1	2	3	4	5	6	7	8	9	10
Kerstin Persson Waye	Professor Occupational and Environmental Medicine The Sahlgrenska Academy University of Gothenburg Sweden	X			X		X				
Anna Preis	Professor Institute of Acoustics Adam Michiewicz University Poland					X	X				
Stephen Stansfeld (Chair)	Professor/Head of the Centre for Psychiatry Barts and Queen Mary University of London United Kingdom							X			
Martin van den Berg	Senior Noise Expert Ministry of Infrastructure and Environment Netherlands	X									
GRADE methodologist											
Jos Verbeek	Senior Researcher Finnish Institute of Occupational Health Finland	X									

Table A1.3. Systematic Review Team

Systematic review topics	Experts involved	Affiliation
Cardiovascular and metabolic diseases	Elise van Kempen	National Institute of Public Health and the Environment (RIVM), Netherlands
	Göran Pershagen	Institute of Environmental Medicine, Karolinska Institute, Sweden
	Maribel Casas Sanahuja	Institute for Global Health (ISGlobal), Spain
	Maria Foraster	Barcelona Institute for Global Health (ISGlobal), Spain and Swiss Tropical and Public Health Institute, Switzerland
Sleep disturbance	Mathias Basner	Department of Psychiatry, Perelman School of Medicine at the University of Pennsylvania, United States of America
	Sarah McGuire	Department of Psychiatry, Perelman School of Medicine at the University of Pennsylvania, United States of America
Hearing impairment and tinnitus	Mariola Sliwinska-Kowalska	Nofer Institute of Occupational Medicine, Poland
	Kamil Rafal Zaborowski	Nofer Institute of Occupational Medicine, Poland
Annoyance	Rainer Guski	Department of Psychology, Ruhr-University, Germany
	Dirk Schreckenberg	ZEUS GmbH, Centre for Applied Psychology, Environmental and Social Research, Germany
	Rudolf Schuemer	Consultant for ZEUS GmbH, Centre for Applied Psychology, Environmental and Social Research, Germany
Cognitive impairment, mental health and well-being	Charlotte Clark	Ove Arup & Partners, United Kingdom
	Katarina Paunovic	Institute of Hygiene and Medical Ecology, Faculty of Medicine, University of Belgrade, Serbia
Adverse birth outcomes	Mark Nieuwenhuijsen	Institute for Global Health (ISGlobal), Spain
	Gordana Ristovska	Institute of Public Health of Republic of Macedonia, the former Yugoslav Republic of Macedonia
	Payam Dadvand	Institute for Global Health (ISGlobal), Spain
Interventions	Lex Brown	Griffith School of Environment/Urban Research Program, Griffith University, Australia
	Irene Van Kamp	National Institute of Public Health and the Environment (RIVM), Netherlands

Table A1.4. External Review Group

Area of expertise	Reference	Area of expertise	Reference
Cardiovascular and metabolic diseases	1	Cognitive impairment, mental health and well-being	5
Sleep disturbance	2	Adverse birth outcomes	6
Hearing impairment/ Tinnitus	3	Environmental noise interventions	7
Annoyance	4	Recommendations and implementation guidance	8

Name	Affiliation	Area of expertise sought for guideline development (see reference numbers above)							
		1	2	3	4	5	6	7	8
Gunn Marit Aasvang	Norwegian Institute of Public Health, Norway		X						
Bernard Berry	Berry Environmental Limited, United Kingdom							X	
Dick Botteldooren	Department of Information Technology, Ghent University, Belgium				X				
Stephen Conaty	South Western Sydney Local Health District, Australia								X
Ulrike Gehring	Institute for Risk Assessment Sciences, Utrecht University, Netherlands						X		
Truls Gjestland	SINTEF, Department of Acoustics, Norway				X				
Mireille Guay	Healthy Environments and Consumer Safety Branch, Health Canada/Government of Canada, Canada		X		X				
Ayse Güven	Audiology Department, Faculty of Heath Sciences, Baskent University, Turkey			X					
Anna Hansell	Centre for Environmental Health & Sustainability, George Davies Centre, University of Leicester, United Kingdom	X							X
Stylianos Kephalopoulos	European Commission, DG Joint Research Centre, Italy							X	X
Yvonne de Kluizenaar	The Netherlands Organization for applied scientific research (TNO), Netherlands							X	
David S. Michaud	Healthy Environments and Consumer Safety Branch, Health Canada/Government of Canada, Canada		X		X				
Arnaud Norena	Université Aix-Marseille, Fédération de Recherche, Laboratoire Cognitive Neuroscience, France			X					
Enembe Okokon	National Institute for Health and Welfare, Finland								X
Dieter Schwela	Stockholm Environment Institute, University of York, United Kingdom								X
Daniel Shepherd	AUT University, Auckland, New Zealand					X			
Mette Sörensen	Danish Cancer Society Research Centre, Denmark	X							X
Rupert Thornley-Taylor	Rupert Taylor Ltd, Noise and Vibration Consultants							X	X
David Welch	School of Population Health, Faculty of Medical and Health Sciences, University of Auckland, New Zealand			X				X	

Table A1.5. Stakeholders and end users that participated in the stakeholder consultation

Area of expertise/interest	Reference	Area of expertise	Reference
Implementation of recommendations on railway noise	1	Implementation of recommendations on wind turbine noise	4
Implementation of recommendations on aircraft noise	2	Implementation of recommendations on leisure noise	5
Implementation of recommendations on road traffic noise	3	Implementation of overall recommendations	6

Organization	Area of expertise specifically sought for Guidelines (see reference number above)					
	1	2	3	4	5	6
Airlines for Europe		X				
Airports Council International Europe (ACI)		X				
Anderson Acoustics		X				
Bundesverband der Deutschen Luftverkehrswirtschaft e.V.		X				
European Automobile Manufacturers’ Association (ACEA)			X			
European Aviation Safety Agency		X				
European Express Association	X					
European Noise Barrier Federation						X
Flughafenverband (ADV)		X				
International Air Transport Association (IATA)		X				
International Civil Aviation Organization (ICAO)		X				
International Union of Railways	X					
Landesamt fuer Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen						X
Public Health Agency of Sweden						X
Stephen Turner Acoustics					X	X
Union Européenne Contre les Nuisances Aeriennes		X				
Vie en.ro.se.						X

Note: in total 53 organizations and institutions had been approached to participate in the stakeholder consultation.

Annex 2. Systematic reviews and background documents used in preparation of the guidelines

Annex 2 provides a detailed list of all the supplementary documents accompanying the WHO environmental noise guidelines for the European Region.[22]

Systematic reviews

- Basner M, McGuire S (2018). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and effects on sleep. Int J Environ Res Public Health. 15(3):pii: E519 (http://www.mdpi.com/1660-4601/15/3/519/htm).
- Brown AL, van Kamp I (2017). WHO environmental noise guidelines for the European Region: a systematic review of transport noise interventions and their impacts on health. Int J Environ Res Public Health. 14(8). pii: E873 (http://www.mdpi.com/1660-4601/14/8/873/htm).
- Clark C, Paunovic K (2018). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and cognition. Int J Environ Res Public Health. 15(2). pii: E285 (http://www.mdpi.com/1660-4601/15/2/285/htm).
- Clark C, Paunovic K (in press). WHO Environmental noise guidelines for the European Region: a systematic review on environmental noise and quality of life, wellbeing and mental health. Int J Environ Res Public Health.
- Guski R, Schreckenberg D, Schuemer R (2017). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and annoyance. Int J Environ Res Public Health. 14(12). pii:1539 (http://www.mdpi.com/1660-4601/14/12/1539/htm).
- Nieuwenhuijsen MJ, Ristovska G, Dadvand P (2017). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and adverse birth outcomes. Int J Environ Res Public Health. 14(10). pii: E1252 (http://www.mdpi.com/1660-4601/14/10/1252/htm).
- Śliwińska-Kowalska M, Zaborowski K (2017). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and permanent hearing loss and tinnitus. Int J Environ Res Public Health. 14(10). pii: E1139 (http://www.mdpi.com/1660-4601/14/10/1139/htm).
- van Kempen E, Casas M, Pershagen G, Foraster M (2018). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and cardiovascular and metabolic effects: a summary. Int J Environ Res Public Health. 15(2). pii: E379 (http://www.mdpi.com/1660-4601/15/2/379/htm).

[22] All references were accessed on 27 June 2018.

Background documents

- Eriksson C, Pershagen G, Nilsson M (2018). Biological mechanisms related to cardiovascular and metabolic effects by environmental noise. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/biological-mechanisms-related-to-cardiovascular-and-metabolic-effects-by-environmental-noise).
- Héroux ME, Verbeek J (2018a). Results from the search for available systematic reviews and meta-analyses on environmental noise. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/results-search-for-available-systematic-reviews-environmental-noise).
- Héroux ME, Verbeek J (2018b). Methodology for systematic evidence reviews for the WHO environmental noise guidelines for the European Region. Copenhagen: WHO Regional Office for Europe (http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/methodology-systematic-evidence-reviews-who-environmental-guidelines-for-the-european-region).

Annex 3. Summary of conflict of interest management

All external contributors to the guidelines, including members of the GDG, Systematic Review Team and External Review Group, completed WHO declaration of interest forms in accordance with WHO's policy for experts. Further, at the initial stage of the project WHO technical staff reviewed and accepted *curricula vitae* of the candidates for the GDG.

At the beginning of the GDG meetings, the participants declared any conflict of interest by submitting declaration of interest forms. Updated declarations of interest were also collected from the members of the GDG, Systematic Review Team and External Review Group at the final stage of the project.

The conflict of interest assessment was done according to WHO procedures. If a conflict was declared, an initial review was undertaken by the WHO Secretariat to assess its relevance and significance. A declared conflict of interest is insignificant or minimal if it is unlikely to affect or to be reasonably perceived to affect the expert's judgment. Insignificant or minimal interests are: unrelated or only tangentially related to the subject of the activity or work and its outcome; nominal in amount or inconsequential in importance; or expired and unlikely to affect current behaviour.

The WHO Secretariat reviewed and assessed the declarations. In one case the legal unit was consulted for advice; in another the potential conflict was reported in the updated declaration of interest at the final stage of the process and assessed unlikely to affect expert's performance; in a further case a member of the GDG was also a co-author of a systematic review owing to the need to support systematic review authors with additional expertise, but there was no remuneration for this activity.

No member of the GDG or the Systematic Review Team was excluded from his or her role in the guideline development process. The declared conflicts of interest of the External Review Group members were considered when interpreting comments during the external review process.

Annex 4. Detailed overview of the evidence of important health outcomes

As a first step of the evidence retrieval process, the GDG defined two categories of health outcome associated with environmental noise: those considered (i) critical or (ii) important, but not critical for decision-making in the guideline development process.

The GDG relied on the critical health outcomes to inform its decisions on priority health outcomes, so only these were used to inform the recommendations. Nevertheless, as the relevance of some of important health outcomes was difficult to estimate *a priori,* systematic reviews were conducted for both critical and important health outcomes.

This annex provides a detailed overview of the evidence of the important health outcomes – namely adverse birth outcomes, quality of life, well-being and mental health and metabolic outcomes – for each of the noise sources. A comprehensive discussion of all the evidence considered (both critical and important) is available in the published systematic reviews (see section 2.3.2 and Annex 2 for details).

1. Road traffic noise

1.1 Adverse birth outcomes

In total, the systematic review found five studies (two with more or less the same population) on road traffic noise and birth outcomes and three related studies on total ambient noise, likely to be mostly road traffic noise. Too few studies for each of the various measures related to adverse birth outcomes were available to undertake a quantitative meta-analysis. There was evidence rated low quality for a relationship between road traffic noise and low birth weight (Dadvand et al., 2014; Gehring et al., 2014; Hjortebjerg et al., 2016; Wu et al., 1996); however, the estimates were imprecise and in some cases not statistically significant. Further, there was no clear relation between exposure to road traffic noise and pre-term delivery, but there was a positive association between road traffic noise and small for gestational age (OR = 1.09; 95% CI: 1.06–1.12 per 6 dB increase). The evidence for both measures of adverse birth outcomes comes from the same publications and this evidence was rated low quality (Gehring et al., 2014; Hystad et al., 2014).

This evidence was supported by one ecological time-series study published recently looking at total ambient noise and various measures related to adverse birth outcomes (Arroyo et al., 2016a; 2016b; Diaz et al., 2016).

1.2 Quality of life, well-being and mental health

Evidence rated moderate quality was found for an effect of road traffic noise on emotional and conduct disorders in childhood (Belojevic et al., 2012; Crombie et al., 2011; Hjortebjerg et al., 2015; Ristovska et al., 2004; Stansfeld et al., 2005; 2009a; Tiesler et al., 2013) and evidence rated moderate quality for an association of road traffic noise with hyperactivity in children (Hjortebjerg et al., 2015; Tiesler et al., 2013).

There was no clear relationship, however, between road traffic noise exposure and self-reported quality of life (evidence rated low quality) (Barcelo Perez & Piñeiro, 2008; Brink, 2011; Clark et al., 2012; Honold et al., 2012; Roswall et al., 2015; Schreckenberg et al., 2010b; Stansfeld et al., 2005; 2009b; van Kempen et al., 2010); medication intake for depression and anxiety (evidence rated very low quality) (Floud et al., 2011; Halonen et al., 2014); depression, anxiety and psychological distress (evidence rated very low quality) (Honold et al., 2012; Stansfeld et al., 2009b); and interview measures of depression and anxiety (evidence rated very low quality) (Stansfeld et al., 2009b).

1.3 Metabolic outcomes

1.3.1 Diabetes

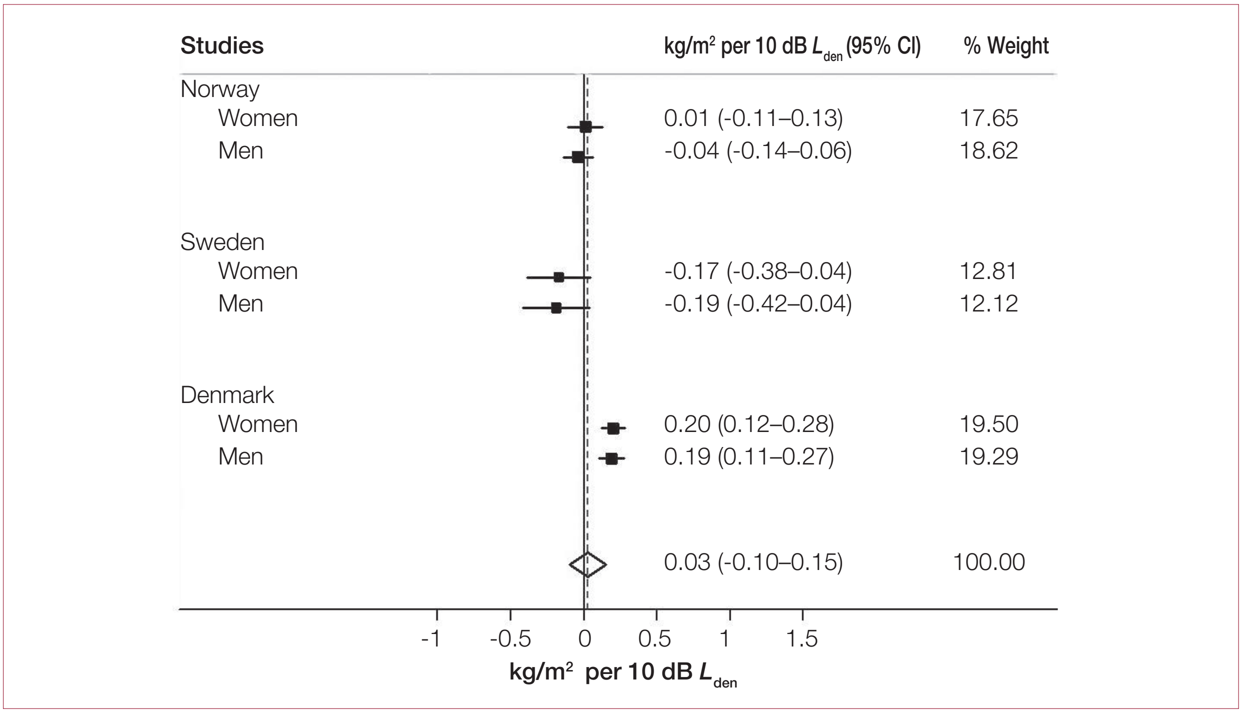
For the relationship between road traffic noise and the incidence of diabetes, one cohort study was identified, which included 57 053 participants and 2752 cases (Sörensen et al., 2013). The estimate of the effect was RR = 1.08 (95% CI: 1.02–1.14) per 10 dB L_{den} increase in noise across the range of 50–70 dB, and therefore the evidence was rated moderate quality.

Furthermore, two cross-sectional studies were identified that looked at the prevalence of diabetes (Selander et al., 2009; van Poll et al., 2014). The studies included 11 460 participants and 242 cases. Both studies reported a harmful effect of noise, and one showed a statistically significant association. However, the results were imprecise and with serious risk of bias, so the evidence was rated very low quality.

1.3.2 Obesity

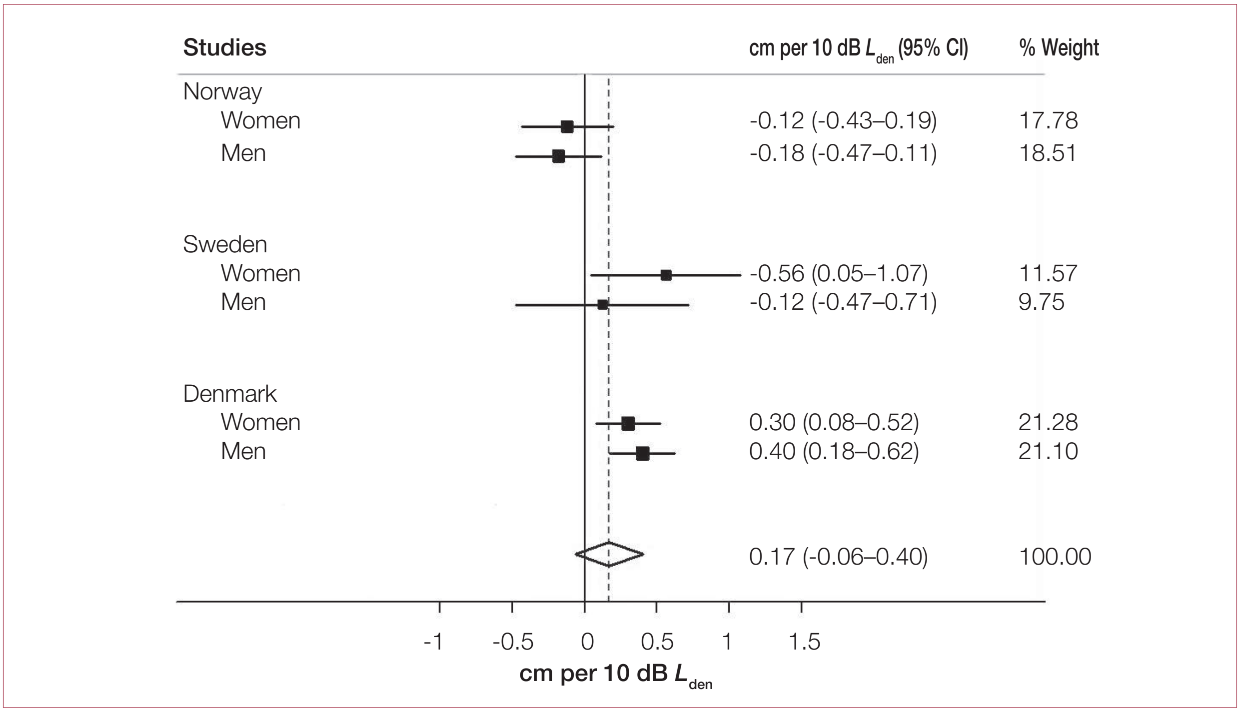
With regard to the association between road traffic noise and change in body mass index (BMI) and waist circumference, three cross-sectional studies were identified, with 71 431 participants (Christensen et al., 2016; Oftedal et al., 2014; 2015; Pyko et al., 2015). For each 10 dB increase in road traffic noise, there was a statistically nonsignificant increase in BMI of 0.03 kg/m^2 (95% CI: –0.10–0.15 kg/m^2) and in waist circumference of 0.17 cm (95% CI: –0.06–0.40 cm). There was inconsistency in the results between the studies; therefore, for both associations, the evidence was rated very low quality (Fig. A4.1 and Fig. A4.2).

Fig. A4.1 The association between exposure to road traffic noise (L_{den}) and BMI in three Nordic studies



Notes: The black vertical line corresponds to no effect of noise exposure. The black dots correspond to the estimated slope coefficients per 10 dB for each sex in each study, with 95% CIs. The diamond designates summary estimates and 95% CIs based on random effects models. The dashed red line corresponds to these summary estimates. Heterogeneity between studies: p = 0.000; heterogeneity between genders: p = 0.360; overall (I-squared = 84.4%, p = 0.000). Weights are from random effect analysis.

Fig. A4.2 The association between exposure to road traffic noise (L_{den}) and waist circumference in three Nordic studies



Notes: The black vertical line corresponds to no effect of noise exposure. The black dots correspond to the estimated slope coefficients per 10 dB for each sex in each study, with 95% CIs. The diamond designates summary estimates and 95% CIs based on random effects models. The dashed red line corresponds to these summary estimates. Heterogeneity between studies: p = 0.001; heterogeneity between genders: p = 0.842; overall (I-squared = 69.0%, p = 0.007). Weights are from random effect analysis.

2. Railway noise

2.1 Adverse birth outcomes

No studies were found, and therefore no evidence was available on the association between railway noise and adverse birth outcomes.

2.2 Quality of life, well-being and mental health

Evidence rated very low quality was found for a weak effect of railway noise exposure on self-reported quality of life or health, albeit from a limited number of studies (Roswall et al., 2015; Torre et al., 2007). There was evidence rated moderate quality for an effect of railway noise on emotional and conduct disorders in childhood (Hjortebjerg et al., 2015), but no clear relationship between railway noise and children's hyperactivity (Hjortebjerg et al., 2015); this evidence was rated moderate quality.

2.3 Metabolic outcomes

2.3.1 Diabetes

One cohort study was identified that looked at the relationship between railway noise and the incidence of diabetes (Sörensen et al., 2013). The cohort study of 57 053 participants, including 2752 cases, found evidence rated moderate quality that there was no considerable effect of railway noise on diabetes, with an RR of 0.97 (95% CI: 0.89–1.05) per 10 dB L_{den} increase in noise.

Furthermore, one cross-sectional study was identified that looked at the relationship between railway noise and the prevalence of diabetes (van Poll et al., 2014), including 9365 participants and 89 cases. An RR of 0.21 (95% CI: 0.05–0.82) per 10 dB L_{den} increase in noise was found, but the reasons for the beneficial effect were not immediately apparent. The evidence in the study was rated very low quality.

2.3.2 Obesity

Regarding the association between railway noise and change in BMI and waist circumference, two cross-sectional studies were identified, with 57 531 participants (Christensen et al., 2016; Pyko et al., 2015). Christensen and colleagues observed a statistically significant increase of 0.18 kg/m^2 (95% CI: 0.00–0.36 kg/m^2) per 10 dB for BMI and 0.62 cm (95% CI: 0.14–1.09 cm) per 10 dB for waist circumference in those exposed to railway noise, at levels above 60 dB L_{den}. Pyko and colleagues found a statistically significant increase in waist circumference of 0.92 cm (95% CI: 0.06–1.78 cm) per 10 dB L_{den}. The corresponding estimate for BMI was statistically nonsignificant, at 0.06 kg/m^2 (95% CI: –0.02–0.16 kg/m^2). The evidence was rated low/very low quality.

3. Aircraft noise

3.1 Adverse birth outcomes

Evidence rated very low quality was available for an association between aircraft noise and pre-term delivery, low birth weight and congenital anomalies, as evidenced by six studies included in the systematic review (Ando & Hattori, 1973; Edmonds et al., 1979; Jones & Tauscher, 1978; Knipschild et al., 1981; Matsui et al., 2003; Schell, 1981). The potential for risk of bias in these was high and the results tended to be inconsistent.

3.2 Quality of life, well-being and mental health

Evidence rated very low quality was available for an effect of aircraft noise on medication intake for depression and anxiety (Floud et al., 2011). There was evidence rated very low quality for an effect of aircraft noise exposure on interview measures of depression and anxiety (Hardoy et al., 2005) and rated low quality for an association of aircraft noise with hyperactivity in children (Clark et al., 2013; Crombie et al., 2011; Stansfeld et al., 2009a).

The evidence showed, however, no substantial effect of aircraft noise on self-reported quality of life or health (Clark et al., 2012; Schreckenberg et al., 2010a; 2010b; Stansfeld et al., 2005; van Kempen et al., 2010) or on emotional and conduct disorders in childhood (Clark et al., 2012; 2013; Crombie et al., 2011; Stansfeld et al., 2005; 2009a). This evidence was rated very low quality.

3.3 Metabolic outcomes

3.3.1 Diabetes

For the relationship between aircraft noise and incidence of diabetes one cohort study was identified, including 5156 participants and 1346 cases (Eriksson et al., 2014). The estimate of the effect was imprecise, with an RR of 0.99 (95% CI: 0.47–2.09) per 10 dB L_{den} increase in noise; the evidence was therefore rated very low quality.

Furthermore, one cross-sectional study was identified that looked at the prevalence of diabetes (van Poll et al., 2014), including 9365 participants and 89 cases. The RR was 1.01 (95% CI: 0.78–1.31) per 10 dB increase in aircraft noise. The evidence was rated very low quality.

3.3.2 Obesity

For the association between aircraft noise and change in BMI and waist circumference, one cohort study was identified, with 5156 participants (Eriksson et al., 2014). For each 10 dB increase in aircraft noise level, the increase in BMI was 0.14 kg/m^2 (95% CI: –0.18–0.45) (evidence rated low quality), and the increase in waist circumference was 3.46 cm (95% CI: 2.13–4.77) (evidence rated moderate quality). The range of noise levels in the study was 48–65 dB L_{den}. In the case of BMI, the change over the whole range in noise values was not statistically significant and was less than what could be considered clinically relevant (3–5% change in BMI); however, for waist circumference, the change was equivalent to an increase of 5.8 cm.

4. Wind turbine noise

4.1 Quality of life, well-being and mental health

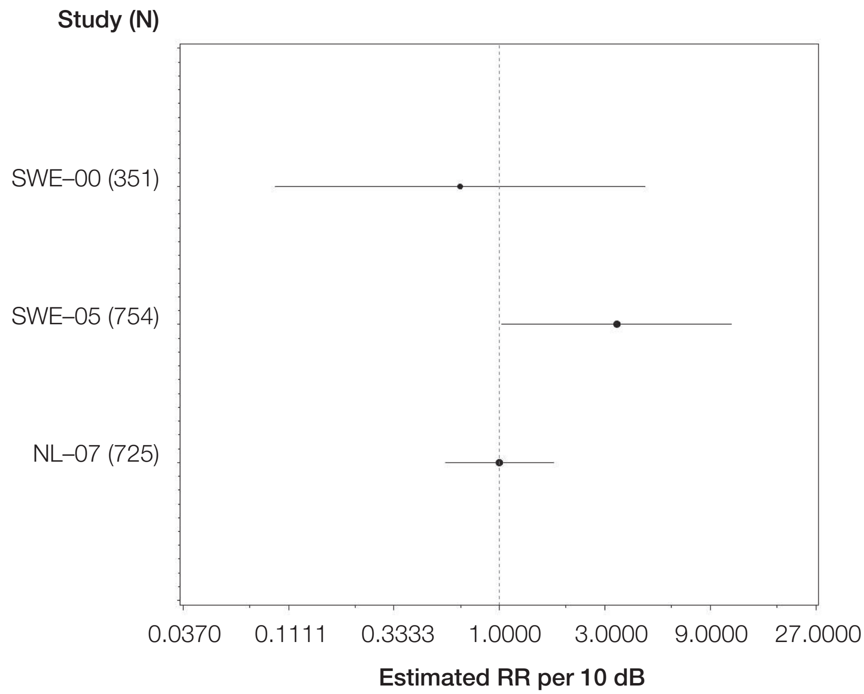
Five low-quality systematic reviews of wind turbine noise effects on mental health and well-being have been carried out (Ellenbogen et al., 2012; Kurpas et al., 2013; Merlin et al., 2013; Onakpoya et al., 2015; Schmidt & Klokker, 2014). These reviews differed in their conclusions and delivered inconsistent evidence that wind turbine noise exposure is associated with poorer quality of life, well-being and mental health. Therefore, the evidence for no substantial effect of wind turbine noise on quality of life, well-being or mental health was rated very low quality.

4.2 Metabolic outcomes

4.2.1 Diabetes

For the relationship between wind turbine noise and prevalence of diabetes, three cross-sectional studies were identified, with a total of 1830 participants (Bakker et al., 2012; Pedersen, 2011; Pedersen & Larsman, 2008; Pedersen & Persson Waye, 2004; 2007; Pedersen et al., 2009; van den Berg et al., 2008). The number of cases was not reported. The effect sizes varied across studies, and only one study found a positive association between exposure to wind turbine noise and the prevalence of diabetes; therefore, no meta-analysis was performed. Due to very serious risk of bias and imprecision in the results, this evidence was rated very low quality. As a result, there is no clear relationship between audible noise (greater than 20 Hz) from wind turbines or wind farms and prevalence of diabetes (Fig. A4.3).

Fig. A4.3 The association between exposure to wind turbine noise (sound pressure level) and self-reported diabetes



Note: The dotted vertical line corresponds to no effect of exposure to wind turbine noise. The black circles correspond to the estimated RR per 10 dB (sound pressure level) and 95% CI.
For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

5. Leisure noise

Owing to a lack of evidence meeting the critieria for systematic reviewing, no results for any of the important health outcomes can be given for exposure to leisure noise.

Annex 4 references

Ando Y, Hattori H (1973). Statistical studies on the effects of intense noise during human fetal life. J Sound Vibrat. 27:101–10.

Arroyo V, Diaz J, Carmona R, Ortiz C, Linares C (2016a). Impact of air pollution and temperature on adverse birth outcomes: Madrid, 2001–2009. Environ Poll. 218:1154–61.

Arroyo V, Diaz J, Ortiz C, Carmona R, Saez M, Linares C (2016b). Short term effect of air pollution, noise and heat waves on preterm births in Madrid (Spain). Environ Res. 145:162–8.

Bakker RH, Pedersen E, van den Berg GP, Stewart RE, Lok W, Bouma J (2012). Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. Sci Total Environ. 425:42–51.

Barcelo Perez C, Piñeiro RG (2008). Potential effect caused by urban noise in housewives from Havana City. Revista Cubana de Higiene y Epidemiologia. 46(2).

Belojevic G, Evans GW, Paunović K, Jakovljevic B (2012). Traffic noise and executive functioning in urban primary school children: the moderating role of gender. J Environ Psychol. 32:337–41.

Brink M (2011). Parameters of well-being and subjective health and their relationship with residential traffic noise exposure – a representative evaluation in Switzerland. Environ Int. 37:723–33.

Christensen JS, Raaschou-Nielsen O, Tjonneland A, Overvad K, Nordsborg RB, Ketzel M et al. (2016). Road traffic and railway noise exposures and adiposity in adults: a cross-sectional analysis of the Danish Diet, Cancer, and Health Cohort. Environ Health Perspect. 124(3):329–35.

Crombie R, Clark C, Stansfeld SA (2011). Environmental noise exposure, early biological risk and mental health in nine to ten year old children: a cross-sectional field study. Environ Health. 10:39.

Clark C, Crombie R, Head J, van Kamp I, van Kempen E, Stansfeld SA (2012). Does traffic-related air pollution explain associations of aircraft and road traffic noise exposure on children's health and cognition? A secondary analysis of the United Kingdom sample from the RANCH project. Am J Epidemiol. 176:327–37

Clark C, Head J, Stansfeld SA (2013). Longitudinal effects of aircraft noise exposure on children's health and cognition: a six-year follow-up of the United Kingdom RANCH cohort. J Environ Psychol. 35:1–9.

Dadvand P, Ostro B, Figueras F, Foraster M, Basagaña X, Valentín A et al. (2014). Residential proximity to major roads and term low birth weight: the roles of air pollution, heat, noise, and road-adjacent trees. Epidemiology. 25(4):518–25.

Diaz J, Arroyo V, Ortiz C, Carmona R, Linares C (2016). Effect of environmental factors on low weight in non-premature births: a time series analysis. PLoS One. 11(10):e0164741.

Edmonds LD, Layde PM, Erickson JD (1979). Airport noise and teratogenesis. Arch Environ Health. 34:243–7.

Ellenbogen J.M, Grace S, Heiger-Bernays WJ, Manwell JF, Mills DA, Sullivan KA, Weisskopf MG (2012). Wind Turbine Health Impact Study: Report of Independent Expert Panel. Massachusetts Department of Environmental Protection, Massachusetts Department of Public Health: Massachusetts, USA.

Eriksson C, Hilding A, Pyko A, Bluhm G, Pershagen G, Östenson CG (2014). Long-term aircraft noise exposure and body mass index, waist circumference, and type 2 diabetes: a prospective study. Environ Health Perspect. 122:687–94.

Floud S, Vigna-Taglianti F, Hansell A, Blangiardo M, Houthuijs D, Breugelmans O et al. (2011). Medication use in relation to noise from aircraft and road traffic in six European countries: results of the HYENA study. Occup Environ Med. 68:518–24.

Gehring U, Tamburic L, Sbihi H, Davies HW, Brauer M (2014). Impact of noise and air pollution on pregnancy outcomes. Epidemiology. 25:351–8.

Halonen JI, Lanki T, Yli-Tuomi T, Turunen AW, Pentti J, Kivimaki M et al. (2014). Associations of traffic noise with self-rated health and psychotropic medication use. Scand J Work Environ Health. 40:235–43.

Hardoy MC, Carta MG, Marci AR, Carbone F, Cadeddu M, Kovess V et al. (2005). Exposure to aircraft noise and risk of psychiatric disorders: the Elmas survey – aircraft noise and psychiatric disorders. Soc Psychiatry Psychiatr Epidemiol. 40:24–6.

Hjortebjerg D, Andersen AMN, Ketzel M, Pedersen M, Raaschou-Nielsen O, Sörensen M (2016). Associations between maternal exposure to air pollution and traffic noise and newborn's size at birth: A cohort study. Environ Int. 95:1–7.

Hjortebjerg D, Andersen AMN, Schultz Christensen J, Ketzel M, Raaschou-Nielsen O, Sunyer J, et al. (2015). Exposure to road traffic noise and behavioral problems in 7-year-old children: a cohort study. Environ Health Perspect. 124:228–34.

Honold J, Beyer R, Lakes T, van der Meer E (2012). Multiple environmental burdens and neighborhood-related health of city residents. J Environ Psychol. 32:305–17.

Hystad P, Davies HW, Frank L, Van Loon J, Gehring U, Tamburic L, Brauer M (2014). Residential greenness and birth outcomes: evaluating the influence of spatially correlated built-environment factors. Environ Health Perspect. 122(10):1095–102.

Jones FN, Tauscher J (1978). Residence under an airport landing pattern as a factor in teratism. Arch Environ Health. 33:10–12.

Knipschild P, Meijer H, Sallé H (1981). Aircraft noise and birthweight. Int Arch Occup Environ Health. 48:131–6.

Kurpas D, Mroczek B, Karakiewicz B, Kassolik K, Andrzejewski W (2013). Health impact of wind farms. Ann Agric Environ Med. 20(3):595–604.

Matsui T, Matsuno T, Ashimine K, Miyakita T, Hiramatsu K, Yamamoto T (2003). Association between the rates of low birth-weight and/or preterm infants and aircraft noise exposure. Nihon Eiseigaku Zasshi. 58:385–94.

Merlin T, Newton S, Ellery B, Milverton J, Farah C (2013). Systematic review of the human health effects of wind farms. Canberra: National Health and Medical Research Council (https://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/eh54_systematic_review_of_the_human_health_effects_of_wind_farms_december_2013.pdf, accessed 28 November 2016).

Oftedal B, Krog NH, Graff-Iversen S, Haugen M, Schwarze P, Aasvang GM (2014). Traffic noise and markers of obesity: a population-based study. In: Proceedings. 11th International Congress on Noise as a Public Health Problem 2014 (ICBEN 2014), Nara, Japan, 1–5 June 2014. Tokyo: Institute of Noise Control Engineering of Japan.

Oftedal B, Krog NH, Pyko A, Eriksson C, Graff-Iversen S, Haugen M et al. (2015). Road traffic noise and markers of obesity: a population-based study. Environ Res. 20(138):144–53.

Onakpoya IJ, O'Sullivan J, Thompson MJ, Heneghan CJ (2015). The effect of wind turbine noise on sleep and quality of life: a systematic review and meta-analysis of observational studies. Environ Int. 82:1–9.

Pedersen E (2011). Health aspects associated with wind turbine noise: results from three field studies. Noise Control Eng J. 59(1):47–53.

Pedersen E, Larsman P (2008). The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines. J Environ Psychol. 28(4):379–89.

Pedersen E, Perrson Waye K (2004). Perception and annoyance due to wind turbine noise – a dose-response relationship. J Acoust Soc Am. 116(6):3460–70.

Pedersen E, Persson Waye K (2007). Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup Environ Med. 64(7):480–6.

Pedersen E, van den Berg F, Bakker R, Bouma J (2009). Response to noise from modern wind farms in the Netherlands. J Acoust Soc Am. 126(2):634–43.

Pyko A, Eriksson C, Oftedal B, Hilding A, Östenson CG, Krog NH et al. (2015). Exposure to traffic noise and markers of obesity. Occup Environ Med. 72(8):594–601.

Ristovska G, Gjorgjev D, Jordanova NP (2004). Psychosocial effects of community noise: Cross sectional study of school children in urban center of Skopje, Macedonia. Croatian Medical Journal, 45, 473–6.

Roswall N, Hogh V, Envold-Bidstrup P, Raaschou-Nielsen O, Ketzel M, Overvad K et al. (2015). Residential exposure to traffic noise and health-related quality of life – a population-based study. PloS One. 13:e0120199.

Schell LM (1981). Environmental noise and human prenatal growth. Am J Phys Anthropol. 56:63–70.

Schmidt JH, Klokker M (2014). Health effects related to wind turbine noise exposure: a systematic review. PloS One. 9(12):e114183.

Schreckenberg D, Griefahn B, Meis M (2010a). The associations between noise sensitivity, reported physical and mental health, perceived environmental quality, and noise annoyance. Noise Health. 12:7–16.

Schreckenberg D, Meis M, Kahl C, Peschel C, Eikmann T (2010b). Aircraft noise and quality of life around Frankfurt Airport. Int J Environ Res Public Health. 7:3382–405.

Selander J, Nilsson ME, Bluhm G, Rosenlund M, Lindqvist M, Nise G et al. (2009). Long-term exposure to road traffic noise and myocardial infarction. Epidemiology. 20(2):272–9.

Sörensen M, Andersen ZJ, Nordsborg RB, Becker T, Tjonneland A, Overvad K et al. (2013). Long-term exposure to road traffic noise and incident diabetes: a cohort study. Environ Health Perspect. 121:217–22.

Stansfeld SA, Berglund B, Clark C, Lopez-Barrio I, Fischer P, Ohrstrom E, et al. (2005). Aircraft and road traffic noise and children's cognition and health: a cross-national study. Lancet. 365:1942–9.

Stansfeld SA, Clark C, Cameron RM, Alfred T, Head J, Haines MM et al. (2009a). Aircraft and road traffic noise exposure and children's mental health. J Environ Psychol. 29:203–7.

Stansfeld SA, Haines MM, Berry B, Burr M (2009b). Reduction of road traffic noise and mental health: an intervention study. Noise Health. 11(44):169–75.

Tiesler CM, Birk M, Thiering E, Kohlbock G, Koletzko S, Bauer CP et al. (2013). Exposure to road traffic noise and children's behavioural problems and sleep disturbance: results from the GINIplus and LISAplus studies. Environ Res. 123:1–8.

Torre GL, Moscato U, Torre FL, Ballini P, Marchi S, Ricciardi W (2007). Environmental noise exposure and population health: a cross-sectional study in the Province of Rome. J Public Health (Oxf). 15:339–44.

van den Berg F, Pedersen E, Bouma J, Bakker R (2008). Project WINDFARMperception. Visual and acoustic impact of wind turbine farms on residents. Groningen: University of Groningen (FP6-2005-Science-and-Society-20 Specific Support Action Project no. 044628; https://www.rug.nl/research/portal/publications/project-windfarmperception-visual-and-acoustic-impact-of-wind-turbine-farms-on-residents(b8745281-02e7-4761-bd06-86363e2be78b).html, accessed 27 November 2016).

van Kempen E, van Kamp I, Lebret E, Lammers J, Emmen H, Stansfeld S (2010). Neurobehavioral effects of transportation noise in primary schoolchildren: a cross-sectional study. Environ Health. 9:25.

van Poll R, Ameling C, Breugelmans O, Houthuis D, van Kempen E, Marra M et al. (2014). Gezondheidsonderzoek Vliegbasis Geilenkirchen (Desk Research) I. Hoofdrapportage: samenvatting, conclusies en aanbevelingen Gezondheidsonderzoek Vliegbasis Geilenkirchen [Health study at the military airport Geilenkirchen (desk research) I. Main report: summary, conclusions and recommendations of the health study at the military airport Geilenkirchen]. Bilthoven: National Institute for Public Health and the Environment (https://zoek.officielebekendmakingen.nl/blg-378125.pdf, accessed 15 March 2017).

Wu TN, Chen LJ, Lai JS, Ko GN, Shen CY, Chang PY (1996). Prospective study of noise exposure during pregnancy on birthweight. Am J Epidemiol. 143(8):792–6.

The WHO Regional Office for Europe

The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

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Noise is an important public health issue. It has negative impacts on human health and well-being and is a growing concern. The WHO Regional Office for Europe has developed these guidelines, based on the growing understanding of these health impacts of exposure to environmental noise. The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. They provide robust public health advice underpinned by evidence, which is essential to drive policy action that will protect communities from the adverse effects of noise. The guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience.

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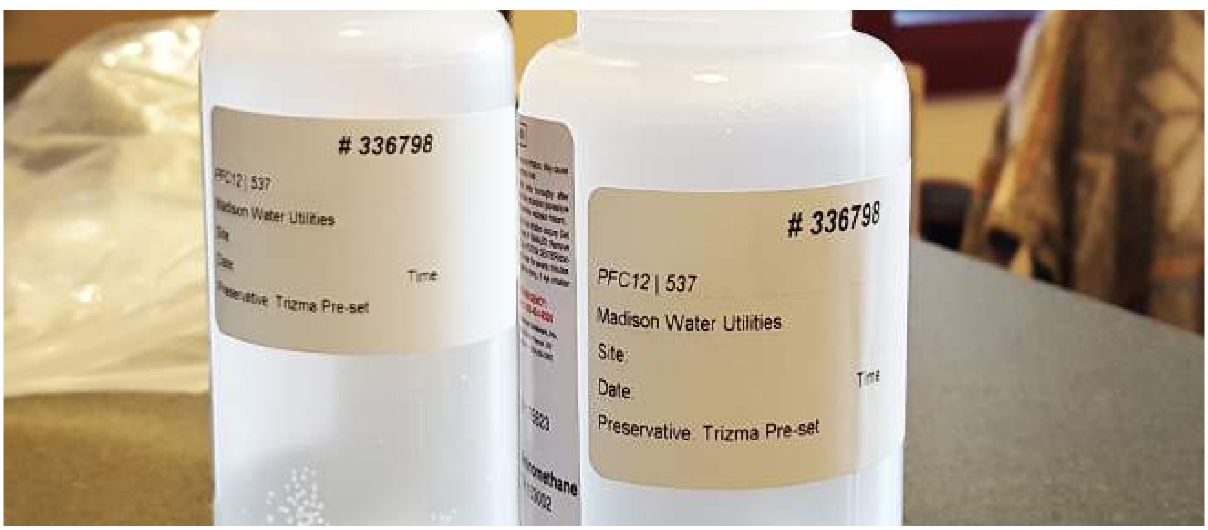
Perfluorinated Compounds

Madison tap water meets all federal and state standards for drinking water safety.

Per and Polyfluoroalkyl Substances (PFAS)

PFAS, or Per and Polyfluoroalkyl Substances, is a class of thousands of chemicals used in everything from food packaging and cookware to upholstery, clothing and firefighting foam. The chemicals do not break down in the environment and are commonly found in dust, air, soil and water.

Madison Water Utility first began in-depth testing for a broad spectrum of PFAS chemicals at all city wells in 2019 at the urging of community members who petitioned the Water Utility Board for comprehensive monitoring. Testing for PFAS isn't required by state or federal regulators, and most communities in Wisconsin do not test drinking water for the compounds.



Latest PFAS Test Results

- At least some PFAS are present in every Madison well, with total amounts ranging from 2.5 to 47 parts-per-trillion.
- All wells in Madison more than meet groundwater standards (https://www.dhs.wisconsin.gov/water/gws-cycle11.htm)recently recommended by the WI Dept. of Health Services for 18 types of PFAS compounds.

- PFAS chemicals are not yet regulated in drinking water, but there could be limits established by the State of Wisconsin for some PFAS comounds over the next 1 to 3 years.

View complete 2020 testing results at all operating wells for more than 30 types of PFAS chemicals. PDF (/water/documents/PFAS_2020.pdf)

Compare proposed Wisconsin PFAS regulatory limit with levels found in Madison wells. PDF (/water/documents/PFOA_PFOS__2020_figure.pdf)

Compare recommended PFAS groundwater standards with levels found in Madison wells (https://www.cityofmadison.com/water/water-quality/water-quality-testing/perfluorinated-compounds/dhs-recommended-groundwater).

To receive all lab reports generated during 2020 PFAS testing (about 300 pages), email water@madisonwater.org (mailto:water@madisonwater.org)

Is Madison's water safe?

Yes, Madison tap water meets all federal and state standards for drinking water safety. If you have special circumstances or want to further purify your water, home filtration (activated carbon filters and reverse osmosis) is an option to reduce PFAS levels.

View map of municipal wells

There are 21 well facilities across Madison that provide the city's water and protect from fires. Wells 15 and 23 are not in service.

View map PDF (/water/documents/Water_Facilities_2020_wells_only.pdf)

Which wells serve your home? Enter your address here (/water/waterquality/mywells.cfm) to find out

False positives and estimated results

New analytical technology can detect PFAS chemicals down to a fraction of one part-per trillion. But looking for chemicals at such ultra-trace levels means that many detections reported by labs are too low to accurately measure. Levels that are below two parts per-trillion are often reported as estimates. Some results may also be false positives.

Madison Water Utility will test all operating wells again in 2021.

Different types of PFAS compounds

Thousands of types of PFAS chemicals have been manufactured, but a just handful have been well-studied or tied to known health risks. Most drinking water regulation focuses on two types of PFAS compounds called PFOA and PFOS, which have been phased out of use in the United States. Madison Water Utility detected PFOA and/or PFOS in sixteen wells. The estimated level of PFOA + PFOS found ranged from 0.5 to 3.4 parts per trillion. The DNR is considering imposing a safe drinking water limit of 20 parts per trillion for PFOA and PFOS in Wisconsin.

Madison Water Utility also found a broad range of other types of PFAS chemicals during its testing. Most types are not regulated by any state. Others are regulated at much higher levels than PFOA and PFOS.

For example, over 80% of the PFAS detected in Well 9 is a single chemical called PFBA. The most restrictive health-based guideline for PFBA in the United States comes from the Minnesota Department of Health and is set at 7,000 parts-per-trillion. Madison Water Utility found a total PFAS concentration in Well 9 of 47 ppt, with 37 ppt coming from PFBA.

At-home filters

While the very low levels of PFAS found in Madison wells don't require large-scale wellhead treatment, Madison Water Utility often gets questions about at-home filters. It is possible to reduce PFAS chemicals in water using a home filter. A recent study by Duke University and North Carolina State University analyzed the effectiveness of a variety of household filters at removing PFAS from tap water.

View the study summary (https://www.cityofmadison.com/water/water-quality/water-quality-testing/perfluorinated-compounds/household-filter-study-pfas)

About one percent of the water pumped to Madison homes is used for drinking and cooking. The rest is used for flushing toilets, doing laundry, dishes, outdoor watering and other needs.

Well 15

Madison Water Utility first discovered PFAS in two Madison wells in 2017 while conducting limited testing at wells near landfills and the airport. One of those wells – Well 15 located on East Washington Ave. – was shut down in 2019 amid community concerns about PFAS chemicals found there. Madison Water Utility just completed a $50,000 feasibility study looking at possible PFAS treatment at Well 15. The utility will now evaluate whether installing a treatment system at Well 15 is the best, most cost-effective option for meeting water supply needs on Madison's east side. The utility believes the chemicals detected in that well likely migrated from Truax Air Field, about a mile away. It's unclear where PFAS chemicals found in other city wells are coming from.

Learn more about PFAS chemicals at well 15. (/water/water-quality/water-quality-testing/perfluorinated-compounds/pfas-at-well-15)

PFAS information from Public Health Madison and Dane County

High concentrations of certain types of PFAS chemicals have been showen to affect health.

View more information on Public Health Madison and Dane County website. (https://www.publichealthmdc.com/environmental-health/environmental-hazards/per-and-polyfluoroalkyl-substances-pfas)

Test results from 2019

View 2019 PFAS testing results here (https://www.cityofmadison.com/water/water-quality/water-quality-testing/perfluorinated-compounds/pfas-water-quality-testing-results-2019).

Water Quality

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PFAS at Well 15

Madison Water Utility first discovered PFAS in two Madison wells in 2017 while conducting limited testing at wells near landfills and the airport. One of those wells – Well 15 located on East Washington Ave. – was shut down in 2019 amid community concerns about PFAS chemicals found there. The utility believes the chemicals detected in that well likely migrated from Truax Air Field, about a mile away.

Latest News

Well 15 Feasibility Study for PFAS Removal *PDF* (/water/documents/2021_Well_15_Feasiblity_Study_PFAS_Removal_Report_Final.pdf)

The final report of the Well 15 feasibility study was completed April 8, 2021. It will be presented to the Water Quality Technical Advisory Committee (https://www.cityofmadison.com/city-hall/committees/water-quality-technical-advisory-committee/4-12-2021) and Water Utility Board (https://www.cityofmadison.com/city-hall/committees/water-utility-board) in April.

Goals of the study:

- Evaluate treatment technologies
- Get a general estimate of upfront and ongoing costs for effective treatments
- Provide a recommended treatment design that would:
  - Remove PFAS.
  - Remove PCE and TCE, eliminating the need for the air stripper system that's currently set up at Well 15.
  - Allow 1000 gallons per minute of water to be produced from the well.

Study results:

A granular activated carbon system was the recommended treatment technology.

- Granular activated carbon successfully removed PFAS, PCE, and TCE.
- The estimated initial cost of the recommended system was $825,000.
  Note: This is a general estimate for the treatment system only. There would be additional costs to modify the building at Well 15 because it is not tall enough.
- The estimated ongoing costs would depend on how frequently the carbon is replaced. The preliminary estimate was $50,000 to $300,000 a year.
- The major components for the recommended system (ex: bag filter units, steel pipes, tank) have a life expectancy of approximately 30 years.

Read the full report: Well 15 Feasibility Study for PFAS Removal: Bench-Scale Testing Report *PDF* (/water/documents/2021_Well_15_Feasiblity_Study_PFAS_Removal_Report_Final.pdf)

What's next?

Madison Water Utility will evaluate different alternatives to determine whether a treatment system at Well 15 is the best, most cost-effective option for meeting water supply needs on Madison's east side.

Well 15 Testing

Madison Water Utility detected low-level concentrations of PFAS chemicals at Well 15 on East Washington Ave. (located near Truax National Air Base). PFAS have been detected at high levels in shallow groundwater at Truax National Air Base, according to the DNR. The base sits just one mile from Well 15.

While water at Well 15 does not exceed any state or federal health-based drinking water standard, Madison Water Utility will not operate the well until the Wisconsin Department of Health Services (DHS) recommends groundwater standards for 34 types of PFAS, which it is currently investigating.

A type of PFAS compound called Perfluorohexanesulfonic Acid (PFHxS) has been detected in Well 15 at around 20-21 parts per trillion (ppt). Wisconsin DHS is working to determine a groundwater standard for for this compound. DHS has already recommended a standard for two other types found in Well 15, called PFOA and PFOS, of 20 ppt. Levels of PFOA and PFOS in Well 15 are below this recommended standard at around 12 ppt.

Well 15 Modeling & Groundwater Study report *PDF* (/water/documents/TechnicalMemo_final.pdf)

This groundwater study was initiated by Madison Water Utility to evaluate the time of travel for PFAS contamination from the Truax Air Field to Well 15 and update the Well 15 capture zones to determine if Truax could be the source of PFAS at Well 15.The study confirmed that Truax is inside Well 15's groundwater capture zone. It also showed that the time of travel for groundwater from Truax to Well 15 is about 35 to 50 years. Based on the study, Madison Water Utility concluded that Truax Air Field is the likely source of low levels of PFAS detected at Well 15.

Water Quality

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Madison Water Utility 2020 PFAS Test Results

MWU 2020 PFAS Results

PFAS Compound	Source	Well 06	Well 06	Well 06	Well 06	Well 07	Well 07	Well 08	Well 08	Well 09	Well 09	Well 09	Well 09	Well 09
	Sample Date	26-May	26-May	26-May	26-May	5-May	5-May	26-May	26-May	26-May	26-May	26-May	26-May	26-May
	Laboratory	TA	WSLH	WSLH	WSLH	TA	WSLH	TA	WSLH	TA	TA	WSLH	WSLH	WSLH
	Lab Method	Mod 537	ISO	537.1	537.1	Mod 537	ISO	Mod 537	537.1	Mod 537	537.1	537.1	537.1	ISO
Perfluorooctanoic acid	**PFOA**	0.82^{J}	<0.356	<0.820	<0.837	1.0^{J}	0.347^{J}	1.1^{J}	0.990	1.2^{J}	0.54^{J}	<0.861	<0.887	<0.359
Perfluorooctanesulfonic acid	**PFOS**	0.47^{J}	<0.356	<0.543	<0.554	<0.47	0.123^{J}	1.5^{J}	0.903	0.68^{J}	0.65^{J}	<0.570	<0.587	<0.359
Perfluorobutanoic acid	**PFBA**	1.4^{J}	<3.56	n/a	n/a	0.60^{JB}	<1.80	1.1^{J}	n/a	37	n/a	n/a	n/a	27.6
Perfluoropentanoic acid	**PFPeA**	0.77^{J}	<0.356	n/a	n/a	<0.42	<0.180	0.67^{J}	n/a	1.0^{J}	n/a	n/a	n/a	0.650
Perfluorohexanoic acid	**PFHxA**	0.93^{J}	0.607	0.708	0.646	<0.50	<0.126	0.75^{J}	<0.624	0.82^{J}	0.79^{J}	<0.629	<0.647	0.485
Perfluoroheptanoic acid	**PFHpA**	0.29^{J}	<0.356	<0.419	<0.428	<0.22	<0.121	0.31^{J}	<0.437	0.35^{J}	<0.50	<0.440	<0.453	<0.359
Perfluorooctanesulfonamide	**FOSA**	1.6^{JB}	<0.356	n/a	n/a	2.4^{B}	0.470^{B}	2.0^{B}	n/a	3.1^{B}	n/a	n/a	n/a	<0.359
Perfluorononanoic acid	PFNA	<0.22	<0.356	<0.319	<0.326	<0.23	<0.0684	<0.23	<0.332	<0.24	<0.50	<0.335	<0.345	<0.359
Perfluorodecanoic acid	PFDA	<0.26	<0.356	<0.730	<0.746	<0.27	<0.133	<0.26	<0.761	<0.27	<0.50	<0.767	<0.790	<0.359
Perfluoroundecanoic acid	PFUnA	<0.91	<0.356	<0.803	<0.820	<0.95	<0.121	<0.93	<0.836	<0.96	<0.50	<0.843	<0.868	<0.359
Perfluorododecanoic acid	**PFDoA**	0.56^{J}	<0.356	<0.915	<0.934	<0.48	<0.0936	<0.47	<0.953	<0.48	<0.50	<0.961	<0.989	<0.359
Perfluorotridecanoic acid	PFTrDA	<1.1	<0.356	<0.803	<0.820	<1.1	<0.146	<1.1	<0.836	<1.1	<0.50	<0.843	<0.868	<0.359
Perfluorotetradecanoic acid	**PFTeDA**	0.52^{J}	<0.356	<0.681	<0.695	<0.25	<0.261	<0.25	<0.709	<0.25	<0.50	<0.715	<0.736	<0.359
Perfluoro-n-hexadecanoic acid	PFHxDA	<0.74	<0.889	n/a	n/a	<0.77	<0.314	<0.75	n/a	<0.78	n/a	n/a	n/a	<0.897
Perfluoro-n-octadecanoic acid	PFODA	<0.38	n/a	n/a	n/a	<0.40	n/a	<0.39	n/a	<0.40	n/a	n/a	n/a	n/a
Perfluorobutanesulfonic acid	**PFBS**	1.1^{J}	0.749	0.855	0.796	<0.17	<0.214	<0.17	<0.402	0.92^{J}	0.89^{J}	0.654	0.680	0.668
Perfluoropentane sulfonic acid	**PFPeS**	0.74^{J}	0.555	n/a	n/a	<0.26	<0.0504	<0.25	n/a	0.26^{J}	n/a	n/a	n/a	<0.359
Perfluorohexanesulfonic acid	**PFHxS**	4.2^{B}	3.37	3.76	3.66	0.75^{JB}	0.545	0.93^{JB}	0.618	1.4^{JB}	1.8^{J}	1.13	1.20	1.09
Perfluoroheptane sulfonic acid	PFHpS	<0.16	<0.356	n/a	n/a	<0.16	<0.0675	<0.16	n/a	<0.17	n/a	n/a	n/a	<0.359
Perfluorononane sulfonic acid	PFNS	<0.13	<0.356	n/a	n/a	<0.14	<0.0450	<0.14	n/a	<0.14	n/a	n/a	n/a	<0.359
Perfluorodecane sulfonic acid	PFDS	<0.27	<0.356	n/a	n/a	<0.28	<0.123	<0.27	n/a	<0.28	n/a	n/a	n/a	<0.359
Perfluorododecanesulfonic acid	PFDoS	<0.37	<0.356	n/a	n/a	<0.39	<0.121	<0.38	n/a	<0.39	n/a	n/a	n/a	<0.359
N-Methyl perfluorooctane sulfonamide	NMeFOSA	<0.36	<0.889	n/a	n/a	<0.37	<0.731	<0.36	n/a	<0.38	n/a	n/a	n/a	<0.897
N-Ethyl perfluorooctane sulfonamide	NEtFOSA	<0.72	<0.889	n/a	n/a	<0.75	<0.584	<0.74	n/a	<0.76	n/a	n/a	n/a	<0.897
N-Methyl perfluorooctane sulfonamidoacetic acid	NMeFOSAA	<2.6	<0.356	<0.950	<0.970	<2.7	<0.184	<2.6	<0.990	<2.7	<0.50	<0.998	<1.03	<0.359
N-Ethyl perfluorooctane sulfonamidoacetic acid	NEtFOSAA	<1.6	<0.356	<0.843	<0.861	<1.6	<0.147	<1.6	<0.879	<1.7	<0.50	<0.886	<0.912	<0.359
N-Methyl perfluorooctane sulfonamidoethanol	**NMeFOSE**	<1.2	<0.356	n/a	n/a	<1.2	<0.180	<1.2	n/a	<1.2	n/a	n/a	n/a	<0.359
N-Ethyl perfluorooctane sulfonamidoethanol	**NEtFOSE**	<0.71	<0.356	n/a	n/a	<0.74	<0.115	<0.72	n/a	<0.74	n/a	n/a	n/a	<0.359
4:2 Fluorotelomer sulfonic acid	4:2 FTS	<4.3	<0.356	n/a	n/a	<4.5	<0.235	<4.4	n/a	<4.5	n/a	n/a	n/a	<0.359
6:2 Fluorotelomer sulfonic acid	**6:2 FTS**	<1.7	<0.356	n/a	n/a	<1.7	<0.0738	<1.7	n/a	<1.7	n/a	n/a	n/a	<0.359
8:2 Fluorotelomer sulfonic acid	8:2 FTS	<1.7	<0.356	n/a	n/a	<1.7	<0.108	<1.7	n/a	<1.7	n/a	n/a	n/a	<0.359
10:2 Fluorotelomer sulfonic acid	10:2 FTS	<0.16	<0.356	n/a	n/a	<0.16	<0.0864	<0.16	n/a	<0.17	n/a	n/a	n/a	<0.359
ADONA	ADONA	<0.15	<0.356	<0.806	<0.823	<0.16	<0.133	<0.15	<0.840	<0.16	<0.50	<0.847	<0.872	<0.359
9Cl-PF3ONS	F-53B Major	<0.20	<0.356	<0.906	<0.925	<0.21	<0.0549	<0.20	<0.944	<0.21	<0.50	<0.952	<0.980	<0.359
11Cl-PF3OUdS	F-53B Minor	<0.27	<0.356	<1.08	<1.10	<0.28	<0.0828	<0.27	<1.13	<0.28	<0.50	<1.13	<1.17	<0.359
HFPA-DA / HFPO-DA	GenX	<1.2	<0.889	<2.11	<2.15	<1.3	<0.480	<1.3	<2.20	<1.3	<0.50	<2.21	<2.28	<0.897
PFOA+PFOS*		1.3	ND	ND	ND	1.0	0.5	2.6	1.9	1.9	1.2	ND	ND	ND
Combined PFAS*		**13**	**5.3**	**5.3**	**5.1**	**4.8**	**1.5**	**8.4**	**2.5**	**47**	**4.7**	**1.8**	**1.9**	**30**

PFAS Compound	Source	Well 11	Well 11	Well 11	Well 11	Well 12	Well 13	Well 14	Well 14	Well 14	Well 14	Well 14	Well 16	Well 16	Well 17	Well 17
	Sample Date	26-May	26-May	26-May	26-May	5-May	26-May	26-May	26-May	26-May	26-May	26-May	26-May	26-May	26-May	26-May
	Laboratory	TA	WSLH	WSLH	WSLH	TA	TA	TA	TA	WSLH	WSLH	WSLH	TA	WSLH	TA	WSLH
	Lab Method	Mod 537	ISO	537.1	537.1	Mod 537	Mod 537	Mod 537	537.1	537.1	537.1	ISO	Mod 537	537.1	Mod 537	537.1
Perfluorooctanoic acid	**PFOA**	1.0^{J}	<0.359	<0.850	<0.838	<0.75	1.4^{J}	1.8	1.4^{J}	1.04	1.32	0.699	1.6^{J}	<0.868	1.0^{J}	<0.872
Perfluorooctanesulfonic acid	**PFOS**	0.75^{JI}	<0.359	<0.562	<0.555	<0.47	0.54^{J}	0.76^{J}	0.99^{J}	<0.571	<0.569	<0.367	1.8	1.20	0.71^{J}	<0.577
Perfluorobutanoic acid	**PFBA**	4.1	3.74	n/a	n/a	0.65^{JB}	1.8	3.9	n/a	n/a	n/a	4.03	1.6^{J}	n/a	0.85^{J}	n/a
Perfluoropentanoic acid	**PFPeA**	0.73^{J}	0.401	n/a	n/a	<0.43	1.6^{J}	2.0	n/a	n/a	n/a	1.49	1.2^{J}	n/a	<0.42	n/a
Perfluorohexanoic acid	**PFHxA**	0.53^{J}	<0.359	<0.620	<0.612	<0.51	1.9	2.2	2.1	1.76	1.57	1.58	1.1^{J}	0.827	<0.50	<0.636
Perfluoroheptanoic acid	**PFHpA**	0.26^{J}	<0.359	<0.434	<0.428	<0.22	0.52^{J}	0.70^{J}	0.78^{J}	0.502	0.513	0.468	0.50^{J}	<0.444	<0.22	<0.446
Perfluorooctanesulfonamide	**FOSA**	1.2^{JB}	<0.359	n/a	n/a	1.5^{JB}	2.4^{B}	2.0^{B}	n/a	n/a	n/a	<0.367	1.7^{B}	n/a	2.5^{B}	n/a
Perfluorononanoic acid	PFNA	<0.23	<0.359	<0.330	<0.326	<0.24	<0.24	<0.24	<0.50	<0.335	<0.334	<0.367	<0.24	<0.338	<0.23	<0.339
Perfluorodecanoic acid	PFDA	<0.26	<0.359	<0.757	<0.746	<0.27	<0.27	<0.27	<0.50	<0.768	<0.766	<0.367	<0.27	<0.773	<0.27	<0.776
Perfluoroundecanoic acid	PFUnA	<0.92	<0.359	<0.831	<0.820	<0.97	<0.96	<0.97	<0.50	<0.844	<0.842	<0.367	<0.96	<0.850	<0.95	<0.853
Perfluorododecanoic acid	**PFDoA**	<0.46	<0.359	<0.948	<0.935	<0.48	<0.48	<0.49	<0.50	<0.962	<0.960	<0.367	<0.48	<0.968	<0.48	<0.973
Perfluorotridecanoic acid	PFTrDA	<1.1	<0.359	<0.831	<0.820	<1.1	<1.1	<1.1	<0.50	<0.844	<0.842	<0.367	<1.1	<0.850	<1.1	<0.853
Perfluorotetradecanoic acid	**PFTeDA**	<0.24	<0.359	<0.705	<0.695	<0.25	<0.25	<0.26	<0.50	<0.716	<0.714	<0.367	<0.25	<0.720	<0.25	<0.723
Perfluoro-n-hexadecanoic acid	PFHxDA	<0.74	<0.897	n/a	n/a	<0.78	<0.78	<0.79	n/a	n/a	n/a	<0.917	<0.78	n/a	<0.77	n/a
Perfluoro-n-octadecanoic acid	PFODA	<0.38	n/a	n/a	n/a	<0.40	<0.40	<0.41	n/a	n/a	n/a	n/a	<0.40	n/a	<0.40	n/a
Perfluorobutanesulfonic acid	**PFBS**	0.48^{J}	0.389	<0.400	<0.394	<0.18	1.1^{J}	1.7^{J}	1.7^{J}	1.28	1.22	1.30	0.85^{J}	0.624	<0.17	<0.410
Perfluoropentane sulfonic acid	**PFPeS**	<0.25	<0.359	n/a	n/a	<0.26	<0.26	0.41^{J}	n/a	n/a	n/a	<0.367	<0.26	n/a	<0.26	n/a
Perfluorohexanesulfonic acid	**PFHxS**	1.7^{B}	1.31	1.29	1.26	<0.15	2.6^{B}	5.0^{B}	6.4	4.15	4.08	4.15	2.9^{B}	2.40	0.77^{JB}	0.597
Perfluoroheptane sulfonic acid	PFHpS	<0.16	<0.359	n/a	n/a	<0.17	<0.17	<0.17	n/a	n/a	n/a	<0.367	<0.17	n/a	<0.16	n/a
Perfluorononane sulfonic acid	PFNS	<0.13	<0.359	n/a	n/a	<0.14	<0.14	<0.14	n/a	n/a	n/a	<0.367	<0.14	n/a	<0.14	n/a
Perfluorodecane sulfonic acid	PFDS	<0.27	<0.359	n/a	n/a	<0.28	<0.28	<0.28	n/a	n/a	n/a	<0.367	<0.28	n/a	<0.28	n/a
Perfluorododecanesulfonic acid	PFDoS	<0.38	<0.359	n/a	n/a	<0.40	<0.39	<0.40	n/a	n/a	n/a	<0.367	<0.39	n/a	<0.39	n/a
N-Methyl perfluorooctane sulfonamide	NMeFOSA	<0.36	<0.897	n/a	n/a	<0.38	<0.38	<0.38	n/a	n/a	n/a	<0.367	<0.37	n/a	<0.37	n/a
N-Ethyl perfluorooctane sulfonamide	NEtFOSA	<0.73	<0.897	n/a	n/a	<0.76	<0.76	<0.77	n/a	n/a	n/a	<0.917	<0.76	n/a	<0.75	n/a
N-Methyl perfluorooctane sulfonamidoacetic acid	NMeFOSAA	<2.6	<0.359	<0.984	<0.971	<2.7	<2.7	<2.7	<0.50	<0.999	<0.996	<0.367	<2.7	<1.01	<2.7	<1.01
N-Ethyl perfluorooctane sulfonamidoacetic acid	NEtFOSAA	<1.6	<0.359	<0.874	<0.862	<1.7	<1.7	<1.7	<0.50	<0.887	<0.885	<0.367	<1.7	<0.893	<1.6	<0.897
N-Methyl perfluorooctane sulfonamidoethanol	**NMeFOSE**	<1.2	<0.359	n/a	n/a	9.0	<1.2	<1.2	n/a	n/a	n/a	<0.367	<1.2	n/a	<1.2	n/a
N-Ethyl perfluorooctane sulfonamidoethanol	**NEtFOSE**	<0.71	<0.359	n/a	n/a	1.5^{J}	<0.74	<0.75	n/a	n/a	n/a	<0.367	<0.74	n/a	<0.74	n/a
4:2 Fluorotelomer sulfonic acid	4:2 FTS	<4.3	<0.359	n/a	n/a	<4.6	<4.5	<4.6	n/a	n/a	n/a	<0.367	<4.5	n/a	<4.5	n/a
6:2 Fluorotelomer sulfonic acid	**6:2 FTS**	<1.7	<0.359	n/a	n/a	<1.8	<1.7	<1.8	n/a	n/a	n/a	<0.367	<1.7	n/a	<1.7	n/a
8:2 Fluorotelomer sulfonic acid	8:2 FTS	<1.7	<0.359	n/a	n/a	<1.8	<1.7	<1.8	n/a	n/a	n/a	<0.367	<1.7	n/a	<1.7	n/a
10:2 Fluorotelomer sulfonic acid	10:2 FTS	<0.16	<0.359	n/a	n/a	<0.17	<0.17	<0.17	n/a	n/a	n/a	<0.367	<0.17	n/a	<0.16	n/a
ADONA	ADONA	<0.15	<0.359	<0.835	<0.824	<0.16	<0.16	<0.16	<0.50	<0.848	<0.845	<0.367	<0.16	<0.853	<0.16	<0.857
9Cl-PF3ONS	F-53B Major	<0.20	<0.359	<0.939	<0.926	<0.21	<0.21	<0.21	<0.50	<0.953	<0.950	<0.367	<0.21	<0.959	<0.21	<0.963
11Cl-PF3OUdS	F-53B Minor	<0.27	<0.359	<1.12	<1.10	<0.28	<0.28	<0.28	<0.50	<1.14	<1.13	<0.367	<0.28	<1.14	<0.28	<1.15
HFPA-DA / HFPO-DA	GenX	<1.3	<0.897	<2.18	<2.15	<1.3	<1.3	<1.3	<0.50	<2.22	<2.21	<0.917	<1.3	<2.23	<1.3	<2.24
PFOA+PFOS*		1.8	ND	ND	ND	ND	1.9	2.6	2.4	1.0	1.3	0.7	3.4	1.2	1.7	ND
Combined PFAS*		**11**	**5.8**	**1.3**	**1.3**	**13**	**14**	**20**	**13**	**8.7**	**8.7**	**14**	**13**	**5.1**	**5.8**	**0.6**

PFAS Compound	Source	Well 18	Well 19	Well 20	Well 24	Well 25	Well 26	Well 27	Well 28	Well 29	Well 29	Well 30	Well 31
	Sample Date	5-May	5-May	5-May	5-May	5-May	26-May	26-May	5-May	5-May	5-May	5-May	5-May
	Laboratory	TA	TA	TA	TA	TA	TA	TA	TA	TA	WSLH	TA	TA
	Lab Method	Mod 537	Mod 537	Mod 537	Mod 537	Mod 537	Mod 537	Mod 537	Mod 537	Mod 537	ISO	Mod 537	Mod 537
Perfluorooctanoic acid	**PFOA**	0.80^{J}	<0.78	<0.73	<0.77	0.82^{J}	0.79^{J}	1.2^{J}	<0.76	0.78^{J}	<0.0973	0.80^{J}	<0.73
Perfluorooctanesulfonic acid	**PFOS**	0.53^{J}	<0.50	<0.47	0.52^{J}	0.62^{J}	0.99^{J}	0.55^{J}	<0.48	<0.48	0.150^{J}	0.51^{J}	<0.46
Perfluorobutanoic acid	**PFBA**	1.0^{JB}	0.70^{JB}	0.48^{JB}	0.64^{JB}	0.45^{JB}	0.90^{J}	1.2^{J}	0.71^{JB}	1.2^{JB}	<1.84	0.61^{JB}	0.41^{JB}
Perfluoropentanoic acid	**PFPeA**	0.49^{J}	<0.45	<0.42	<0.44	<0.41	0.42^{J}	0.93^{J}	<0.44	<0.44	<0.184	<0.41	<0.42
Perfluorohexanoic acid	**PFHxA**	<0.49	<0.53	<0.50	<0.52	<0.49	<0.48	0.87^{J}	<0.52	<0.52	<0.128	<0.49	<0.50
Perfluoroheptanoic acid	**PFHpA**	<0.21	<0.23	<0.22	<0.23	<0.21	<0.21	0.30^{J}	<0.22	<0.22	<0.124	<0.21	<0.21
Perfluorooctanesulfonamide	**FOSA**	2.6^{B}	2.1^{B}	1.8^{B}	2.9^{B}	3.2^{B}	1.8^{B}	2.2^{B}	2.6^{B}	3.6^{B}	0.261^{JB}	3.7^{B}	4.4^{B}
Perfluorononanoic acid	PFNA	<0.23	<0.25	<0.23	<0.24	<0.23	<0.22	<0.23	<0.24	<0.24	<0.0697	<0.23	<0.23
Perfluorodecanoic acid	PFDA	<0.26	<0.28	<0.27	<0.28	<0.26	<0.26	<0.27	<0.28	<0.28	<0.136	<0.26	<0.27
Perfluoroundecanoic acid	PFUnA	<0.94	<1.0	<0.95	<0.99	<0.92	<0.91	<0.95	<0.98	<0.99	<0.124	<0.93	<0.94
Perfluorododecanoic acid	**PFDoA**	<0.47	<0.51	<0.47	<0.50	<0.46	<0.45	<0.48	<0.49	<0.49	<0.0954	<0.46	<0.47
Perfluorotridecanoic acid	PFTrDA	<1.1	<1.2	<1.1	<1.2	<1.1	<1.1	<1.1	<1.2	<1.2	<0.149	<1.1	<1.1
Perfluorotetradecanoic acid	**PFTeDA**	<0.25	<0.27	<0.25	<0.26	0.29^{J}	<0.24	<0.25	<0.26	<0.26	<0.266	<0.24	<0.25
Perfluoro-n-hexadecanoic acid	PFHxDA	<0.76	<0.82	<0.77	<0.80	<0.75	<0.73	<0.77	<0.79	<0.80	<0.320	<0.75	<0.76
Perfluoro-n-octadecanoic acid	PFODA	<0.39	<0.42	<0.40	<0.41	<0.39	<0.38	<0.40	<0.41	<0.41	n/a	<0.39	<0.39
Perfluorobutanesulfonic acid	**PFBS**	<0.17	<0.18	<0.17	<0.18	<0.17	0.25^{J}	0.62^{J}	<0.18	<0.18	<0.218	<0.17	<0.17
Perfluoropentane sulfonic acid	**PFPeS**	<0.26	<0.28	<0.26	<0.27	<0.25	<0.25	<0.26	<0.27	<0.27	<0.0514	<0.25	<0.26
Perfluorohexanesulfonic acid	**PFHxS**	0.46^{JB}	0.30^{JB}	0.25^{JB}	0.28^{JB}	<0.14	0.92^{JB}	1.8^{B}	0.26^{JB}	0.43^{JB}	0.131^{J}	0.30^{JB}	0.26^{JB}
Perfluoroheptane sulfonic acid	PFHpS	<0.16	<0.17	<0.16	<0.17	<0.16	<0.16	<0.16	<0.17	<0.17	<0.0688	<0.16	<0.16
Perfluorononane sulfonic acid	PFNS	<0.14	<0.15	<0.14	<0.14	<0.13	<0.13	<0.14	<0.14	<0.14	<0.0459	<0.13	<0.14
Perfluorodecane sulfonic acid	PFDS	<0.27	<0.29	<0.28	<0.29	<0.27	<0.26	<0.28	<0.29	<0.29	<0.126	<0.27	<0.27
Perfluorododecanesulfonic acid	PFDoS	<0.38	<0.41	<0.39	<0.41	<0.38	<0.37	<0.39	<0.40	<0.40	<0.124	<0.38	<0.39
N-Methyl perfluorooctane sulfonamide	NMeFOSA	<0.37	<0.40	<0.37	<0.39	<0.36	<0.35	<0.37	<0.38	<0.39	<0.745	<0.36	<0.37
N-Ethyl perfluorooctane sulfonamide	NEtFOSA	<0.74	<0.80	<0.75	<0.78	<0.73	<0.72	<0.75	<0.78	<0.78	<0.595	<0.73	<0.75
N-Methyl perfluorooctane sulfonamidoacetic acid	NMeFOSAA	<2.6	<2.8	<2.7	<2.8	<2.6	<2.6	<2.7	<2.8	<2.8	<0.188	<2.6	<2.7
N-Ethyl perfluorooctane sulfonamidoacetic acid	NEtFOSAA	<1.6	<1.7	<1.6	<1.7	<1.6	<1.6	<1.6	<1.7	<1.7	<0.150	<1.6	<1.6
N-Methyl perfluorooctane sulfonamidoethanol	**NMeFOSE**	<1.2	<1.3	<1.2	<1.3	<1.2	<1.2	<1.2	<1.3	<1.3	<0.184	<1.2	<1.2
N-Ethyl perfluorooctane sulfonamidoethanol	**NEtFOSE**	<0.72	<0.78	<0.73	<0.77	<0.71	<0.70	<0.74	<0.76	<0.76	<0.117	<0.72	<0.73
4:2 Fluorotelomer sulfonic acid	4:2 FTS	<4.4	<4.8	<4.5	<4.7	<4.4	<4.3	<4.5	<4.6	<4.7	<0.239	<4.4	<4.5
6:2 Fluorotelomer sulfonic acid	**6:2 FTS**	<1.7	<1.8	<1.7	<1.8	<1.7	<1.6	<1.7	<1.8	<1.8	<0.0752	<1.7	3.0^{J}
8:2 Fluorotelomer sulfonic acid	8:2 FTS	<1.7	<1.8	<1.7	<1.8	<1.7	<1.6	<1.7	<1.8	<1.8	<0.110	<1.7	<1.7
10:2 Fluorotelomer sulfonic acid	10:2 FTS	<0.16	<0.17	<0.16	<0.17	<0.16	<0.16	<0.16	<0.17	<0.17	<0.0881	<0.16	<0.16
ADONA	ADONA	<0.15	<0.17	<0.16	<0.16	<0.15	<0.15	<0.16	<0.16	<0.16	<0.136	<0.15	<0.15
9Cl-PF3ONS	F-53B Major	<0.20	<0.22	<0.21	<0.22	<0.20	<0.20	<0.21	<0.21	<0.22	<0.0560	<0.20	<0.21
11Cl-PF3OUdS	F-53B Minor	<0.27	<0.29	<0.28	<0.29	<0.27	<0.26	<0.28	<0.29	<0.29	<0.0844	<0.27	<0.27
HFPA-DA / HFPO-DA	GenX	<1.3	<1.4	<1.3	<1.4	<1.3	<1.2	<1.3	<1.3	<1.3	<0.489	<1.3	<1.3
PFOA+PFOS*		1.3	ND	ND	0.5	1.4	1.8	1.8	ND	0.8	0.2	1.3	ND
Combined PFAS*		**5.9**	**3.1**	**2.5**	**4.3**	**5.4**	**6.1**	**9.7**	**3.6**	**6.0**	**0.5**	**5.9**	**8.1**

NOTES:

All results in ng/L or parts per trillion (ppt)

Faded results with < indicate result was below detection limit

Results with J indicate an estimated value due to being below reporting limit

Results with B indicate the PFAS was also detected in the laboratory method blank

Varying results and levels of detection are due to differences in analytical methods and lab capabilities

* - this is an estimate derived from the sum of estimated values

n/a - not analyzed

ND - none detected

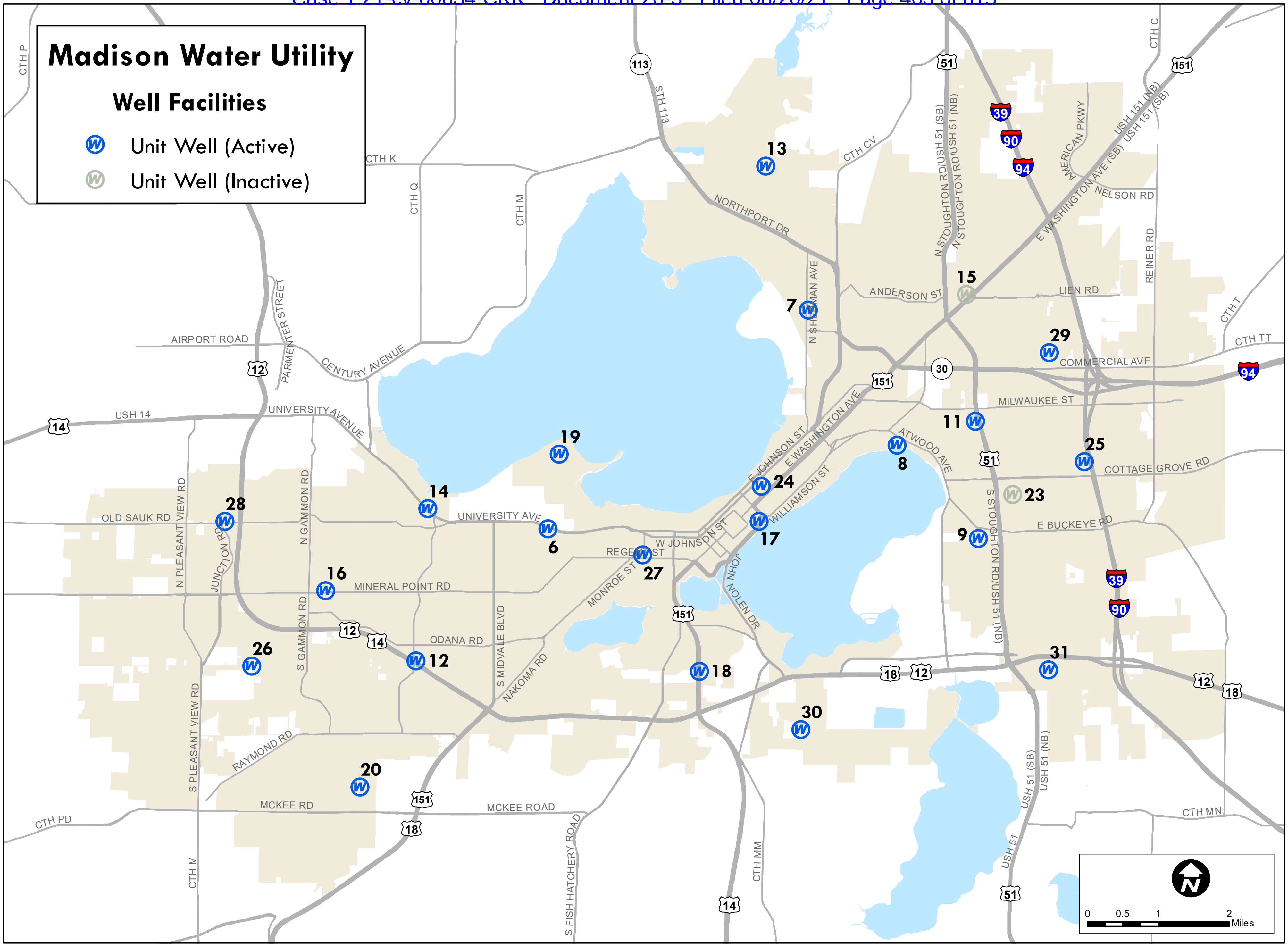
Lab: TA = TestAmerica

Lab: WSLH = WI State Laboratory of Hygiene

Method: 537.1 - EPA Standard Method

Method: Mod 537 - Modified EPA Method 537

Method: ISO - Modified ISO 21675


Madison Water Utility
Well Facilities
Unit Well (Active)
Unit Well (Inactive)
13
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20
NORTHPORT DR
ANDERSON ST
LIEN RD
COMMERCIAL AVE
MILWAUKEE ST
COTTAGE GROVE RD
E BUCKEYE RD
AIRPORT ROAD
CENTURY AVENUE
UNIVERSITY AVENUE
UNIVERSITY AVE
OLD SAUK RD
MINERAL POINT RD
ODANA RD
MCKEE RD
MCKEE ROAD
RAYMOND RD
NAKOMA RD
MONROE ST
REGENT ST
W JOHNSON ST
E JOHNSON ST
E WASHINGTON AVE
WILLIAMSON ST
ATWOOD AVE
NOLEN DR
NELSON RD
AMERICAN PKWY
E WASHINGTON AVE (SB)
USH 151 (NB)
USH 151 (SB)
N STOUGHTON RD/USH 51 (SB)
N STOUGHTON RD/USH 51 (NB)
S STOUGHTON RD/USH 51 (NB)
USH 51 (SB)
USH 51 (NB)
N SHERMAN AVE
PARMENTER STREET
N PLEASANT VIEW RD
S PLEASANT VIEW RD
JUNCTION RD
N GAMMON RD
S GAMMON RD
S MIDVALE BLVD
S FISH HATCHERY ROAD
REINER RD
CTH P
CTH K
CTH Q
CTH M
CTH CV
CTH C
CTH T
CTH TT
CTH PD
CTH MN
CTH MM
STH 113
USH 14
0 0.5 1 2 Miles

https://madison.com/wsj/news/local/environment/dnr-fish-from-yahara-chain-of-lakes-contaminated-with-pfas-anglers-warned-to-limit-consumption/article_3b86574b-56d4-518e-9124-ccf4f6dd899b.html

ALERT TOP STORY

DNR: Fish from Yahara chain of lakes contaminated with PFAS; anglers warned to limit consumption

Chris Hubbuch | Wisconsin State Journal
Jun 9, 2021

Health officials are warning anglers to limit consumption of fish from all but two of Madison's lakes after new test results revealed high levels of toxic "forever chemicals."

The Department of Natural Resources announced the warnings Wednesday based on tests of fish collected last year from the Yahara River chain of lakes.

Based on new test results, the DNR has expanded existing advisories for Starkweather Creek and Lake Monona to include all waters downstream to the Rock River, including lakes Waubesa and Kegonsa.

The DNR released data showing fish had levels of one compound, PFOS, above the health standard recommended by an interstate commission for the Great Lakes region. PFOS has been linked to cancer, high cholesterol and decreased immunity.

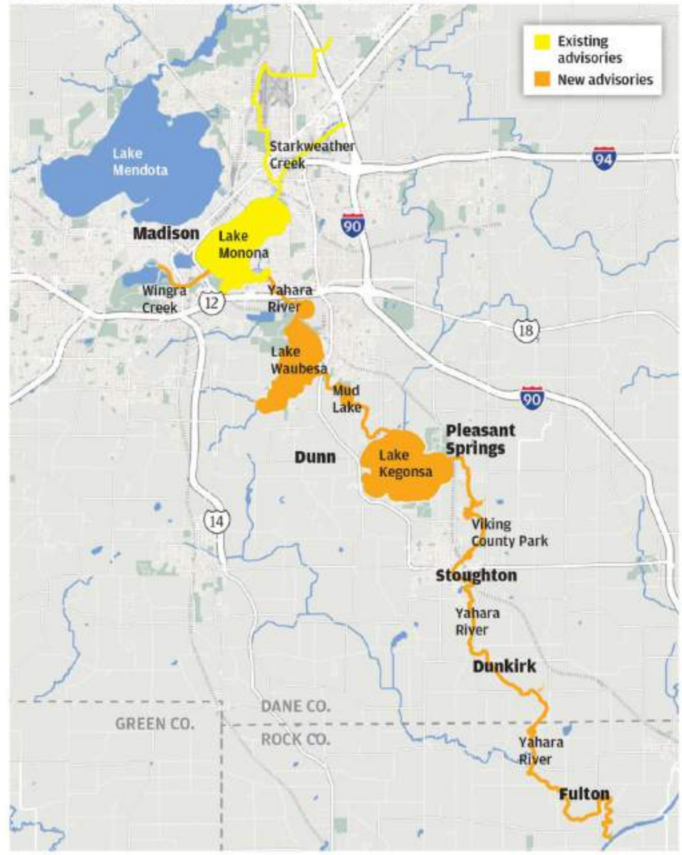
Nathan Kloczko, site evaluation program coordinator for the Department of Health Services said people who've been eating fish from the lakes may want to talk to their doctors about individual health concerns.

Kloczko said the consumption advisories seek to balance the risks of contaminants such as PFOS against the health benefits of eating fish.

"Fish are an excellent source of lean protein and omega fatty acids," he said. "The risk assessments … take all of that into account."

Fish consumption advisories

Health officials have issued new fish consumption advisories for the Yahara Chain of Lakes after tests showed elevated levels of toxic PFAS compounds.



maps4news.com/©HERE, Lee Enterprises graphic

The DHS recommends eating crappie, largemouth bass, northern pike and walleye no more than once a month. The agency says it is safe to eat bluegill, yellow perch and pumpkinseed once a week.

Data provided by the DNR show PFOS concentrations were all below the level considered safe to eat by the Great Lakes Consortium for Fish Consumption Advisories, although average levels were at or above what the New Jersey Department of Environmental Protection has recommended for children and women of childbearing age.

Wisconsin's health advisories are uniform across all ages, which environmental advocate Maria Powell calls "problematic." Powell also criticized the state for focusing only on PFOS and not the thousands of other less-studied compounds.

"This 'one-size-fits-all' approach does not protect everyone in the population, especially the most vulnerable," Powell said. "People are ingesting all of the PFAS in the fish, not just one at a time. They all add to the toxicity."

While PFOS was not found at dangerous levels in fish from lakes Mendota and Wingra, a once-a-month advisory remains in effect for carp because of high PCB levels. The DNR publishes advisories for specific species from around the state in an **annual guidebook** available on the agency website.

Anglers concerned

Jack Hurst, an active member of the Yahara Fishing Club since 1953, said PFAS is a growing concern for the club, which was formed to protect the rights of anglers to use the lakes.

“I don’t eat 'em out of Monona anymore,” Hurst said.

Angler and environmentalist Touyeng Xiong called the news disheartening.

Xiong said he and his father used to eat crappie from Monona Bay but stopped after learning about PFAS contamination.

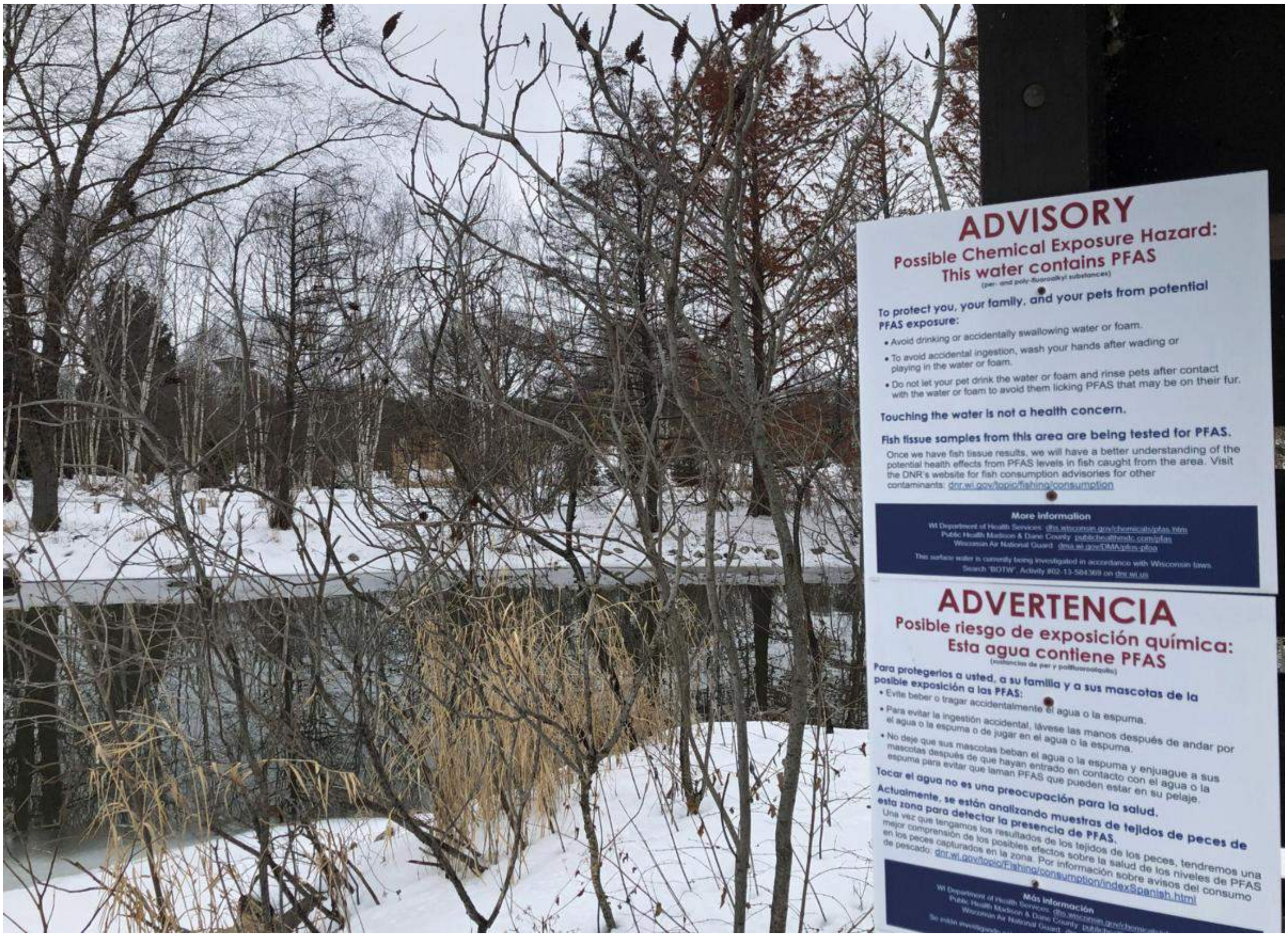

Xiong

JOHN HART, STATE JOURNAL ARCHIVES

He worries that others are unaware or unconcerned by the advisories.

“I still see people pretty regularly fishing there,” Xiong said. “I always wonder if they know of the current conditions.”

Early last year officials **warned anglers to limit consumption of certain fish from Lake Monona** after tests showed elevated levels of PFAS in fish from the lake and Starkweather Creek.



Signs installed in 2019 by Public Health Madison & Dane County caution against consuming water from Starkweather Creek, which is contaminated with hazardous chemicals known as PFAS.

CHRIS HUBBUCH, STATE JOURNAL

The DNR has since issued PFAS consumption advisories for **smelt from Lake Superior** and **trout from Silver Creek** in the Fort McCoy Army base in Monroe County. PFAS advisories were previously in place for fish caught in three pools of the Mississippi River.

In January the DNR said it had found PFAS compounds in all five Madison lakes -- in some cases above proposed surface water standards -- but did not provide guidance on the safety of fish caught there.

No source named

The DNR has not identified a source for the contamination.

It's been almost three years since the agency ordered the city of Madison, Dane County and the Wisconsin National Guard to clean up PFAS contamination sites at the airport where firefighters trained for decades with fluorinated foams that contaminated soil and groundwater. PFAS have also been found in water draining from airport storm sewers into Starkweather Creek.

That cleanup has not begun, but earlier this year the DNR approved a plan by all three entities to further investigate the source of the contamination.

The plan aims to find where PFAS-contaminated groundwater is seeping into the stormwater system and seal up leaky pipes. It also calls for additional sampling of Starkweather Creek to get a better idea of where PFAS are coming from.

The National Guard says it has received authorization from the Department of Defense to move forward with an investigation through the federal Superfund, a process that could take 13 years or more.

"People just not doing their jobs is what it amounts to," Hurst said. "They know about it and they don't do anything about it."

State Sen. Melissa Agard, D-Madison, called on Republican lawmakers to pass legislation requiring the DNR to establish enforcement standards for PFAS in air, water and soil and to hold polluters responsible for cleanup.

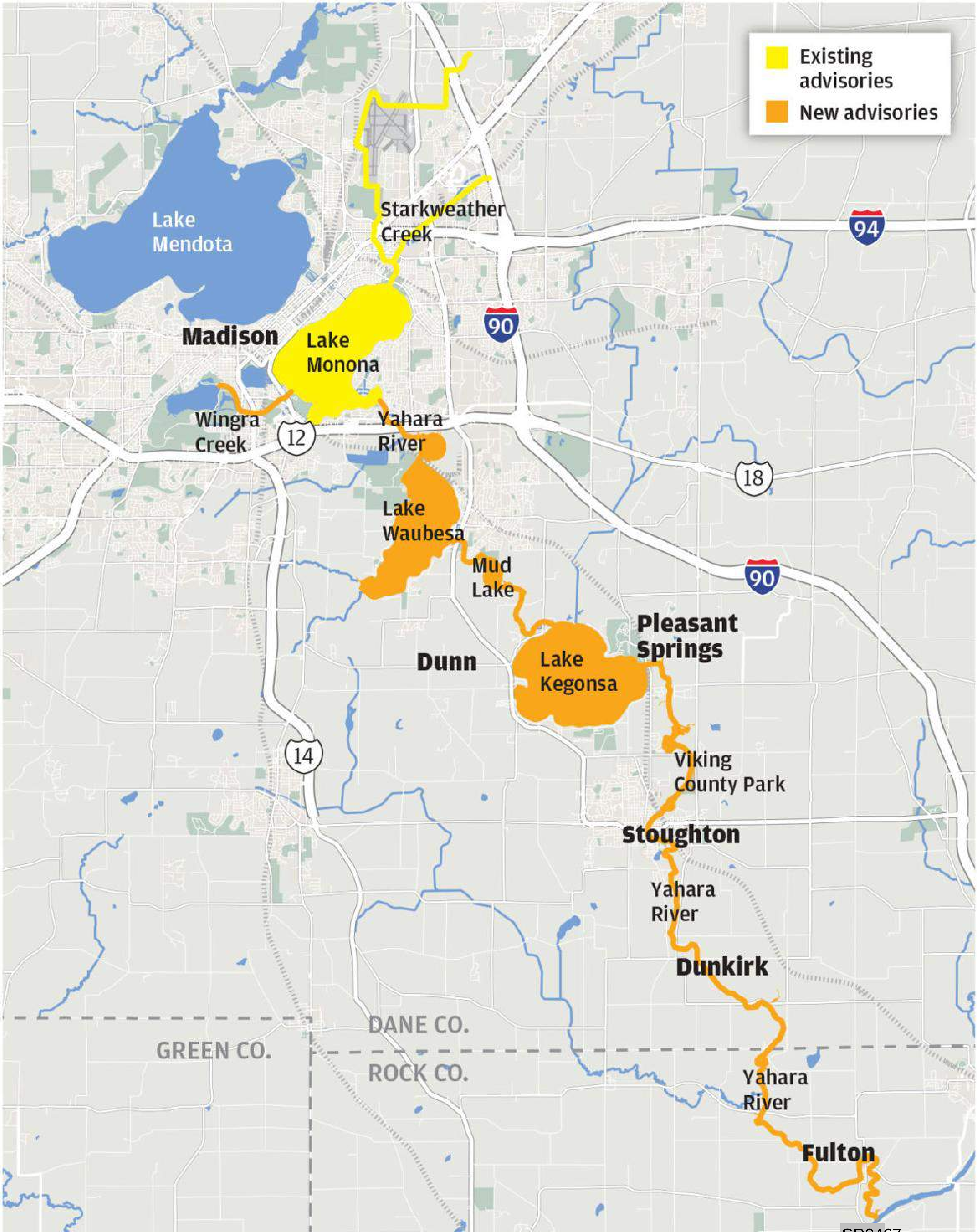
The bill, re-introduced this spring after Republicans denied it a vote in the last session, has support from environmental and public health organizations but not manufacturing and industrial groups.

"Water is life, and addressing PFAS should not be a partisan issue," Agard said. "It affects the health of people in blue and red districts."

Chris Hubbuch | Wisconsin State Journal
Covers energy and the environment for the Wisconsin State Journal. Rhymes with Lubbock. Contact him at 608-252-6146.

Fish consumption advisories

Health officials have issued new fish consumption advisories for the Yahara Chain of Lakes after tests showed elevated levels of toxic PFAS compounds.



SR0467

maps4news.com/©HERE, Lee Enterprises graphic https://madison.com/wsj/news/local/environment/madison-mayor-calls-on-national-guard-to-speed-up-truax-investigation-after-pfas-found-in/article_a10459ea-3454-595b-a63b-5cb4c88c138c.html

BREAKING TOPICAL

PFAS POLLUTION STARKWEATHER CREEK

Madison mayor calls on National Guard to speed up Truax investigation after PFAS found in Starkweather Creek

Chris Hubbuch | Wisconsin State Journal
Oct 9, 2019

Dave Duane, of Madison, tries to catch panfish Monday in Starkweather Creek.

AMBER ARNOLD, STATE JOURNAL

Chris Hubbuch | Wisconsin State Journal

In the wake of reports of elevated levels of hazardous chemicals in Starkweather Creek, Madison Mayor Satya Rhodes-Conway renewed calls Tuesday for the Wisconsin Air National Guard to address soil and groundwater contamination at Truax Field.

The state Department of Natural Resources **released test results Monday showing concentrations of highly fluorinated chemicals known as PFAS** at more than 24 times the level considered safe by Michigan, one of the few states to adopt surface water standards.

The DNR said it plans further investigation to identify potential sources of contamination, but firefighting foam used in training at Truax Field, where the west branch of Starkweather Creek originates, has long been a known source.

In a statement, Rhodes-Conway called on the National Guard to complete a site investigation into the extent of PFAS contamination and implement a clean-up plan "as soon as possible."

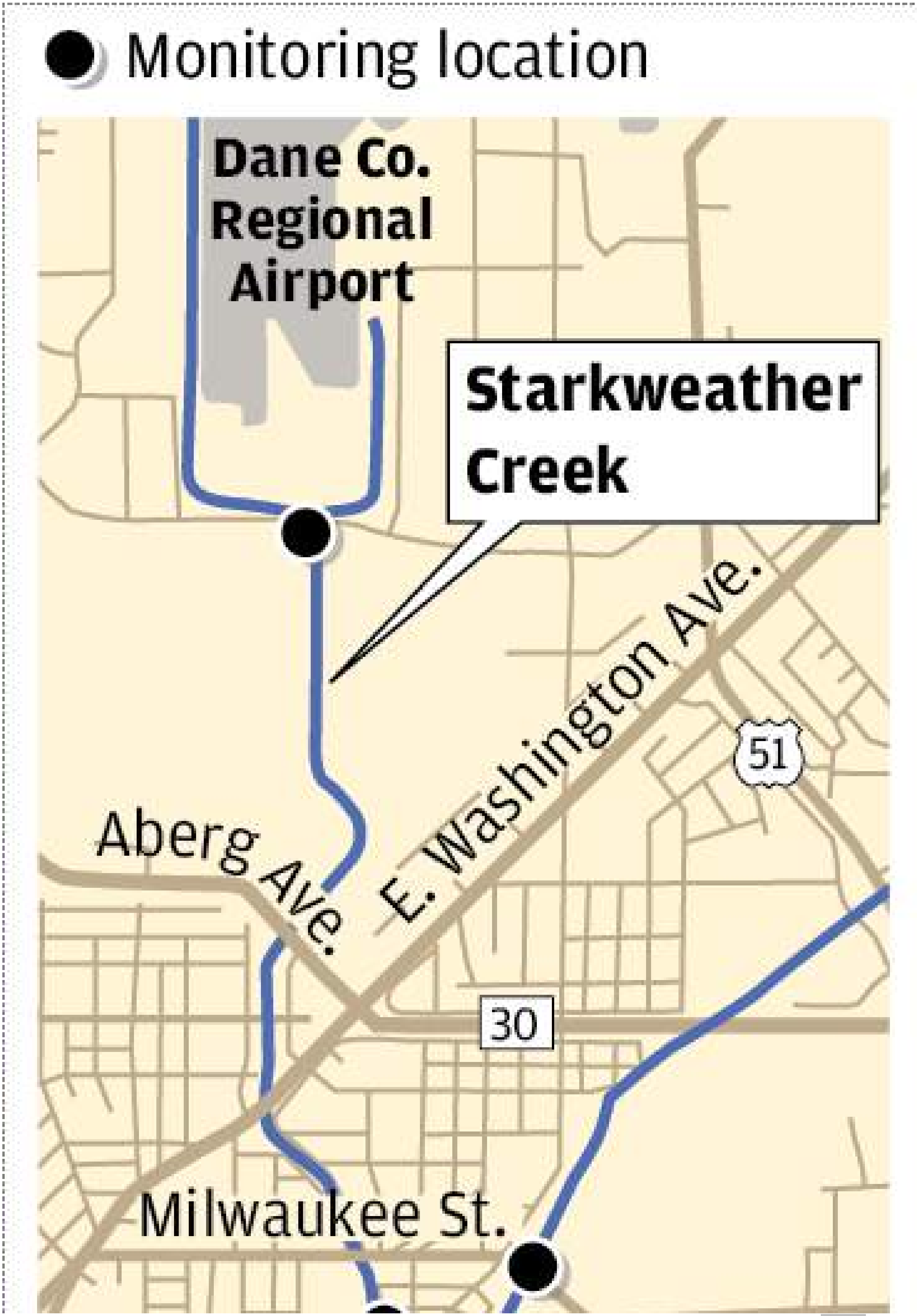
"The Wisconsin National Guard takes this issue very seriously, and we will continue to work with the city, the county, the DNR and other partners statewide to ensure we remain in compliance with all federal advisory levels for PFOS/PFOA," Capt. Joe Trovato of the Wisconsin Air National Guard said in an email.


Rhodes-Conway

MICHELLE STOCKER

Trovato did not say if the Guard has any immediate plans to complete the comprehensive PFAS investigation agreed to by the Guard, city and county in 2018.

The city Engineering Department has said the National Guard cannot “safely and legally” start construction of projects to accommodate a squadron of **F-35 fighter jets the Air Force wants to station there** without a complete site investigation.


Monitoring location
Dane Co. Regional Airport
Starkweather Creek
E. Washington Ave.
51
Aberg Ave.
30
Milwaukee St.

Public Health Madison and Dane County is working to create signs advising the public of the presence of PFAS, including warnings against people or pets drinking the water and suggesting people wash their hands after touching the water.

The signs will not include any specific warnings against consumption of fish from the stream but will refer to state guidelines related to PCBs, which suggest children and pregnant women not eat panfish more than once a week, said Public Health spokeswoman Sarah Mattes.

Mattes said the department is consulting with Friends of Starkweather Creek and local residents about the best placement for signs and whether they should be posted in languages other than English.

Concern for anglers

The DNR is still awaiting test results on fish collected from Starkweather Creek and is considering a more comprehensive fish monitoring program next year.

Maria Powell, executive director of the Midwest Environmental Justice Organization, said anglers need to be warned now that fish could contain much higher concentrations of PFAS than water tests indicate.

"People are fishing from the mouth of the creek and eating it right now," Powell said. "Given these high PFAS levels in water, the levels in fish are very likely much higher. Will anglers be warned?"

Madison mayor wants details on cause of July transformer explosion, says public deserves full report

The mayor said the PFAS contamination of Starkweather Creek does not affect the city's drinking water, which is drawn from deep wells.

However, the Madison Water Utility has voluntarily shut down Well 15 on East Washington Avenue, which is near the airport, because of elevated levels of PFAS, and the utility is expecting results this week from tests at three seasonal wells, including Well 8, which is near Truax Field.

Madison to keep contaminated East Side well offline except in 'extreme' water shortage

Cancer risk

PFAS are a group of chemicals found in numerous products, including foam used to fight oil-based fires. Studies have shown two of these compounds, PFOA and PFOS, may increase people's risk of cancer and affect cholesterol levels, childhood behavior, the immune system and the ability to get pregnant.

There are no federal health standards, but the DNR is working to establish water standards for PFOA and PFOS.

The state Department of Health Services has recommended a combined groundwater enforcement standard of 20 parts per trillion for those two compounds but has not issued any guidance on surface water. Michigan has set surface water standards of 11 to 12 ppt for PFOS, the compound most likely to build up in fish.

The test results announced Monday were from the first round of samples taken this summer from five bodies of water near known or suspected PFAS contamination sites, including firefighting training grounds and two spots where elevated levels were previously found in fish and wildlife.

Of the five sites surveyed, the west branch of Starkweather Creek near Fair Oaks Avenue, in Madison, had the highest concentration of PFOA and PFOS, at 43 ppt and 270 ppt. Samples taken near Atwood Avenue, just above a popular fishing spot where the creek enters Lake Monona, showed a combined PFAS concentration of 187 ppt.

Tests results released last month showed potentially dangerous amounts of PFAS entered Lake Monona after a July 19 transformer explosion near Downtown Madison.

Samples from the storm sewer outlets on July 25 had PFOA and PFOS concentrations between 17.4 and 21.9 ppt. Including some newer unregulated PFAS compounds, the concentrations were as high as 92 ppt.

Chris Hubbuch | Wisconsin State Journal

Covers energy and the environment for the Wisconsin State Journal. Rhymes with Lubbock. Contact him at 608-252-6146.

https://madison.com/wsj/news/local/environment/madison-mayor-city-council-members-seek-funds-for-pfas-testing-at-airport-training-areas/article_44183258-2992-5c40-a851-b4fabeda7f00.html

ALERT

MADISON | PFAS CONTAMINATION

Madison mayor, City Council members seek funds for PFAS testing at airport training areas

Chris Hubbuch | Wisconsin State Journal
Nov 10, 2020

AMBER ARNOLD, STATE JOURNAL

Chris Hubbuch | Wisconsin State Journal

More than two years after state authorities first ordered testing, Madison city leaders are seeking funds to test for pollution at firefighting training areas near the Dane County Regional Airport.

A budget amendment sponsored by Mayor Satya Rhodes-Conway and three City Council members requests an additional $50,000 next year for PFAS "testing and planning at the Dane County Regional Airport, Air National Guard 115th Fighter Wing Base, and surrounding area."

The city, along with Dane County and the Wisconsin National Guard, is responsible for investigation and cleanup of suspected contamination at two former training areas near the airport.

A memo sent to council members by Deputy Mayor Christie Baumel said the city doesn't yet have a clear sense of what testing and planning will occur next year.

"That scope of work will be informed by the findings of the initial testing as well as any further requests from the DNR based on the test results," Baumel wrote. "Nonetheless, we would like to be prepared to act."

Wisconsin health officials recommend groundwater caps for 22 contaminants; list includes pesticides, PFAS

The amendment, sponsored by council members Syed Abbas, Grant Foster and Marsha Rummel, is one of **a dozen up for consideration Tuesday** that together would add about $870,000 to the $349 million budget approved by the finance committee.

PFAS, a group of largely unregulated synthetic compounds found in firefighting foam and other products, has been shown to increase the risk of cancer and other ailments. The compounds have been found in drinking water, groundwater, surface water, soil, sediments, air, fish and wildlife, and have been **detected in all of Madison's municipal wells**.

The state Department of Natural Resources first notified the city, county and military in June 2018 about potential PFAS contamination at a former testing site near International Lane and Darwin Road. The agency requested that the three parties conduct soil, groundwater and surface water testing that summer to determine the extent of PFAS contamination and any potential remediation plans.

In October 2019, after **high levels of PFAS were found in Starkweather Creek**, the DNR sent another letter to the city, county and National Guard notifying them that all were legally responsible for **contamination at two "burn pits" where firefighters had trained with PFAS foams**.

The mayor responded the next day with a news release **calling on the Air National Guard to address contamination** at Truax Field but made no mention of the burn pit investigation. City leaders told the DNR they did not believe the city should be responsible for contamination at either site.

But the DNR maintains that the city provided firefighting services for Truax Field and owned the Darwin Road site until 1974, when the federal government required the use of PFAS foams at military bases.

"We are still investigating what our proportion of total responsibility may be," said Hannah Mohelnitzky, public information officer for the city's engineering division. "Which includes researching the total number of users of those sites and when we started using PFAS-containing firefighting foams."

Environmental contamination concerns taint Oscar Mayer redevelopment plan

Dane County officials last year **requested $200,000 to address PFAS contamination** at the airport. Results from the county's first round of testing are expected to be delivered to the DNR in the coming weeks.

The DNR is monitoring more than 40 PFAS contamination sites around the state, most of which the agency says can be traced to firefighting foam. Several contaminated sites at the Dane County Regional Airport have been linked to training areas used for decades by the Wisconsin Air National Guard and local fire departments.

Beautiful and resilient: bluff country landscapes key for species survival as planet warms

Chris Hubbuch | Wisconsin State Journal

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https://madison.com/wsj/news/local/environment/dnr-says-air-force-f-35-study-didnt-address-pfas-contamination-at-truax/article_b1737fc0-5031-5061-9e06-4554f1bae930.html

TOP STORY

TRUAX FIELD | ENVIRONMENTAL CONCERNS

DNR says Air Force F-35 study didn't address PFAS contamination at Truax

Chris Hubbuch | Wisconsin State Journal
Nov 1, 2019

Wisconsin environmental regulators say the Air Force has not accounted for all the environmental impacts of stationing a squadron of F-35 jets in Madison, which they contend will require a yet-unfunded investigation of existing pollution.

In a letter Wednesday, the Department of Natural Resources said the military's draft environmental impact statement fails to address contamination of hazardous chemicals known as PFAS, which are used in firefighting foam and have been found at high levels throughout Truax Field.

The DNR also raises concerns about the impact of noise on wildlife and public lands, specifically the 2,000-acre Cherokee Marsh, nearly half of which would be subject to higher noise levels, according to the Air Force's models.

F-35 opponents say jets have brought 'chaos' to Burlington, want more answers from Air Force
Chris Hubbuch | Wisconsin State Journal

While it mentions three construction projects near sites where PFAS have likely been spilled, the 1,099-page environmental study does not discuss the probability of widespread PFAS contamination or the need for a complete site investigation, which the DNR ordered in 2018.

The DNR said a 2018 preliminary investigation does not meet state requirements and said the extent and nature of PFAS contamination has not been determined, although results of the preliminary study indicate there is a likelihood of contamination "across much of the installation."

Report: Dane County airport stormwater contributing PFAS to Starkweather Creek
Chris Hubbuch | Wisconsin State Journal

The Pentagon has identified Madison and Montgomery, Alabama, as the preferred sites for two squadrons of F-35s as soon as 2023.

If selected, Truax would require up to $120 million in construction to prepare for the new planes. Planning is already underway for $34 million worth of projects that could start next year if the mission is granted.

The DNR said all planned construction projects will require a site investigation, and the National Guard may need permits for any contaminated soil or water.

The agency's comments echo those of the city, which argues the Guard can't "safely and legally" begin construction without a complete site investigation.

PFAS are a group of chemicals found in numerous products. Studies have shown two of these compounds may increase people's risk of cancer and affect cholesterol levels, childhood behavior, the immune system and the ability to get pregnant.

The DNR in 2018 informed the 115th Fighter Wing, along with the Dane County Regional Airport and the city of Madison, that they were responsible for possible PFAS contamination at former firefighter training sites — known as burn pits — near the base.

Madison mayor calls on National Guard to speed up Truax investigation after PFAS found in Starkweather Creek

Chris Hubbuch | Wisconsin State Journal

DNR says Air Force F-35 study didn't address PFAS contamination at

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The 115th agreed to take the lead on the required investigation, which it said would be done as part of a nationwide study of bases expected to be completed by September, but Capt. Joe Trovato said the Pentagon has not provided funding or authorization for the Wisconsin National Guard to conduct that investigation.

Trovato said PFAS testing would be done in connection with any individual construction project and remediation plans developed if necessary independent of a comprehensive site investigation.

“The Wisconsin National Guard appreciates the Wisconsin DNR’s comments on the draft EIS for the F-35 along with all comments from the community, legislators and other stakeholders,” Trovato said, “so that the best decision can be made not only for the Air Force, but for the surrounding communities as well.”

Friday is the deadline to **submit comments** on the 1,099-page EIS. A final decision by the secretary of the Air Force is expected in February, 30 days after the final EIS is released.

Chris Hubbuch | Wisconsin State Journal

Covers energy and the environment for the Wisconsin State Journal. Rhymes with Lubbock. Contact him at 608-252-6146.

https://madison.com/wsj/news/local/environment/pfos-contamination-lands-lake-monona-on-impaired-waters-list/article_8d7975c4-d0e3-501b-a1c8-f89fe310b6ea.html

ALERT

PFOS contamination lands Lake Monona on impaired waters list

Chris Hubbuch | Wisconsin State Journal
Aug 17, 2021

A sign near Monona Bay in Madison warns anglers to limit consumption of fish caught there. The Department of Natural Resources has proposed to include Lake Monona on its list of impaired waters because it contains a "forever chemical" known as PFOS.

CHRIS HUBBUCH, STATE JOURNAL

Chris Hubbuch | Wisconsin State Journal

Madison's Lake Monona, contaminated with hazardous "forever chemicals," is among 92 lakes, rivers and streams added to Wisconsin's list of polluted waters.

Watch: DNR officials pledge action on water pollution

The state Department of Natural Resources on Monday released a proposed list of 743 "impaired" waters that cannot support recreation or healthy plant and animal populations, and that contain fish that may be unsafe to eat.

Wisconsin has about 15,000 lakes, 86,000 miles of streams and rivers, and 650 miles of Great Lakes shoreline.

With clock ticking on Dane County landfill, focus turns to reducing food waste
Chris Hubbuch | Wisconsin State Journal

More than half the new listings are for waters with too much phosphorus, which can come from urban and farm runoff and causes **algae to grow faster than ecosystems can handle**. About a third of the new listings were for high levels of bacteria such as E. coli.

The DNR is proposing to drop 22 bodies of water from the list, which must be updated every two years to comply with the federal Clean Water Act. The DNR is **accepting comments** on the **proposed list** through Oct. 1.

Waters on the list must have a restoration plan to improve habitat or recreation opportunities, or to make their fish safe for consumption. The DNR says the majority of impaired waters can be used as long as people are warned about water quality and fish that might not be safe to eat.

A water body can be listed for multiple contaminants.

Wisconsin DNR leaders promise continued focus on clean water
Chris Hubbuch | Wisconsin State Journal

Other Dane County additions to the list include Lake Mendota's Gov. Nelson State Park beach, Lake Monona's Schluter beach and Wingra Creek, which were added because of E. coli.

High phosphorus levels resulted in the addition of Stewart Lake, Tiedeman's Pond and new sections of Six Mile and Mud creeks.

Starkweather Creek, already listed because of metals and chloride contamination and for having too much sediment, will now also be listed because it's contaminated with E. coli and the "forever chemical" known as PFOS.

Lake Monona and Starkweather Creek, along with the Biron and Petenwell flowages, are the state's first inland bodies of water making the list because of PFOS contamination. Sections of the Mississippi River between Pepin and La Crosse counties were listed in 2008 for PFOS contamination.

Environmentalists ask feds to deny funding for Dairyland gas plant
Chris Hubbuch | Wisconsin State Journal

Still, state officials have **warned anglers to limit consumption of fish** from all but two of the Madison area's lakes — Wingra and Mendota — because of elevated concentrations of PFOS, a human-made compound linked to cancer, high cholesterol and decreased immunity.

Lake Monona was already on the list for PCBs and phosphorus contamination.

The DNR is proposing to drop a PCB listing for Lake Mendota that's been in place since 1998 and a chloride listing for the Yahara River, which would remain listed for phosphorus.

Photos: See how Madison's lakes have changed since the 19th century

Mounds on Edgewood Dr.

https://madison.com/ct/news/local/neighborhoods/plan-commission-halts-raemisch-farm-development-over-f35s-environmental-impacts/article_254f3677-10c3-5296-8d57-71a658bf94f2.html

Plan Commission halts Raemisch Farm development over F35s, environmental impacts

Nicholas Garton
Apr 15, 2021

An aerial photo shows the Raemisch Farm property on Madison's north side.

Nicholas Garton

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Uncertainty around the future impact of the noise from F35 fighter jets based at Madison's Truax Field led to the city's Plan Commission halting a major development proposal earlier this week.

The Plan Commission on Monday reviewed a proposal to rezone property at 4000-4150 Packers Ave. and 4201 N. Sherman Ave. in order to allow construction of 124 single family homes as well as a potential mix of condominiums, apartment buildings, mixed-use buildings and commercial space called Raemisch Farm.

The Rifkin Group, a Madison-based company, has partnered with Quam Engineering from McFarland to build the proposal on an area currently zoned for agriculture with non-residential marshy wetland, located directly west of the Dane County Regional Airport and the Truax Field Air National Guard Base.

The applicants have appeared before the Plan Commission eight times since July 2020 and the proposal also appeared before the City Council in October 2020. Each time, the proposal has been referred to a later meeting and delayed.

During Monday's Plan Commission meeting, concerns were raised by opponents of the proposal who said it would create a number of environmental issues by reducing the area's woodland and natural area. Residents living in the area said acres of marshy wetland and wooded areas are gathering places for rare birds, ducks, geese and other animals.

Additionally, the nature-heavy area provides opportunities and uses for outdoor learning for students of Lake View Elementary School, which borders the proposed area.

Last summer, the Northside Planning Council created a working group to help residents learn about the proposal and discuss some of the issues involved or float ideas about what the proposal should include. But on Monday night, residents representing the working group said that none of their concerns had been addressed by the development team despite numerous meetings.

"Mr. Rifkin had listened to our concerns and he actually met with a small group of us several times. He came to walk the school forest with our work group," said Michelle Ellinger, who represented the working group. "On April 1 of this year, we had our final meeting with Mr. Rifkin. ... At this meeting the workgroup expressed our concerns with the current plat design and at that time we learned that this plat would not be changed at all. It was the exact same plat, so here we are. After a full year with knowledge of our work and these issues, this plan remains unchanged."

The impending and controversial arrival of F-35 fighter jets at Truax was also a major issue for residents, members of the commission, and City Council members who went on record during the meeting.

During the meeting on Monday, commissioners asked city staff if it was possible to approve zoning changes currently and then revisit the zoning of the proposed area years down the road when the impact of the F-35s is more known. Ald. Syed Abbas, whose north side district includes the proposed development, wondered about the unknown impact of the fighter jets on communities located near the airport.

City staff informed the commissioners that the zoning changes before them weren't able to be changed at the meeting.

As a result, Alds. Marsha Rummel and Patrick Heck, both of whom represent east side districts, made a motion to place the proposal on file without prejudice.

“This proposal isn’t quite there,” Rummel said. “There are so many unanswered questions. We can’t make serious changes later. While I think this is a good place to build new housing — single-family if we can, or mixed-use or low residential/medium residential — I just have grave concerns about the plat on Packers Avenue and what kind of quality can go there and until I have more information on that, I don’t really want to approve this.”

Heck pointed to the issues of habitability once the F-35s are here.

“For me it’s about the unknown impact of the F-35s and I liked what Ald. (Sayed) Abbas had to say about if we have to wait five years to understand the impacts, that we can still minimize the chances that people are going to be living in uninhabitable zones by potentially rethinking the eastern portion along Packers Ave.,” Heck said.

The motion to deny the proposal passed unanimously.

Nicholas Garton

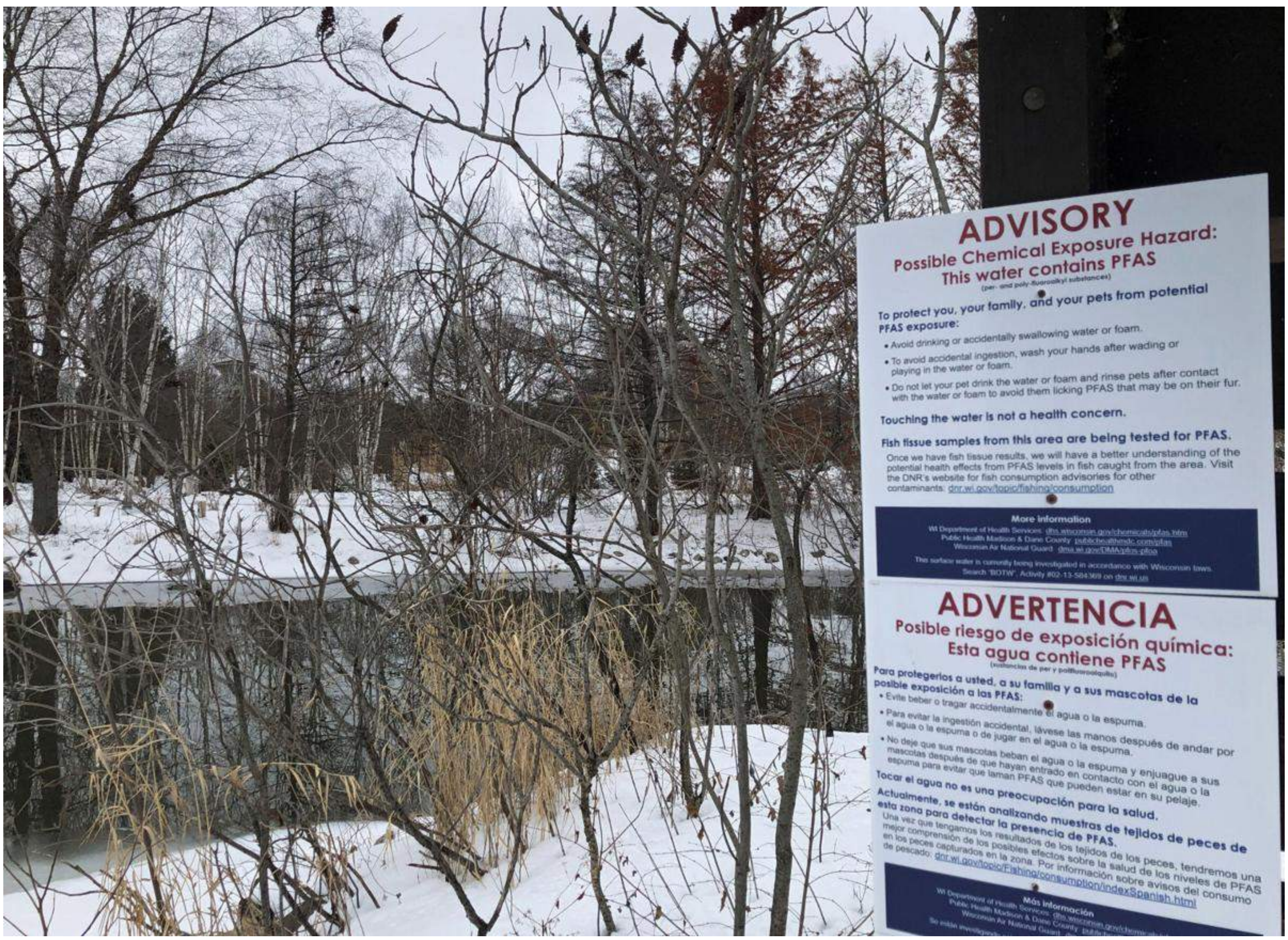
https://madison.com/wsj/news/local/environment/dnr-orders-new-plan-to-stop-spread-of-pfas-at-madison-airport-after-experimental-treatment/article_75265398-0636-5b66-b992-148ec1eba362.html

ALERT

POLLUTION | PFAS 'FOREVER CHEMICALS'

DNR orders new plan to stop spread of PFAS at Madison airport after experimental treatment fails

Chris Hubbuch | Wisconsin State Journal
Jan 27, 2021



Signs installed in 2019 by Public Health Madison & Dane County caution against consuming water from Starkweather Creek, which is contaminated with hazardous chemicals known as PFAS.

CHRIS HUBBUCH, STATE JOURNAL

Chris Hubbuch | Wisconsin State Journal

The Department of Natural Resources says an experimental technology has failed to keep so-called "forever chemicals" from the Madison airport out of Madison's lakes and streams, but county officials say they need more time to test it.

In May, after tests showed stormwater from the airport contained high levels of hazardous PFAS compounds, Dane County announced plans to test a system of booms and “bioavailable absorbent media” — also known as BAM — to treat water draining into Starkweather Creek.

In letters sent Thursday to city and county officials, the DNR said the treatment “has not proven to be successful in reducing PFAS concentrations” in water from the outfall.

The DNR has given the city and county until April 16 to come up with a new plan to keep PFAS from leaving the property.

Airport spokesman Michael Riechers provided a written statement saying “comprehensive results are not yet available,” for the project, but preliminary results are “promising.”

“However, as the process continues to be reengineered and refined, additional testing is required to determine its scalability and effectiveness in this particular environment,” Riechers said. “The cleanup technology being tested is working on other sites and may be a feasible solution at the airport.”

Riechers said the county and its partners continue to assess the feasibility of using the technology for interim mitigation and long-term remediation and have yet to spend all of the $15,760 set aside for the BAM treatment.

“This is a results-driven process and the technology is continually being refined to deliver more consistent results,” Riechers said. “As such, there isn’t a specific date by which we can confidently say results will be finalized.”

Little is known about the **experimental treatment** which, according to the manufacturer, Orin Technologies, uses a honeycomb-type substance made mostly of carbon and derived from “a proprietary blend of organic materials” to soak up and eliminate biodegradable compounds. The county hasn’t clarified how the technology works with PFAS, which don’t break down naturally.

Watch now: Midwest governors encourage residents to plan for vaccination

Governors and lieutenant governors from Illinois, Wisconsin, Indiana, Michigan, Kentucky, Minnesota and Ohio are encouraging residents to make a plan for how they can get the coronavirus vaccine once they become eligible.

No results have been posted to the DNR's online spills database.

Christine Haag, director of the DNR's remediation and redevelopment program, said the DNR's assessment of the technology was based on conversations with airport staff who are carrying out the tests.

"None of the data from the BAM technology has been submitted to DNR," Haag said.

Madison city council member Syed Abbas, whose district includes neighborhoods around the airport, said the county has not provided the council with information either.

"We did not receive any information about how it is working, how much it costs," Abbas said.

Dane County Supervisor Yogesh Chawla, who represents the district south of the airport where Starkweather Creek empties into Lake Monona, said he also has not received information about the test.

State officials last year **warned people to limit consumption of fish** from Lake Monona because of elevated levels of PFAS, which accumulates in the body and has been linked to cancer and other diseases.

Just last week the DNR reported that **PFAS have been found in all five of Madison's lakes** — with the highest levels found in those downstream from Starkweather Creek, which the agency said confirmed suspicions that the airport is the primary source of contamination.

The DNR is now testing fish from each of the lakes.

PFAS have been found **in groundwater beneath the airport** and in **stormwater draining into Starkweather Creek** at concentrations thousands of times higher than recommended health standards.

In June 2018, the DNR notified Dane County, the city of Madison and the Wisconsin Air National Guard that they share responsibility for the contamination at sites used for firefighter training between the 1950s and 1980s.

But so far the BAM pilot is the only cleanup effort undertaken, according to information posted to the DNR's spills database.

Dane County has **budgeted $200,000 this year** to address PFAS contamination at the airport, and has agreed to pay engineering firm Mead and Hunt up to $800,000 for remediation. The city council last year allocated $50,000 for PFAS "testing and planning" around the airport.

Riechers

Chris Hubbuch | Wisconsin State Journal

Covers energy and the environment for the Wisconsin State Journal. Rhymes with Lubbock. Contact him at 608-252-6146.

https://madison.com/ct/news/local/govt-and-politics/long-road-ahead-for-addressing-pfas-contamination-at-dane-county-airport/article_ef870b74-20d2-57ef-bad5-9231f3285075.html

ALERT

Long road ahead for addressing PFAS contamination at Dane County airport

Abigail Becker | The Capital Times
Jun 4, 2021

A view of Starkweather Creek from Milwaukee Street in Madison photographed in 2019. Dane County is working to improve storm water pipes that may be leaking or broken to address the movement of PFAS compounds from the airport via Starkweather Creek.

MICHELLE STOCKER

Abigail Becker | The Capital Times

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It could be another two to four years before Dane County has enough information to know how to address contamination at the airport caused by PFAS — a group of manmade chemicals that can exist in the environment for possibly centuries.

For years, firefighting efforts at Dane County Regional Airport and Truax Field on Madison's north side, which also houses the Wisconsin Air National Guard's 115th Fighter Wing, included using a substance that contained PFAS. The Federal Aviation Administration continues to require using this substance, citing its effectiveness. In 2018, the Department of Natural Resources found PFAS contamination in soils and groundwater underneath the guard's base.

Since then, Dane County, the city of Madison and the Wisconsin Air National Guard — all named by the Wisconsin Department of Natural Resources in 2019 as responsible for remediating contamination at the airport — have been dealing with the issue.

"Although there aren't quick answers here, it doesn't mean we're not making progress," Dane County assistant corporation counsel Amy Tutwiler said at a County Board committee of the whole meeting Thursday addressing PFAS remediation at the airport. "We are all committed to solving this problem for the community."

It's a tricky problem with the responsible parties working on various ongoing solutions.

Complicating the situation, the Air National Guard is **moving forward with construction** of a 19,000-square-foot, state-of-the-art F-35 flight simulator facility that requires demolishing a 4,600-square-foot facility on the base, disturbing the contaminated soil.

Also, the county's agreement with the Air National Guard for firefighting expired, which airport director Kim Jones said leaves the two "working under a handshake agreement" to provide these services.

Some question if the county can use this joint use agreement to force the Guard to clean up PFAS before building new structures. But Jones said that's not an option for this type of agreement, which details responsibilities for the joint facilities and their operations.

“Its intent is to address the airfield joint use; it is not to address environmental issues,” Jones said.

The DNR is working with the Guard on how its construction project can move forward and to regulate the management of contaminated soils through the project’s material management plans.

Col. Michael Hinman said 20% of the construction site contains PFAS, though the levels are below the DNR’s recommendations for appropriate levels. Currently, the Guard is looking to remediate the soil because the landfill won't accept it. The other costly option would be to ship the soil to a facility in Oregon.

“In the National Guard, we live in the community we serve and we share the community’s concern about any possible impacts on drinking water sources,” Lt. Col. Dan Statz, deputy commander of the 115th Mission Support Group, said.

Statz said the Air National Guard has “no intention” of discontinuing firefighting services at the airport. Also, he said the Guard plans to continue construction and soil remediation as regulators allow.

County Supervisor Yogesh Chawla, District 6, is concerned that more wells in the Madison area could be affected by PFAS. The city of **Madison shut down Well 15**, located near the airport, in March 2019 after discovering PFAS.

Madison’s **water utility recommended implementing conservation measures** to balance water supply on the east side and across the city given the continued closure of this well.

“We are already seeing real pressures on providing the drinking water that is needed for our community,” Chawla said in an interview.

He asked Tutwiler to provide a legal opinion on how the county could regulate activity at the airport using its storm water ordinances.

“The county needs to explore any and all authority that we have to keep our drinking water supply safe,” Chawla said. "To date, it has been disappointing that our elected officials haven’t taken these concerns more seriously.”

[***Dane County leans in to remote work for environmental benefits***]

Ongoing work

Last September, the Air National Guard Readiness Center chose Truax Field to receive a remedial investigation for PFAS. This effort, which is coordinated by the U.S. Army Corps of Engineers, involves collecting data to determine the extent of contamination and assess risk to human health and the environment.

This two- to four-year effort is the **third step in a federal process** established by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)— also known as Superfund — that oversees the cleanup of hazardous materials.

“That’s a huge milestone in the CERCLA process,” Statz said.

Next up: a feasibility study that will develop and evaluate possible remedies. This could take another four years, according to the guard.

While the remedial investigation will address former fire training areas on Darwin Road and Pearson Street, the DNR approved interim actions to reduce the movement of PFAS compounds from the airport via Starkweather Creek.

These actions include studying samples of Starkweather Creek to better understand the distribution and concentration of PFAS in the creek in areas within and just downstream of the airport boundary. Also, Dane County is working to improve storm water pipes that may be leaking or broken.

“The goal is to grout and basically tighten where contamination at highest levels is coming in, so we can prevent groundwater from infiltrating the system,” Tutwiler said, noting a goal of completing the work in the fall.

Dane County is also looking into technology that could potentially remove PFAS substances by capturing and containing them and working on reducing the discharge of PFAS coming from the storm water system into Starkweather Creek.

Tutwiler told the County Board there's many reasons to have confidence the situation is being handled effectively, professionally and transparently.

"We're not dealing with a situation that is out of control," Tutwiler said. "But it does take time."

To date, a public town hall on airport remediation that was delayed by the pandemic has not been rescheduled. Jones said she hopes to hold it before September. More **information can be found on the airport's website**.

This story has been updated to reflect that the Federal Aviation Administration mandates that airports use a firefighting agent containing PFAS.

*Share your opinion on this topic by sending a letter to the editor to **tctvoice@madison.com**. Include your full name, hometown and phone number. Your name and town will be published. The phone number is for verification purposes only. Please keep your letter to 250 words or less.*

Abigail Becker

Abigail Becker joined The Capital Times in 2016, where she primarily covers city and county government. She previously worked for the Wisconsin Center for Investigative Journalism and the Wisconsin State Journal.

Abigail Becker | The Capital Times

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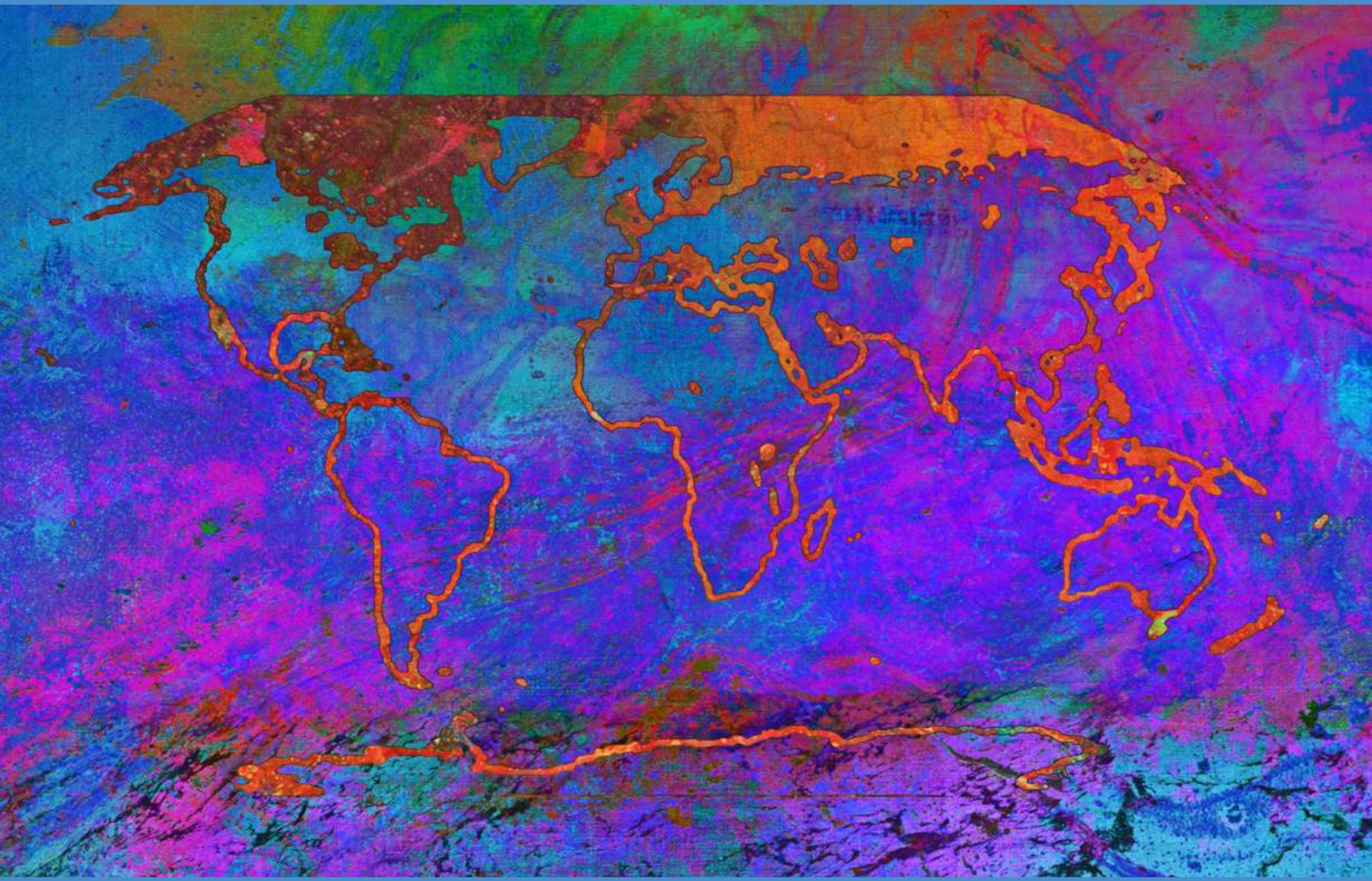
INTERGOVERNMENTAL PANEL ON climate change

Climate Change 2021

The Physical Science Basis

Summary for Policymakers



WGI

Working Group I contribution to the
Sixth Assessment Report of the
Intergovernmental Panel on Climate Change

WMO UNEP

Summary for Policymakers

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Introduction

This Summary for Policymakers (SPM) presents key findings of the Working Group I (WGI) contribution to the IPCC's Sixth Assessment Report (AR6)[1] on the physical science basis of climate change. The report builds upon the 2013 Working Group I contribution to the IPCC's Fifth Assessment Report (AR5) and the 2018–2019 IPCC Special Reports[2] of the AR6 cycle and incorporates subsequent new evidence from climate science[3].

This SPM provides a high-level summary of the understanding of the current state of the climate, including how it is changing and the role of human influence, the state of knowledge about possible climate futures, climate information relevant to regions and sectors, and limiting human-induced climate change.

Based on scientific understanding, key findings can be formulated as statements of fact or associated with an assessed level of confidence indicated using the IPCC calibrated language[4].

The scientific basis for each key finding is found in chapter sections of the main Report, and in the integrated synthesis presented in the Technical Summary (hereafter TS), and is indicated in curly brackets. The AR6 WGI Interactive Atlas facilitates exploration of these key synthesis findings, and supporting climate change information, across the WGI reference regions[5].

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[1] Decision IPCC/XLVI-2.

[2] The three Special reports are: Global warming of 1.5°C: an IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (SR1.5); Climate Change and Land: an IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL); IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC).

[3] The assessment covers scientific literature accepted for publication by 31 January 2021.

[4] Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: *virtually certain* 99–100% probability, *very likely* 90–100%, *likely* 66–100%, *about as likely as not* 33–66%, *unlikely* 0–33%, *very unlikely* 0–10%, *exceptionally unlikely* 0–1%. Additional terms (*extremely likely* 95–100%, *more likely than not* >50–100%, and *extremely unlikely* 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*. This is consistent with AR5. In this Report, unless stated otherwise, square brackets [x to y] are used to provide the assessed *very likely* range, or 90% interval.

[5] The Interactive Atlas is available at https://interactive-atlas.ipcc.ch

A. The Current State of the Climate

Since AR5, improvements in observationally based estimates and information from paleoclimate archives provide a comprehensive view of each component of the climate system and its changes to date. New climate model simulations, new analyses, and methods combining multiple lines of evidence lead to improved understanding of human influence on a wider range of climate variables, including weather and climate extremes. The time periods considered throughout this Section depend upon the availability of observational products, paleoclimate archives and peer-reviewed studies.

A.1 It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred.

{2.2, 2.3, Cross-Chapter Box 2.3, 3.3, 3.4, 3.5, 3.6, 3.8, 5.2, 5.3, 6.4, 7.3, 8.3, 9.2, 9.3, 9.5, 9.6, Cross-Chapter Box 9.1} **(Figure SPM.1, Figure SPM.2)**

A.1.1 Observed increases in well-mixed greenhouse gas (GHG) concentrations since around 1750 are unequivocally caused by human activities. Since 2011 (measurements reported in AR5), concentrations have continued to increase in the atmosphere, reaching annual averages of 410 ppm for carbon dioxide (CO_2), 1866 ppb for methane (CH_4), and 332 ppb for nitrous oxide (N_2O) in 2019[6]. Land and ocean have taken up a near-constant proportion (globally about 56% per year) of CO_2 emissions from human activities over the past six decades, with regional differences (*high confidence*)[7]. {2.2, 5.2, 7.3, TS.2.2, Box TS.5}

A.1.2 Each of the last four decades has been successively warmer than any decade that preceded it since 1850. Global surface temperature[8] in the first two decades of the 21st century (2001-2020) was 0.99 [0.84-1.10] °C higher than 1850-1900[9]. Global surface temperature was 1.09 [0.95 to 1.20] °C higher in 2011–2020 than 1850–1900, with larger increases over land (1.59 [1.34 to 1.83] °C) than over the ocean (0.88 [0.68 to 1.01] °C). The estimated increase in global surface temperature since AR5 is principally due to further warming since 2003–2012 (+0.19 [0.16 to 0.22] °C). Additionally, methodological advances and new datasets contributed approximately 0.1ºC to the updated estimate of warming in AR6[10].

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[6] Other GHG concentrations in 2019 were: PFCs (109 ppt CF_4 equivalent); SF_6 (10 ppt); NF_3 (2 ppt); HFCs (237 ppt HFC-134a equivalent); other Montreal Protocol gases (mainly CFCs, HCFCs, 1032 ppt CFC-12 equivalent). Increases from 2011 are 19 ppm for CO_2, 63 ppb for CH_4 and 8 ppb for N_2O.

[7] Land and ocean are not substantial sinks for other GHGs.

[8] The term 'global surface temperature' is used in reference to both global mean surface temperature and global surface air temperature throughout this SPM. Changes in these quantities are assessed with *high confidence* to differ by at most 10% from one another, but conflicting lines of evidence lead to *low confidence* in the sign of any difference in long-term trend. {Cross-Section Box TS.1}

[9] The period 1850–1900 represents the earliest period of sufficiently globally complete observations to estimate global surface temperature and, consistent with AR5 and SR1.5, is used as an approximation for pre-industrial conditions.

[10] Since AR5, methodological advances and new datasets have provided a more complete spatial representation of changes in surface temperature, including in the Arctic. These and other improvements have additionally increased the estimate of global surface temperature change by approximately 0.1 ºC, but this increase does not represent additional physical warming since the AR5.

A.1.3 The *likely* range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019[11] is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is *likely* that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by –0.1°C to 0.1°C, and internal variability changed it by –0.2°C to 0.2°C. It is *very likely* that well-mixed GHGs were the main driver[12] of tropospheric warming since 1979, and *extremely likely* that human-caused stratospheric ozone depletion was the main driver of cooling of the lower stratosphere between 1979 and the mid-1990s.
{3.3, 6.4, 7.3, Cross-Section Box TS.1, TS.2.3} **(Figure SPM.2)**

A.1.4 Globally averaged precipitation over land has *likely* increased since 1950, with a faster rate of increase since the 1980s (*medium confidence*). It is *likely* that human influence contributed to the pattern of observed precipitation changes since the mid-20th century, and *extremely likely* that human influence contributed to the pattern of observed changes in near-surface ocean salinity. Mid-latitude storm tracks have *likely* shifted poleward in both hemispheres since the 1980s, with marked seasonality in trends (*medium confidence*). For the Southern Hemisphere, human influence *very likely* contributed to the poleward shift of the closely related extratropical jet in austral summer.
{2.3, 3.3, 8.3, 9.2, TS.2.3, TS.2.4, Box TS.6}

A.1.5 Human influence is *very likely* the main driver of the global retreat of glaciers since the 1990s and the decrease in Arctic sea ice area between 1979–1988 and 2010–2019 (about 40% in September and about 10% in March). There has been no significant trend in Antarctic sea ice area from 1979 to 2020 due to regionally opposing trends and large internal variability. Human influence *very likely* contributed to the decrease in Northern Hemisphere spring snow cover since 1950. It is *very likely* that human influence has contributed to the observed surface melting of the Greenland Ice Sheet over the past two decades, but there is only *limited evidence*, with *medium agreement*, of human influence on the Antarctic Ice Sheet mass loss.
{2.3, 3.4, 8.3, 9.3, 9.5, TS.2.5}

A.1.6 It is *virtually certain* that the global upper ocean (0–700 m) has warmed since the 1970s and *extremely likely* that human influence is the main driver. It is *virtually certain* that human-caused CO_2 emissions are the main driver of current global acidification of the surface open ocean. There is *high confidence* that oxygen levels have dropped in many upper ocean regions since the mid-20th century, and *medium confidence* that human influence contributed to this drop.
{2.3, 3.5, 3.6, 5.3, 9.2, TS.2.4}

A.1.7 Global mean sea level increased by 0.20 [0.15 to 0.25] m between 1901 and 2018. The average rate of sea level rise was 1.3 [0.6 to 2.1] mm yr^{-1} between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm yr^{-1} between 1971 and 2006, and further increasing to 3.7 [3.2 to 4.2] mm yr^{-1} between 2006 and 2018 (*high confidence*). Human influence was *very likely* the main driver of these increases since at least 1971.
{2.3, 3.5, 9.6, Cross-Chapter Box 9.1, Box TS.4}

A.1.8 Changes in the land biosphere since 1970 are consistent with global warming: climate zones have shifted poleward in both hemispheres, and the growing season has on average lengthened by up to two days per decade since the 1950s in the Northern Hemisphere extratropics (*high confidence*).
{2.3, TS.2.6}

[11] The period distinction with A.1.2 arises because the attribution studies consider this slightly earlier period. The observed warming to 2010–2019 is 1.06 [0.88 to 1.21] °C.

[12] Throughout this SPM, 'main driver' means responsible for more than 50% of the change.

Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

Changes in global surface temperature relative to 1850-1900

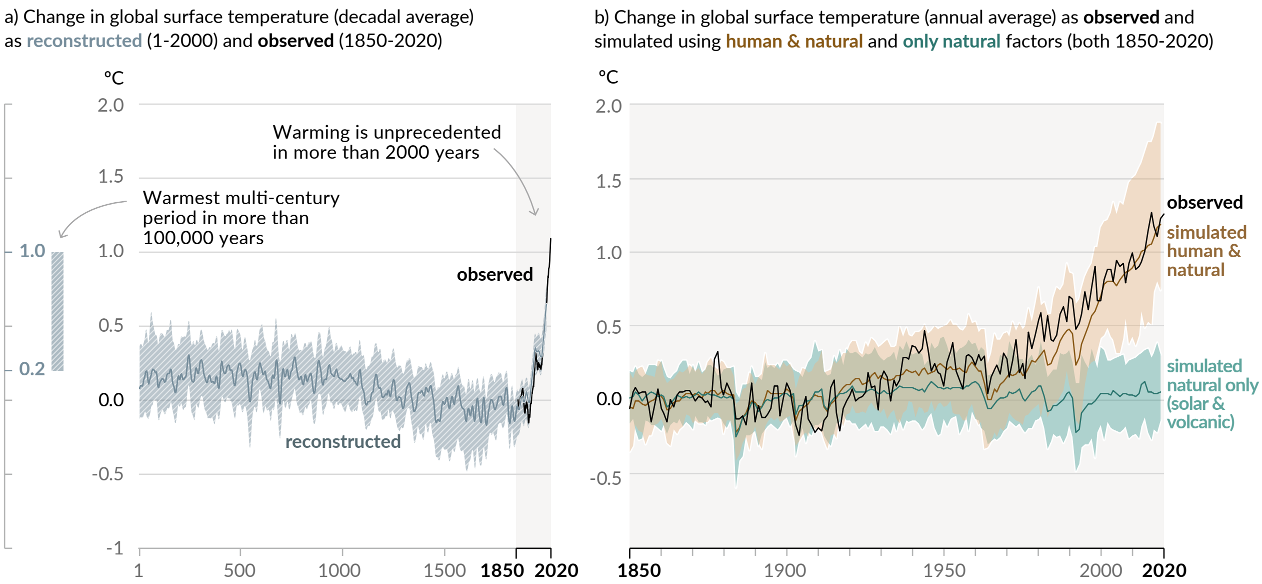


Figure SPM.1: History of global temperature change and causes of recent warming.

Panel a): Changes in global surface temperature reconstructed from paleoclimate archives (solid grey line, 1–2000) **and from direct observations** (solid black line, 1850–2020), both relative to 1850–1900 and decadally averaged. The vertical bar on the left shows the estimated temperature (*very likely* range) during the warmest multi-century period in at least the last 100,000 years, which occurred around 6500 years ago during the current interglacial period (Holocene). The Last Interglacial, around 125,000 years ago, is the next most recent candidate for a period of higher temperature. These past warm periods were caused by slow (multi-millennial) orbital variations. The grey shading with white diagonal lines shows the *very likely* ranges for the temperature reconstructions.

Panel b): Changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to CMIP6 climate model simulations (see Box SPM.1) of the temperature response to both human and natural drivers (brown), and to only natural drivers (solar and volcanic activity, green). Solid coloured lines show the multi-model average, and coloured shades show the *very likely* range of simulations. (see Figure SPM.2 for the assessed contributions to warming).

{2.3.1, 3.3, Cross-Chapter Box 2.3, Cross-Section Box TS.1, Figure 1a, TS.2.2}

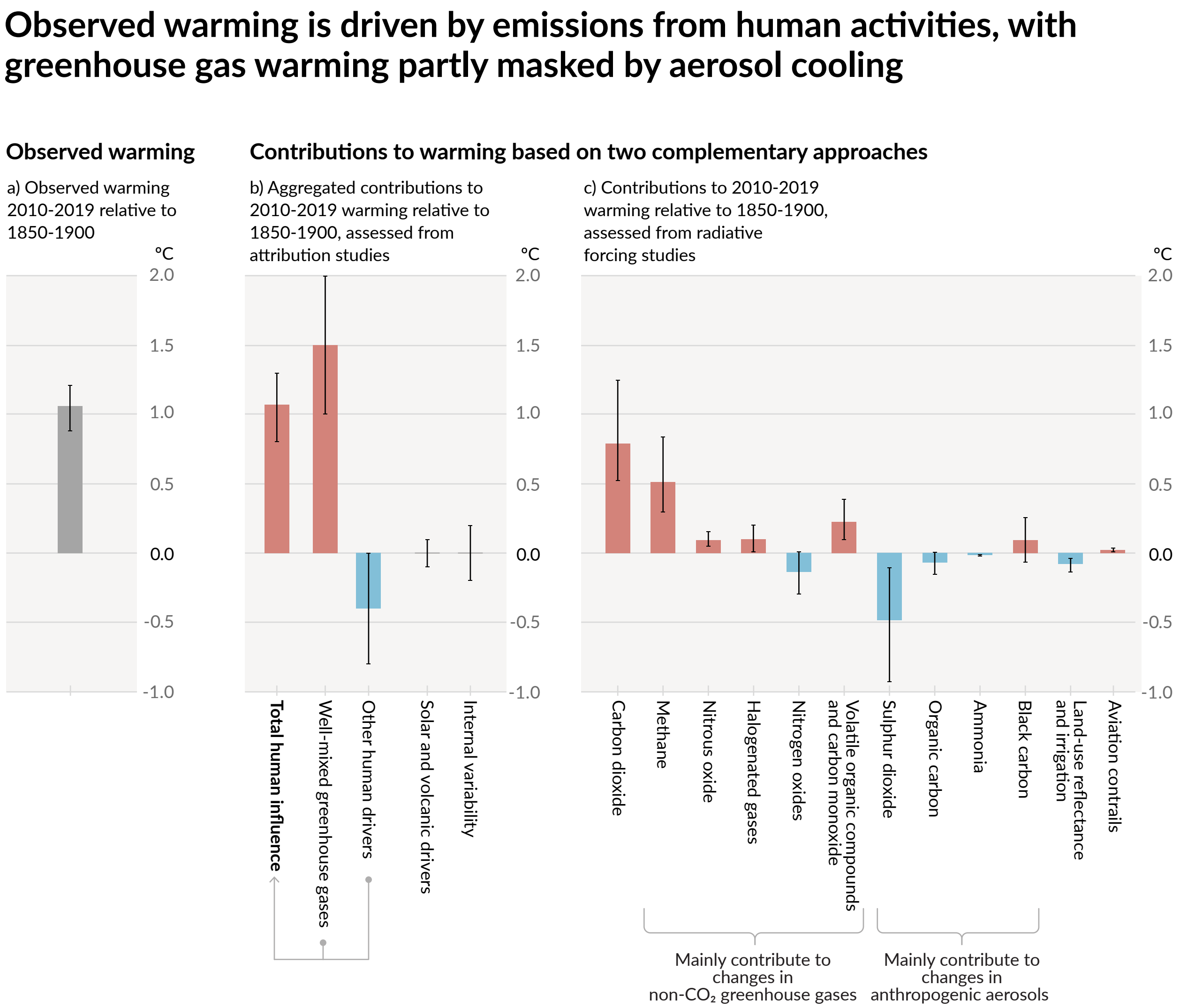


Figure SPM.2: Assessed contributions to observed warming in 2010–2019 relative to 1850–1900.

Panel a): Observed global warming (increase in global surface temperature) and its *very likely* range {3.3.1, Cross-Chapter Box 2.3}.

Panel b): Evidence from attribution studies, which synthesize information from climate models and observations. The panel shows temperature change attributed to total human influence, changes in well-mixed greenhouse gas concentrations, other human drivers due to aerosols, ozone and land-use change (land-use reflectance), solar and volcanic drivers, and internal climate variability. Whiskers show *likely* ranges {3.3.1}.

Panel c): Evidence from the assessment of radiative forcing and climate sensitivity. The panel shows temperature changes from individual components of human influence, including emissions of greenhouse gases, aerosols and their precursors; land-use changes (land-use reflectance and irrigation); and aviation contrails. Whiskers show *very likely* ranges. Estimates account for both direct emissions into the atmosphere and their effect, if any, on other climate drivers. For aerosols, both direct (through radiation) and indirect (through interactions with clouds) effects are considered.{6.4.2, 7.3}

A.2 The scale of recent changes across the climate system as a whole and the present state of many aspects of the climate system are unprecedented over many centuries to many thousands of years.

{Cross-Chapter Box 2.1, 2.2, 2.3, 5.1} **(Figure SPM.1)**

A.2.1 In 2019, atmospheric CO_2 concentrations were higher than at any time in at least 2 million years (*high confidence)*, and concentrations of CH_4 and N_2O were higher than at any time in at least 800,000 years (*very high confidence*). Since 1750, increases in CO_2 (47%) and CH_4 (156%) concentrations far exceed, and increases in N_2O (23%) are similar to, the natural multi-millennial changes between glacial and interglacial periods over at least the past 800,000 years (*very high confidence*).
{2.2, 5.1, TS.2.2}

A.2.2 Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2000 years (*high confidence*). Temperatures during the most recent decade (2011–2020) exceed those of the most recent multi-century warm period, around 6500 years ago[13] [0.2°C to 1°C relative to 1850–1900] (*medium confidence*). Prior to that, the next most recent warm period was about 125,000 years ago when the multi-century temperature [0.5°C to 1.5°C relative to 1850–1900] overlaps the observations of the most recent decade (*medium confidence*).
{Cross-Chapter Box 2.1, 2.3, Cross-Section Box TS.1} **(Figure SPM.1)**

A.2.3 In 2011–2020, annual average Arctic sea ice area reached its lowest level since at least 1850 (*high confidence*). Late summer Arctic sea ice area was smaller than at any time in at least the past 1000 years (*medium confidence*). The global nature of glacier retreat, with almost all of the world's glaciers retreating synchronously, since the 1950s is unprecedented in at least the last 2000 years (*medium confidence*).
{2.3, TS.2.5}

A.2.4 Global mean sea level has risen faster since 1900 than over any preceding century in at least the last 3000 years (*high confidence*). The global ocean has warmed faster over the past century than since the end of the last deglacial transition (around 11,000 years ago) (*medium confidence*). A long-term increase in surface open ocean pH occurred over the past 50 million years (*high confidence*), and surface open ocean pH as low as recent decades is unusual in the last 2 million years (*medium confidence*).
{2.3, TS.2.4, Box TS.4}

[13] As stated in section B.1, even under the very low emissions scenario SSP1-1.9, temperatures are assessed to remain elevated above those of the most recent decade until at least 2100 and therefore warmer than the century-scale period 6500 years ago.

A.3 Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5.
{2.3, 3.3, 8.2, 8.3, 8.4, 8.5, 8.6, Box 8.1, Box 8.2, Box 9.2, 10.6, 11.2, 11.3, 11.4, 11.6, 11.7, 11.8, 11.9, 12.3} **(Figure SPM.3)**

A.3.1 It is *virtually certain* that hot extremes (including heatwaves) have become more frequent and more intense across most land regions since the 1950s, while cold extremes (including cold waves) have become less frequent and less severe, with *high confidence* that human-induced climate change is the main driver[14] of these changes. Some recent hot extremes observed over the past decade would have been *extremely unlikely* to occur without human influence on the climate system. Marine heatwaves have approximately doubled in frequency since the 1980s (*high confidence*), and human influence has *very likely* contributed to most of them since at least 2006.
{Box 9.2, 11.2, 11.3, 11.9, TS.2.4, TS.2.6, Box TS.10} **(Figure SPM.3)**

A.3.2 The frequency and intensity of heavy precipitation events have increased since the 1950s over most land area for which observational data are sufficient for trend analysis (*high confidence*), and human-induced climate change is *likely* the main driver. Human-induced climate change has contributed to increases in agricultural and ecological droughts[15] in some regions due to increased land evapotranspiration[16] (*medium confidence*).
{8.2, 8.3, 11.4, 11.6, 11.9, TS.2.6, Box TS.10} **(Figure SPM.3)**

A.3.3 Decreases in global land monsoon precipitation[17] from the 1950s to the 1980s are partly attributed to human-caused Northern Hemisphere aerosol emissions, but increases since then have resulted from rising GHG concentrations and decadal to multi-decadal internal variability (*medium confidence*). Over South Asia, East Asia and West Africa increases in monsoon precipitation due to warming from GHG emissions were counteracted by decreases in monsoon precipitation due to cooling from human-caused aerosol emissions over the 20th century (*high confidence*). Increases in West African monsoon precipitation since the 1980s are partly due to the growing influence of GHGs and reductions in the cooling effect of human-caused aerosol emissions over Europe and North America (*medium confidence*).
{2.3, 3.3, 8.2, 8.3, 8.4, 8.5, 8.6, Box 8.1, Box 8.2, 10.6, Box TS.13}

[14] Throughout this SPM, 'main driver' means responsible for more than 50% of the change.

[15] Agricultural and ecological drought (depending on the affected biome): a period with abnormal soil moisture deficit, which results from combined shortage of precipitation and excess evapotranspiration, and during the growing season impinges on crop production or ecosystem function in general. Observed changes in meteorological droughts (precipitation deficits) and hydrological droughts (streamflow deficits) are distinct from those in agricultural and ecological droughts and addressed in the underlying AR6 material (Chapter 11).

[16] The combined processes through which water is transferred to the atmosphere from open water and ice surfaces, bare soil, and vegetation that make up the Earth's surface.

[17] The global monsoon is defined as the area in which the annual range (local summer minus local winter) of precipitation is greater than 2.5 mm day^{-1}. Global land monsoon precipitation refers to the mean precipitation over land areas within the global monsoon.

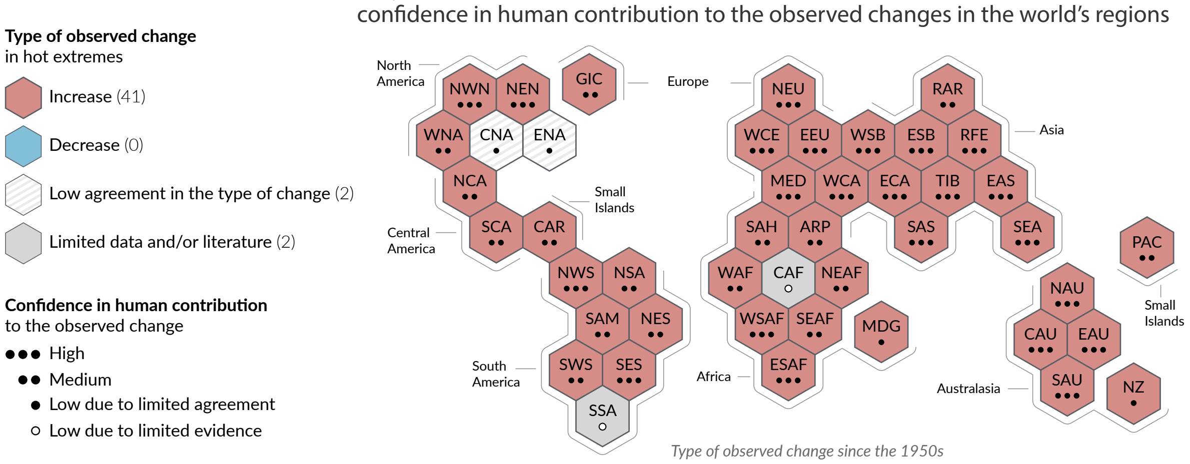
A.3.4 It is *likely* that the global proportion of major (Category 3–5) tropical cyclone occurrence has increased over the last four decades, and the latitude where tropical cyclones in the western North Pacific reach their peak intensity has shifted northward; these changes cannot be explained by internal variability alone (*medium confidence*). There is *low confidence* in long-term (multi-decadal to centennial) trends in the frequency of all-category tropical cyclones. Event attribution studies and physical understanding indicate that human-induced climate change increases heavy precipitation associated with tropical cyclones (*high confidence*) but data limitations inhibit clear detection of past trends on the global scale. {8.2, 11.7, Box TS.10}

A.3.5 Human influence has *likely* increased the chance of compound extreme events[18] since the 1950s. This includes increases in the frequency of concurrent heatwaves and droughts on the global scale (*high confidence*); fire weather in some regions of all inhabited continents (*medium confidence*); and compound flooding in some locations (*medium confidence*). {11.6, 11.7, 11.8, 12.3, 12.4, TS.2.6, Table TS.5, Box TS.10}

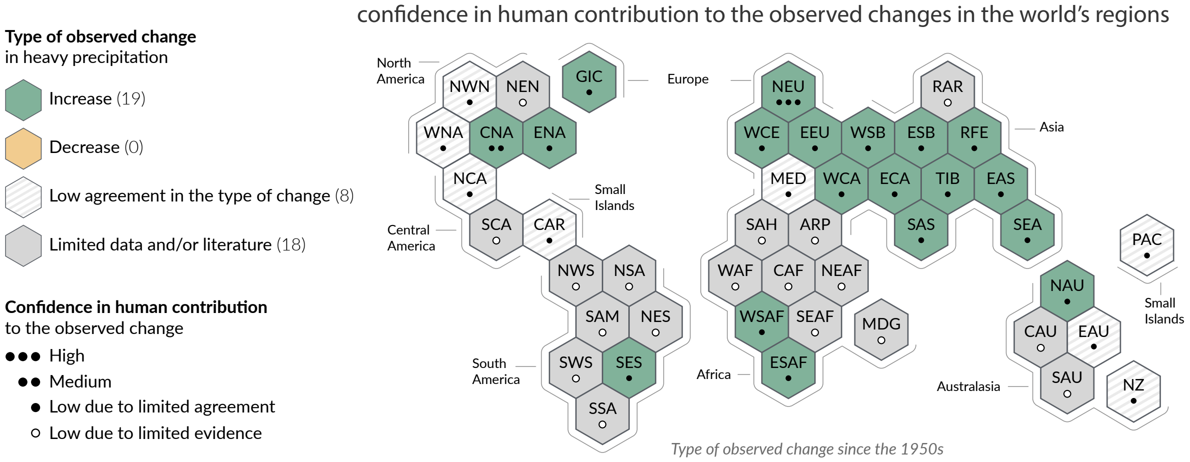
[18] Compound extreme events are the combination of multiple drivers and/or hazards that contribute to societal or environmental risk. Examples are concurrent heatwaves and droughts, compound flooding (e.g., a storm surge in combination with extreme rainfall and/or river flow), compound fire weather conditions (i.e., a combination of hot, dry, and windy conditions), or concurrent extremes at different locations.

Climate change is already affecting every inhabited region across the globe with human influence contributing to many observed changes in weather and climate extremes

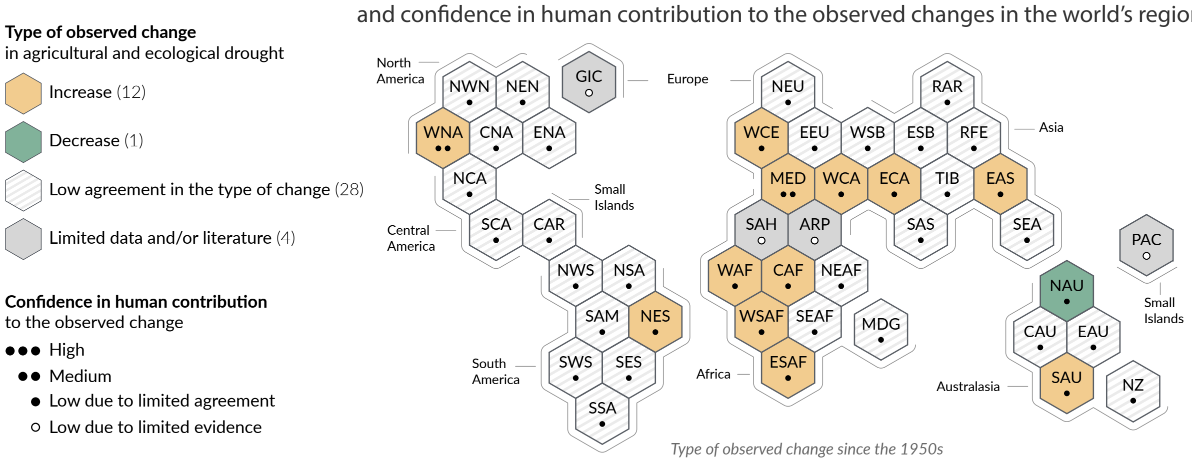
a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions



b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions



c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions



Each hexagon corresponds to one of the IPCC AR6 WGI reference regions

NWN *North-Western North America*

IPCC AR6 WGI reference regions: **North America: *NWN*** *(North-Western North America,* ***NEN*** *(North-Eastern North America),* ***WNA*** *(Western North America),* ***CNA*** *(Central North America),* ***ENA*** *(Eastern North America),* **Central America: *NCA*** *(Northern Central America),* ***SCA*** *(Southern Central America),* ***CAR*** *(Caribbean),* **South America: *NWS*** *(North-Western South America),* ***NSA*** *(Northern South America),* ***NES*** *(North-Eastern South America),* ***SAM*** *(South American Monsoon),* ***SWS*** *(South-Western South America),* ***SES*** *(South-Eastern South America),* ***SSA*** *(Southern South America),* **Europe: *GIC*** *(Greenland/Iceland),* ***NEU*** *(Northern Europe),* ***WCE*** *(Western and Central Europe),* ***EEU*** *(Eastern Europe),* ***MED*** *(Mediterranean),* **Africa: *MED*** *(Mediterranean),* ***SAH*** *(Sahara),* ***WAF*** *(Western Africa),* ***CAF*** *(Central Africa),* ***NEAF*** *(North Eastern Africa),* ***SEAF*** *(South Eastern Africa),* ***WSAF*** *(West Southern Africa),* ***ESAF*** *(East Southern Africa),* ***MDG*** *(Madagascar),* **Asia: *RAR*** *(Russian Arctic),* ***WSB*** *(West Siberia),* ***ESB*** *(East Siberia),* ***RFE*** *(Russian Far East),* ***WCA*** *(West Central Asia),* ***ECA*** *(East Central Asia),* ***TIB*** *(Tibetan Plateau),* ***EAS*** *(East Asia),* ***ARP*** *(Arabian Peninsula),* ***SAS*** *(South Asia),* ***SEA*** *(South East Asia),* **Australasia: *NAU*** *(Northern Australia),* ***CAU*** *(Central Australia),* ***EAU*** *(Eastern Australia),* ***SAU*** *(Southern Australia),* ***NZ*** *(New Zealand),* **Small Islands: *CAR*** *(Caribbean),* ***PAC*** *(Pacific Small Islands)*

Figure SPM.3: Synthesis of assessed observed and attributable regional changes.

The IPCC AR6 WGI inhabited regions are displayed as **hexagons** with identical size in their approximate geographical location (see legend for regional acronyms). All assessments are made for each region as a whole and for the 1950s to the present. Assessments made on different time scales or more local spatial scales might differ from what is shown in the figure. The **colours** in each panel represent the four outcomes of the assessment on observed changes. White and light grey striped hexagons are used where there is *low agreement* in the type of change for the region as a whole, and grey hexagons are used when there is limited data and/or literature that prevents an assessment of the region as a whole. Other colours indicate at least *medium confidence* in the observed change. The **confidence level** for the human influence on these observed changes is based on assessing trend detection and attribution and event attribution literature, and it is indicated by the number of dots: three dots for *high confidence*, two dots for *medium confidence* and one dot for *low confidence* (filled: limited agreement; empty: limited evidence).

Panel a) For hot extremes, the evidence is mostly drawn from changes in metrics based on daily maximum temperatures; regional studies using other indices (heatwave duration, frequency and intensity) are used in addition. Red hexagons indicate regions where there is at least *medium confidence* in an observed increase in hot extremes.

Panel b) For heavy precipitation, the evidence is mostly drawn from changes in indices based on one-day or five-day precipitation amounts using global and regional studies. Green hexagons indicate regions where there is at least *medium confidence* in an observed increase in heavy precipitation.

Panel c) Agricultural and ecological droughts are assessed based on observed and simulated changes in total column soil moisture, complemented by evidence on changes in surface soil moisture, water balance (precipitation minus evapotranspiration) and indices driven by precipitation and atmospheric evaporative demand. Yellow hexagons indicate regions where there is at least *medium confidence* in an observed increase in this type of drought and green hexagons indicate regions where there is at least *medium confidence* in an observed decrease in agricultural and ecological drought.

For all regions, table TS.5 shows a broader range of observed changes besides the ones shown in this figure. Note that SSA is the only region that does not display observed changes in the metrics shown in this figure, but is affected by observed increases in mean temperature, decreases in frost, and increases in marine heatwaves.

{11.9, Table TS.5, Box TS.10, Figure 1, Atlas 1.3.3, Figure Atlas.2}

A.4 Improved knowledge of climate processes, paleoclimate evidence and the response of the climate system to increasing radiative forcing gives a best estimate of equilibrium climate sensitivity of 3°C with a narrower range compared to AR5. {2.2, 7.3, 7.4, 7.5, Box 7.2, Cross-Chapter Box 9.1, 9.4, 9.5, 9.6}

A.4.1 Human-caused radiative forcing of 2.72 [1.96 to 3.48] W m^{-2} in 2019 relative to 1750 has warmed the climate system. This warming is mainly due to increased GHG concentrations, partly reduced by cooling due to increased aerosol concentrations. The radiative forcing has increased by 0.43 W m^{-2} (19%) relative to AR5, of which 0.34 W m^{-2} is due to the increase in GHG concentrations since 2011. The remainder is due to improved scientific understanding and changes in the assessment of aerosol forcing, which include decreases in concentration and improvement in its calculation (*high confidence*).
{2.2, 7.3, TS.2.2, TS.3.1}

A.4.2 Human-caused net positive radiative forcing causes an accumulation of additional energy (heating) in the climate system, partly reduced by increased energy loss to space in response to surface warming. The observed average rate of heating of the climate system increased from 0.50 [0.32 to 0.69] W m^{-2} for the period 1971–2006[19], to 0.79 [0.52 to 1.06] W m^{-2} for the period 2006–2018[20] (*high confidence*). Ocean warming accounted for 91% of the heating in the climate system, with land warming, ice loss and atmospheric warming accounting for about 5%, 3% and 1%, respectively (*high confidence*).
{7.2, Box 7.2, TS.3.1}

A.4.3 Heating of the climate system has caused global mean sea level rise through ice loss on land and thermal expansion from ocean warming. Thermal expansion explained 50% of sea level rise during 1971–2018, while ice loss from glaciers contributed 22%, ice sheets 20% and changes in land water storage 8%. The rate of ice sheet loss increased by a factor of four between 1992–1999 and 2010–2019. Together, ice sheet and glacier mass loss were the dominant contributors to global mean sea level rise during 2006-2018. (*high confidence*)
{Cross-Chapter Box 9.1, 9.4, 9.5, 9.6}

A.4.4 The equilibrium climate sensitivity is an important quantity used to estimate how the climate responds to radiative forcing. Based on multiple lines of evidence[21], the *very likely* range of equilibrium climate sensitivity is between 2°C (*high confidence*) and 5°C (*medium confidence*). The AR6 assessed best estimate is 3°C with a *likely* range of 2.5°C to 4°C (*high confidence*), compared to 1.5°C to 4.5°C in AR5, which did not provide a best estimate.
{7.4, 7.5, TS.3.2}

[19] cumulative energy increase of 282 [177 to 387] ZJ over 1971–2006 (1 ZJ = 10^{21} J).

[20] cumulative energy increase of 152 [100 to 205] ZJ over 2006–2018.

[21] Understanding of climate processes, the instrumental record, paleoclimates and model-based emergent constraints (see glossary).

B. Possible Climate Futures

A set of five new illustrative emissions scenarios is considered consistently across this report to explore the climate response to a broader range of greenhouse gas (GHG), land use and air pollutant futures than assessed in AR5. This set of scenarios drives climate model projections of changes in the climate system. These projections account for solar activity and background forcing from volcanoes. Results over the 21st century are provided for the near-term (2021–2040), mid-term (2041–2060) and long-term (2081–2100) relative to 1850–1900, unless otherwise stated.

Box SPM.1: Scenarios, Climate Models and Projections

Box SPM.1.1: This report assesses the climate response to five illustrative scenarios that cover the range of possible future development of anthropogenic drivers of climate change found in the literature. They start in 2015, and include scenarios[22] with high and very high GHG emissions (SSP3-7.0 and SSP5-8.5) and CO_2 emissions that roughly double from current levels by 2100 and 2050, respectively, scenarios with intermediate GHG emissions (SSP2-4.5) and CO_2 emissions remaining around current levels until the middle of the century, and scenarios with very low and low GHG emissions and CO_2 emissions declining to net zero around or after 2050, followed by varying levels of net negative CO_2 emissions[23] (SSP1-1.9 and SSP1-2.6) as illustrated in Figure SPM.4. Emissions vary between scenarios depending on socio-economic assumptions, levels of climate change mitigation and, for aerosols and non-methane ozone precursors, air pollution controls. Alternative assumptions may result in similar emissions and climate responses, but the socio-economic assumptions and the feasibility or likelihood of individual scenarios is not part of the assessment.
{TS.1.3, 1.6, Cross-Chapter Box 1.4} **(Figure SPM.4)**

Box SPM.1.2: This report assesses results from climate models participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6) of the World Climate Research Programme. These models include new and better representation of physical, chemical and biological processes, as well as higher resolution, compared to climate models considered in previous IPCC assessment reports. This has improved the simulation of the recent mean state of most large-scale indicators of climate change and many other aspects across the climate system. Some differences from observations remain, for example in regional precipitation patterns. The CMIP6 historical simulations assessed in this report have an ensemble mean global surface temperature change within 0.2°C of the observations over most of the historical period, and observed warming is within the *very likely* range of the CMIP6 ensemble. However, some CMIP6 models simulate a warming that is either above or below the assessed *very likely* range of observed warming.
{1.5, Cross-Chapter Box 2.2, 3.3, 3.8, TS.1.2, Cross-Section Box TS.1} (Figure SPM.1 b, Figure SPM.2)

Box SPM.1.3: The CMIP6 models considered in this Report have a wider range of climate sensitivity than in CMIP5 models and the AR6 assessed *very likely* range, which is based on multiple lines of evidence. These CMIP6 models also show a higher average climate sensitivity than CMIP5 and the AR6 assessed best estimate. The higher CMIP6 climate sensitivity values compared to CMIP5 can be traced to an amplifying cloud feedback that is larger in CMIP6 by about 20%.
{Box 7.1, 7.3, 7.4, 7.5, TS.3.2}

Box SPM.1.4: For the first time in an IPCC report, assessed future changes in global surface temperature, ocean warming and sea level are constructed by combining multi-model projections with observational constraints based on past simulated warming, as well as the AR6 assessment of climate sensitivity. For other quantities, such robust methods do not yet exist to constrain the projections. Nevertheless, robust projected

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[22] Throughout this report, the five illustrative scenarios are referred to as SSPx-y, where 'SSPx' refers to the Shared Socio-economic Pathway or 'SSP' describing the socio-economic trends underlying the scenario, and 'y' refers to the approximate level of radiative forcing (in W m^{-2}) resulting from the scenario in the year 2100. A detailed comparison to scenarios used in earlier IPCC reports is provided in Section TS1.3 and 1.6 and 4.6. The SSPs that underlie the specific forcing scenarios used to drive climate models are not assessed by WGI. Rather, the SSPx-y labelling ensures traceability to the underlying literature in which specific forcing pathways are used as input to the climate models. IPCC is neutral with regard to the assumptions underlying the SSPs, which do not cover all possible scenarios. Alternative scenarios may be considered or developed.

[23] Net negative CO_2 emissions are reached when anthropogenic removals of CO_2 exceed anthropogenic emissions. {Glossary}

geographical patterns of many variables can be identified at a given level of global warming, common to all scenarios considered and independent of timing when the global warming level is reached. {1.6, Box 4.1, 4.3, 4.6, 7.5, 9.2, 9.6, Cross-Chapter Box 11.1, Cross-Section Box TS.1}

Future emissions cause future additional warming, with total warming dominated by past and future CO_2 emissions

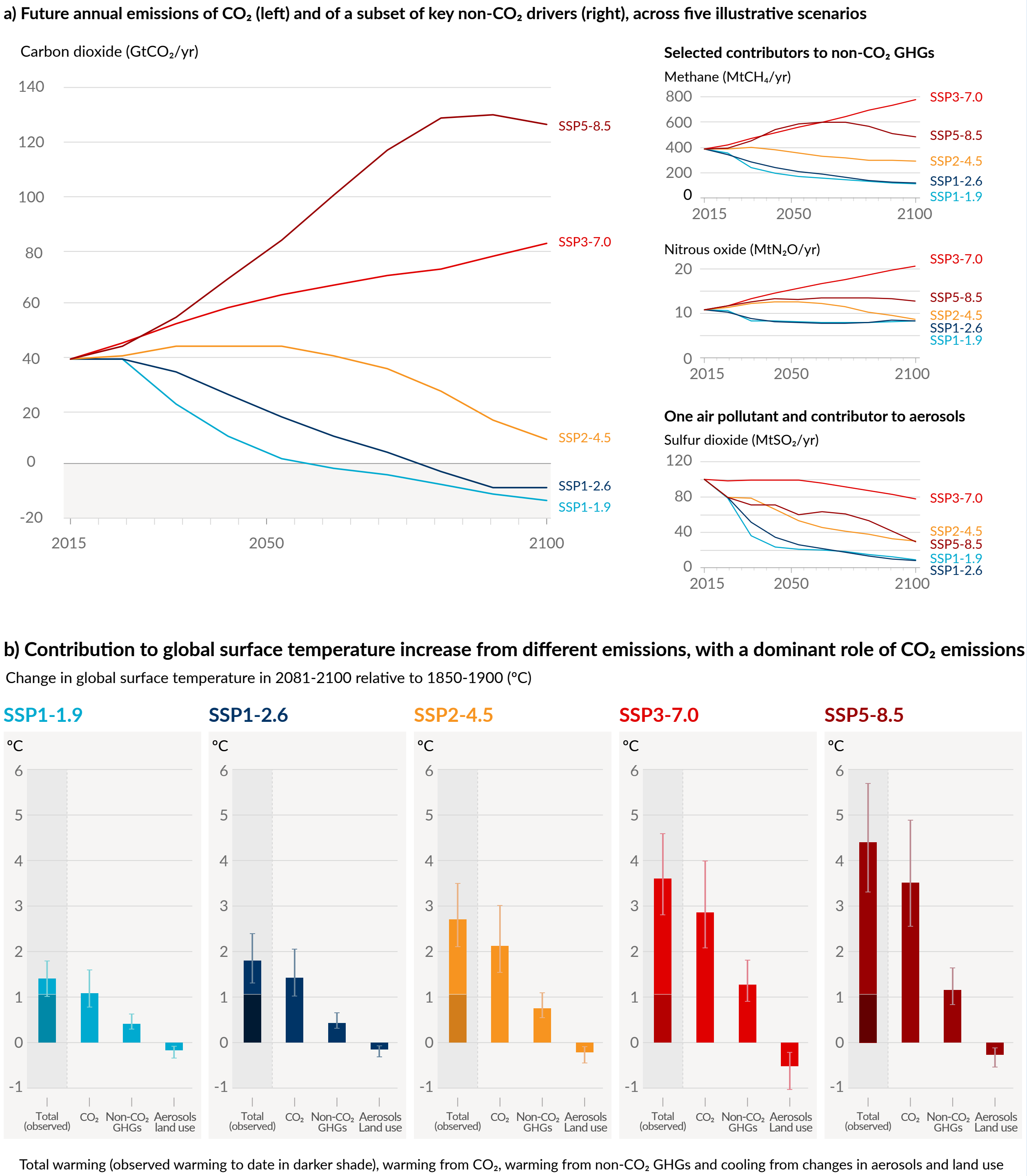


Figure SPM.4: Future anthropogenic emissions of key drivers of climate change and warming contributions by groups of drivers for the five illustrative scenarios used in this report.

The five scenarios are SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5.

Panel a) Annual anthropogenic (human-caused) emissions over the 2015–2100 period. Shown are emissions trajectories for carbon dioxide (CO_2) from all sectors ($GtCO_2$/yr) (left graph) and for a subset of three key non-CO_2 drivers considered in the scenarios: methane (CH_4, $MtCH_4$/yr, top-right graph), nitrous oxide (N_2O, MtN_2O/yr, middle-right graph) and sulfur dioxide (SO_2, $MtSO_2$/yr, bottom-right graph, contributing to anthropogenic aerosols in panel b).

Panel b) Warming contributions by groups of anthropogenic drivers and by scenario are shown as change in global surface temperature (°C) in 2081–2100 relative to 1850–1900, with indication of the observed warming to date. Bars and whiskers represent median values and the *very likely* range, respectively. Within each scenario bar plot, the bars represent total global warming (°C; total bar) (see Table SPM.1) and warming contributions (°C) from changes in CO_2 (CO_2 bar), from non-CO_2 greenhouse gases (non-CO_2 GHGs bar; comprising well-mixed greenhouse gases and ozone) and net cooling from other anthropogenic drivers (aerosols and land-use bar; anthropogenic aerosols, changes in reflectance due to land-use and irrigation changes, and contrails from aviation; see Figure SPM.2, panel c, for the warming contributions to date for individual drivers). The best estimate for observed warming in 2010–2019 relative to 1850–1900 (see Figure SPM.2, panel a) is indicated in the darker column in the total bar. Warming contributions in panel b are calculated as explained in Table SPM.1 for the total bar. For the other bars the contribution by groups of drivers are calculated with a physical climate emulator of global surface temperature which relies on climate sensitivity and radiative forcing assessments.

{Cross-Chapter Box 1.4, 4.6, Figure 4.35, 6.7, Figure 6.18, 6.22 and 6.24, Cross-Chapter Box 7.1, 7.3, Figure 7.7, Box TS.7, Figures TS.4 and TS.15}

B.1 Global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades.

{2.3, Cross-Chapter Box 2.3, Cross-Chapter Box 2.4, 4.3, 4.4, 4.5} **(Figure SPM.1, Figure SPM.4, Figure SPM.8, Table SPM.1, Box SPM.1)**

B.1.1 Compared to 1850–1900, global surface temperature averaged over 2081–2100 is *very likely* to be higher by 1.0°C to 1.8°C under the very low GHG emissions scenario considered (SSP1-1.9), by 2.1°C to 3.5°C in the intermediate scenario (SSP2-4.5) and by 3.3°C to 5.7°C under the very high GHG emissions scenario (SSP5-8.5)[24]. The last time global surface temperature was sustained at or above 2.5°C higher than 1850–1900 was over 3 million years ago (*medium confidence*).
{2.3, Cross-Chapter Box 2.4, 4.3, 4.5, Box TS.2, Box TS.4, Cross-Section Box TS.1} **(Table SPM.1)**

Table SPM.1: Changes in global surface temperature, which are assessed based on multiple lines of evidence, for selected 20-year time periods and the five illustrative emissions scenarios considered. Temperature differences relative to the average global surface temperature of the period 1850–1900 are reported in °C. This includes the revised assessment of observed historical warming for the AR5 reference period 1986–2005, which in AR6 is higher by 0.08 [–0.01 to 0.12] °C than in the AR5 (see footnote 10). Changes relative to the recent reference period 1995–2014 may be calculated approximately by subtracting 0.85°C, the best estimate of the observed warming from 1850–1900 to 1995–2014. {Cross-Chapter Box 2.3, 4.3, 4.4, Cross-Section Box TS.1}

[24] Changes in global surface temperature are reported as running 20-year averages, unless stated otherwise.

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

B.1.2 Based on the assessment of multiple lines of evidence, global warming of 2°C, relative to 1850–1900, would be exceeded during the 21st century under the high and very high GHG emissions scenarios considered in this report (SSP3-7.0 and SSP5-8.5, respectively). Global warming of 2°C would *extremely likely* be exceeded in the intermediate scenario (SSP2-4.5). Under the very low and low GHG emissions scenarios, global warming of 2°C is *extremely unlikely* to be exceeded (SSP1-1.9), or *unlikely* to be exceeded (SSP1-2.6)[25]. Crossing the 2°C global warming level in the mid-term period (2041–2060) is *very likely* to occur under the very high GHG emissions scenario (SSP5-8.5), *likely* to occur under the high GHG emissions scenario (SSP3-7.0), and *more likely than not* to occur in the intermediate GHG emissions scenario (SSP2-4.5)[26].
{4.3, Cross-Section Box TS.1} **(Table SPM.1, Figure SPM.4, Box SPM.1)**

B.1.3 Global warming of 1.5°C relative to 1850-1900 would be exceeded during the 21st century under the intermediate, high and very high scenarios considered in this report (SSP2-4.5, SSP3-7.0 and SSP5-8.5, respectively). Under the five illustrative scenarios, in the near term (2021-2040), the 1.5°C global warming level is *very likely* to be exceeded under the very high GHG emissions scenario (SSP5-8.5), *likely* to be exceeded under the intermediate and high GHG emissions scenarios (SSP2-4.5 and SSP3-7.0), *more likely than not* to be exceeded under the low GHG emissions scenario (SSP1-2.6) and *more likely than not* to be reached under the very low GHG emissions scenario (SSP1-1.9)[27]. Furthermore, for the very low GHG emissions scenario (SSP1-1.9), it is *more likely than not* that global surface temperature would decline back to below 1.5°C toward the end of the 21st century, with a temporary overshoot of no more than 0.1°C above 1.5°C global warming.
{4.3, Cross-Section Box TS.1} **(Table SPM.1, Figure SPM.4)**

[25] SSP1-1.9 and SSP1-2.6 are scenarios that start in 2015 and have very low and low GHG emissions and CO_2 emissions declining to net zero around or after 2050, followed by varying levels of net negative CO_2 emissions.

[26] Crossing is defined here as having the assessed global surface temperature change, averaged over a 20-year period, exceed a particular global warming level.

[27] The AR6 assessment of when a given global warming level is first exceeded benefits from the consideration of the illustrative scenarios, the multiple lines of evidence entering the assessment of future global surface temperature response to radiative forcing, and the improved estimate of historical warming. The AR6 assessment is thus not directly comparable to the SR1.5 SPM, which reported likely reaching 1.5°C global warming between 2030 and 2052, from a simple linear extrapolation of warming rates of the recent past. When considering scenarios similar to SSP1-1.9 instead of linear extrapolation, the SR1.5 estimate of when 1.5°C global

B.1.4 Global surface temperature in any single year can vary above or below the long-term human-induced trend, due to substantial natural variability[28]. The occurrence of individual years with global surface temperature change above a certain level, for example 1.5°C or 2ºC, relative to 1850–1900 does not imply that this global warming level has been reached[29].
{Cross-Chapter Box 2.3, 4.3, 4.4, Box 4.1, Cross-Section Box TS.1} **(Table SPM.1, Figure SPM.1, Figure SPM.8)**

B.2 Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, and heavy precipitation, agricultural and ecological droughts in some regions, and proportion of intense tropical cyclones, as well as reductions in Arctic sea ice, snow cover and permafrost. {4.3, 4.5, 4.6, 7.4, 8.2, 8.4, Box 8.2, 9.3, 9.5, Box 9.2, 11.1, 11.2, 11.3, 11.4, 11.6, 11.7, 11.9, Cross-Chapter Box 11.1, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11} **(Figure SPM.5, Figure SPM.6, Figure SPM.8)**

B.2.1 It is *virtually certain* that the land surface will continue to warm more than the ocean surface (*likely* 1.4 to 1.7 times more). It is *virtually certain* that the Arctic will continue to warm more than global surface temperature, with *high confidence* above two times the rate of global warming.
{2.3, 4.3, 4.5, 4.6, 7.4, 11.1, 11.3, 11.9, 12.4, 12.5, Cross-Chapter Box 12.1, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Section Box TS.1, TS.2.6} **(Figure SPM.5)**

B.2.2 With every additional increment of global warming, changes in extremes continue to become larger. For example, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves (*very likely*), and heavy precipitation (*high confidence*), as well as agricultural and ecological droughts[30] in some regions (*high confidence*). Discernible changes in intensity and frequency of meteorological droughts, with more regions showing increases than decreases, are seen in some regions for every additional 0.5°C of global warming (*medium confidence*). Increases in frequency and intensity of hydrological droughts become larger with increasing global warming in some regions (*medium confidence*). There will be an increasing occurrence of some extreme events unprecedented in the observational record with additional global warming, even at 1.5°C of global warming. Projected percentage changes in frequency are higher for rarer events (*high confidence*).
{8.2, 11.2, 11.3, 11.4, 11.6, 11.9, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1, TS.2.6} **(Figure SPM.5, Figure SPM.6)**

warming is first exceeded is close to the best estimate reported here.

[28] Natural variability refers to climatic fluctuations that occur without any human influence, that is, internal variability combined with the response to external natural factors such as volcanic eruptions, changes in solar activity and, on longer time scales, orbital effects and plate tectonics.

[29] The internal variability in any single year is estimated to be ± 0.25°C (5–95% range, *high confidence*).

[30] Projected changes in agricultural and ecological droughts are primarily assessed based on total column soil moisture. See footnote 15 for definition and relation to precipitation and evapotranspiration.

B.2.3 Some mid-latitude and semi-arid regions, and the South American Monsoon region, are projected to see the highest increase in the temperature of the hottest days, at about 1.5 to 2 times the rate of global warming (*high confidence*). The Arctic is projected to experience the highest increase in the temperature of the coldest days, at about 3 times the rate of global warming (*high confidence*). With additional global warming, the frequency of marine heatwaves will continue to increase (*high confidence*), particularly in the tropical ocean and the Arctic *(medium confidence)*.
{Box 9.2, 11.1, 11.3, 11.9, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1, 12.4, TS.2.4, TS.2.6} **(Figure SPM.6)**

B.2.4 It is *very likely* that heavy precipitation events will intensify and become more frequent in most regions with additional global warming. At the global scale, extreme daily precipitation events are projected to intensify by about 7% for each 1°C of global warming (*high confidence*). The proportion of intense tropical cyclones (categories 4-5) and peak wind speeds of the most intense tropical cyclones are projected to increase at the global scale with increasing global warming (*high confidence*).
{8.2, 11.4, 11.7, 11.9, Cross-Chapter Box 11.1, Box TS.6, TS.4.3.1} **(Figure SPM.5, Figure SPM.6)**

B.2.5 Additional warming is projected to further amplify permafrost thawing, and loss of seasonal snow cover, of land ice and of Arctic sea ice (*high confidence*). The Arctic is *likely* to be practically sea ice free in September[31] at least once before 2050 under the five illustrative scenarios considered in this report, with more frequent occurrences for higher warming levels. There is *low confidence* in the projected decrease of Antarctic sea ice.
{4.3, 4.5, 7.4, 8.2, 8.4, Box 8.2, 9.3, 9.5, 12.4, Cross-Chapter Box 12.1, Atlas.5, Atlas.6, Atlas.8, Atlas.9, Atlas.11, TS.2.5} **(Figure SPM.8)**

[31] monthly average sea ice area of less than 1 million km^2 which is about 15% of the average September sea ice area observed in 1979-1988

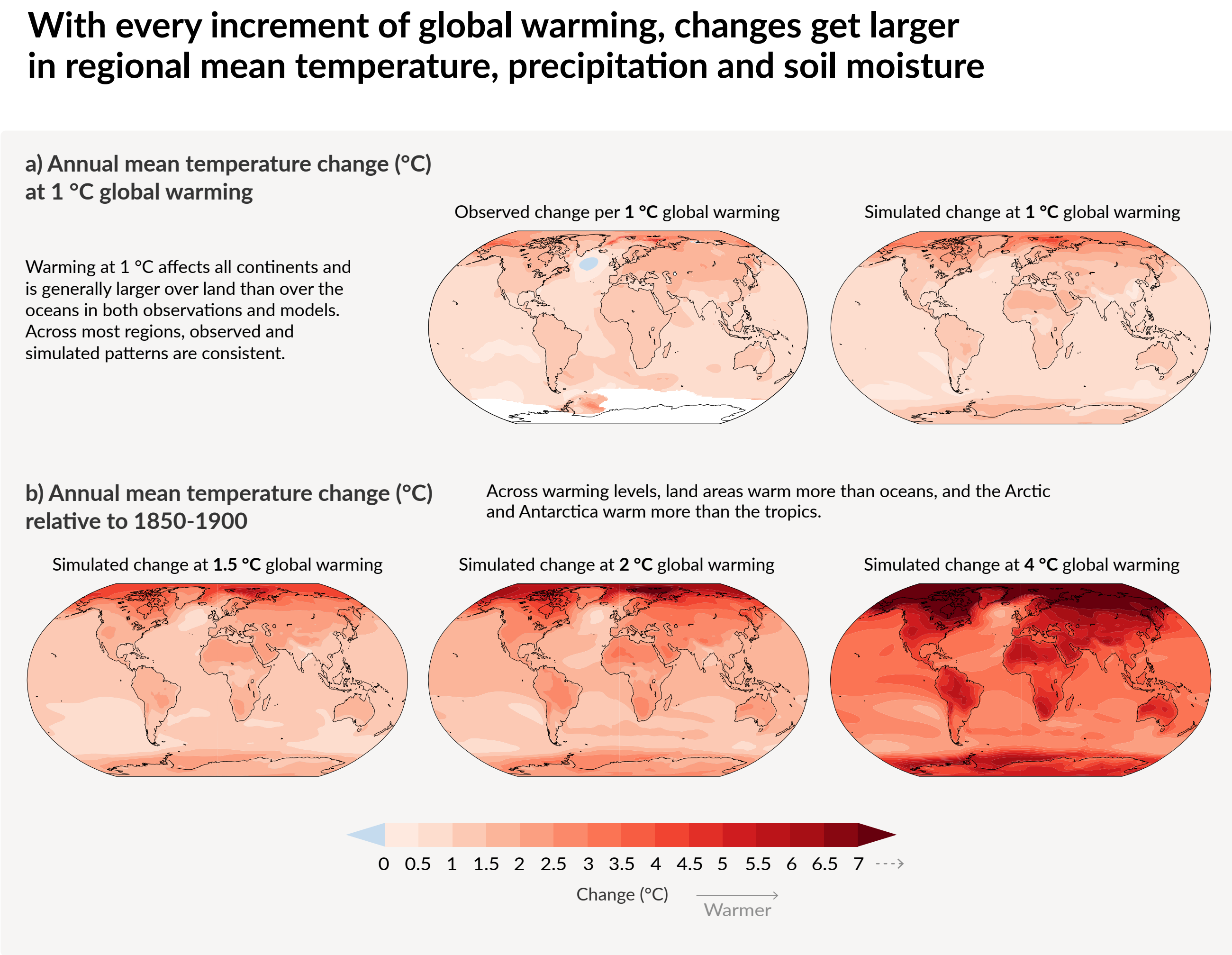
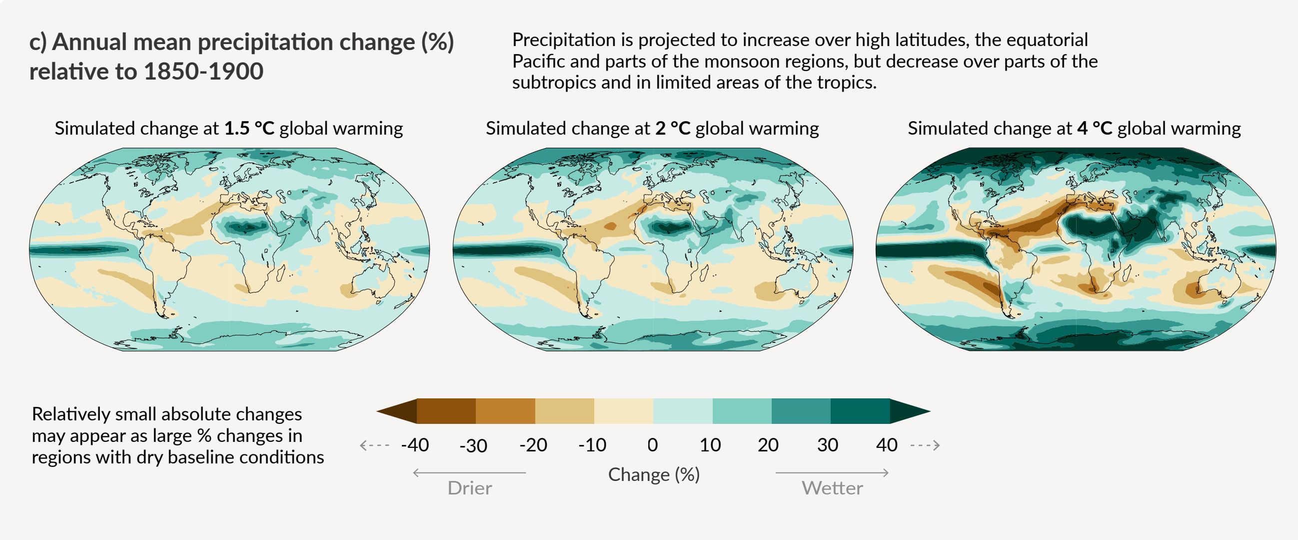
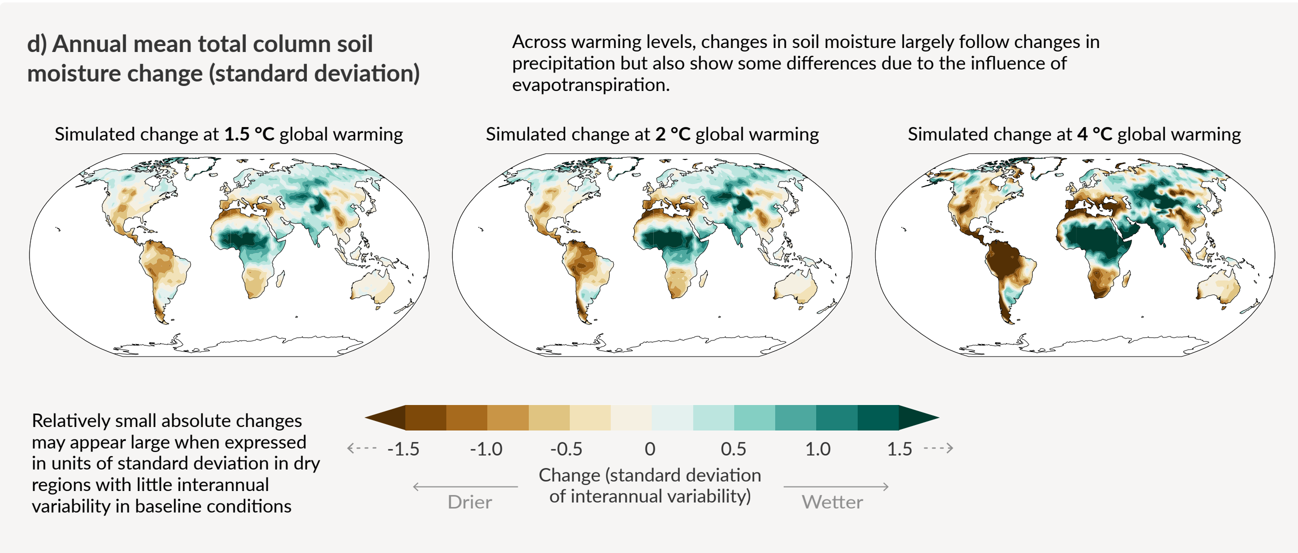


Figure SPM.5: Changes in annual mean surface temperature, precipitation, and soil moisture.

Panel a) Comparison of observed and simulated annual mean surface temperature change. The **left map** shows the observed changes in annual mean surface temperature in the period of 1850–2020 per °C of global warming (°C). The local (i.e., grid point) observed annual mean surface temperature changes are linearly regressed against the global surface temperature in the period 1850–2020. Observed temperature data are from Berkeley Earth, the dataset with the largest coverage and highest horizontal resolution. Linear regression is applied to all years for which data at the corresponding grid point is available. The regression method was used to take into account the complete observational time series and thereby reduce the role of internal variability at the grid point level. White indicates areas where time coverage was 100 years or less and thereby too short to calculate a reliable linear regression. The **right map** is based on model simulations and shows change in annual multi-model mean simulated temperatures at a global warming level of 1°C (20-year mean global surface temperature change relative to 1850–1900). The triangles at each end of the color bar indicate out-of-bound values, that is, values above or below the given limits.

Panel b) Simulated annual mean temperature change (°C), panel c) precipitation change (%), and panel d) total column soil moisture change (standard deviation of interannual variability) at global warming levels of 1.5°C, 2°C and 4°C (20-yr mean global surface temperature change relative to 1850–1900). Simulated changes correspond to CMIP6 multi-model mean change (median change for soil moisture) at the corresponding global warming level, i.e. the same method as for the right map in panel a).





In **panel c),** high positive percentage changes in dry regions may correspond to small absolute changes. In **panel d),** the unit is the standard deviation of interannual variability in soil moisture during 1850–1900. Standard deviation is a widely used metric in characterizing drought severity. A projected reduction in mean soil moisture by one standard deviation corresponds to soil moisture conditions typical of droughts that occurred about once every six years during 1850–1900. In panel d), large changes in dry regions with little interannual variability in the baseline conditions can correspond to small absolute change. The triangles at each end of the color bars indicate out-of-bound values, that is, values above or below the given limits. Results from all models reaching the corresponding warming level in any of the five illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) are averaged. Maps of annual mean temperature and precipitation changes at a global warming level of 3°C are available in Figure 4.31 and Figure 4.32 in Section 4.6.

Corresponding maps of panels b), c) and d) including hatching to indicate the level of model agreement at grid-cell level are found in Figures 4.31, 4.32 and 11.19, respectively; as highlighted in CC-box Atlas.1, grid-cell level hatching is not informative for larger spatial scales (e.g., over AR6 reference regions) where the aggregated signals are less affected by small-scale variability leading to an increase in robustness.

{TS.1.3.2, Figure TS.3, Figure TS.5, Figure 1.14, 4.6.1, Cross-Chapter Box 11.1, Cross-Chapter Box Atlas.1}

Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming

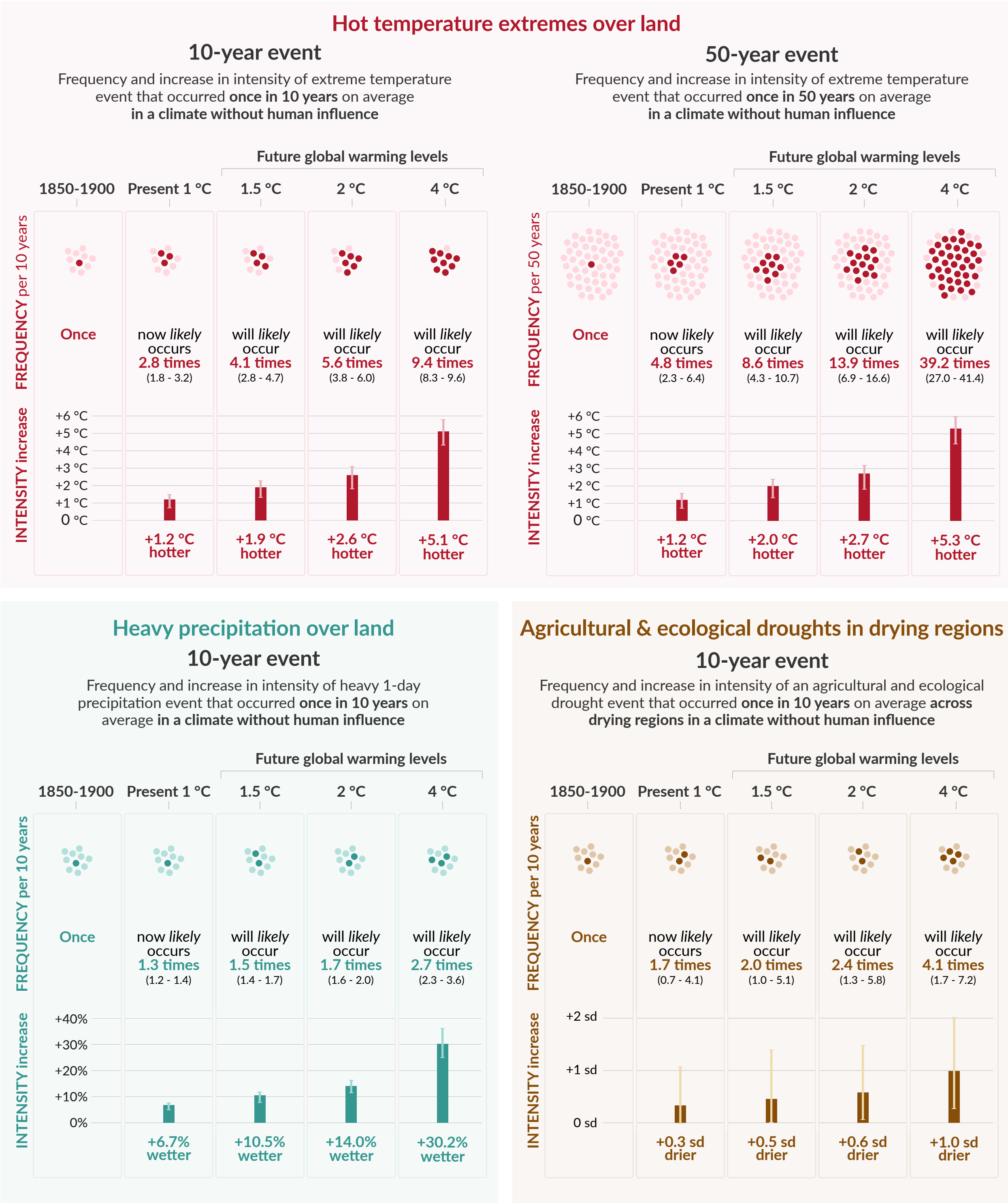


Figure SPM.6: Projected changes in the intensity and frequency of hot temperature extremes over land, extreme precipitation over land, and agricultural and ecological droughts in drying regions.

Projected changes are shown at global warming levels of 1°C, 1.5°C, 2°C, and 4°C and are relative to 1850-1900[9] representing a climate without human influence. The figure depicts frequencies and increases in intensity of 10- or 50-year extreme events from the base period (1850-1900) under different global warming levels.
Hot temperature extremes are defined as the daily maximum temperatures over land that were exceeded on average once in a decade (10-year event) or once in 50 years (50-year event) during the 1850–1900 reference period. **Extreme precipitation events** are defined as the daily precipitation amount over land that was exceeded on average once in a decade during the 1850–1900 reference period. **Agricultural and ecological drought events** are defined as the annual average of total column soil moisture below the 10th percentile of the 1850–1900 base period. These extremes are defined on model grid box scale. For hot temperature extremes and extreme precipitation, results are shown for the global land. For agricultural and ecological drought, results are shown for drying regions only, which correspond to the AR6 regions in which there is at least *medium confidence* in a projected increase in agricultural/ecological drought at the 2°C warming level compared to the 1850–1900 base period in CMIP6. These regions include W. North-America, C. North-America, N. Central-America, S. Central-America, Caribbean, N. South-America, N.E. South-America, South-American-Monsoon, S.W. South-America, S. South-America, West & Central-Europe, Mediterranean, W. Southern-Africa, E. Southern-Africa, Madagascar, E. Australia, S. Australia (Caribbean is not included in the calculation of the figure because of the too small number of full land grid cells). The non-drying regions do not show an overall increase or decrease in drought severity. Projections of changes in agricultural and ecological droughts in the CMIP5 multi-model ensemble differ from those in CMIP6 in some regions, including in part of Africa and Asia. Assessments on projected changes in meteorological and hydrological droughts are provided in Chapter 11. {11.6, 11.9}

In the **'frequency' section,** each year is represented by a dot. The dark dots indicate years in which the extreme threshold is exceeded, while light dots are years when the threshold is not exceeded. Values correspond to the medians (in bold) and their respective 5–95% range based on the multi-model ensemble from simulations of CMIP6 under different SSP scenarios. For consistency, the number of dark dots is based on the rounded-up median. In the **'intensity' section,** medians and their 5–95% range, also based on the multi-model ensemble from simulations of CMIP6, are displayed as dark and light bars, respectively. Changes in the intensity of hot temperature extremes and extreme precipitations are expressed as degree Celsius and percentage. As for agricultural and ecological drought, intensity changes are expressed as fractions of standard deviation of annual soil moisture.

{11.1, 11.3, 11.4, 11.6, Figure 11.12, Figure 11.15, Figure 11.6, Figure 11.7, Figure 11.18}

B.3 Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events.
{4.3, 4.4, 4.5, 4.6, 8.2, 8.3, 8.4, 8.5, Box 8.2, 11.4, 11.6, 11.9, 12.4, Atlas.3} **(Figure SPM.5, Figure SPM.6)**

B.3.1 There is strengthened evidence since AR5 that the global water cycle will continue to intensify as global temperatures rise (*high confidence*), with precipitation and surface water flows projected to become more variable over most land regions within seasons (*high confidence*) and from year to year (*medium confidence*). The average annual global land precipitation is projected to increase by 0–5% under the very low GHG emissions scenario (SSP1-1.9), 1.5-8% for the intermediate GHG emissions scenario (SSP2-4.5) and 1–13% under the very high GHG emissions scenario (SSP5-8.5) by 2081–2100 relative to 1995-2014 (*likely* ranges). Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and limited areas in the tropics in SSP2-4.5, SSP3-7.0 and SSP5-8.5 (*very likely*). The portion of the global land experiencing detectable increases or decreases in seasonal mean precipitation is projected to increase (*medium confidence*). There is *high confidence* in an earlier onset of spring snowmelt, with higher peak flows at the expense of summer flows in snow-dominated regions globally.
{4.3, 4.5, 4.6, 8.2, 8.4, Atlas.3, TS.2.6, Box TS.6, TS.4.3} **(Figure SPM.5)**

B.3.2 A warmer climate will intensify very wet and very dry weather and climate events and seasons, with implications for flooding or drought (*high confidence*), but the location and frequency of these events depend on projected changes in regional atmospheric circulation, including monsoons and mid-latitude storm tracks. It is *very likely* that rainfall variability related to the El Niño–Southern Oscillation is projected to be amplified by the second half of the 21st century in the SSP2-4.5, SSP3-7.0 and SSP5-8.5 scenarios.
{4.3, 4.5, 4.6, 8.2, 8.4, 8.5, 11.4, 11.6, 11.9, 12.4, TS.2.6, TS.4.2, Box TS.6} **(Figure SPM.5, Figure SPM.6)**

B.3.3 Monsoon precipitation is projected to increase in the mid- to long term at global scale, particularly over South and Southeast Asia, East Asia and West Africa apart from the far west Sahel (*high confidence*). The monsoon season is projected to have a delayed onset over North and South America and West Africa (*high confidence*) and a delayed retreat over West Africa (*medium confidence*).
{4.4, 4.5, 8.2, 8.3, 8.4, Box 8.2, Box TS.13}

B.3.4 A projected southward shift and intensification of Southern Hemisphere summer mid-latitude storm tracks and associated precipitation is *likely* in the long term under high GHG emissions scenarios (SSP3-7.0, SSP5-8.5), but in the near term the effect of stratospheric ozone recovery counteracts these changes (*high confidence*). There is *medium confidence* in a continued poleward shift of storms and their precipitation in the North Pacific, while there is *low confidence* in projected changes in the North Atlantic storm tracks.
{TS.4.2, 4.4, 4.5, 8.4, TS.2.3}

B.4 Under scenarios with increasing CO_2 emissions, the ocean and land carbon sinks are projected to be less effective at slowing the accumulation of CO_2 in the atmosphere.
{4.3, 5.2, 5.4, 5.5, 5.6} **(Figure SPM.7)**

B.4.1 While natural land and ocean carbon sinks are projected to take up, in absolute terms, a progressively larger amount of CO_2 under higher compared to lower CO_2 emissions scenarios, they become less effective, that is, the proportion of emissions taken up by land and ocean decrease with increasing cumulative CO_2 emissions. This is projected to result in a higher proportion of emitted CO_2 remaining in the atmosphere (*high confidence*).
{5.2, 5.4, Box TS.5} **(Figure SPM.7)**

B.4.2 Based on model projections, under the intermediate scenario that stabilizes atmospheric CO_2 concentrations this century (SSP2-4.5), the rates of CO_2 taken up by the land and oceans are projected to decrease in the second half of the 21st century (*high confidence*). Under the very low and low GHG emissions scenarios (SSP1-1.9, SSP1-2.6), where CO_2 concentrations peak and decline during the 21st century, land and oceans begin to take up less carbon in response to declining atmospheric CO_2 concentrations (*high confidence*) and turn into a weak net source by 2100 under SSP1-1.9 (*medium confidence*). It is *very unlikely* that the combined global land and ocean sink will turn into a source by 2100 under scenarios without net negative emissions[32] (SSP2-4.5, SSP3-7.0, SSP5-8.5).
{4.3, 5.4, 5.5, 5.6, Box TS.5, TS.3.3}

B.4.3 The magnitude of feedbacks between climate change and the carbon cycle becomes larger but also more uncertain in high CO_2 emissions scenarios (*very high confidence*). However, climate model projections show that the uncertainties in atmospheric CO_2 concentrations by 2100 are dominated by the differences between emissions scenarios (*high confidence*). Additional ecosystem responses to warming not yet fully included in climate models, such as CO_2 and CH_4 fluxes from wetlands, permafrost thaw and wildfires, would further increase concentrations of these gases in the atmosphere (*high confidence*).
{5.4, Box TS.5, TS.3.2}

[32] These projected adjustments of carbon sinks to stabilization or decline of atmospheric CO_2 are accounted for in calculations of remaining carbon budgets.

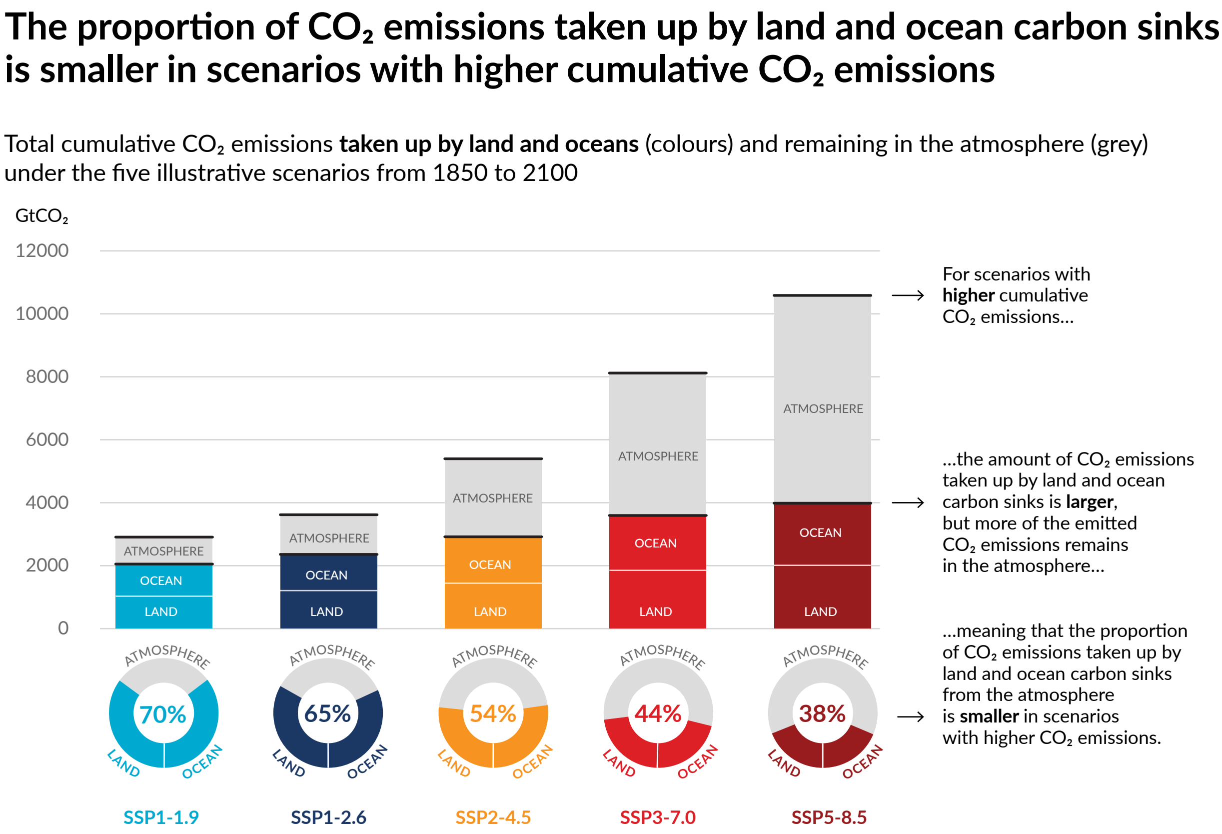


Figure SPM.7: Cumulative anthropogenic CO2 emissions taken up by land and ocean sinks by 2100 under the five illustrative scenarios.

The cumulative anthropogenic (human-caused) carbon dioxide (CO_2) emissions taken up by the land and ocean sinks under the five illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) are simulated from 1850 to 2100 by CMIP6 climate models in the concentration-driven simulations. Land and ocean carbon sinks respond to past, current and future emissions, therefore cumulative sinks from 1850 to 2100 are presented here. During the historical period (1850-2019) the observed land and ocean sink took up 1430 $GtCO_2$ (59% of the emissions).

The **bar chart** illustrates the projected amount of cumulative anthropogenic CO_2 emissions ($GtCO_2$) between 1850 and 2100 remaining in the atmosphere (grey part) and taken up by the land and ocean (coloured part) in the year 2100. The **doughnut chart** illustrates the proportion of the cumulative anthropogenic CO_2 emissions taken up by the land and ocean sinks and remaining in the atmosphere in the year 2100. Values in % indicate the proportion of the cumulative anthropogenic CO_2 emissions taken up by the combined land and ocean sinks in the year 2100. The overall anthropogenic carbon emissions are calculated by adding the net global land use emissions from CMIP6 scenario database to the other sectoral emissions calculated from climate model runs with prescribed CO_2 concentrations[33]. Land and ocean CO_2 uptake since 1850 is calculated from the net biome productivity on land, corrected for CO_2 losses due to land-use change by adding the land-use change emissions, and net ocean CO_2 flux.

{Box TS.5, Box TS.5, Figure 1, 5.2.1, Table 5.1, 5.4.5, Figure 5.25}

[33] The other sectoral emissions are calculated as the residual of the net land and ocean CO_2 uptake and the prescribed atmospheric CO_2 concentration changes in the CMIP6 simulations. These calculated emissions are net emissions and do not separate gross anthropogenic emissions from removals, which are included implicitly.

B.5 Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level. {Cross-Chapter Box 2.4, 2.3, 4.3, 4.5, 4.7, 5.3, 9.2, 9.4, 9.5, 9.6, Box 9.4} (Figure SPM.8)

B.5.1 Past GHG emissions since 1750 have committed the global ocean to future warming (*high confidence*). Over the rest of the 21st century, *likely* ocean warming ranges from 2–4 (SSP1-2.6) to 4–8 times (SSP5-8.5) the 1971–2018 change. Based on multiple lines of evidence, upper ocean stratification (*virtually certain*), ocean acidification (*virtually certain*) and ocean deoxygenation (*high confidence*) will continue to increase in the 21st century, at rates dependent on future emissions. Changes are irreversible on centennial to millennial time scales in global ocean temperature (*very high confidence*), deep ocean acidification (*very high confidence*) and deoxygenation (*medium confidence*).
{4.3, 4.5, 4.7, 5.3, 9.2, TS.2.4} **(Figure SPM.8)**

B.5.2 Mountain and polar glaciers are committed to continue melting for decades or centuries (*very high confidence*). Loss of permafrost carbon following permafrost thaw is irreversible at centennial timescales (*high confidence*). Continued ice loss over the 21st century is *virtually certain* for the Greenland Ice Sheet and *likely* for the Antarctic Ice Sheet. There is *high confidence* that total ice loss from the Greenland Ice Sheet will increase with cumulative emissions. There is *limited evidence* for low-likelihood, high-impact outcomes (resulting from ice sheet instability processes characterized by deep uncertainty and in some cases involving tipping points) that would strongly increase ice loss from the Antarctic Ice Sheet for centuries under high GHG emissions scenarios[34]. {4.3, 4.7, 5.4, 9.4, 9.5, Box 9.4, Box TS.1, TS.2.5}

B.5.3 It is *virtually certain* that global mean sea level will continue to rise over the 21st century. Relative to 1995-2014, the *likely* global mean sea level rise by 2100 is 0.28-0.55 m under the very low GHG emissions scenario (SSP1-1.9), 0.32-0.62 m under the low GHG emissions scenario (SSP1-2.6), 0.44-0.76 m under the intermediate GHG emissions scenario (SSP2-4.5), and 0.63-1.01 m under the very high GHG emissions scenario (SSP5-8.5), and by 2150 is 0.37-0.86 m under the very low scenario (SSP1-1.9), 0.46-0.99 m under the low scenario (SSP1-2.6), 0.66-1.33 m under the intermediate scenario (SSP2-4.5), and 0.98-1.88 m under the very high scenario (SSP5-8.5) (*medium confidence*)[35]. Global mean sea level rise above the *likely* range – approaching 2 m by 2100 and 5 m by 2150 under a very high GHG emissions scenario (SSP5-8.5) (*low confidence*) – cannot be ruled out due to deep uncertainty in ice sheet processes.
{4.3, 9.6, Box 9.4, Box TS.4} **(Figure SPM.8)**

B.5.4 In the longer term, sea level is committed to rise for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and will remain elevated for thousands of years (*high confidence*). Over the next 2000 years, global mean sea level will rise by about 2 to 3 m if warming is limited to 1.5°C, 2 to 6 m if limited to 2°C and 19 to 22 m with 5°C of warming, and it will continue to rise over subsequent millennia (*low confidence*). Projections of multi-millennial global mean sea level rise are consistent with reconstructed levels during past warm climate periods: *likely* 5–10 m higher than today around 125,000 years ago, when global temperatures were *very likely* 0.5°C–1.5°C higher than 1850–1900; and *very likely* 5–25 m higher roughly 3 million years ago, when global temperatures were 2.5°C–4°C higher (*medium confidence*).
{2.3, Cross-Chapter Box 2.4, 9.6, Box TS.2, Box TS.4, Box TS.9}

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[34] Low-likelihood, high-impact outcomes are those whose probability of occurrence is low or not well known (as in the context of deep uncertainty) but whose potential impacts on society and ecosystems could be high. A tipping point is a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly. {Cross-Chapter Box 1.3, 1.4, 4.7}

[35] To compare to the 1986–2005 baseline period used in AR5 and SROCC, add 0.03 m to the global mean sea level rise estimates. To compare to the 1900 baseline period used in Figure SPM.8, add 0.16 m.

Human activities affect all the major climate system components, with some responding over decades and others over centuries

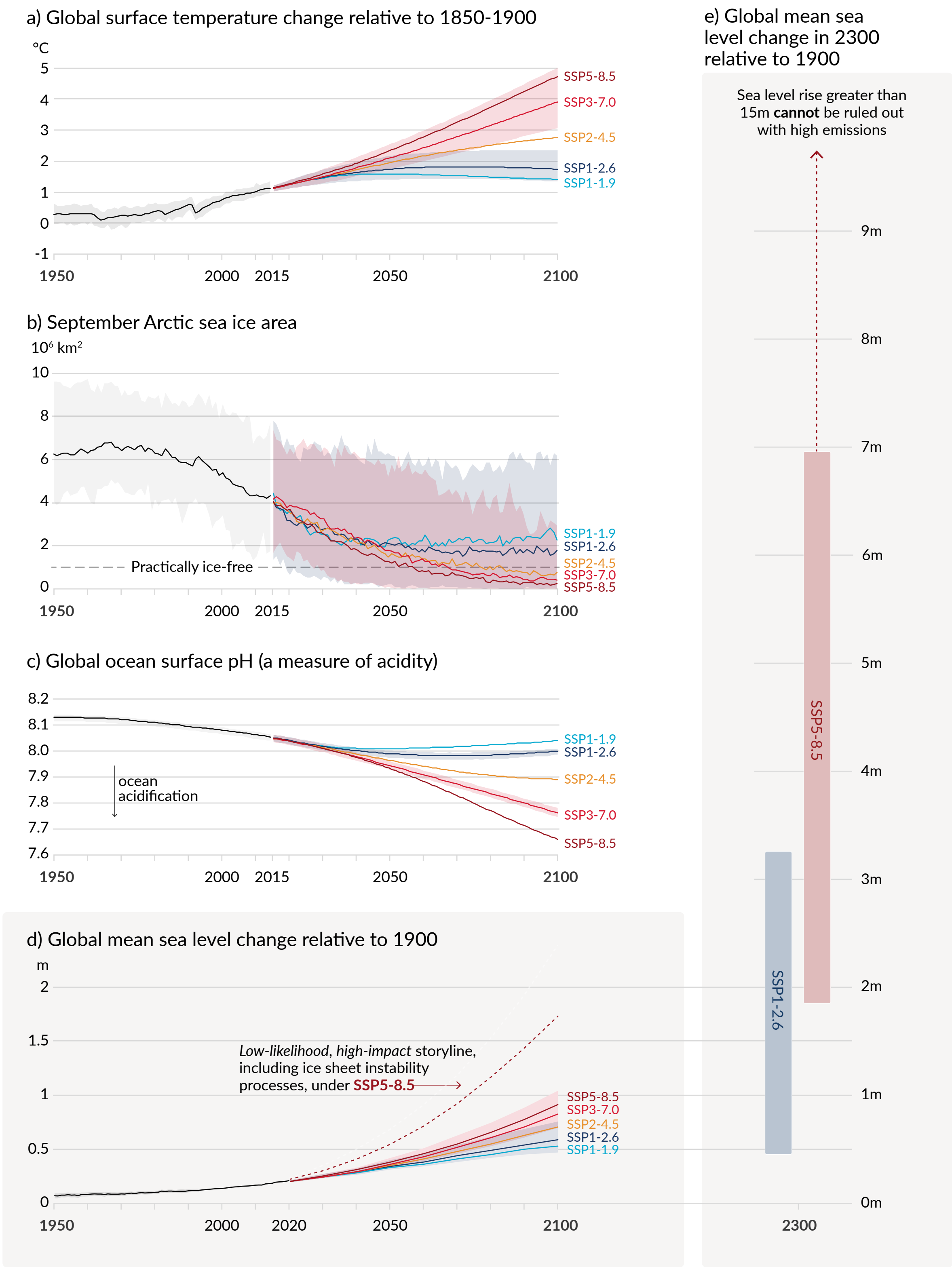

Figure SPM.8: Selected indicators of global climate change under the five illustrative scenarios used in this report.

The projections for each of the five scenarios are shown in colour. Shades represent uncertainty ranges – more detail is provided for each panel below. The black curves represent the historical simulations (panels a, b, c) or the observations (panel d). Historical values are included in all graphs to provide context for the projected future changes.

Panel a) Global surface temperature changes in °C relative to 1850–1900. These changes were obtained by combining CMIP6 model simulations with observational constraints based on past simulated warming, as well as an updated assessment of equilibrium climate sensitivity (see Box SPM.1). Changes relative to 1850–1900 based on 20-year averaging periods are calculated by adding 0.85°C (the observed global surface temperature increase from 1850–1900 to 1995–2014) to simulated changes relative to 1995–2014. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.

Panel b) September Arctic sea ice area in 10^6 km^2 based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0. The Arctic is projected to be practically ice-free near mid-century under mid- and high GHG emissions scenarios.

Panel c) Global ocean surface pH (a measure of acidity) based on CMIP6 model simulations. *Very likely* ranges are shown for SSP1-2.6 and SSP3-7.0.

Panel d) Global mean sea level change in meters relative to 1900. The historical changes are observed (from tide gauges before 1992 and altimeters afterwards), and the future changes are assessed consistently with observational constraints based on emulation of CMIP, ice sheet, and glacier models. *Likely* ranges are shown for SSP1-2.6 and SSP3-7.0. Only *likely* ranges are assessed for sea level changes due to difficulties in estimating the distribution of deeply uncertain processes. The dashed curve indicates the potential impact of these deeply uncertain processes. It shows the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice sheet processes that cannot be ruled out; because of *low confidence* in projections of these processes, this curve does not constitute part of a *likely* range. Changes relative to 1900 are calculated by adding 0.158 m (observed global mean sea level rise from 1900 to 1995–2014) to simulated and observed changes relative to 1995–2014.

Panel e): Global mean sea level change at 2300 in meters relative to 1900. Only SSP1-2.6 and SSP5-8.5 are projected at 2300, as simulations that extend beyond 2100 for the other scenarios are too few for robust results. The 17th–83rd percentile ranges are shaded. The dashed arrow illustrates the 83rd percentile of SSP5-8.5 projections that include low-likelihood, high-impact ice sheet processes that cannot be ruled out.

Panels b) and c) are based on single simulations from each model, and so include a component of internal variability. Panels a), d) and e) are based on long-term averages, and hence the contributions from internal variability are small.

{Figure TS.8, Figure TS.11, Box TS.4 Figure 1, Box TS.4 Figure 1, 4.3, 9.6, Figure 4.2, Figure 4.8, Figure 4.11, Figure 9.27}

C. Climate Information for Risk Assessment and Regional Adaptation

Physical climate information addresses how the climate system responds to the interplay between human influence, natural drivers and internal variability. Knowledge of the climate response and the range of possible outcomes, including low-likelihood, high impact outcomes, informs climate services – the assessment of climate-related risks and adaptation planning. Physical climate information at global, regional and local scales is developed from multiple lines of evidence, including observational products, climate model outputs and tailored diagnostics.

C.1 Natural drivers and internal variability will modulate human-caused changes, especially at regional scales and in the near term, with little effect on centennial global warming. These modulations are important to consider in planning for the full range of possible changes.

{1.4, 2.2, 3.3, Cross-Chapter Box 3.1, 4.4, 4.6, Cross-Chapter Box 4.1, 4.4, Box 7.2, 8.3, 8.5, 9.2, 10.3, 10.4, 10.6, 11.3, 12.5, Atlas.4, Atlas.5, Atlas.8, Atlas.9, Atlas.10, Cross-Chapter Box Atlas.2, Atlas.11}

C.1.1 The historical global surface temperature record highlights that decadal variability has enhanced and masked underlying human-caused long-term changes, and this variability will continue into the future (*very high confidence*). For example, internal decadal variability and variations in solar and volcanic drivers partially masked human-caused surface global warming during 1998–2012, with pronounced regional and seasonal signatures (*high confidence*). Nonetheless, the heating of the climate system continued during this period, as reflected in both the continued warming of the global ocean (*very high confidence*) and in the continued rise of hot extremes over land (*medium confidence*).
{1.4, 3.3, Cross-Chapter Box 3.1, 4.4, Box 7.2, 9.2, 11.3, Cross-Section Box TS.1} **(Figure SPM.1)**

C.1.2 Projected human caused changes in mean climate and climatic impact-drivers (CIDs)[36], including extremes, will be either amplified or attenuated by internal variability[37] (*high confidence*). Near-term cooling at any particular location with respect to present climate could occur and would be consistent with the global surface temperature increase due to human influence (*high confidence*).
{1.4, 4.4, 4.6, 10.4, 11.3, 12.5, Atlas.5, Atlas.10, Atlas.11, TS.4.2}

C.1.3 Internal variability has largely been responsible for the amplification and attenuation of the observed human-caused decadal-to-multi-decadal mean precipitation changes in many land regions *(high confidence)*. At global and regional scales, near-term changes in monsoons will be dominated by the effects of internal variability (*medium confidence*). In addition to internal variability influence, near-term projected changes in precipitation at global and regional scales are uncertain because of model uncertainty and uncertainty in forcings from natural and anthropogenic aerosols (*medium confidence*).
{1.4, 4.4, 8.3, 8.5, 10.3, 10.4, 10.5, 10.6, Atlas.4, Atlas.8, Atlas.9, Atlas.10, Cross-Chapter Box Atlas.2, Atlas.11, TS.4.2, Box TS.6, Box TS.13}

[36] Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions. CID types include heat and cold, wet and dry, wind, snow and ice, coastal and open ocean.

[37] The main internal variability phenomena include El Niño–Southern Oscillation, Pacific Decadal variability and Atlantic Multi-decadal variability through their regional influence.

C.1.4 Based on paleoclimate and historical evidence, it is *likely* that at least one large explosive volcanic eruption would occur during the 21st century[38]. Such an eruption would reduce global surface temperature and precipitation, especially over land, for one to three years, alter the global monsoon circulation, modify extreme precipitation and change many CIDs (*medium confidence*). If such an eruption occurs, this would therefore temporarily and partially mask human-caused climate change.
{4.4, Cross-Chapter Box 4.1, 2.2, 8.5, TS.2.1}

C.2 With further global warming, every region is projected to increasingly experience concurrent and multiple changes in climatic impact-drivers. Changes in several climatic impact-drivers would be more widespread at 2°C compared to 1.5°C global warming and even more widespread and/or pronounced for higher warming levels.

{8.2, 9.3, 9.5, 9.6, Box 10.3, Box 11.3, Box 11.4, 11.3, 11.4, 11.5, 11.6, 11.7, 11.9, 12.2, 12.3, 12.4, 12.5, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1} **(Table SPM.1, Figure SPM.9)**

C.2.1 All regions[39] are projected to experience further increases in hot climatic impact-drivers (CIDs) and decreases in cold CIDs (*high confidence*). Further decreases are projected in permafrost, snow, glaciers and ice sheets, lake and Arctic sea ice (*medium* to *high confidence*)[40]. These changes would be larger at 2°C global warming or above than at 1.5°C (*high confidence*). For example, extreme heat thresholds relevant to agriculture and health are projected to be exceeded more frequently at higher global warming levels (*high confidence*).
{9.3, 9.5, 11.3, 11.9, 12.3, 12.4, 12.5, Atlas.4, Atlas.5, Atlas.6, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, TS.4.3, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1} **(Table SPM.1, Figure SPM.9)**

C.2.2 At 1.5°C global warming, heavy precipitation and associated flooding are projected to intensify and be more frequent in most regions in Africa and Asia (*high confidence*), North America (*medium* to *high confidence*)[40] and Europe (*medium confidence*). Also**,** more frequent and/or severe agricultural and ecological droughts are projected in a few regions in all continents except Asia compared to 1850–1900 (*medium confidence*); increases in meteorological droughts are also projected in a few regions (*medium confidence*). A small number of regions are projected to experience increases or decreases in mean precipitation (*medium confidence*).
{11.4, 11.5, 11.6, 11.9, Atlas.4, Atlas.5, Atlas.7, Atlas.8, Atlas.9, Atlas.10, Atlas.11, TS.4.3} **(Table SPM.1)**

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[38] Based on 2,500 year reconstructions, eruptions more negative than –1 W m^{-2} occur on average twice per century.

[39] Regions here refer to the AR6 WGI reference regions used in this Report to summarize information in sub-continental and oceanic regions. Changes are compared to averages over the last 20–40 years unless otherwise specified. {1.4, 12.4, Atlas.1, Interactive Atlas}.

[40] The specific level of confidence or likelihood depends on the region considered. Details can be found in the Technical Summary and the underlying Report.

C.2.3 At 2°C global warming and above, the level of confidence in and the magnitude of the change in droughts and heavy and mean precipitation increase compared to those at 1.5°C. Heavy precipitation and associated flooding events are projected to become more intense and frequent in the Pacific Islands and across many regions of North America and Europe (*medium* to *high confidence*)[40]. These changes are also seen in some regions in Australasia and Central and South America (*medium confidence*). Several regions in Africa, South America and Europe are projected to experience an increase in frequency and/or severity of agricultural and ecological droughts with *medium* to *high confidence*[40]; increases are also projected in Australasia, Central and North America, and the Caribbean with *medium confidence*. A small number of regions in Africa, Australasia, Europe and North America are also projected to be affected by increases in hydrological droughts, and several regions are projected to be affected by increases or decreases in meteorological droughts with more regions displaying an increase (*medium confidence*). Mean precipitation is projected to increase in all polar, northern European and northern North American regions, most Asian regions and two regions of South America (*high confidence*).
{11.4, 11.6, 11.9, 12.4, 12.5, Atlas.5, Atlas.7, Atlas.8, Atlas.9, Atlas.11, TS.4.3, Cross-Chapter Box 11.1, Cross-Chapter Box 12.1} **(Table SPM.1, Figure SPM.5, Figure SPM.6, Figure SPM.9)**

C.2.4 More CIDs across more regions are projected to change at 2°C and above compared to 1.5°C global warming (*high confidence*). Region-specific changes include intensification of tropical cyclones and/or extratropical storms (*medium confidence*), increases in river floods (*medium* to *high confidence*)[40], reductions in mean precipitation and increases in aridity (*medium* to *high confidence*)[40], and increases in fire weather (*medium* to *high confidence*)[40]. There is *low confidence* in most regions in potential future changes in other CIDs, such as hail, ice storms, severe storms, dust storms, heavy snowfall, and landslides.
{11.7, 11.9, 12.4, 12.5, Atlas.4, Atlas.6, Atlas.7, Atlas.8, Atlas.10, TS.4.3.1, TS.4.3.2, TS.5, Cross-Chapter Box, 11.1, Cross-Chapter Box 12.1} **(Table SPM.1, Figure SPM.9)**

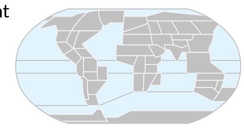
C.2.5 It is *very likely* to *virtually certain*[40] that regional mean relative sea level rise will continue throughout the 21st century, except in a few regions with substantial geologic land uplift rates. Approximately two-thirds of the global coastline has a projected regional relative sea level rise within ±20% of the global mean increase (*medium confidence*). Due to relative sea level rise, extreme sea level events that occurred once per century in the recent past are projected to occur at least annually at more than half of all tide gauge locations by 2100 (*high confidence*). Relative sea level rise contributes to increases in the frequency and severity of coastal flooding in low-lying areas and to coastal erosion along most sandy coasts (*high confidence*).
{9.6, 12.4, 12.5, Box TS.4, TS.4.3, Cross-Chapter Box 12.1} **(Figure SPM.9)**

C.2.6 Cities intensify human-induced warming locally, and further urbanization together with more frequent hot extremes will increase the severity of heatwaves (*very high confidence*). Urbanization also increases mean and heavy precipitation over and/or downwind of cities (*medium confidence*) and resulting runoff intensity (*high confidence*). In coastal cities, the combination of more frequent extreme sea level events (due to sea level rise and storm surge) and extreme rainfall/riverflow events will make flooding more probable (*high confidence*).
{8.2, Box 10.3, 11.3, 12.4, Box TS.14}

C.2.7 Many regions are projected to experience an increase in the probability of compound events with higher global warming (*high confidence*). In particular, concurrent heatwaves and droughts are *likely* to become more frequent. Concurrent extremes at multiple locations become more frequent, including in crop-producing areas, at 2°C and above compared to 1.5°C global warming (*high confidence*).
{11.8, Box 11.3, Box 11.4, 12.3, 12.4, TS.4.3, Cross-Chapter Box 12.1} **(Table SPM.1)**

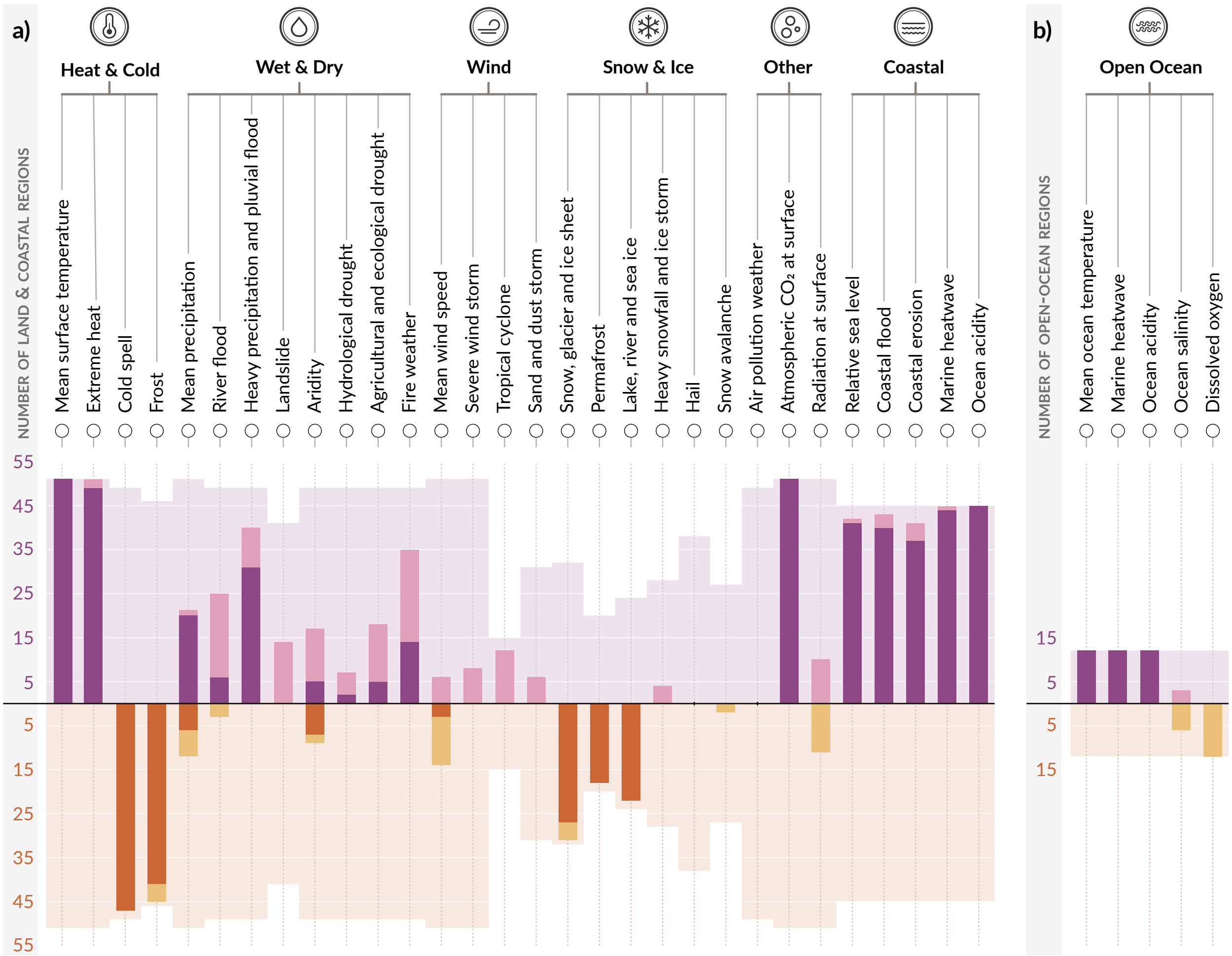
Multiple climatic impact-drivers are projected to change in all regions of the world

Climatic impact-drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions. The CIDs are grouped into seven types, which are summarized under the icons in the figure. All regions are projected to experience changes in at least 5 CIDs. Almost all (96%) are projected to experience changes in at least 10 CIDs and half in at least 15 CIDs. For many CIDs there is wide geographical variation in where they change and so each region are projected to experience a specific set of CID changes. Each bar in the chart represents a specific geographical set of changes that can be explored in the WGI Interactive Atlas.



interactive-atlas.ipcc.ch

Number of land & coastal regions (a) and **open-ocean regions** (b) where each **climatic impact-driver** (CID) is projected to **increase** or **decrease** with ***high** confidence* (dark shade) or ***medium** confidence* (light shade)



BAR CHART LEGEND

- Regions with ***high** confidence* **increase**
- Regions with ***medium** confidence* **increase**
- Regions with ***high** confidence* **decrease**
- Regions with ***medium** confidence* **decrease**

LIGHTER-SHADED 'ENVELOPE' LEGEND

The height of the lighter shaded 'envelope' behind each bar represents the maximum number of regions for which each CID is relevant. The envelope is symmetrical about the x-axis showing the maximum possible number of relevant regions for CID increase (upper part) or decrease (lower part).

ASSESSED FUTURE CHANGES

Changes refer to a 20–30 year period centred around 2050 and/or consistent with 2°C global warming compared to a similar period within 1960-2014 or 1850-1900.

Figure SPM.9: Synthesis of the number of AR6 WGI reference regions where climatic impact-drivers are projected to change.

A total of 35 climatic impact-drivers (CIDs) grouped into seven types are shown: heat and cold, wet and dry, wind, snow and ice, coastal, open ocean and other. For each CID, the bar in the graph below displays the number of AR6 WGI reference regions where it is projected to change. The **colours** represent the direction of change and the level of confidence in the change: purple indicates an increase while brown indicates a decrease; darker and lighter shades refer to *high* and *medium confidence*, respectively. Lighter background colours represent the maximum number of regions for which each CID is broadly relevant.

Panel a) shows the 30 CIDs relevant to the **land and coastal regions** while **panel b)** shows the 5 CIDs relevant to the **open ocean regions.** Marine heatwaves and ocean acidity are assessed for coastal ocean regions in panel a) and for open ocean regions in panel b). Changes refer to a 20–30 year period centred around 2050 and/or consistent with 2°C global warming compared to a similar period within 1960-2014, except for hydrological drought and agricultural and ecological drought which is compared to 1850-1900. Definitions of the regions are provided in Atlas.1 and the Interactive Atlas (see *interactive-atlas.ipcc.ch*).

{Table TS.5, Figure TS.22, Figure TS.25, 11.9, 12.2, 12.4, Atlas.1} **(Table SPM.1)**

C.3 Low-likelihood outcomes, such as ice sheet collapse, abrupt ocean circulation changes, some compound extreme events and warming substantially larger than the assessed *very likely* range of future warming cannot be ruled out and are part of risk assessment.

{1.4, Cross-Chapter Box 1.3, Cross-Chapter Box 4.1, 4.3, 4.4, 4.8, 8.6, 9.2, Box 9.4, Box 11.2, 11.8, Cross-Chapter Box 12.1} **(Table SPM.1)**

C.3.1 If global warming exceeds the assessed *very likely* range for a given GHG emissions scenario, including low GHG emissions scenarios, global and regional changes in many aspects of the climate system, such as regional precipitation and other CIDs, would also exceed their assessed *very likely* ranges (*high confidence*). Such low-likelihood high-warming outcomes are associated with potentially very large impacts, such as through more intense and more frequent heatwaves and heavy precipitation, and high risks for human and ecological systems particularly for high GHG emissions scenarios.
{Cross-Chapter Box 1.3, 4.3, 4.4, 4.8, Box 9.4, Box 11.2, Cross-Chapter Box 12.1, TS.1.4, Box TS.3, Box TS.4} **(Table SPM.1)**

C.3.2 Low-likelihood, high-impact outcomes[34] could occur at global and regional scales even for global warming within the *very likely* range for a given GHG emissions scenario. The probability of low-likelihood, high impact outcomes increases with higher global warming levels (*high confidence*). Abrupt responses and tipping points of the climate system, such as strongly increased Antarctic ice sheet melt and forest dieback, cannot be ruled out (*high confidence*).
{1.4, 4.3, 4.4, 4.8, 5.4, 8.6, Box 9.4, Cross-Chapter Box 12.1, TS.1.4, TS.2.5, Box TS.3, Box TS.4, Box TS.9**}** **(Table SPM.1)**

C.3.3 If global warming increases, some compound extreme events[18] with low likelihood in past and current climate will become more frequent, and there will be a higher likelihood that events with increased intensities, durations and/or spatial extents unprecedented in the observational record will occur (*high confidence*).
{11.8, Box 11.2, Cross-Chapter Box 12.1, Box TS.3, Box TS.9}

C.3.4 The Atlantic Meridional Overturning Circulation is *very likely* to weaken over the 21st century for all emission scenarios. While there is *high confidence* in the 21st century decline, there is only *low confidence* in the magnitude of the trend. There is *medium confidence* that there will not be an abrupt collapse before 2100. If such a collapse were to occur, it would *very likely* cause abrupt shifts in regional weather patterns and water cycle, such as a southward shift in the tropical rain belt, weakening of the African and Asian monsoons and strengthening of Southern Hemisphere monsoons, and drying in Europe. {4.3, 8.6, 9.2, TS2.4, Box TS.3}

C.3.5 Unpredictable and rare natural events not related to human influence on climate may lead to low-likelihood, high impact outcomes. For example, a sequence of large explosive volcanic eruptions within decades has occurred in the past, causing substantial global and regional climate perturbations over several decades. Such events cannot be ruled out in the future, but due to their inherent unpredictability they are not included in the illustrative set of scenarios referred to in this Report. {2.2, Cross-Chapter Box 4.1, Box TS.3} **(Box SPM.1)**

D. Limiting Future Climate Change

Since AR5, estimates of remaining carbon budgets have been improved by a new methodology first presented in SR1.5, updated evidence, and the integration of results from multiple lines of evidence. A comprehensive range of possible future air pollution controls in scenarios is used to consistently assess the effects of various assumptions on projections of climate and air pollution. A novel development is the ability to ascertain when climate responses to emissions reductions would become discernible above natural climate variability, including internal variability and responses to natural drivers.

D.1 From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO_2 emissions, reaching at least net zero CO_2 emissions, along with strong reductions in other greenhouse gas emissions. Strong, rapid and sustained reductions in CH_4 emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality.

{3.3, 4.6, 5.1, 5.2, 5.4, 5.5, 5.6, Box 5.2, Cross-Chapter Box 5.1, 6.7, 7.6, 9.6} **(Figure SPM.10, Table SPM.2)**

D.1.1 This Report reaffirms with *high confidence* the AR5 finding that there is a near-linear relationship between cumulative anthropogenic CO_2 emissions and the global warming they cause. Each 1000 $GtCO_2$ of cumulative CO_2 emissions is assessed to *likely* cause a 0.27°C to 0.63°C increase in global surface temperature with a best estimate of 0.45°C[41]. This is a narrower range compared to AR5 and SR1.5. This quantity is referred to as the transient climate response to cumulative CO_2 emissions (TCRE). This relationship implies that reaching net zero[42] anthropogenic CO_2 emissions is a requirement to stabilize human-induced global temperature increase at any level, but that limiting global temperature increase to a specific level would imply limiting cumulative CO_2 emissions to within a carbon budget[43]. {5.4, 5.5, TS.1.3, TS.3.3, Box TS.5} **(Figure SPM.10)**

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[41] In the literature, units of °C per 1000 PgC are used, and the AR6 reports the TCRE *likely* range as 1.0°C to 2.3°C per 1000 PgC in the underlying report, with a best estimate of 1.65°C.

[42] condition in which anthropogenic carbon dioxide (CO_2) emissions are balanced by anthropogenic CO_2 removals over a specified period.

[43] The term carbon budget refers to the maximum amount of cumulative net global anthropogenic CO_2 emissions that would result in limiting global warming to a given level with a given probability, taking into account the effect of other anthropogenic climate forcers. This is referred to as the total carbon budget when expressed starting from the pre-industrial period, and as the remaining carbon budget when expressed from a recent specified date (see Glossary). Historical cumulative CO_2 emissions determine to a large degree warming to date, while future emissions cause future additional warming. The remaining carbon budget indicates how much CO_2 could still be emitted while keeping warming below a specific temperature level.

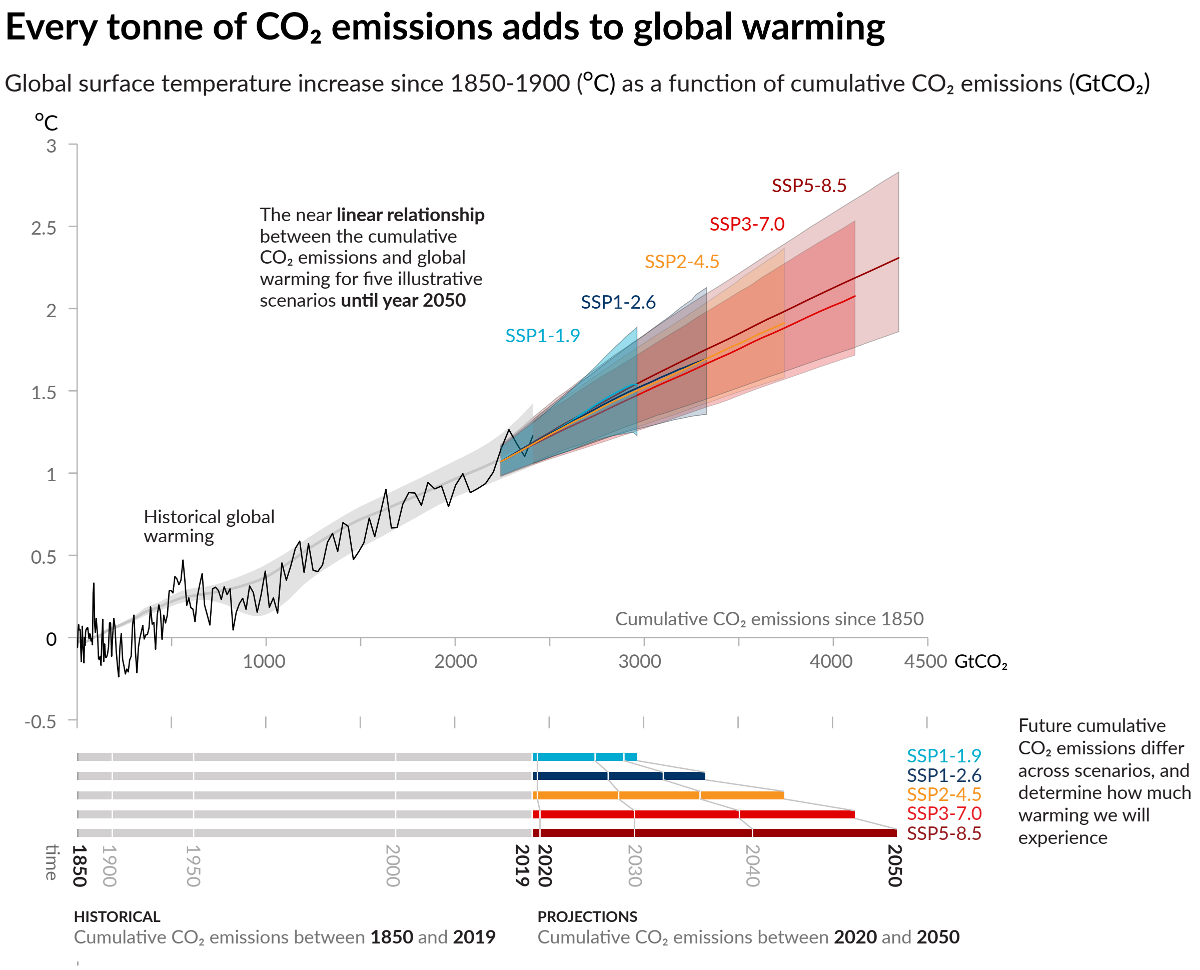

Figure SPM.10: Near-linear relationship between cumulative CO2 emissions and the increase in global surface temperature.

Top panel: Historical data (thin black line) shows observed global surface temperature increase in °C since 1850–1900 as a function of historical cumulative carbon dioxide (CO_2) emissions in $GtCO_2$ from 1850 to 2019. The grey range with its central line shows a corresponding estimate of the historical human-caused surface warming (see Figure SPM.2). Coloured areas show the assessed *very likely* range of global surface temperature projections, and thick coloured central lines show the median estimate as a function of cumulative CO_2 emissions from 2020 until year 2050 for the set of illustrative scenarios (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, see Figure SPM.4). Projections use the cumulative CO_2 emissions of each respective scenario, and the projected global warming includes the contribution from all anthropogenic forcers. The relationship is illustrated over the domain of cumulative CO_2 emissions for which there is *high confidence* that the transient climate response to cumulative CO_2 emissions (TCRE) remains constant, and for the time period from 1850 to 2050 over which global CO_2 emissions remain net positive under all illustrative scenarios as there is *limited evidence* supporting the quantitative application of TCRE to estimate temperature evolution under net negative CO_2 emissions.

Bottom panel: Historical and projected cumulative CO_2 emissions in $GtCO_2$ for the respective scenarios.

{Figure TS.18, Figure 5.31, Section 5.5}

D.1.2 Over the period 1850–2019, a total of 2390 ± 240 (*likely* range) $GtCO_2$ of anthropogenic CO_2 was emitted. Remaining carbon budgets have been estimated for several global temperature limits and various levels of probability, based on the estimated value of TCRE and its uncertainty, estimates of historical warming, variations in projected warming from non-CO_2 emissions, climate system feedbacks such as emissions from thawing permafrost, and the global surface temperature change after global anthropogenic CO_2 emissions reach net zero.
{5.1, 5.5, Box 5.2, TS.3.3} **(Table SPM.2)**

Table SPM.2: **Estimates of historical CO_2 emissions and remaining carbon budgets.** Estimated remaining carbon budgets are calculated from the beginning of 2020 and extend until global net zero CO_2 emissions are reached. They refer to CO_2 emissions, while accounting for the global warming effect of non-CO_2 emissions. Global warming in this table refers to human-induced global surface temperature increase, which excludes the impact of natural variability on global temperatures in individual years. {Table TS.3, Table 3.1, Table 5.1, Table 5.7, Table 5.8, 5.5.1, 5.5.2, Box 5.2}

Global warming between 1850–1900 and 2010–2019 *(°C)*	Historical cumulative CO_2 emissions from 1850 to 2019 *($GtCO_2$)*
1.07 (0.8–1.3; *likely* range)	2390 (± 240; *likely* range)

Approximate global warming relative to 1850–1900 until temperature limit *(°C)**(1)	Additional global warming relative to 2010–2019 until temperature limit *(°C)*	Estimated remaining carbon budgets from the beginning of 2020 *($GtCO_2$)* — *Likelihood of limiting global warming to temperature limit*(2)*					Variations in reductions in non-CO_2 emissions*(3)
		17%	*33%*	*50%*	*67%*	*83%*	
1.5	0.43	900	650	500	400	300	Higher or lower reductions in accompanying non-CO_2 emissions can increase or decrease the values on the left by 220 $GtCO_2$ or more
1.7	0.63	1450	1050	850	700	550	
2.0	0.93	2300	1700	1350	1150	900	

*(1) Values at each 0.1°C increment of warming are available in Tables TS.3 and 5.8.
*(2) This likelihood is based on the uncertainty in transient climate response to cumulative CO_2 emissions (TCRE) and additional Earth system feedbacks, and provides the probability that global warming will not exceed the temperature levels provided in the two left columns. Uncertainties related to historical warming (±550 $GtCO_2$) and non-CO_2 forcing and response (±220 $GtCO_2$) are partially addressed by the assessed uncertainty in TCRE, but uncertainties in recent emissions since 2015 (±20 $GtCO_2$) and the climate response after net zero CO_2 emissions are reached (±420 $GtCO_2$) are separate.
*(3) Remaining carbon budget estimates consider the warming from non-CO_2 drivers as implied by the scenarios assessed in SR1.5. The Working Group III Contribution to AR6 will assess mitigation of non-CO_2 emissions.

D.1.3 Several factors that determine estimates of the remaining carbon budget have been re-assessed, and updates to these factors since SR1.5 are small. When adjusted for emissions since previous reports, estimates of remaining carbon budgets are therefore of similar magnitude compared to SR1.5 but larger compared to AR5 due to methodological improvements[44].
{5.5, Box 5.2, TS.3.3} **(Table SPM.2)**

D.1.4 Anthropogenic CO_2 removal (CDR) has the potential to remove CO_2 from the atmosphere and durably store it in reservoirs (*high confidence*). CDR aims to compensate for residual emissions to reach net zero CO_2 or net zero GHG emissions or, if implemented at a scale where anthropogenic removals exceed anthropogenic emissions, to lower surface temperature. CDR methods can have potentially wide-ranging effects on biogeochemical cycles and climate, which can either weaken or strengthen the potential of these methods to remove CO_2 and reduce warming, and can also influence water availability and quality, food production and biodiversity[45] (*high confidence*).
{5.6, Cross-Chapter Box 5.1, TS.3.3}

D.1.5 Anthropogenic CO_2 removal (CDR) leading to global net negative emissions would lower the atmospheric CO_2 concentration and reverse surface ocean acidification (*high confidence*). Anthropogenic CO_2 removals and emissions are partially compensated by CO_2 release and uptake respectively, from or to land and ocean carbon pools (*very high confidence*). CDR would lower atmospheric CO_2 by an amount approximately equal to the increase from an anthropogenic emission of the same magnitude (*high confidence*). The atmospheric CO_2 decrease from anthropogenic CO_2 removals could be up to 10% less than the atmospheric CO_2 increase from an equal amount of CO_2 emissions, depending on the total amount of CDR (*medium confidence*). {5.3, 5.6, TS.3.3}

D.1.6 If global net negative CO_2 emissions were to be achieved and be sustained, the global CO_2-induced surface temperature increase would be gradually reversed but other climate changes would continue in their current direction for decades to millennia (*high confidence*). For instance, it would take several centuries to millennia for global mean sea level to reverse course even under large net negative CO_2 emissions (*high confidence*).
{4.6, 9.6, TS.3.3}

D.1.7 In the five illustrative scenarios, simultaneous changes in CH_4, aerosol and ozone precursor emissions, that also contribute to air pollution, lead to a net global surface warming in the near and long-term (*high confidence*). In the long term, this net warming is lower in scenarios assuming air pollution controls combined with strong and sustained CH_4 emission reductions (*high confidence*). In the low and very low GHG emissions scenarios, assumed reductions in anthropogenic aerosol emissions lead to a net warming, while reductions in CH_4 and other ozone precursor emissions lead to a net cooling. Because of the short lifetime of both CH_4 and aerosols, these climate effects partially counterbalance each other and reductions in CH_4 emissions also contribute to improved air quality by reducing global surface ozone (*high confidence*).
{6.7, Box TS.7} **(Figure SPM.2, Box SPM.1)**

[44] Compared to AR5, and when taking into account emissions since AR5, estimates in AR6 are about 300–350 $GtCO_2$ larger for the remaining carbon budget consistent with limiting warming to 1.5°C; for 2°C, the difference is about 400–500 $GtCO_2$.

[45] Potential negative and positive effects of CDR for biodiversity, water and food production are methods-specific, and are often highly dependent on local context, management, prior land use, and scale. IPCC Working Groups II and III assess the CDR potential, and ecological and socio-economic effects of CDR methods in their AR6 contributions.

D.1.8 Achieving global net zero CO_2 emissions is a requirement for stabilizing CO_2-induced global surface temperature increase, with anthropogenic CO_2 emissions balanced by anthropogenic removals of CO_2. This is different from achieving net zero GHG emissions, where metric-weighted anthropogenic GHG emissions equal metric-weighted anthropogenic GHG removals. For a given GHG emission pathway, the pathways of individual greenhouse gases determine the resulting climate response[46], whereas the choice of emissions metric[47] used to calculate aggregated emissions and removals of different GHGs affects what point in time the aggregated greenhouse gases are calculated to be net zero. Emissions pathways that reach and sustain net zero GHG emissions defined by the 100-year global warming potential are projected to result in a decline in surface temperature after an earlier peak (*high confidence*).
{4.6, 7.6, Box 7.3, TS.3.3}

D.2 Scenarios with very low or low GHG emissions (SSP1-1.9 and SSP1-2.6) lead within years to discernible effects on greenhouse gas and aerosol concentrations, and air quality, relative to high and very high GHG emissions scenarios (SSP3-7.0 or SSP5-8.5). Under these contrasting scenarios, discernible differences in trends of global surface temperature would begin to emerge from natural variability within around 20 years, and over longer time periods for many other climatic impact-drivers (*high confidence*). {4.6, Cross-Chapter Box 6.1, 6.6, 6.7, 9.6, Cross-Chapter Box 11.1, 11.2, 11.4, 11.5, 11.6, 12.4, 12.5} **(Figure SPM.8, Figure SPM.10)**

D.2.1 Emissions reductions in 2020 associated with measures to reduce the spread of COVID-19 led to temporary but detectible effects on air pollution (*high confidence*), and an associated small, temporary increase in total radiative forcing, primarily due to reductions in cooling caused by aerosols arising from human activities (*medium confidence*). Global and regional climate responses to this temporary forcing are, however, undetectable above natural variability (*high confidence*). Atmospheric CO_2 concentrations continued to rise in 2020, with no detectable decrease in the observed CO_2 growth rate (*medium confidence*)[48].
{Cross-Chapter Box 6.1, TS.3.3}

D.2.2 Reductions in GHG emissions also lead to air quality improvements. However, in the near term[49], even in scenarios with strong reduction of GHGs, as in the low and very low GHG emission scenarios (SSP1-2.6 and SSP1-1.9), these improvements are not sufficient in many polluted regions to achieve air quality guidelines specified by the World Health Organization (*high confidence*). Scenarios with targeted reductions of air pollutant emissions lead to more rapid improvements in air quality within years compared to reductions in GHG emissions only, but from 2040, further improvements are projected in scenarios that combine efforts to reduce air pollutants as well as GHG emissions with the magnitude of the benefit varying between regions (*high confidence*). {6.6, 6.7, Box TS.7}.

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[46] A general term for how the climate system responds to a radiative forcing (see Glossary).

[47] The choice of emissions metric depends on the purposes for which gases or forcing agents are being compared. This report contains updated emission metric values and assesses new approaches to aggregating gases.

[48] For other GHGs, there was insufficient literature available at the time of the assessment to assess detectable changes in their atmospheric growth rate during 2020.

[49] Near term: (2021–2040)

D.2.3 Scenarios with very low or low GHG emissions (SSP1-1.9 and SSP1-2.6) would have rapid and sustained effects to limit human-caused climate change, compared with scenarios with high or very high GHG emissions (SSP3-7.0 or SSP5-8.5), but early responses of the climate system can be masked by natural variability. For global surface temperature, differences in 20-year trends would *likely* emerge during the near term under a very low GHG emission scenario (SSP1-1.9), relative to a high or very high GHG emission scenario (SSP3-7.0 or SSP5-8.5). The response of many other climate variables would emerge from natural variability at different times later in the 21st century (*high confidence*).
{4.6, Cross-Section Box TS.1} **(Figure SPM.8, Figure SPM.10)**

D.2.4 Scenarios with very low and low GHG emissions (SSP1-1.9 and SSP1-2.6) would lead to substantially smaller changes in a range of CIDs[36] beyond 2040 than under high and very high GHG emissions scenarios (SSP3-7.0 and SSP5-8.5). By the end of the century, scenarios with very low and low GHG emissions would strongly limit the change of several CIDs, such as the increase in the frequency of extreme sea level events, heavy precipitation and pluvial flooding, and exceedance of dangerous heat thresholds, while limiting the number of regions where such exceedances occur, relative to higher GHG emissions scenarios (*high confidence*). Changes would also be smaller in very low compared to low emissions scenarios, as well as for intermediate (SSP2-4.5) compared to high or very high emissions scenarios (*high confidence*). {9.6, Cross-Chapter Box 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.9, 12.4, 12.5, TS.4.3}

News in pursuit of truth

PEOPLE & PLACES

Panic attacks. Ringing ears. Shaking walls. Happy 1-year anniversary to the F-35s.

By **Grace Elletson**
Sep 27 2020

A formal ceremony commemorating the arrival of the F-35 Lightning II aircraft to the 158th Fighter Wing was held at the Vermont Air National Guard base in South Burlington on Oct. 19, 2019. Photo by Glenn Russell/VTDigger

Jen Lazer didn't think that motherhood in Burlington, Vermont, would include desensitizing her baby to the frequent roar of F-35 fighter jets.

"She stares at the sky and shakes and cries and grabs me. She thrusts her head into my chest," Lazer said. "We explain that there are machines that make big noises; they're planes. But she's so little. The heartbreak feels immediate."

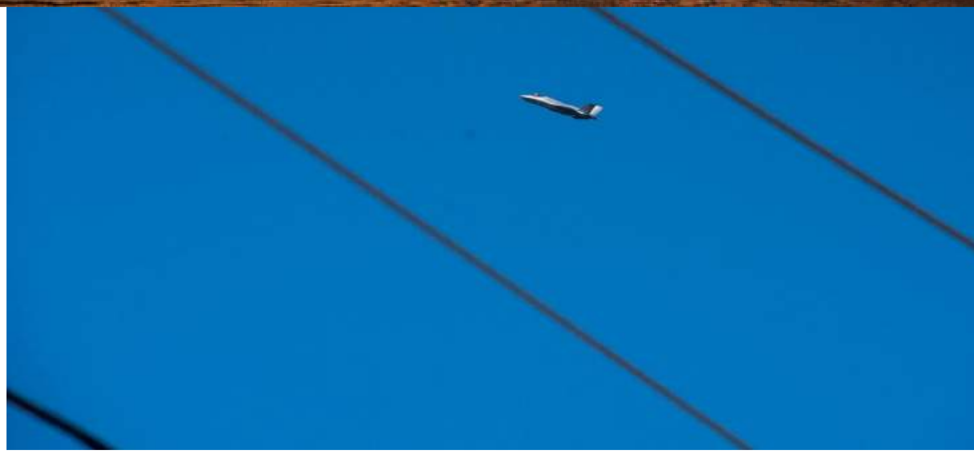
For the past year, this has been her reality. Lazer's daughter, who is barely a year old, has begun her life attempting to make sense of the $80 million, 115-decibel-roaring hunk of metal flying overhead. It's an almost daily trauma that Lazer didn't think her daughter would have to overcome.

"There's the broader heartbreak of it, where I'm trying to teach her to feel comfortable with military jets overhead," Lazer said. "These are really advanced military sounds that I don't want her growing up having to learn to be comfortable with."

The Lazers are one family among many whose lives have been disrupted by the jets that arrived at the Burlington International Airport almost exactly a year ago. Many residents in the jets' flight path — which covers parts of Burlington, Winooski and Williston — say the jets are more than just a nuisance. They're hurting their quality of life and degrading their health.

For years, residents warned officials about what would happen if the jets came to town. They pointed to research conducted by the Vermont Department of Health that found repeated exposure to the decibel levels achieved by the jets can cause hearing loss. In 2018, Burlington residents voted to cancel the F-35 basing. Burlington Mayor Miro Weinberger refused to sign a resolution supporting that vote. The jets came anyway.

Both the Winooski and South Burlington city councils voted to halt the arrival of the jets. Residents and physicians protested against the jets for days outside Sen. Patrick Leahy's office. Multiple court challenges attempted to stop the arrival of the jets. All that failed, and the jets came anyway.



A Vermont Air National Guard F-35 fighter jet flies over Burlington on Friday, September 18, 2020. Photo by Glenn Russell/VTDigger

Col. David Shevchik Jr., commander of the Vermont Air National Guard Air 158th Fighter Wing, said he's continuing to attend city council and selectboard meetings in an effort to quell concerns. But ultimately, his fleet has a job to do. Because the F-16 jets that had been stationed at the airport have been phased out, his unit needs to become a mission-ready wing of F-35 jets in the next 16 months.

"We certainly understand that there are concerns," Shevchik said. "That's why it's important for us to balance our community considerations, within reason, while we're still meeting the mission and training requirements. And that's obviously difficult to do, but it's important to do."

Does he think it's still safe for residents to live within the jets' flight path?

"Absolutely," Shevchik said.

'It makes my insides rattle'

The ringing in Amanda Lavertu's ears didn't exist until the F-35A Lightning II aircraft arrived.

"It's been loud. Very loud," Lavertu said, who lives near the Winooski traffic circle. When the jets fly over, they shake the walls of her shower. They petrify her older dog, who she said sinks to his belly and crawls toward cover when the jets roar over. He'll hide under the kitchen table or in a nearby closet.

Lavertu's Apple watch records decibel levels; when an ambulance passes by, it'll get into the 80s. A loud truck might hit 50 or 60 decibels. But when the jets fly over, she said her watch records a 90-100 decibel level. And that's inside her home.

"And I started wondering about that because I was getting a ringing in my ear, and I've never had ringing in my ear," Lavertu said. "And it's getting even more drastic. Like it's even more of a constant than even when we first moved in. And prior to that, I didn't have it."

Megan Brazeil of Burlington says she suffers anxiety attacks when Vermont Air National Guard F-35 fighter jets fly overhead. Seen on Friday, September 18, 2020. Photo by Glenn Russell/VTDigger

Megan Brazeil, who lives in Burlington's Old North End, said being outside when the jets fly over has become unbearable for her.

"They're so loud, they trigger a physical response. Because I do have a panic disorder, and I have anxiety attacks or panic attacks. And they give me panic attacks," Brazeil said. "The first time, I thought I was going to have a seizure. I was freaking out."

"It makes my insides rattle," she said. Brazeil said the other day she tried to go to North Beach to practice mediation and yoga to help ease her anxiety. But the sudden and unpredictable roar of the jets broke her peace. "They're so loud," she said. "And there's no escaping."

Brazeil said she wants to move from her current home in the North End, and the jets are a strong contributing factor. Lavertu said she also plans to move away from Winooski because of the overwhelming presence of the jets.

Afterburners aren't the problem

Jeanne Keller, who lives on Bilodeau Parkway in Burlington with her husband, said the jets have "seriously degraded the quality of our lives."

"The first problem is the sound. When they take off and land, it is qualitatively different than the sound of the F-16. It is a much deeper, more resonant sound," Keller said. Previously, Burlington International Airport housed a fleet of F-16 jets. Keller, who has lived in her home for over 30 years, said the sound difference between the two jets is clearly noticeable.

time. Then there's a lull. We don't know how long the lull is going to be so we wait for the other shoe to drop and then another four take off," she said.

"So there are days when, four times a day for 20 minutes, while they're taking off, and then 20 minutes when they come back and land, we can't talk," Keller said. "We can't talk on the phone. We can't talk to each other. We can't hear music. And it doesn't matter whether we're inside or outside."

South Burlington residents Barb Sirvis and Jim Maloney examine a noise impact map during a public meeting on the Noise Compatibility Program at the Burlington International Airport in South Burlington on Thursday, October 24, 2019. Photo by Glenn Russell/VTDigger

She wondered if the jets are so loud because of afterburner use — auxiliary jets that increase thrust and noise on takeoff. But Shevchik said that's not the case. In the time that the F-35s have been stationed in Burlington, an afterburner was used only once out of hundreds of flights, and that was by mistake.

Graber said it was used by a pilot who had returned from a training program where afterburners are used more frequently because it was at a high altitude, and the air is thinner than in Burlington. Because Burlington has cooler temperatures and a lower elevation, the extra thrust isn't needed.

The current noise levels have driven a spike in complaints against the F-35 program. According to data provided by the National Guard, it received 665 negative calls or emails about the jets so far in 2020. All but 16 of those complaints were related to the jets' noise. During the three months they landed in Burlington during 2019, the Guard received 62 noise complaints.

While the F-16 jets were stationed at the airport, the guard received 195 noise complaints in 2015, 152 in 2016, 20 in 2017 and only one in 2018.

Some residents appreciate the presence of the jets and see them as a patriotic symbol that Burlington should be proud to house.

Courtney Weisert wrote in an email that the jets are one of her favorite elements of Burlington life.

"I love hearing our very own Green Mountain Boy pilots practicing their craft," Weisert wrote. "My newborn sleeps right through it but I hope one day when she's older, she gets to appreciate the sound as well." According to a LinkedIn page, Weisert is an instructor at the Vermont Army National Guard.

Burlington resident Susan Winston said she thinks the jets are "exciting." She said she was at the airport the day they arrived last September.

"I think they bring a sense of security, having them here," Winston said. "They bring economic growth, which you know, what city can't use that right now? I love watching them take off and land, I really do."

That's according to the latest projections drafted by Burlington airport officials. Nic Longo, deputy director of aviation, knows this is frustrating to homeowners who are experiencing uncomfortable levels of noise right now.

"The airport really does want to help any individual with any of their unique needs and perspectives of noise," Longo said. "I do want to sit and meet with them. And if it comes down to all 2,600 dwelling units, I would do that in a heartbeat."

Longo said the Federal Aviation Administration just recently approved the airport's Noise Compatibility Program, which details the different efforts the airport plans to make to address noise mitigation and lowered home values due to the jets. Now these programs will be eligible for funding, which Longo said the state will have to apply for yearly.

This year, the airport will kick off an acoustical home-testing pilot program. Ten houses will be selected within the 65-decibel flight path map drawn up by the airport, and they'll be tested to determine if they're eligible for soundproofing. If the test finds that the jets cause an 45-decibel sound within the home, it's likely they'll be approved.

Once this testing is completed, next year the airport can apply for money to do the soundproofing. Longo said the airport is able to soundproof 50 houses a year at an estimated $50,000 each, which is why it'll likely take more than a decade to finish.

The airport has also received approval for a home purchase assurance program and sale assistance program.

Through the purchase assurance program, homeowners within the flight path can sell their home to the airport at a fair market value after an appraisal. The airport would soundproof the home and resell it, not at a profit, Longo said. If all 2,600 homes participated in that program, it would cost an estimated $60 million.

Through the sale assistance program, homeowners can receive a fair market appraisal by the airport and then sell the home on the open market themselves. If they get an offer below the market value, the airport would pay the difference. If all 2,600 homes participated in that program, it would cost an estimated $13 million.

The most recent FAA noise mitigation grant came earlier this month. The airport secured $6.3 million to construct sound monitoring units, soundproof the Chamberlain Elementary School in South Burlington and build new terminal infrastructure.

For all grants awarded by the FAA to complete these programs, there's an expectation that municipalities have to pick up 10% of the cost, which some officials have strongly opposed.

What the mayors say

Neither Burlington Mayor Miro Weinberger nor Winooski Mayor Kristine Lott responded to direct questions about whether they believe it's safe for residents to live within the F-35 flight path. (After Weinberger's communication coordinator, Olivia LaVecchia, was pressed for an answer, she said the mayor has given VTDigger hours of interviews on this subject and his statement tries to address this question.)

In an emailed response to VTDigger, Weinberger said he continues to support the basing of the F-35 jets despite it being a "very challenging decision with both real benefits and clear concerns" to invite them to the city.

"I continue to believe it was the correct course for the reasons that I outlined in an op-ed published in VTDigger in April 2018," Weinberger wrote. "The city continues to work closely with our federal delegation and other partners to mitigate the impacts of the basing where possible, including our recent work to successfully secure $3.49 million for soundproofing at Chamberlin Elementary School and additional funds for a noise monitoring program."

"This work to secure resources is ongoing," Weinberger wrote, "and will continue to yield new quality-of-life supports for the neighborhoods surrounding the airport."

Lott wrote in an email to VTDigger that she has "concerns about the potential increase in health risks" associated with the F-35s, but wouldn't say if she thinks it's currently unsafe for residents to live in the flight path. She frequently hears from residents who both support and criticize the F-35s.

"Winooski's City Council has been passing resolutions that oppose the basing of F-35s at the Burlington International Airport since 2012 and even entered into a lawsuit a few years ago," Lott wrote. "The lawsuit was not successful and the resolutions did not sway our state and federal leaders on their decision to bring these jets to our region."

She said Winooski officials have now turned their attention to noise mitigation efforts, which are moving forward.

University of Vermont Medical Center staff look on as four Vermont Air National Guard F-35 jets fly over the Burlington hospital to thank health care workers on Friday, May 22, 2020. Photo by Glenn Russell/VTDigger

[REPORT AN ERROR] [UPLOAD A DOCUMENT][TIP DROP]

Filed under:
PEOPLE & PLACES
Tags: Burlington, David Shevchik Jr., F-35, National Guard, Vermont Department of Health

About Grace

Grace Elletson is VTDigger's government accountability reporter, covering politics, state agencies and the Legislature. She is part of the BOLD Women's Leadership Network and a recent graduate of Ithaca College, where she was editor in chief of the Ithacan. She previously interned for the Chronicle of Higher Education, The Christian Science Monitor and The Cape Cod Times, her hometown newspaper.

Email: grace@vtdigger.org
View all stories by Grace Elletson

Send us your thoughts

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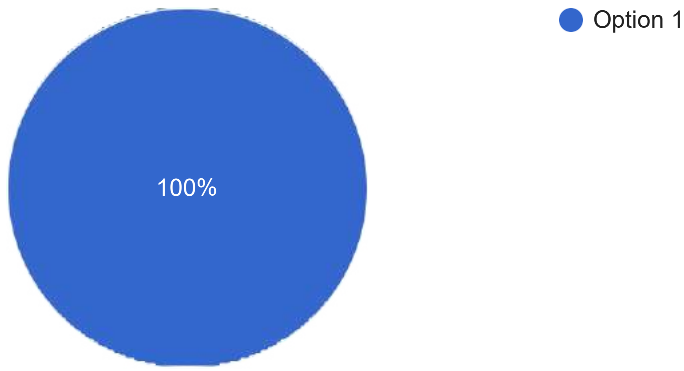
[RECENT STORIES]

SR0547

Complaint Form

447 responses

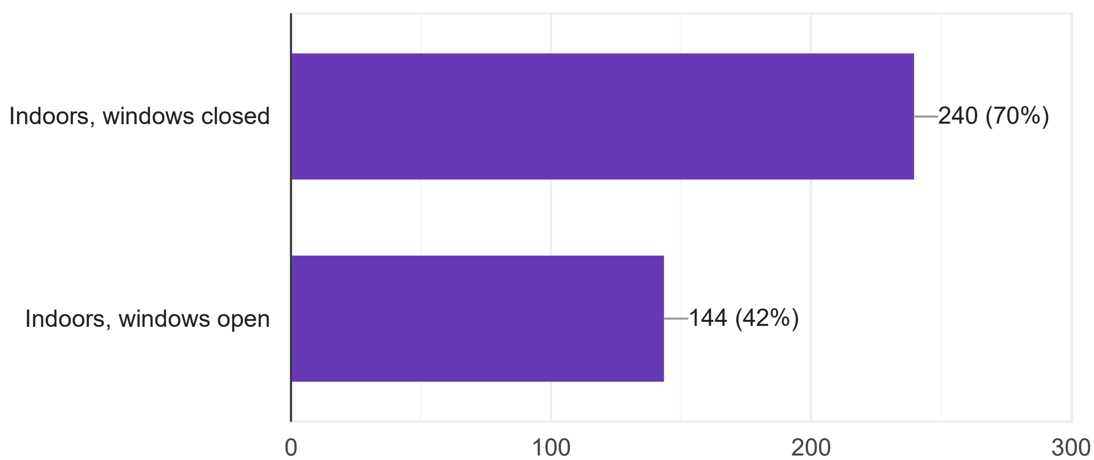
13 responses



Were you indoors or outside when exposed to F-35 noise?

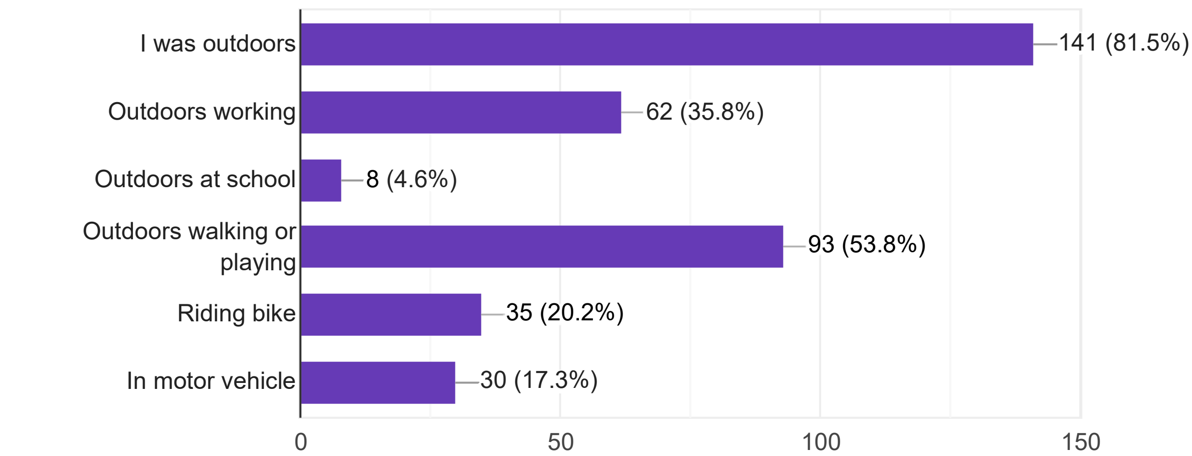
If you were indoors were the windows open or closed?

343 responses



If you were outdoors check all that apply

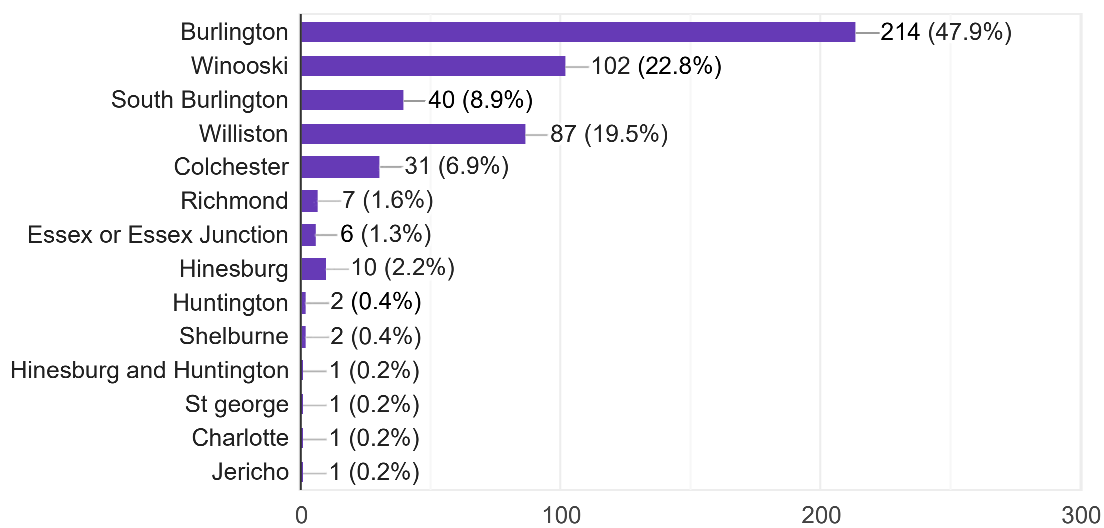
173 responses



Town, location, date, and time when you were exposed to F-35

Town where I was exposed to F-35

447 responses



Give address or cross streets where you were exposed to F-35 noise

424 responses

297 Abigail Dr

70 Bilodeau Ct.

67 Roseade Parkway

190 Elmwood

Staniford rd

Hood and Hawthorne

Loomis & Greene St

25 North Street

North Brownell Road

Give date and time of your exposure to F-35 noise

440 responses

5/27/21

4/8/21

Usually around 4:00pm to as late as 10pm

4/7/2021

April 8 2021 7:50-7:52pm

4/7/21

5/19/21

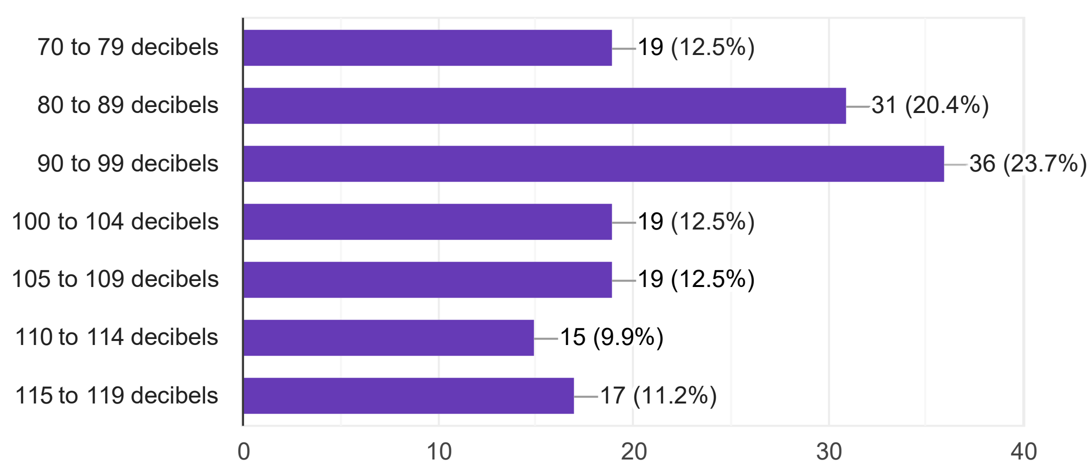
4/16/21 5:20pm

10x today (and tonight)? I lost track

Noise Level

If you had a noise measurement device, what was your measurement of peak F 35 noise level?

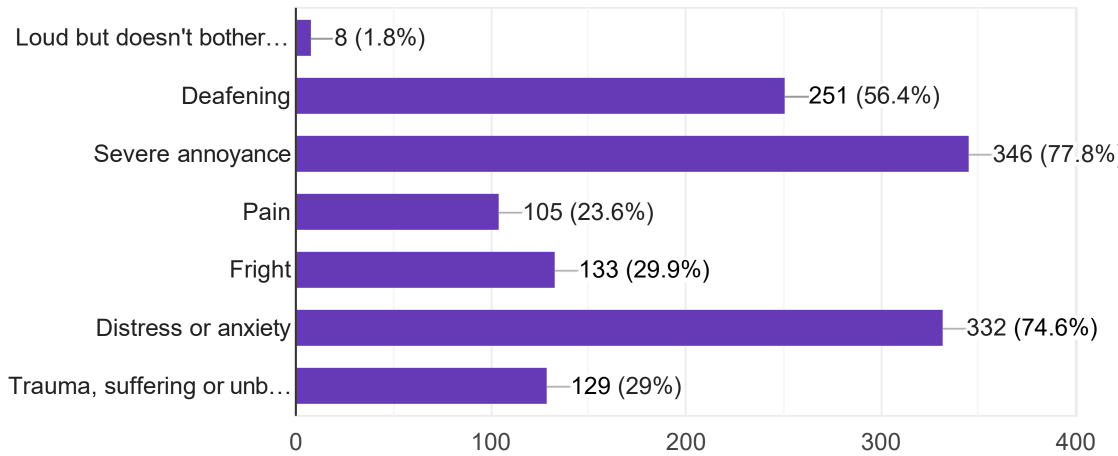
152 responses



Overall experience

Your overall experience with F-35 noise

445 responses



Further describe your experience in your own words if desired

305 responses

Always stops conversations, blocks bird songs and upsets dog

Inside, at first I thought it was thunder it was so loud! 6 min later I can still here it. Saw the aircraft from my window. Noise is annoying and very stressful to think about death and the military.

It's fucking AWFUL

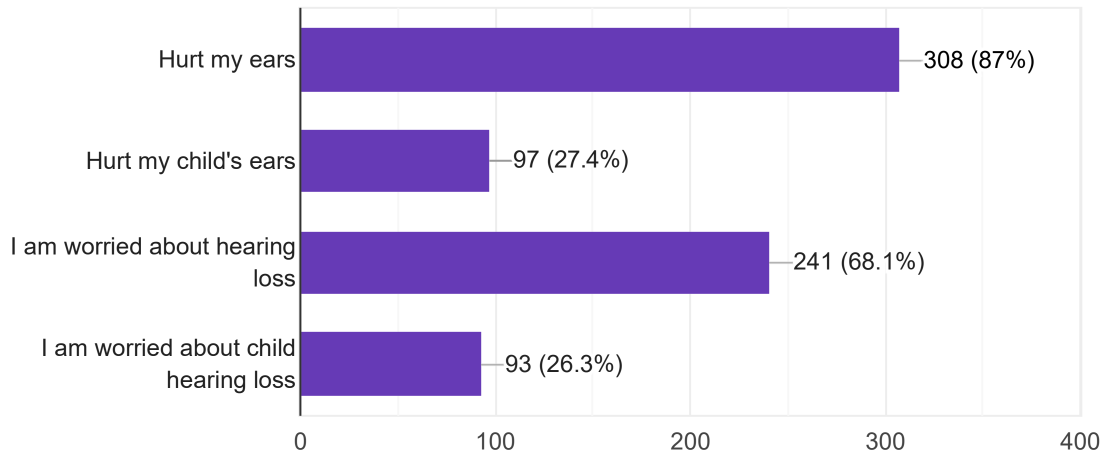
When they started taking off, I checked the time and said "Did the clocks change? It's not 9:20AM" --- which is the time we generally start preparing ourselves for the sudden but predicatable scream and roar of the F-35 morning flights departing. It was only not "deafening" because this morning they took off south, terrorizing the people in Williston, Richmond, Hinesburg, and Huntington, instead of us in East End Burlington and Winooski. I generally measure 80db constant inside my Burlington home during north-facing take offs. Outside far worse, especially when the butt-end of the F-35 is facing me as the jets climb.

So, now our earlier mornings are also going to be ruined for the war games practice?

Effects on Your Ears and Hearing

Effect of your exposure to F-35 noise on your ears and hearing

354 responses



Further describe ear pain or worry about hearing loss in your own words if desired

132 responses

When jets first arrived I had an inadvertent exposure to them taking off near Kirby Rd in So Burlington with my cat windows open causing severe pain and ringing lasting several days. Since then, ears have been much more prone to pain.

It's ABSURD

I hated working in a garden raising organic food and feeling like the place was being in a war.

Repeat exposure to these noise levels are inhumane

Buzzing in ears

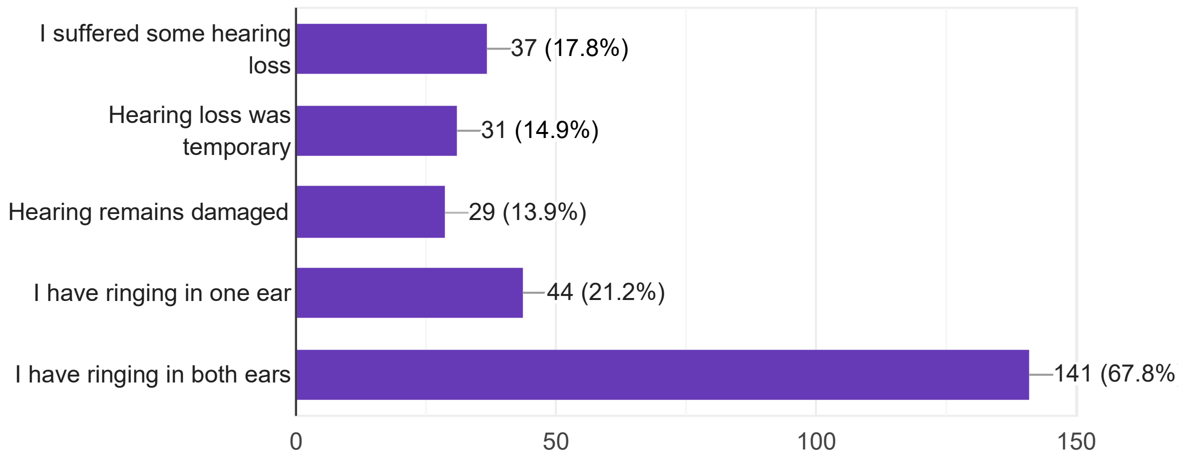
No pain. Stop exaggerating your claims

Not worried about hearing damage. Noise brings all human communication to a hard stop

Effects on your hearing

Hearing loss

208 responses



Further describe effect on your hearing in your own words if desired

62 responses

perhaps I need to purchase military grade ear protection and wear it all day?

Exposure isn't long enough to suffer hearing loss.

I have a constant singing sound in my ears "zzzzzng" Hearing loss doesn't come back.

cascade of stress chemicals- increased heart rate and utter anger and sadness that VT Representatives think this is ok! They have the facts and CHOOSE to put constituents at risk. THAT should be a crime. Accountability? It's time.

It hurts and is by no means reasonable.

Can’t hear well during or after the noise.

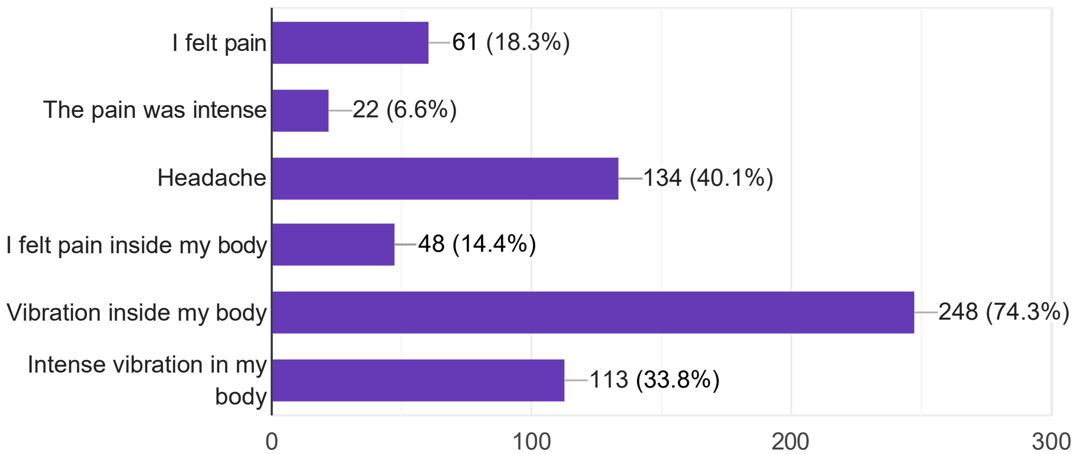
This noise exacerbates tenitus

No effect on hearing.

Effects on Your body

Did the F-35 cause pain or internal vibration?

334 responses



Further describe the pain or the vibration in your own words if desired

77 responses

Inside so felt a mild vibration in my head.

The very low frequency of the F-35 when taking off or screaming overhead preparing for landing is qualitatively so different from the F-16s. No comparison. I can feel it in my chest when they take off. This cannot be healthy.

I felt really agitated. Anxious.

unbelievable! criminal! deliberately, knowingly exposing my family to health risk / pain

Couldn't settle thought after, buzzing ongoing

If anyone checks these, they're a liar.

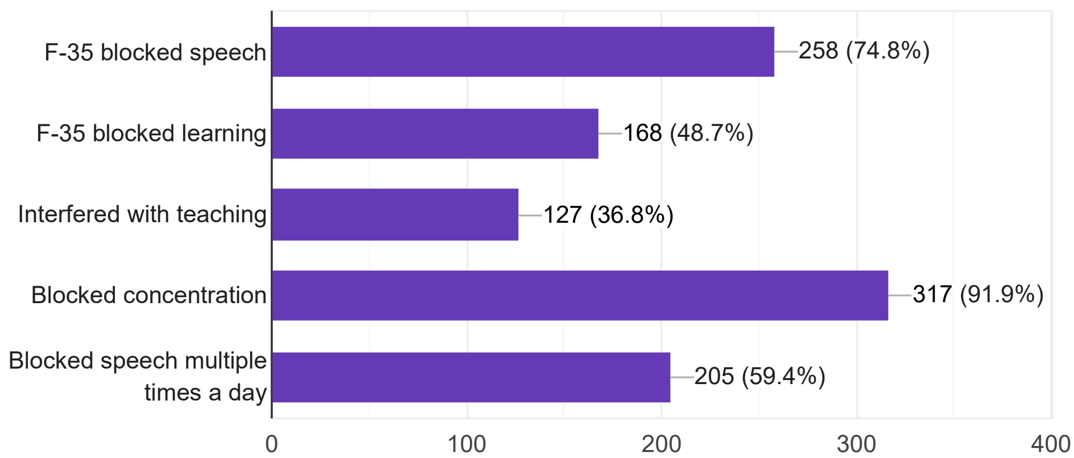
Like I said, like a jackhammer on my brain. My stomach feels the rumble.

I have migraines and the tension and sound exacerbates them.

Speech & learning

In the Environmental Impact Statement the Air Force states that high aircraft noise levels can impair learning. Please describe your experience of F-35 while learning at home or at school.

345 responses



Describe effect of F-35 noise in your speaking or learning at home or in a classroom at school in own words if desired

124 responses

Distracted me, forgot what I was doing.

Impossible to carry on conversation or even think during the six minutes of constant roar and rumble while a "pod" of four-packs takes off.

cannot concentrate or speak/hear when flying over

My dogs and I come inside when the planes fly over. The dogs hate them.

Learning, teaching, concentrating is impossible when these planes fly over like right now.

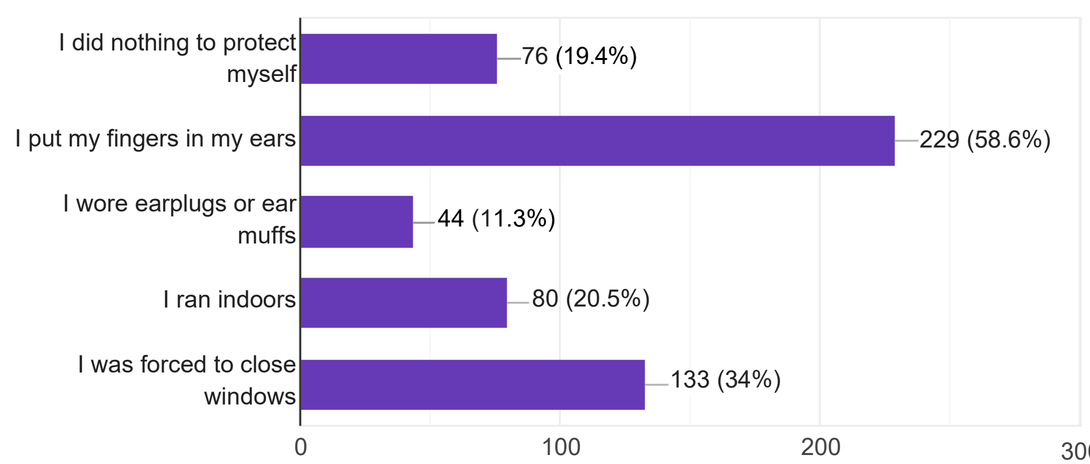
If it flies during class or video lecture I cannot hear what is going on, or I cannot speak in class. This also affect other students in the class so everyone just has to stop for a while. Class time is valuable and expensive.

Very disruptive

Protective measures

What did you do to protect yourself from the F-35 noise?

391 responses



Your action to protect yourself from F-35 noise in your own words if desired

136 responses

Hands covering ears

There is NOTHING that can be done. Stopping my ears for the six minutes it takes for each pod of four-packs to take off is hopeless but I keep hoping it will work. Still, there is no talking, music, bird sounds or wind in the trees while they are taking off. It's like time and the world stops and waits for it to end.

there's nothing to do

I am buying earmuffs tomorrow because I am irritated by having to choose between covering my ears or continuing with my current tasks.

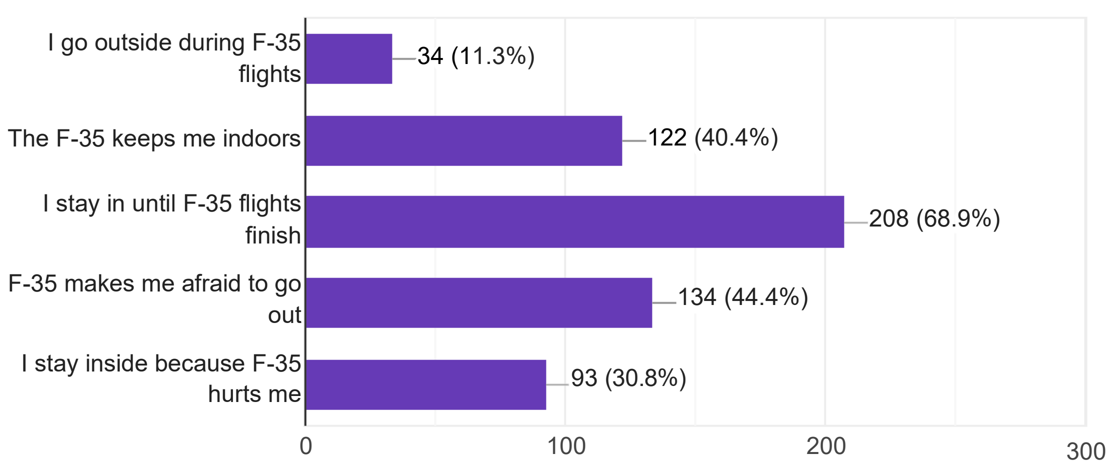
they knew from the beginning that there was nothing they could do to mitigate noise /health risks and should be held accountble

I had my door open to my deck to let air in but when I started to hear the f-35 I got up to close it

Does F-35 Keep You Indoors?

Do the daily F-35 flights keep you confined indoors for a period of time?

302 responses



In your own words if desired: Are you kept inside by F-35 flights?

131 responses

No

Yes

Sometimes, but the flight pattern is so random I never know when they will fly by... sometimes it is multiple times in one day!

It's not a matter of inside or outside! It's deafening EVERYWHERE

It wouldn't help. Can still feel and hear them taking off and landing.

There is no schedule so I am regularly caught outside with my toddler during flights

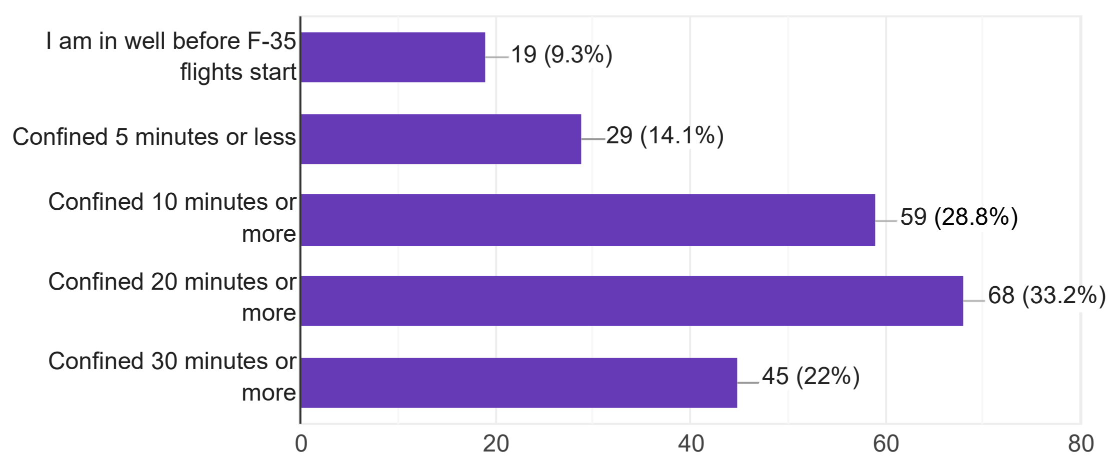
I work as a gardener and am an avid walker and biked. I am outside most of the time. These flights are causing me great distress!

Luckily if the f-35s fly over where I am working outside, I am already wearing ear protection for the chainsaw.

How long are you confined indoors?

Does the varying F-35 takeoff time keep you confined indoors longer than the actual flight time?

205 responses



Are you kept inside a longer time than the actual F-35 flights? How long does the F-35 noise keep in you inside, in your own words if desired

80 responses

No

I'm not sure how to answer this. I can hear them a long way away.

The noise lasts 2 to 3 minutes. I stop what I am doing for this period to cover my ears and hopefully prevent hearing loss.

unscheduled for safety reasons? define that.

I don't really know what time they fly because my day varies, I don't adjust my activity

Lmao. Is the F35 holding a gun to your head telling you to stay inside?

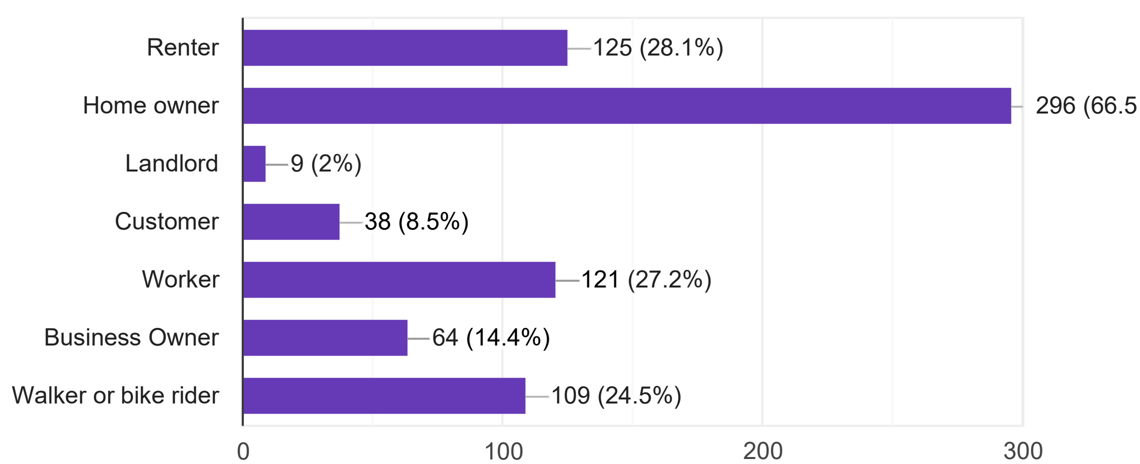
I do not have the schedule. Am usually indoors

Yes, we know they vary the times so we will often give a full hour buffer around the typical times of day we know they will fly. They do sometimes randomly fly at

Status--Renter, home owner, worker . . .

Reasons I was in the area affected by F-35 noise

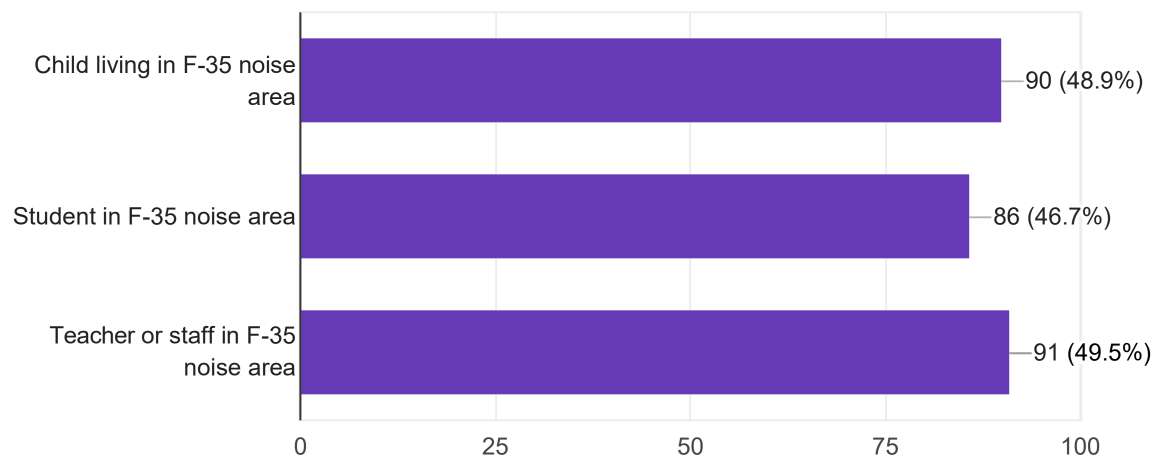
445 responses



Status--Child, student, teacher

Check all that apply to further describe your reasons for being in the F-35 noise area

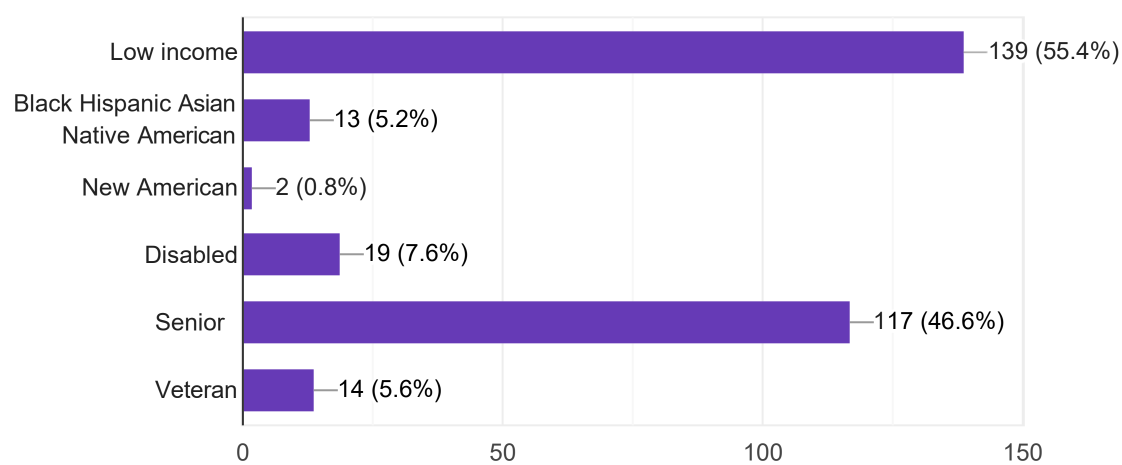
184 responses



Disproportionate impact

In its Environmental Impact Statement, the Air Force states that the F-35 flights in Burlington will have "disproportionate impact" on low income and minority populations. Please indicate your status.

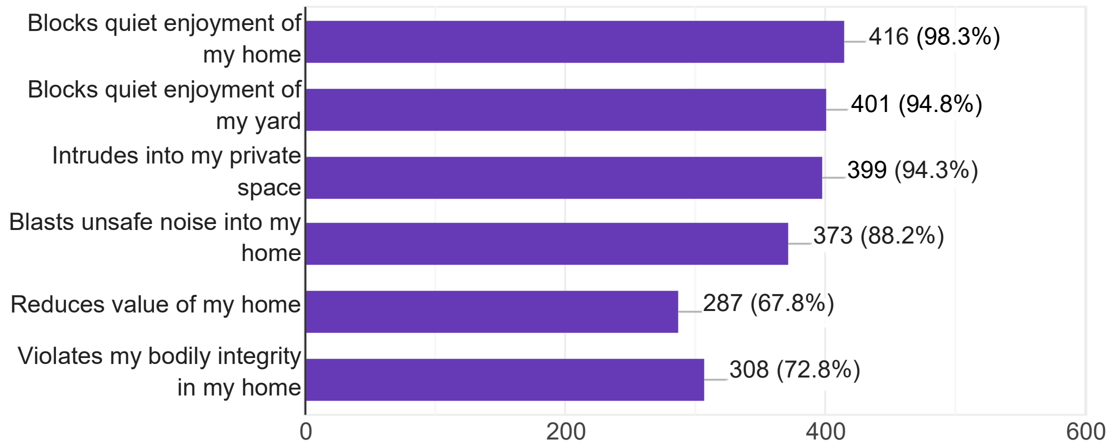
251 responses



My Home, Yard, and Family

F-35 effects on home, yard, & family. Check all that apply.

423 responses



F-35 impact on your home and family in your own words if desired

103 responses

all of the above

Constant rage

I would NEVER show my house to potential buyer at any time they might be taking off or landing. I would NEVER buy a house that faces this assault every day like we now do.

VTANG has told me that they do NOT consider multiple calls from the same person---as that person is a " complainer"--so if I committed multiple assaults, only one counts? Good to know that's how this rigged system protects people---not that they should even be here, ruining VT

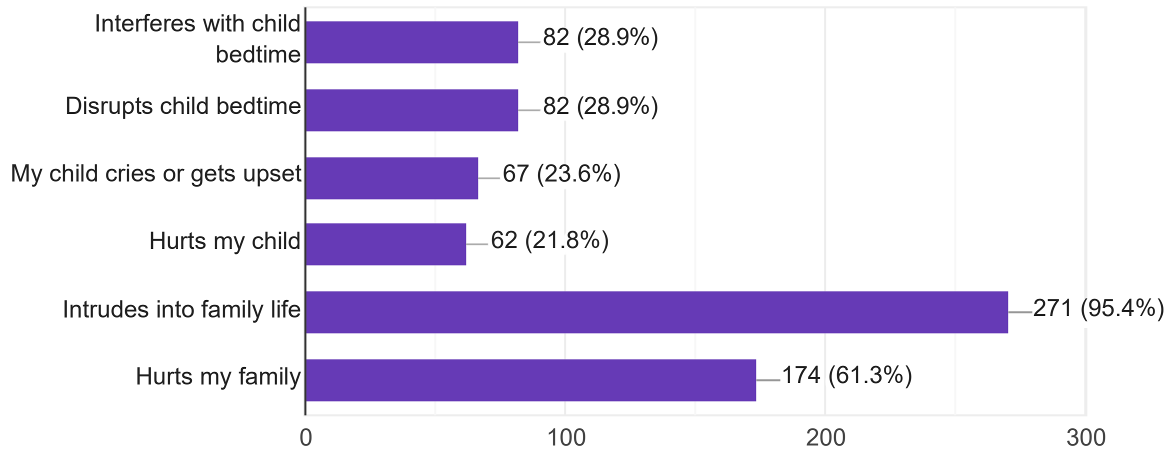
The noise causes moments of acute anxiety and fear when otherwise at rest in my home.

The F35s should not be stationed in a residential area. I also live in the commercial

Night Flights of the F-35

Check all that apply to night flights of the F-35

284 responses



F-35 night flight impact on your home and family in your own words if desired

81 responses

I have no young children but I can only imagine the impact on my neighbors who do. When multiple pairs of jets build their crescendo several times an evening

Inarticulatable rage at the magnitude of this stupidity

I can't wait for flights to be over.

GET F35's OUT OF VT NOW and hold politicians who rigged this basing accountable for the damage and suffering they knowingly cause

Usually by 8 PM I try to wind down and relax due to sleep issues. The f-35s at night disrupt my quiet relaxation time

Again, y'all chose to live near an airport. That's on you.

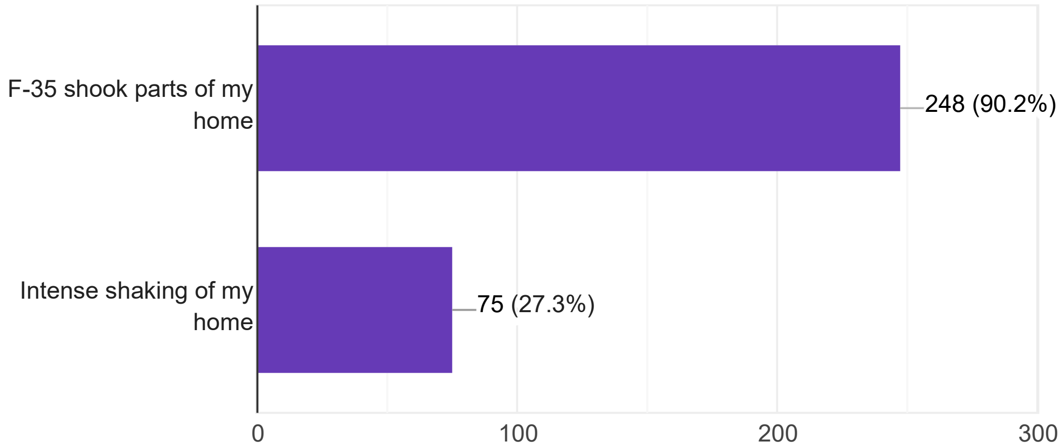
makes it hard to go to bed on time and go to sleep. I'm 70.

TOTAL BULLSHIT

Physical Impact on My Home

F-35 shaking of my home. Check all that apply.

275 responses



F-35 physical impact on your home in your own words if desired

85 responses

Noise

No shaking.

Windows vibrate

the vibrations knocked a clock off the wall

Have listed earlier in form. Deep resonating vibration in frame of house and windows that we never experienced with the F-16s. And we are supposedly in a sound zone that was IMPROVED by the F-35s vs F-16. TOTAL LIE!

this time? far alarm, broken glass

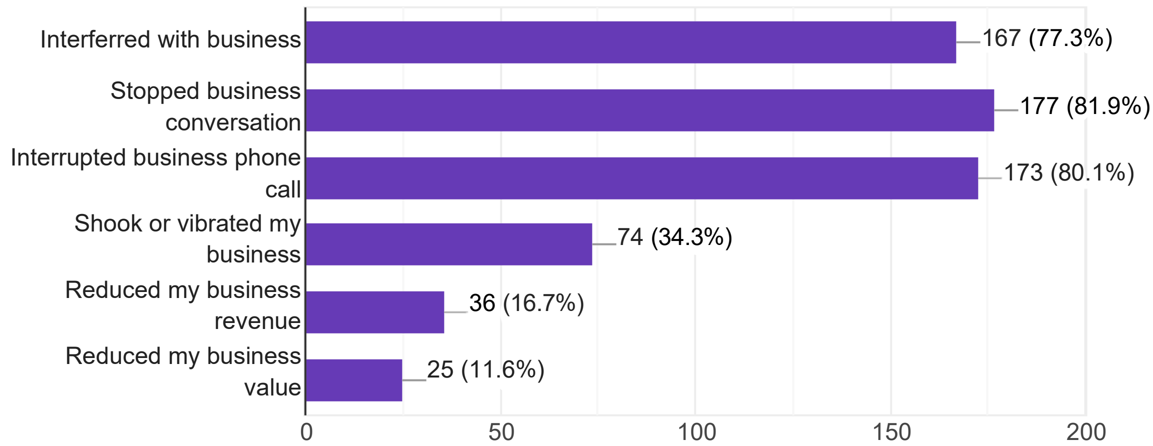
It's a plane... Not an earthquake generator.

House Shaking

Impacts on my businesses

My business. Check all that apply.

216 responses



F-35 impact on your business in your own words if desired

65 responses

Distracted me from working on business at home.

I take a lot of Zoom classes and webinars and can't talk when the planes go over.

Frequently experience interruptions in work meetings due to noise

Interrupts all business communication when they are flying during the day.

TOTAL BULLSHIT

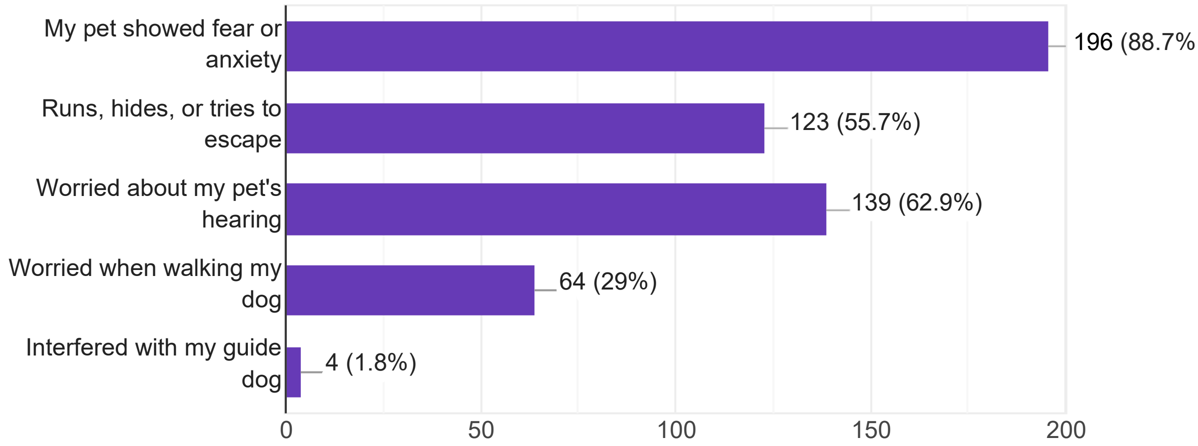
I don't know if my clients choose to work with others because it's annoying to try and communicate with me when we are so often interrupted, I just know it stops all communication until they pass. Depending on where the client is, sometimes right after it stops for me, we have to stop for them as they pass my client's house.

Both my wife and I own and run businesses in Winooski, Burlington, and my business also has a shop in Essex Junction. The F-35s have interrupted sales meetings, client meetings, team meetings, zoom meetings, phone calls, outdoor

Impact on pets

My dog or cat. Check all that apply

221 responses



Impact of F-35 on your dog, cat, or other pet in your own words if desired

47 responses

No pets

Worried about pets well being. Worried about wildlife.

And mine is the cattest of all cats, and still runs scared while they are taking off, but there is no escape.

I'm worried about my gecko's hearing in the summer when the windows need to be open (no ac) she is a small animal and cannot handle the same level of stress as a dog or cat

Pets don't care.

TOTAL BULLSHIT

N/A

As a dog trainer I have heard first-hand from many clients who live in areas of

Contact information

My name (optional)

227 responses

David Nacmanie

Mike Chamness

Nicholas Gray

Terry Marron

Susan Parente

G

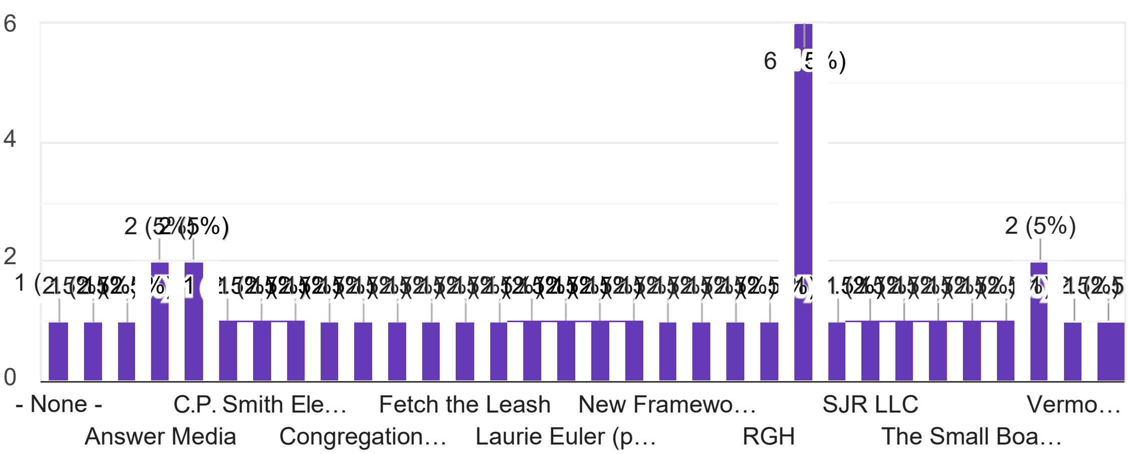
Craig Chevrier

Paul Rocheleau

Adam Jacobs

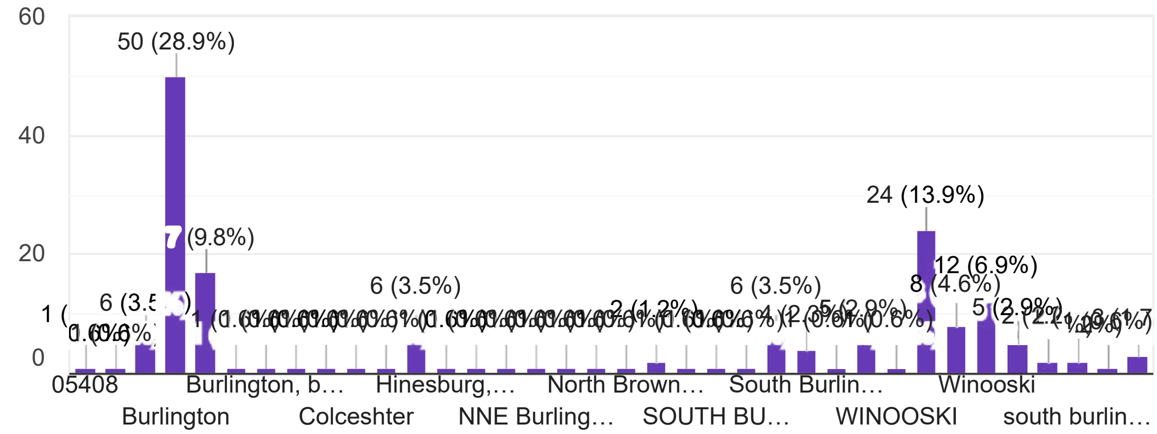
My business's name (if applicable)

40 responses



My home or business town (optional)

173 responses



My home or business street address (optional)

118 responses

Pearl St

637 CHRISTMAS LN

North Brownell Road.

49 Pleasant Acres Drive

37 Bright Street

29 HILDRED DRIVE

360 White Street

205 Archibald

25 North Street

My telephone number (optional)

75 responses

18028783953

802-557-0628

8023243081

8023496328

8023561668

8022383356

504.209.4960

8028815811

8027341936

Provided below are further responses available by scrolling through the online survey.

Further describe your experience in your own words if desired 305 responses

Always stops conversations, blocks bird songs and upsets dog

Inside, at first I thought it was thunder it was so loud! 6 min later I can still here it. Saw the aircraft from my window.

Noise is annoying and very stressful to think about death and the military.

It's fucking AWFUL

When they started taking off, I checked the time and said "Did the clocks change? It's not 9:20AM" --- which is the time we generally start preparing ourselves for the sudden but predicatable scream and roar of the F-35 morning flights departing. It was only not "deafening" because this morning they took off south, terrorizing the people in Williston, Richmond, Hinesburg, and Huntington, instead of us in East End Burlington and Winooski. I generally measure 80db constant inside my Burlington home during north-facing take offs. Outside far worse, especially when the butt-end of the F-35 is facing me as the jets climb. So, now our earlier mornings are also going to be ruined for the war games practice? Senator Leahy: how about using earmarks to do a study on (1) what other assignments can be given to our Air Guard so the F-35s don't have to be based here and (2) better uses for decommissioned F-35 BTV base, than terrorizing civilians for no good reason?

I was working in my community garden plot and the flotilla of F-35s shot past one at a time. Then they began to make a circle following each other. It seemed like the community garden was in the center. Another senior citizen in his garden plot and I put her hands over our ears. It seems like they were playing some game of follow the leader. They circle about three times, flew off and then flew higher in a tight formation.

horrifyingly low and loud---total political disregard for people here---hateful

My toddler screams in agony and runs for protection from us everytime the F-35s fly over our house

My 3 year old son started crying and yelling no while looking at the sky with his hands over his ears. It’s unbearable for him

I was trying to have a phone conversation and had to call back after the noise passed overhead , lasting approximately 3 minutes! The 2nd time I was trying to relax after a long day. Not conducive at all!

I did not sign up to live in what sounds like a war zone.

whistling screaming explosive - shattering the morning

Need to pause my indoor activities/conversation until the noise passes because I cannot hear....it is night time...

Chaos

Our students were taking the Federal SBAC exams which require quiet concentration. It is difficult to achieve best results when loud disruptions like this occur.

They're freaking awesome.

The planes were scarily loud today, roaring overhead

TOTAL BULLSHIT

They are horrible and I warn people about it if they are thinking about moving here. Quality of life has decreased since they arrived.

Untenable. We had six go over while working outside, we had to put down tools and cover our ears. We couldn't communicate at all over it, and with 6 passes, it went on and on, completely disrupting what we were trying to say to each other. It's just not fair. This is the wrong place for this kind of outrageous intensity. It seems the frequency is going up and the times of day are getting worse. It really pisses us off. There's got to be something we can do to stop this insanity.

We were trying to teach and our class was disrupted by the loud noise. The students couldn't hear us and we had to stop the teaching/learning process.

I love Winooski and now I avoid it. I visit friends regularly there and the noise gives me headaches. I live in downtown Burlington and have to stop my work meetings every time the jets are out. I also work at UVM and have to stop meetings or close windows to avoid the headaches. It was such a mistake to bring them here. The community knew it was going to be bad but Senator Leahy did not care at all.

Unacceptable
Music classroom class had to stop because we couldn't hear ourselves over the planes. 1st graders scared of the roar.
Planes roaring over our house from 8:45pm-9:35 pm at unknown intervals and groups. Our daughter waking up crying in fear. Walls and windows shaking (they always do). My one night to get sleep and go to bed early as a parent and business owner ruined, and being so agitated with feelings of "why do we live here? Am I being an irresponsible parent exposing my child and family to this stress? Should we move? Why are they doing this to us? Can nothing be done?" Such a feeling of helplessness and desperation and anger, I was shaking and couldn't get back to sleep.
I teach evening classes from my home and the noise very much interrupted my classes on both nights they were heard. I could not hear my students on Zoom and it was very distracting for everyone. I had one student who lives in Winooski and her dog went and hid in the bathroom because he was scared by the noise and couldn't participate in the rest of class due to stress.
not the level of noise you said it would be
Horrible and overwhelming
Again, these flights interrupted a phone cal with a customer. They are INSANELY loud today! I hate putting my life on hold whenever they fly by.
Remind me EVERYTIME of the horrors of war, the pain all sides cause. Rattles my psychologically and physiologically for 10-30 minutes. Also so loud I cannot talk to others, cannot hear others. So loud I have to cover my ears and I feel like my sinuses and brain is shaking.
7 or 8 very loud takeoffs. 3 or 4 at a time, was out walking w/ my partner and could not hear each other shouting over the noise. absolutely obnoxious
Horrifying! When will the men who put this here be held accountable for deliberately, knowingly putting residents-taxpayers at risk .Our bodies are not your runway. GO AWAY
the F-35 began warming up while we were relaxing on our deck; this was our warning that we needed to go inside soon. The warm up is an extended droning sound that alters my mental/emotional outlook from content/relaxed to annoyed/angry. Having to adjust our plans to retreat from the onslaught of further noise attack is frustrating.
some were even lower than usual - loud is an understatement
whole house shook, windows, pets scrambling, deafening! LOATHE them.
Trying to enjoy the peaceful scenery of Vermont in the new park in the middle of town – totally disrupted by F-35 noise to the point I couldn't hear my partner speaking right next to me. Not what living in a Vermont city is meant to be like.
All conversation ceases. Cover grandchild's ears and hurry home. Still loud indoors with windows shut. Only good thing is it doesn't last forever.
One after the other. It's the sound of death
My dog shakes from anxiety and I won't raise my kid here any longer.
Several times last week when I was a outside I had to cover my ears because the noise was so loud and uncomfortable. I had to stop conversations as well several times.
My 5 year old is afraid of them, we try to take our dog for a walk and she cries; I go for runs in the woods or work in my garden during work breaks and it's a really unfortunate additon; sometimes I try to join work meetings online outdoors when it's nice outside and I can't if they are out
this noise is hazardous to hearing, and harmful to environment for animals of most species
It was not as annoying as the civilian planes.
Was reading and writing at my desk on my laptop, and was startled by the noise and it lingered for for five minutes making it hard to concentrate or get anything done. Afterwords I was filled with thoughts of war and hate and pain and death. So now I'm fully distracted and jarred.
The last few jets flew right over our house. I was inside with windows closed and has reading of over 90db! This is absolutely ridiculous and unnecessary. They have been flying since 10 am and just circling overhead with low rumble at times. This is not the 2-3 min a day of noise, but nearly 2 hours of noise. Hardly what our officials promised which would be a minor annoyance.
This cannot be good for my long term mental health, or that of our amazing wildlife for that matter

I live right under the flight path in Winooski. I was on the phone when the first pair of F35s came in for a landing, and was unable to get to my hearing protectors fast enough to avoid the pain of the extremely loud noise. I was unable to carry on a phone conversation when the planes went over. This is the first time I remember being disrupted late on a SATURDAY EVENING!! I feel for all the children and adults who were asleep by 9pm and were so scarily jarred awake.

I don't have a particular "experience" related to the flying of F35s in my area. It's jet noise and it's not overly disruptive to me. Sometimes I have to pause a conversation for a few moments or turn up the radio, but that's about it.

My young daughter's cover their ears and run inside. One often cries when she hears the planes coming.

The flyovers are painfully loud this morning. Is there something new? Are they flying lower? Have they adjusted their flight paths in some way? Living with this level of disruptive noise is awful--why is that happening? I moved here, to a quiet, residential, civilian neighborhood and now feel like I'm living on a military base.

I was outside, working on my yard, and the noise actually hurt my ears. I went inside, took a phone call, and even inside, I had to go to the basement in order to not disrupt my conversation. The jets are unacceptably loud

Was sitting with my 9 y/o and her friends enjoying our first creemee of the season when an F-35 flew overhead. The sound was deafening and we all covered our ears and cringed in pain. It put a damper on what was a fun, peaceful respite from the heat and covid anxiety.

Awful, can't hear music even with headphones on inside.

The noise is out of control. It causes my ears to hurt. The noise is vey destructive. I work night shift so usually I am woken out of a deep sleep from the jets.They cause a lot of stress and anxiety as I feel I never know when they are actually going to come. They disrupt any phone calls I have. It feels criminal to me that these jets are flying over our communities, essentially terrorizing us.

The noise disrupts me at my job, makes my plates and glasswear shake and terrorizes my children and animals.

Frighteningly loud flyover just now. For the first time, my cat jumped and looked terrified.

Shook the literal poop out of me.

The noise was so loud I had to pause my phone conversation, but really it was the vibration - rattling the windows and even knocking a figurine off of my bookshelf - that unnerved me.

Just a taste of what summer will look like with the kids playing on the back porch, partial windows open and deafening roar of the jets and vibrating windows over the otherwise quiet of birds chirping. We shouldn't have to worry about hearing loss for our kids in their own backyard 10 minutes away from the airport (which doesn't even fall in the airport's noise map radius)

I was unable to converse with people immediately around me. Multiple flights overhead, about 5 that evening. The afternoon I heard them, I was working on Zoom and the sound transferred through my speakers, disrupting my Zoom call

It takes over

Disruptive and truly a blight on the community that I felt pride in previously

Night flights are again beginning earlier than what we were originally told.

Annoying in the day time. But after 9pm on a school night? My kids are in bed. C'mon

I am inside, windows CLOSED, and the dryer is on. Still, the plane was so loud it scared the hell outta me.

Infuriating

ear pressure/pain, heart shaking along with the windows, whole body assault. 5min. before the UNSCHEDULED take-offs, I was admiring the song of a cardinal by the window

Breaks into anything else that I am doing.

these aircraft have destroyed quality of life in vermont. If its not in the evenings, its in the daytime while I am walking my dogs. They shake the house, and create huge amounts of anxiety, and everything must stop until all 8 of them take off or pass...I cannot imagine what it will be like when all 20 or 30 that are slated to arrive are on base. in other parts of the country where I have lived that military planes fly (new mexico + north carolina) they NEVER take off anywhere near residential areas or fly so low that it creates the issues these are creating because the AIRPORTS are 20 min outside of town . We are not equipped, geographically to support this.

Every time the planes go by, they set off my infant sons baby monitor. The monitor reads the noise from the planes as being just as loud as when my son is crying right next to the monitor. It lights all the way up the red section of lights, indicating a high volume. This is particularly annoying when the planes pass at his bedtime.

The noise prevents any communication. We must stop any activity involving communication until it's over, and we never know when it will be over. Meetings are constantly interrupted, then cancelled after the third or fourth interruption. This has impacted my ability to do business. I moved to Vermont because it's supposed to be a peaceful state, not a war zone. The Guard was useless when we were actually attacked on 9/11. I don't fear Vermont being attacked, but if we ever were I'd choose that, I'd choose risking death by highly unlikely enemy attack from those pesky Canadians then living daily under the assault of these useless, overpriced toys that serve as welfare for military contractors.

It makes me so angry because I have no escape or control over my experience. I can't fully participate in meetings, conversations. It disrupts my sleep as well. There is no place to go to shut out the noise.

I am a psychotherapist seeing clients through video conferencing at home. Even with windows closed the noise comes in and shakes up the sessions. This week's "night flying" begins in mid-afternoon and the planes are louder than ever and I have been frightened by the noise, and anxious about when it is going to start up again. I've taken my phone out on the deck to have the caller (not a client) hear the planes and they could not believe how loud it was.

I was on a zoom conference and had to keep muting and was unable to participate

Woke up my one year old from sleeping and scared my 5 year old who was about to fall asleep. These jets are incredibly loud and make living in Winooski untenable.

I live in Burlington and the occasions of F35's overhead are too numeoros to limit to the previous questions. I live in the old north end and work downtown. On a regular basis, even while indoors, with closed windows, I need to cease conversation, zoom meetings, telephone calls and wait several minutes to resume. The experience is deafening, frightening and disturbing. When i am outside, I hsve had to cover my ears, paralyzed in place or dodge for indoor shelter on numerous occasions. I am not delicate. I grew up in NYC surrounded by subways, ambulances, fire engines. NOTHING in my experience compares to this. The fact that it is a regular occurrence is also appalling. For a state that prides itself on Act 250, not polluting the visual landscape, how is this noise pollution justified? Moreover, as we face a climate crisis, how many tax dollars and how much fuel is consumed, and to what end? Many have framed this as a controversy that is or is not about supporting our military. Preposterous. The guard men,women and families live here too and should have a livelihood, but not at the psychologicl, aural expense of all our children and neighbors. It is like living in a military zone. The first time I heard them, moving from Montpelier to Burlington, I thought Burlington was under military style attack.

Increased flights this week and warm weather makes working at home difficult to impossible - headaches past two days

I was attempting to host a public event attended by ~90 people on Zoom and I could not facilitate because no one on the other end could hear me when I came off mute because the planes were so loud. I had to shout for someone else to speak until the take-offs ended.

The F-35 flights prevent me from being able to work. I produce educational videos and lead, live virtual trainings online. If I am recording a video when the f-35s fly i have to stop and start over. This is causing me to lose hours of work. If I am giving a live training when the f-35s fly I have to stop and explain to the trainees to wait while I go on mute. It is embarrassing, frustrating and maddening to have my work be disrupted so frequently. I video conference with people all over the world, and the noise here in Vermont is by far the most disruptive on virtual calls.

This is an atrocious invasion into our lives. It scares our pet, makes conversation impossible, the nighttime flights disturb our ability to sleep. The noise pollutes the serenity of Vermont's natural beauty and most likely alarms our wildlife. I have friends who tell me their kids cry. These vessels of war are not welcome in our skies. Planes like this should Not be based near such a large population area.

No peace here...sadly, just practice for nuclear war while destroying this local community.

The noise of the jets has interrupted business calls I've attended (thankfully none I was hosting). They are loud enough to drown out any other noise in my apartment.

Heard multiple times during the week living in Richmond. Extremely loud, comes out of nowhere, unable to concentrate

I have a feeling of deafness.

I live in Winooski but will be moving soon in large part because of the unbearable noise. I suffer from PTSD and find the jet noise physically distressing-- ear pain as well as anxiety. While appreciate the preparedness of the Guard, personally I have found the current practices incompatible with daily life in Winooski. I have had phone calls, zoom meetings, and workshops interrupted by jet noise. My dog is afraid to walk in areas where we have happened to be when jets have gone over. The disruption has been significant.

...and to think, just earlier I was grateful that at least I could enjoy a Sunday morning in peace, following several days in a row of horrendous NOISE / F35 assault

Oh my god, I hate these F-35s so much. I hope the government (federal, state, local) offers a buy out so I can afford to leave this ridiculous situation. I have been forced into a way of life that I never signed on for. I am not a soldier, I should not be living on a military base.

10:10pm F35's flying over

Truly awful.

Unsettling and very disappointing that we have to endure this almost every day. To the point that i'm seriously thinking on moving out of this state. Even though I love my house.

We were told night flights would run from 4 to 10 pm, but the planes are taking off earlier than specified today. With absolutely no predictability, it's impossible to plan/prepare for these flights. I now have to sit and wait until all the planes are done before I can resume my work on the phone with customers.

My grandchild is scared to death of the noise and there is no reason for flights around bedtime

It makes my two year old scared

7:45 is my young children's bedtime. Jet noises are distressing enough during the day but at bedtime when we are trying to settle it is scary and disruptive to my kids. It is a highly inappropriate time for young children.

I was involved with a Zoom meeting and could not hear the other participants during the time it took the several F-35s to fly over my house.

Every time a F-35 flys overhead I'm concerned about my child waking up, concerned for people outside, concerned for animals. Its very loud and aggressive

They are scary and loud, I hate hearing them over my home.

disrupted Hebrew class, had to stop multiple times, lost significant amount of class time

This is the fourth time today flights have interrupted my work. They are unbearably loud. I feel as though I'm living in a war zone, given how often everything in my house is brought to a complete standstill so I can plug my ears while machines of war fly over my otherwise lovely, quiet home in my otherwise civilian, residential neighborhood.

flying directly overhead extremely loud

The noise was so intense and so distressing I could not remain outside on my own property

OTHER (203) SEE SHEETS

Further describe ear pain or worry about hearing loss in your own words if desired 132 responses

When jets first arrived I had an inadvertent exposure to them taking off near Kirby Rd in So Burlington with my cat windows open causing severe pain and ringing lasting several days. Since then, ears have been much more prone to pain.

It's ABSURD

I hated working in a garden raising organic food and feeling like the place was being in a war.

Repeat exposure to these noise levels are inhumane

Buzzing in ears

No pain. Stop exaggerating your claims

Not worried about hearing damage. Noise brings all human communication to a hard stop

When my hands are full and I'm not able to push my palms hard into my ears it's like a jackhammer on my brain. It's so f'n offensive!

The strong noise gives me headaches.

We all plug our ears and hum quietly to counterract the sheer violence of the sound. Our daughter is trained to run to us whenever she hears the engines start up or begin to come near us, and she buries her head in our bodies and we cover her ears at risk to our own. While outdoors, we run indoors immediately and shut all windows and doors if we can. We adjust our walks or outdoor time to try to miss them (if we know when they are flying, sometimes they vary the schedule and we can't anticipate). So we carry noise cancelling headphones for our daughter with our stroller, like gas masks as if we were in war. Which is honestly what living with the F-35s feels a little bit like.

So loud I have to Cover my ears. I feel like my whole head is shaking and throbbing.

afterburners in this mix of take-offs. My ears are ringing 8:02pm and I can STILL hear them

My concern about hearing loss led me to have a hearing exam this year, which documented the beginning of hearing loss.

ears ringing and have established hearing damage- but then they KNEW this was a risk to our health before the basing---criminals

Ears started ringing afterwards and later in the day

When outside in Winooski my ears start ringing and my son 2.5yo covers his right away. My dog starts shaking from anxiety

Can’t hear anything else when this is happening and level of noise feels uncomfortable.

Why would you put this hazardous machine in the most populates place in Vermont!t?!

None.

these jets need to fly out and away to do their trailing. There is no reason they need to fly overhead constantly. Very disruptive

I have ringing in my ears for a minute after the rumbling stops

I have tinnitus in both ears, and am very concerned about making it worse with the noise of these planes.

I do not experience ear pain or worry about hearing loss due to the presence of the F35s.

I have ringing in my ears immediately after

The ear pain from the jets is intense for me and my kids and I worry about hearing loss for all of us.

Not only the ear pain but worse is the stress hormones that are probably more dangerous.

There needs to be further noise studies done to understand the impact these jets have on the kids

Indoors, no ear pain, noise freaked me out

i have ringing in both my ears courtesy of corrupt politicians and this basing--and I don't take that lightly.

Constantly reminding me of war and death, conflict and loss.

i already have hearing loss and these planes are causing increased deterioration.

Since these planes arrived I have been diagnosed with tinnitus. I pray every day they will stop, the ringing in my ears is constant and worsened. If I do kill myself, I will be publishing a letter to the Washington Post explaining the cause so you won't be able to cover it up.

Feels like it could br damaging my ears
Nervous about the impact of noise on my young children
I worry that being exposed to this level of noise on a daily basis could hurt my hearing.
Sometimes felt pain in ears
Couldn't work
I don't have my own kids but have worked with young kids and am very aware of how many little ones live in this area, including infants. All the professional trainings I've had in child development make me concerned for the kids who are exposed to these noise levels on a regular basis. For me the noise is physically painful. For infants, it must be excruciating. And they can't make the choice to go inside or close the windows.
should be "NOISE CONCERN" line not complaints---I'm not just complaining. I want these people to know they are deliberately assaulting thousands w/o any concern, disregarding AF testimony outlining the dangers to this community's hearing.
I'm fairly sure I suffer from tinnitus thanks to the airplanes and every time they fly by it gets louder and annoying
This erodes our quality of life and property values as well.
Mostly great
It's not just in the ears, it's everywhere. It's as if your inner organs are vibrating. It's painful.
Feels like an earache
Luckily we were all inside, I am worried that if my children were outside they could sustain irreparable hearing damage.
While outside with my children Need tobhold my hands over their ears. It's a sharp, deafening vibration.
The repeated takeoffs at over 100 db are concerning for my hearing. I will not walk around my home/yard with ear protection just waiting for the next jet to take off!
Sometimes there is a ringing in my ears when the planes pass from a certain direction. I'm not sure why some are louder than others, I assume it is my home's position in the flight path but I'm not sure.
My ears ring continuously after the jets have passed.
Deadening and hurt ears. I sought shelter.
Everyday multi-exposure to noise not good for my hearing.
So loud it leaves ringing noise. You can feel it vibrate your whole house and body.
tinnitus
I am already hearing impaired..this exposure can exacerbate it
I've been having more headaches and tinnitus episodes since the flights started
I am a neuroscientist, and am aware of the damage that prolonged exposure to >100 dB sounds can cause. I am certain that these planes are damaging the hearing of many residents in Burlington and the surrounding towns. It is inexcusable to blatantly cause permanent damage to citizens in this way.
Can't hear your own voice, can't hear anything but Hell
My hearing is already not as good as it used to be, but my child's should be protected.
The noise sends vibrations through my entire body, so I am very concerned about what it's doing to my hearing
I am worried that being subjected to this level of noise almost daily will have last effects down the road
I've been suffering migraines lately with the barometric pressure changes of spring. The violence on my ears worsens my migraines or triggers new headaches
Defining
completely disrupts my ability to perform at work. Distracts train of thought, inhibits ability to follow and participate in meeting for my work, writing is completely impossible, and causes physiological symptoms of anxiety/panic due to sensory overwhelm. I am not even able to plan for these distractions, as there is no consistent fight schedule.
Uncomfortable feeling. Used hands to close ears.
I have very acute hearing and this noise is a full body experience. Not just my ears. It makes me tremble. I am unable to think. It makes me feel afraid, powerless, distressed.
Could not hear any thing but the roar of the planes
These planes are too loud

This is the second time today the F 35's flew overhead, the first ETA 10 minutes were tolerable and then it got so loud I had to sit inside the house with my ears covered

Repeated exposure on a daily basis is damaging

Even wearing ear plugs the intense volume is a huge concern for our hearing

When I walk or jog. I feel the need to cover my ears(noise is too loud). Unfortunately, can't do that when I am biking.

The sound hurt my ears

Yes, I do worry about hearing loss.

It physically pounds and vibrates my entire body. It causes piercing ear pain.

I was indoors with windows closed and could not be heard over the noise. When I stuck my DB reader out the door for an audio reading, the meter peaked over 110dbs several times.

There is long lasting affects as my child all have done poorly on their hearing tests at the doctor and my tinnitus had increased over the years from prolonged exposure.

The noise is anxiety inducing, I didn't have a decibel reading but felt very loud.

I have to plug my ears or use noise canceling headphones, and it's still unbearable. I can't do anything for at least 20 minutes as I recover.

I already have hearing loss and the F35 creates more deafening noise

None

No effect

Really loud to the point of pain in my ears

Its so loud even at that distance that it makes me worry that my hearing is being damaged.

I have tinnitus and the sound exacerbates the condition

Pain and sense of pressure

already a senior, don't need more impact on hearing

I do not live in the "unfit for residential use" zone. My fear for my own hearing and my wife's is that an F-35 will fly over when we are outdoors and unprepared.

People who do not protect their ears from this level of intensity WILL suffer loss over time. This is a class action law suit waiting to happen no doubt. Give it a few years. I personally will make sure of it. It will be easy to win with the data collected from decibel readers readily available and being used in the area by citizens.

My tinnitus has gotten much worse and now it is continuous. Before jets fly over it was only intermittent and the volume of ringing in my ears was much lower. Now I am distracted so much by my tinnitus, I am left with this condition!

Causes tinnitus

Several times I've been in situation where my ears hurt for several minutes after experience of jets flying over. One time was very serious when pain lasted hours

My ears hurt afterwards and I get headaches

Felt the pressure on my ears

If I had been outside for long, I would definitely have been exposed to sustained and damaging noise levels.

Ringing in the ears

The very loud mix of sound frequencies seems especially likely to cause hearing damage.

It's piercing, and this is coming from some one who loves live music. The damage from the sounds of the planes is worse than any speaker at any concert. It literally hurts.

Headache, anxiety, irritability

painful to my ears. I thought that my years in the military were over.

No ear pain but it makes my whole head shake

OTHER (31) SEE SHEETS

Further describe effect on your hearing in your own words if desired 62 responses

perhaps I need to purchase military grade ear protection and wear it all day?
Exposure isn't long enough to suffer hearing loss.
I have a constant singing sound in my ears "zzzzzng" Hearing loss doesn't come back.
cascade of stress chemicals- increased heart rate and utter anger and sadness that VT Representatives think this is ok! They have the facts and CHOOSE to put constituents at risk. THAT should be a crime. Accountability? It's time.
It hurts and is by no means reasonable.
Can’t hear well during or after the noise.
This noise exacerbates tenitus
No effect on hearing.
The F35s have not had any effect on my hearing.
I was exposed to the jets a few weeks ago every night during our evening walk (around 8 PM around the ONE of Burlington). My daughter and I both got headaches and ear pain afterward.
I haven't experienced hearing loss yet. I don't think constant exposure to that level of noise is healthy.
Can't hear anything else for about 60 seconds, but i think it's temporary
For the hearing impaired this noise sets off tinnitus making it hard to function.
I had perfect hearing before the planes, no problems at all. Now I have to repeatedly ask "what?" anytime someone speaks to me. It's made it hard to socialize and have fun. The military is ruining our lives in pursuit of more money. I will never vote for anyone who does not support severely cutting the military's unbelievably bloated and disgusting budget. The Pentagon is a shameful symbol of everything wrong with our country, Americans live like paupers and our children starve while the military brass live like Saudi kings.
I have ringing but cannot attribute it to anything in particular.
Painful sound, pressure
'm fairly sure I suffer from tinnitus thanks to the airplanes and every time they fly by it gets louder and annoying
I'm concerned about the long-term effects of noise pollution on my body, others bodies and animals.
I haven't had my hearing checked, but I'm sure it can't be getting better.
I stepped outside to take a DB reading on my porch. That short exposure resulted in temporary ringing my ears.
I just have some ringing.
I have had my hearing ruined by a number of things - and I can still hear this!
intense vibrations, windows shaking, scrambling to shut windows---so nice, right?
Temporary ringing and dizziness
ringing in ears has been since f-35 arrival only
Tinnitus is at an all time high
I have previously never experienced tinnitus. I now experience it in both ears after living on the flight path for 2 years.
the quality of life that I had when I purchased this property has been trashed by these monster machines
It is quiet now and my ears are still both ringing
My ears feel like they're buzzing after the jets fly overhead
Severely ANNOYING
I have no clue how this is affecting my hearing. And for me to find that information out I would have to pay out-of-pocket to go to a doctor and probably should’ve had a baseline measure of hearing Prior to the F 35’s invading my neighborhood. But again, all that would be out of pocket of a civilian citizen.
Since an inadvertent initial painful encounter near the airport my ears have been experiencing low buzz or hum
I did not check anything above, but likely could if this noise level does not change.
I'm afraid of the vast effects the keys will have on my hearing over the decades as I continue to live in my home.
No lasting effects beyond 20 min at this time
I hae hearing loss and fear the noise of the F35 can cause additional loss and tinnitus
None

No effect
Pat Leahy's polluters.
I have tinnitus and the planes complicate that condition
Pre and post hearing tests will help to prove loss
I now qualify for hearing aids, after going for a hearing test
Since I have not had my hearing checked it's difficult to say how much damage has been done.
Painfully loud and sustained.
Even without my hearing aids on, this noise is deafening. No conversation possible.
painful
I've lost high tone in both ears
I woke up a few nights after the jets flew overhead with ringing ears that were actually painful enough to wake me up.
My ears ring for several minutes after they've gone
Worsens Tinnitus
not sure if my tinnitus is FROM the f35s, but it really doesn't help!
Upsetting annoying angering AND totally unnecessary during global pandemic. HEARTLESS makes me HATE Miro, Leahy and Sanders AND the Military who shoved this down our throats in SpITE of 3 cities agreeing NO basing !!!!!!!!!
I'm unsure.
Ringing stops after a minute, but this can only get worse.
maybe i need to ask VTANG what military grade ear protection they use, buy it and then take them to small claims court to reimburse me? frustrating to be singled out as disposable residents by mis-representatives
I had ringing in both ears temporarily after getting home.
Not sure how much of my hearing loss is from F-35s
RInging in ears
Ringing in my ears goes louder during and a few minutes after
I already suffer from moderate hearing loss and wear hearing aids. The noise of the planes is more painful now that I wear hearing aids, previously it was uncomfortable and annoying. There have been times where I had to remove my hearing aids to reduce the pain.
My hearing has declined dramatically since the F-35s invaded Winooski

Further describe the pain or the vibration in your own words if desired 77 responses

Inside so felt a mild vibration in my head.
The very low frequency of the F-35 when taking off or screaming overhead preparing for landing is qualitatively so different from the F-16s. No comparison. I can feel it in my chest when they take off. This cannot be healthy.
I felt really agitated. Anxious.
unbelievable! criminal! deliberately, knowingly exposing my family to health risk / pain
Couldn't settle thought after, buzzing ongoing
If anyone checks these, they're a liar.
Like I said, like a jackhammer on my brain. My stomach feels the rumble.
I have migraines and the tension and sound exacerbates them.
My whole head feels like it is shaking... especially my sinuses.
cascade of stress chemicals in the body-plus the obvious
Felt my feet vibrating.
The roar of this failed fighter jet pauses sympathetic vibrations throughout my body: Not good vibrations.
No pain.
The noise just vibrates thru you body
I do not experience pain or disruptive vibration as a result of the F35s flying over/by.
At times, if outside do feel vibration.
Today I was rattled which triggered my brain into fight/flight/freeze. I now have a headache.
None
Creates tightening, increased heart rate, stress, shot of adrenalin throughout my body, neck tightens, feels of anxiety and hard to breathe
I was leaning against a wall in my home and felt the vibration
Sometimes I have a headache for a few minutes after the jets have passed.
Any time in Williston, my body vibrates and sometimes vehicle if I'm driving
When I happen to be outside when the jets pass, my entire body registers pain as well as vibrations-- pain mostly in my ears with a headache right afterwards. The vibrations are worst in my stomach, which isn't great for somebody with PTSD.
it shakes everything around you
Heart rate went up. Shortness of breath. Nausea
It's like nothing I've ever experienced before in all of my 47 years. I can't imagine what it's doing to the elderly and the young. Plus, there is no way that an infant can sleep through that trauma. Plus of course there are the animals...not just pets, but also wildlife. Way to go Green Mountain State!
Inside my own home, with windows and doors closed my body was vibrates by the low frequency sound waves. My home shakes at least for a moment during every flyover.
I don’t feel pain, but I feel a vibration in my chest. The planes were flying towards Williston today and that seems to make the vibration worse for me.
Migraine with these planes is absolutely unbearable
It takes over the moment - very distracting
My ears hurt.
Distress and headache.
human body organs heart brain all vibrating along with the structure i call home, not to mention the cascade of stress chemicals coursing thru the body
everything vibrating even a minute or so after they have taken off and are well into the flight
The vibration when the planes are low over your location is sickening. Especially for persons with anxiety, this is a noxious stimulus.
disturbing

i am hyper-auditory as part of my neurodivergence, and the F-35s cause a visceral feeling of sensory overwhelm and resultant panic. (Sweating, elevated heart rate, chest tightness, hyperventilation)

Uncomfortable pain and vibration inside body, like machinery too close.

I wear the best noise cancelling headphones I can afford. They do almost nothing to reduce the sound and absolutely nothing about the vibration. It is a full body experience. Very abusive.

I A severe pain in my wallet (to the tune of $1.8 trillion)

I feel anger. Psychological warfare. I pray to God, archangel Michael, and Master Jesus, please end the f-35s in Vermont, please end the actions of war, please end the causes of war.

Noise sensitive with resulting anxiety

I get 'all shook up' and takes awhile to regain my calm

trembling, fearful

It was a whole body experience, vibrating my body and my home.

The jets can cause massive headaches when outside or if the windows are open. If I'm outside my body feels stress and pressure.

I have to stop and put my hands over my ears until the F35 is gone or else the noise can kill ear cells

Immediate joy and envious - I would love to take a ride in one

No pain

I felt a swelling sense of national pride

The fact one can feel this in their body proves the intensity level is dangerous to the ears.

The vibration stops me in my tracks and causes a disruption to what ever I am doing

Ear pain for a few minutes after exposure to f35 jet noise

Should not be in a residential area.

Stressful neck pain

It's especially difficult to concentrate on riding my bike safely with the anger and frustration I feel when exposed to this sudden and unexpected noise.

My whole head especially where my sinuses are I feel like it’s shaking. My heart was fucking racing A mile a minute and I felt like it was triggering a panic attack. It completely disrupted my work for the morning. The military can go fuck themselves Because their flaunting of unnecessary war machines is making me hurt physically and makes me want to kill myself.

No pain or vibration

I never take medicine lightly, but I had to take a Tylenol in order to finish out my work day since my headache was so bad.

When they fly over, it is very low over residential neighborhoods. My whole apartment complex shakes, anything on windows rattle and can feel the vibration from the sky

I woke up from sleeping terrified. My heart was racing and I felt extreme anxiety

HATE what they are doing to our community HATE

Again, I felt this THROUGH my laptop.

I feel pain inside my ears and I feel vibration inside my chest when the planes fly over.

My heart is pounding from the fright, and I can feel increased blood pressure. "Fight or flight" response to sudden shrieking as they approached to land.

Hard to describe. It causes me great anxiety not being able to escape it; in part due to not knowing how many more passings are to come after exposure to the first.

Pain and vibrations in body can trigger panic attacks for me. When I am driving, walking to pick-up my kids at school, trying to do work from home, being unsure when I may have a panic attack triggered is incredible unsafe.

I have to get psychologically and physically ready each time the planes come through. The vibrations cause me much stress and pain, so much I can not continue my work at times.

Not this time, although I have felt internal vibration form the F-35 before.

Deep unsettled sensation - creates anxiety

Hurts my ears. Makes me furious and that is bad for my heart. I have heart condition

Uncomfortable.

Moderate pain in my ears. I have only had issues with vibration once so far but it was jarring and anxiety inducing and went in for several minutes.

My heart rate increased and my whole chest vibated.

Internal organs especially but not only the heart were vibrating in a terribly invasive and very uncomfortable way. This is unhealthy and unjust

The stress this places on my mental health is extreme. I am filled with rage every time these planes take off.

Describe effect of F-35 noise in your speaking or learning at home or in a classroom at school in own words if desired 124 responses

Distracted me, forgot what I was doing.

Impossible to carry on conversation or even think during the six minutes of constant roar and rumble while a "pod" of four-packs takes off.

cannot concentrate or speak/hear when flying over

My dogs and I come inside when the planes fly over. The dogs hate them.

Learning, teaching, concentrating is impossible when these planes fly over like right now.

If it flies during class or video lecture I cannot hear what is going on, or I cannot speak in class. This also affect other students in the class so everyone just has to stop for a while. Class time is valuable and expensive.

Very disruptive

Oh no.... You have to stop talking for a minute. Get over it.

I am a psychotherapist and the planes interfered with my sessions

Impossible

Living and working outside near the Burlington airport when the F-35's take off is terrible, inconvenient, and anxiety-inducing to say this least. I work at an outdoor school at Rock Point and most days we need to pause our group activities for several minutes at a time in order to wait for the deafening sound of the engines during takeoff to subside. Meanwhile, we have a group of 25 or so elementary children waiting impatiently for instruction, to hear the rest of a story, or the rules of a game, depending on what activity we are involved in at that time. Then we have to try to regain the attention of the kids that we lost during this time, which can be difficult at times. Doing this everyday is exhausting, disheartening, and makes me not want to be here. It feels abusive and wrong to have these jets taking off in such a densely populated area. This is unsustainable and greatly reduces the quality of life in the Burlington area. Please stop flying them at BTV.

I work from home teaching computers to adults and when the jets go by we just have to stop altogether. There's no way to communicate through that.

We have to stop meetings for the time the noise is happening. One colleague lives in Winooski, some others in the Burlington, So. Burlington area. When we have online meetings we can hear the jets in the meeting as it hits my Winooski colleague first and then we know the noise is coming to Burlington so we have to stop until the noise is over for all of us.

Music class had to stop once again because we cannot hear ourselves think nor make music in the school.

All learning has to completely stop

My wife and I both have had to work from home during the pandemic, and she works from home usually. It is impossible for us to speak or be heard in critical work meetings while jets are going over.

See previous answer, but I teach evening dog training classes via Zoom from my home. The noise was extremely disruptive to my classes on both Tuesday and Wednesday evenings. Students could not hear me due to noise levels, and I had one dog who lives in Winooski who got so scared by the noise he hid in the bathroom and was too stressed to join class and learn.

Impossible to do zoom until they have passed.

Interferes with phone conversations, zoom calls, in person conversations.

can't hear anything but "our " good neighbors" attack

It has hindered me when on the phone for work on many occasion, having to ask customers to standby until noise clears. I cannot talk to my child when they fly over and he covers his ears each time they do. Moving back to Switzerland, where family values still mean something.

When teaching a class I have to stop instruction when jets are flying by. Students can not hear and it's very difficult for anyone to concentrate. Although it's even louder when outdoors, it is very loud and disruptive indoors as well.

I teach at UVM and have been having to teach remotely at home and it is a huge disturbance for that. My family and I are outside a lot and we have to stop all conversation during F-35 noise.

While working on the computer it blocks out both my speaking while on line as well as the computer speaking visual information on the monitor.
No impact on learning.
I was taking an online class and couldn't hear my teacher
N/A
My day/thoughts/speech is interrupted (I'm sometimes home with my children and sometimes teaching out of the home) whenever the planes are going over.
Blocked my ability to have a conversation
Interupts studying at home and business calls.
Had to stop piano lessons for this horribleness
I have to pause and am distracted EVERY DAY by the jets. Sometimes we have to pause for a quite a while as they fly over my various co-workers' houses and our office, since we are all remote.
Working from home my colleagues are shocked from the background noise and I regularly have to pause and delay the conversation until the jets have cleared the area
Distracting and impedes flow of conversation, makes it difficult to hear the person you're with, even online
I'm not in school
blocked conversation w/ business and medical
unbearable.
I have missed essential parts of meetings with hospitals, clients, families, staff
INTERFERES WITH COUNSELING AND WITH CONCENTRATION AS A PROFESSIONAL!!!!!
Feels like we are living in a war zone
My students cannot hear me and I cannot hear myself. If I am recording an educational video or leaving a recorded comment I have to start over. It’s maddening and I feel like I am at my wits end.
I have had to routinely stop teaching for several minutes each interval that the planes were taking off and landing. I teach in Winooski and the flight path is often directly over our building.
I can talk with the children I teach when they fly or hear what they are asking me
Stops interaction and communication between teacher and kids
disrupted Hebrew class, had to stop multiple times, lost significant amount of class time
these planes fly over multiple time per day and this was the added weekend flights of the month
Everything has to stop when they go by. Everything.
My daughter has delayed speech
I was working on a project and had to stop talking
I am teaching remotely due to the pandemic and the F35 noise makes it hard for me to hear my students or be head by them. Students are all over the Burlington area.
I have been doing several zoom meetings per week for work and they have interrupted my work almost every single time I have a meeting. It’s infuriating.
Everything stopped as they passed over.
Unable to hold any conversation, in person or on the phone.
It makes living and working in Winooski untenable
Class had to stop again in my sound proofed music classroom
We cannot hear or teach when they fly over. We often have to stop and wait for them to be gone. This is really disruptive.
I homeschool my son - we can't hear anything when they're flying over
I am a teacher in Winooski and this severely interferes with teaching and learning
Has negatively impacted my ability to teach and learn as a PhD student and professor at UVM. When the planes start, I cannot hold class and must mute my Zoom and wait until they are done (sometimes they are quite spaced apart). If I am learning, I miss content.
too loud to have a conversation

Completely ruined the lesson. Parents are paying good money to have their children attend these after school programs.
I have had to pause my remote teaching of classes as planes flew over. I have also had students complain about the sound, including having to turn off the sound/microphones while planes flew over.
I cannot hear or speak for long periods of time during meetings/calls, and leaves me incredibly frustrated, impeding my ability to concentrate
I was about to get on a work call, and had to delay the meeting in order to be able to speak and hear. This is incredibly frustrating, and causes me to lose focus and concentration. This is very irritating, and takes me a while to get back on track, but leave me angry and frustrated with the fact that so many of us are subjected to this level of noise.
Myself and my students literally have to stop what they are doing. I have MANY students covering their ears. They are scared if we are outdoors and they go over.
All conversation halted. Homework interrupted.
I am a horticultural writer. I am unable to process information (learn, write, work) while the jets are overhead and for a lengthy period of time afterwards.
Completely interrupts learning
multiple meetings today were interrupted and concentration is hard to regain when your left wondering and waiting for another flight
Conversing at normal volumes is impossible.
The sound is too loud to concentrate. It's extremely obnoxious.
these jets do not just fly over once a day, they are circling overhead in the sky with rumbling
F 35 noise and vibrations STOP our lives, and certainly disrupts concentration and learning
I am a therapist who works from home, and even with windows closed am unable to hold sessions via telehealth when the F-35s are flying above because I can't hear anything (and no one can hear me).
Retired so not in a classroom setting but all conversation stops when they fly over.
I'm a teacher and I was in a remote meeting which could not continue to the noise.
I was reading to my 7-year-old at bedtime. The planes interrupted us. Bedtime is our only time to connect, the only time we read together now.
I was in class and couldn't hear the teacher even with the volume all the way up. I was also disoriented during and after since it was so loud, so it took a bit of time to get back into class.
There are several minutes in my life that are affected, were all activities have to stop. It's a major inconvenience in addition to the physical and mental stress.
Why are they training in the evening? At 8pm??
Have to mute myself and can't hear others in meetings. Sometimes I've counted up to 10 planes and I don't know how to schedule meetings around it. Cannot focus
Flights also around 11am. There were 2 brutally loud flights yesterday.
None
No impact
One cannot continue with online work when these planes are flying over; they are incredibly disruptive, for many minutes at a time, several times per day.
I was trying to relay information when the jets came & it interrupted my concentration.
It is difficult to concentrate during the fly overs. The sound envelopes the entire atmosphere inside and outside of the house.
Conversation and phone calls are.impossible as is listening to news music etc
Stopped my evening reading.
Unable to hear or participate in conversations, reading, writing, comprehension, disrupts tasks at hand.
when they fly overhead you can only stop in horror that they are containing to assault us 4-7 x/week
Unable to hold conversation, can not hear when they fly over head.
When the F35 are flying I cannot hear when I am on the phone talking to others. I also cannot hear another person talking.

You can not speak with someone in person or over a zoom call (yes it’s that disturbing indoors with windows closed)
It's impossible to learn/do anything but wait until it's over. F-35's are extremely intrusive.
I have to mute my computer multiple times a day due to meetings happening while the planes are flying over.
I was about to get ready to sit down to get work done and I’m so fucking shaken I can’t get anything done.
Just interrupts conversation for a minute
The noise interrupted an important work meeting, in which learning, sharing, and assignments were being discussed.
It is so loud you cannot be heard until the noise is gone.

Your action to protect yourself from F-35 noise in your own words if desired 136 responses

Hands covering ears
There is NOTHING that can be done. Stopping my ears for the six minutes it takes for each pod of four-packs to take off is hopeless but I keep hoping it will work. Still, there is no talking, music, bird sounds or wind in the trees while they are taking off. It's like time and the world stops and waits for it to end.
there's nothing to do
I am buying earmuffs tomorrow because I am irritated by having to choose between covering my ears or continuing with my current tasks.
they knew from the beginning that there was nothing they could do to mitigate noise /health risks and should be held accountble
I had my door open to my deck to let air in but when I started to hear the f-35 I got up to close it
We closed the classroom windows despite the need to keep good air circulation due to Covid 19. Children still are not vaccinated
There's no need to protect yourself. Grow up.
No escape
I don't use fingers in my ears, I press my palms against my ears. Inside is slightly better, but not much if windows are open.
I'm protecting in a way that I can. I'm happy to wear mi mask because it protects the community from Covid-19, a disease that cannot be controlled. However it bothers me to have to use earplugs to protect myself from an insensitive decision from our distinguished Senator
We all plug our ears and hum quietly to counterract the sheer violence of the sound and to assert our safety. Our daughter is trained to run to us whenever she hears the engines start up or begin to come near us, and she buries her head in our bodies and we cover her ears at risk to our own. While outdoors, we run indoors immediately and shut all windows and doors if we can. We adjust our walks or outdoor time to try to miss them (if we know when they are flying, sometimes they vary the schedule and we can't anticipate). So we carry noise cancelling headphones for our daughter with our stroller, like gas masks as if we were in war. Which is honestly what living with the F-35s feels a little bit like.
I was busy holding my phone to record the db level of 108
I wear noise cancelling headphones while working, I had the volume CRANKED all the way up, and I could still BARELY hear my customer.
Covered ears with my hands (not fingers). Which meant I couldn’t do anything else but stand there while the war machines won.
Research clearly says there is NO mitigation for this level of noise assault
jump to close doors / windows...the stress of that in my own home- my animals running around freaked out-from peace to chaotic.
Don't have an option to "protect myself" from insanely loud noise while I'm out doors.
There's nothing you can do to protect yourself
I try to cover my ears when I can. Even indoors the whole building shakes, glas clinks and noise is unbearable. Can't hear anything but the planes when they fly over us.
I covered my ears with my hands.
Despite headphones and closed thermo pane windows the noise is still intollerable.
No action was required, they are not that loud.
I was inside my home!
I own two pairs of Safety Works hearing protectors. One pair lives in my car, to be grabbed if I am caught outside at home when the planes go overhead. The other pair lives in my apartment in an easily accessible place. I have had to use them so often over the last year that the over-the-head piece snapped and broke last week.
I do not feel that it is necessary to protect myself from F35 noise, as I do not feel they're damaging me in any way.

My windows were already closed and the noise is deafening. I'm afraid to be outside during flight times due to the hearing loss issues
Ran to the bathroom
I was already inside with only a few windows open
Fuck me for wanting to enjoy an open window I guess?
Couldn't go outside or near windows until it is over... been almost 10 minutes and I can still hear it.
My company recently bought me $300 active noise cancelling headphones. They still don't block most of the noise out, and they do nothing for the whole-house vibrations
fingers in the ears---laughable and hardly effective- and often caught with things in my hands, including work projects, the phone...you know...LIFE. we should each purchase military grade ear protection and one at a time, take them to small claims court for the expense / exposure. eventually someone will win.
It's all I can focus on for a couple minutes, just death and killing
not much you can do. removed my hearing aids
The only effective action is to leave the house, get in the car and drive away.
I can't enjoy an open window in my OWN HOUSE
I cover my ears when outside. It hurts.
When I am outside with my kids I cover there ears at the sacrifice of my own hearing, when I am outside by myself I cover my own ears.
I am inside with the windows closed. I am usually on a virtual call and cannot cover my ears or put my fingers in them.
See above
Closing windows has some, minimal effect. Noise cancelling headphones can also help.
My hands cover my ears
Just to note, going inside makes a difference but there is still significant noise and vibration. Even with closed windows I have been on zoom calls and phone calls and had to pause, usually with loss of the flow of the conversation. This has most frequently been in the afternoons, but also frequently in the evenings and as my family is heading for bed around 9pm.
I like opening windows to get some fresh air in my house but it is imposible having them open as the noise is unbearable. I have to stop doing what I'm doing to run around the house up and down to close windows like a chicken without a head as it is so loud that I don't even know which window to close first.
My kids cover their ears and run to me
not this time but other times today when they flew over I put ear muffs on
I was recording the 106 db on my phone and taking screen shots
I believe I should not be required to protect myself from this awful sound while on my own property. The noise is not compatible with day to day activitiy in a residential neighborhood. It should not be permitted.
Looking for noise cancelling earplugs
My windows are already closed and I still have double storm windows installed from the winter season. Even so my DB meter got readings between 90-99 DBs indoors. With the one minute average hovering around 85 for the entire 10 minutes of flyovers.
I protect myself and my children whenever possible
I did nothing this time.
I'm inside my own home, what more can I do?
it depends on my activity whether I cover my ears or not. If I am recording db level I do not but when gardening I will cover ears with hands
We leave the door open, without a screen, so our cat can run inside during fly overs because he is terrified.
I'm already inside with closed windows and the sound is deafening so there's really not much more I can do!
hide, cover ears
Putting fingers in ears, humming to drown out noise.
Not only was I forced to close windows on this otherwise beautiful spring day, I also had to close interior doors and still the noise was too loud to continue with my work.

I bought active noise canceling headphones so I could TRY to work with the F35s roaring. They don't work.
noise level is distressing even with windows closed
I was wearing active noise cancelling headphones while on a customer call. The noise cancelling did nothing.
I can't do anything, it keeps coming
Sometimes they are so loud that plugged ears is insufficient and I must actually bury my head under a pillow.
go in the house & close doors & windows - even so, unable to have a conversation inside
All the children covered their ears. Later that night I had to close my windows and it was still unbearably loud. The F16s were NOTHING like this, not remotely as loud.
Partick Leahy's polluting bastards have to go away.
I couldn’t protect myself as I was busy covering my infants ears
Covered my child's ears but then I could not cover my own
I covered my ears
did my best to still follow my meeting via headphones, but my participation was still impossible, and i missed critical elements of our team meeting to the extent that I will need a follow up to learn what i missed
I wear top shelf ear protectors intended for working with heavy equipment. They have little to no effect as the terrible effect of these jets is a vibration as well as a deafening sound.
Be more outspoken about overpriced, under-utilised, Faustian deals with the devil !!
hold corrupt politicians accountable, spread the story nationwide, get support from all of VT not just locally
The first 8 to 10 minutes weren’t that bad and then it got to the point where it was so loud I had to cover my ears and I felt like my whole body was shaking. I had to go inside and now I’m sitting inside waiting for them to stop filling out the stupid form and I am totally lost concentration from the work I was doing outside
everything possible
Indoors, I have to put my fingers in my ears to tolerate the noise which even then is still ridiculously loud. It is unreasonable that I should be subjected to this degree of disruption in my own home from an external source several times a day.
i have ordered noise cancelling headphones!
Wearing noise cancelling headphones but still can't hear people in my webex meeting
As I am on telehealth often, I cannot cover my ears because it is not professional.
i am not certain what to do this summer. having the windows open makes the noise unbearable.
See above, had to choose between protecting my dog and myself
I have to cover my ears or else it feels as if my ears are going to bleed.
Noise canceling headphones, calm music, ran into corner of home
Put hands over my ears
None
Nothing
I was outside - only thing I could do was put my hands over my ears.
We should not have to cover our ears, go inside the house or take any precaution to avoid loud sounds such as the F35. Basing the planes in a community such as Burlington was the worst decision the city and state has ever made. The planes are overly disruptive to the environment.
Absolutely can't stand the disruption and not being able to have windows open on a beautiful day
can't be outside, have to come inside, have to close windows
Left my position to go more internally into my apt, and kept hands covering ears
Cover ears, end conversations, it is not possible to escape effects of noise even in my own home with windows closed!
Pat Leahy's polluting bastards are unwanted.
Already inside with windows shut. Fuck these planes
I was sitting in my home , inside but still the db are 70+ each time
Sadly I've decreased the amount of time I am outside because I don't want to "get caught" unprotected walking outside in the neighborhood.

I have closed windows and plugged my ears but I have found no way to protect my hearing because I never know when they are going to fly over.

Went inside. Closed all doors. Windows were already sealed with double storm windows still installed. Covered my ears while outdoors. Could not converse with my spouse while indoors.

OTHER (35) SEE SHEETS

In your own words if desired: Are you kept inside by F-35 flights? 131 responses

No
Yes
Sometimes, but the flight pattern is so random I never know when they will fly by... sometimes it is multiple times in one day!
It's not a matter of inside or outside! It's deafening EVERYWHERE
It wouldn't help. Can still feel and hear them taking off and landing.
There is no schedule so I am regularly caught outside with my toddler during flights
I work as a gardener and am an avid walker and biked. I am outside most of the time. These flights are causing me great distress!
Luckily if the f-35s fly over where I am working outside, I am already wearing ear protection for the chainsaw.
No but walks outside are not enjoyable. You can not converse and be heard or enjoy the sounds of nature.
Where did the F35 touch you?
Yes, even louder outside
Depends what I'm doing. If I have the choice, yes, I go inside. otherwise I just stand where I am, drop what I'm holding and put my hands on my ears and wait.
If I'm in the Winooski area I go indoors. I do t know when they will go out so it's hard. I go into my car if needed
Yes, our entire household sets our routines based on the flights. We ensure our daughter, and all of us, will be indoors with doors and windows closed during their typical flight windows in the morning and afternoon. If we are caught outdoors, we run inside if we are close; or carry noise cancelling headphones with our daughter on her stroller or in a backpack to put those on when they fly over. Our house shakes and the sound is still so loud in our home when they go over that we all have to plug our ears anyway, but the house provides at least some shelter and reduction of exposure to the sheer volume and vibration of being outdoors.
when i am not already outside
No because I don't know the flight patterns. On days in which I am not feeling well, I would consider staying inside with music blaring.
I wish I had been indoors for this
Tonight take-offs started at 7:55pm and at 8:02pm I could still hear them. My whole house shook with the explosive protracted take-offs of 8+ F35's. My heart vibrated, I loathe them. I don't support this on any level.
absolutely- what informed person would expose themselves to bodily harm
They destroy everything here and around the globe. They pollute, rob people on every level of life itself! no support for people who opt to shave their heads and train to drop bombs/kill. Just another morning in Willston...could be peaceful, working and listening to the birds not F'ers. What madness and lies brought them here.
I try to avoid taking child for walk or playground but there is no set schedule, so I can't plan and we usually hurry home.
I try to stay indoors when I can, even then it's way too loud. Winooski gets hit hard by the noise. When outsite my ears start ringing, so my entire family tries covering their ears.
Sometimes I go inside but often I cover my ears.
Yes, I often move inside until they finish.
while I do go outside during some flights, and when not working, I find whatever I am doing has to stop until; the flights have passed. This sometimes takes as long as 5 minutes
No, the F35s do not keep me inside.
This is hard to stay inside till they finish flying b/c you never know how many will be flying. The weather will be improving soon and folks will be outside more . Are we all supposed to run inside or walk around with ear protection on? Really!!!
I study online during the day, so am mostly indoors when they go over. With warm weather here, I will be outdoors more often, and am afraid of getting caught outdoors without hearing protectors.

No.
We immediately go inside when we hear them coming.
I don't intentionally go out during flights and try to avoid doing so, but often am caught outside without an indoor place to retreat to.
I have stayed inside with my windows closed, which was rare for me. I am less likely to be outside since they arrived, afraid to be caught outside when they fly by.
I'm not staying confined in my house but I'm regularly frustrated when out with the kids when they fly by.
Yes, I am waiting for it to be over before I can go work outside
yes- I feel the vibrations and readiness prep before they even take-off sometimes. I'm afraid to throw open the windows on a beautiful VT morning, knowing and not knowing they will fly over, shattering the peace. So they "have me" on alert even as I prepare for my own day, rearranging my steps...my life...adjusting to avoid the ferocious high decibel blasts, assault on my health, my well being, my ears, my cardiovascular system, my brain...the list. But also, my spirit, my sense of safety, my sense of being home is taken from me. Saddens me. Makes me angry. How dare them "select me" to this exposure as "ok" and on a global level, it's appalling the impacts on this planet, killing, climate, all of it. Old men dream of nuclear war. And of course, follow the money. And to the folks who quip, "it's only 6 min"---let me hold your head under water for 6 min twice a day?
They bother me no matter where i am
Even getting in a car is not an escape
when they are this loud, I will not go out. Scares and upsets me, plus it's painful. why go out into that?
I hate it, I feel like I bought a house only to lose access to its backyard during the summer.
If I'm planning to go out and I hear the jets, I'll wait until I no longer hear them.
If I knew when the jets were going to be flying I might stay indoors and close the windows, cancel all my phone calls and schedule everything around the flight plan; but I never have any warning. I guess I am just as afraid of experiencing these awful things indoors as outdoors, and anyway for me staying indoors isn't really an option. As I said, wherever I am these flights are a significant disruption to my daily life. They have impacted my sense of wellbeing as well as interrupting all aspects of my day.
Even at 10:10pm we're not able to relax in our own home
I only go out to take sound measurements
Sadly I do not keep tabs on their flight schedule so often times we are caught outside, typically with the kids and the dog. It's painful.
Since flight times are not known I try to maintain a normal routine UT when out doors during fly overs it is extremely painful
I step outside sometimes to get readings outside and am always overwhelmed by how my louder it is. Today (as most days) during the peak noise my DB meter maxed out at 110 DBs. The one minute average for the minute I was outside was over 100 DBs. Completely intolerable and dangerous!
If we're outside I typically have to run inside with the children. We rush to shit windows as well.
No, I may shut the windows if children are napping. I need to be outdoors and they are so loud and I'm so frustrated that we have to listen to them so much.
If I lived in the flightpath I would be!
Yes, I am outside much less than I used to be and keep my windows closed.
yes---best we can given the fact that for undisclosed reasons, we're not privy to schedules as with the F16's---unsafe? From who? Terrorists? Journalists recording them? EXPLAIN that VTANG
I am more often already outside. I don't go outside because I hear them. Once out I can't escape them. Except to cover my ears.
Even indoors with windows shut it is still too loud and hurts my ears
I am afraid when I take my children out that these planes are going to fly over. My 5 year old now knows how to protect his ears, but we have to stop whatever we are doing and I cover my 1 year olds years and subject myself to the noise.
how could I avoid it? they fly at all different times

If I had any clue when the flights were happening I'd stay inside.
it's not even safe to stay inside! Nice Spring-Summer ahead...but not here.
i can't seem to find flight schedules. If i knew when they're coming I'd stay inside
Yes, also the pandemic keeps me inside
just when you think it's safe to finally go outside...10:08am...BLASTING overhead? F35!
Every time the F-35s fly over I run inside with my dog until they pass.
YES!
I do not know when they'll be flying, but they are usually when I am working or trying to sleep, so more often than not, I'm indoors (but very inconvenienced)
I don't want to be outside when Patrick's polluting bastards (F-35's) are in flight.
We have to run indoors every time they fly over
It is impossible to walk my dog during the flights as he acts like he is about to be abducted by ailens and runs around in terror
I am kept inside because the noise is unbearable outside.
From April-October it makes no difference being indoors or out as the windows are open. During the winter, closed windows helps, but reduces the vibrational effects very little.
I can only swear, and wait for the roaring to stop. This deployment is a severe detriment to our quality of life.
absolutely! who in their right mid would subject themselves to this level of bodily harm
I go out to record db level with phone
This is fucking bullshit that I live in Vermont, hippie progressive land And I have to stop working to run inside because you're flying military planes above my house in a residential area
wheb I can get away from all the noise I go inside, yes
The F-35 flights have reduced my quality of life and I am considering moving.
I arrange my daily activities because of the activity
I never know when they will strike; if I'm inside when they start (or in my car), I certainly stay in until they're over. Often I'm outside when they fly over, and that can truly be a deafening, panic-inducing experience.
I wish it were that simple, but of course we don't know when the flights will happen. If a sortie starts while I'm indoors I can stay in until it's done, but my daily walks are essential to my health & if I'm out walking when flights start, I can't get inside.
I have to move inside of the jets go by when I'm outside for to the stress it causes on my and my children's bodies.
Unbearable outside not tolerable inside. Trapped and pacing until complete
Simply stop my bike and pull to side of the road and put my hands over my ears for the 3-4 minutes that the F35 fly directly overhead
No I run outside to see them and wave to them
I keep a pair of ear muffs in my car. If I go outside at my house and the jets roar, I can dash for the car. If I am helping harvest in the Intervale, I have to stop what I'm doing and put my fingers in my ears, as I have not yet gotten in the habit of carrying my ear muffs into the field.
I live in a home with very flimsy walls and staying indoors with the windows closed does not protect me from the noise and vibration so it makes me feel there is literally nowhere to hide.
Not a good area to have such loud noise over my home. I don't live in a war zone.
Only if I am in my own yard where I can retreat inside. If I am out walking, of course that is not possible.
If I am in South Burlington, I stay inside until the jets are gone.
Either inside or out the noise and disruption is horrendous
I don't know the schedule, therefore I have a physical reaction anytime they fly over.
I try to avoid being outside when they are active.
People should not be forced indoors. And even indoors, the jets make talking on the phone impossible.
Since they refuse to release an actual schedule, it's impossible to avoid them. I am regularly outside on walks when multiple F-35s go screaming by overhead. "morning" is not a schedule. They know when they will be taking off. This

isn't a war. They don't need to surprise us. They should give us the most basic decency of informing us of the time that they will be taking off so that we can avoid them if at all possible (which we shouldn't have to do).
It is not always possible to seek shelter during fly overs!!!
we will all be outside soon trying to enjoy our homes only to be forced inside several times a day 4-7 days a week. It is a disgrace to our local, state and federal government to allow this to continue!
I've decreased the amount of time I spend outside quite a bit as I feel tense not knowing when I will be exposed to the noise.
I am afraid of being outside when the planes fly over, it hurts my ears.
Because the flight schedule is unpredictable and often coincides with my commute schedule, there's nothing I can do to avoid being subjected to these flights.
No, my life isn't changed.
When they are flying overhead we are forced to go indoors to protect our hearing.
During flights I ware hearing protection. Noise is unbareable.
Today I am. I was going to go outside and work in my garden and then do a walk and now I literally just wanna fucking shoot myself in the head. Thankfully I don't have a gun but the military does and EVERY TIME I hear the war machines I'm reminded of all the horrible atrocities the USA and other countries have done because of greed and Need for power. And that makes me feel horrible as an empathetic human being. It makes me feel like I don't even want to be part of this planet.

OTHER (27)

Are you kept inside a longer time than the actual F-35 flights? How long does the F-35 noise keep in you inside, in your own words if desired 80 responses

No
I'm not sure how to answer this. I can hear them a long way away.
The noise lasts 2 to 3 minutes. I stop what I am doing for this period to cover my ears and hopefully prevent hearing loss.
unscheduled for safety reasons? define that.
I don't really know what time they fly because my day varies, I don't adjust my activity
Lmao. Is the F35 holding a gun to your head telling you to stay inside?
I do not have the schedule. Am usually indoors
Yes, we know they vary the times so we will often give a full hour buffer around the typical times of day we know they will fly. They do sometimes randomly fly at different times, which is really challenging to feel like we can make good choices to minimally protect ourselves from this severe nuisance and health risk.
you never know how many jets are going to fly over. We had 16 fly over in one time period
the above doesn't take into consideration the PTSD...knowing they're coming, hesitating to step out or hurry through a walk, running to open and shut and open and shut windows, dreading the morning assault...actually planning around it! So, the days these thing fly, they rule life under the flight path. I want to strap Leahy to my driveway and let him experience it w/o his fingers in his ears. Criminal.
no schedule -never know- have to even time a walk around the,. guesswork. It wrecks life here.
Doesn't matter where i am, it shakes up everything around me and the noise is by far unreasonable.
The question is Why should I have to stop whatever I am doing, and why should the F-35 have to worry about security? If the F-35 is worried about security, shouldn't we all be worried and move its presence from Vermont?
The F35s do not keep me inside.
F35 noise or anticipating F35 noise does not keep me inside.
About 20 minutes, now that there are more of them. That's about how long it takes of late.
I never know when or how long it will be so I hide indoors for at least 30 mins
The phased flying is even more frustrating that you think the noise is over and then another set of 3-4 fly by a few minutes later and then another set start a few minutes later. Just get it over with one time.
Fear- of being exposed to noise
it keeps me indoors even before they're blasting overhead---wondering, hesitating to take a walk or work outside, etc. open all the windows. Have to consider decibels. And no schedule...for "safety reasons". Define SAFETY...theirs not ours. Disturbing on so many levels.
just trying to avoid the discomfort and hearing damage..they are frightening
We never know when it's going to happen or end. Having precise windows of time would be very helpful for scheduling, but would not increase the quality of life. Being forced to live in a war zone is punitive beyond any measure.
I can't figure out the timing and don't think it is fair I should have to be figuring this out, planning my work and my outdoor time around the constantly varied flight times.
Last night was 20+ minutes with gaps between them that I was unable to enjoy my home.
Because it's rarely a single jet, I'd estimate the total time at 5-10 minutes.
I have no idea when the F35s will be taking off, in flight, or landing. I moved here from out of state last summer. What I would say about the varied timing is that it keeps me on my toes in a very undesirable and unhealthy way. Again, I have PTSD. This is not compatible with being around military aircraft that make war noises near me at unpredictable times.
TOO LONG!
I am afraid to go out of my house after 8 am as we never know when they are going to fly by and for how long because they keep coming on groups of 2-4 planes

Unable to answer this question
I go inside during the flyovers and make my way back out when I am sure they are done. This makes it very difficult to plan to get things done outside. (My business includes a fair amount of outside work) also I am extremely concerned about my kids being exposed. Since the flights are mostly unpredictable (we are alerted when they will be flying a lot or at night, but otherwise completely uninformed when to expect this intense intrusion into our home and neighborhood) it severely impacts our quality of life.
disruptive to my enjoyment outdoors
I don't let the jets dictate my indoor or outdoor time. They need to be removed from Vermont. The "economic benefit " is not worth it.
Varying the times makes the sound unpredictable and far worse
no schedule- no way to know safety and enjoy where i live
Yes, once inside in the evening, I rarely go out again ... reduces quality of life.
Cumulatively, for today I was affected adversely by the noise for over an hour. My wife complained at dinner. It is ruining the neighborhood and family and school life.
I never know when the last one is finished, so I typically wait for awhile before going outside
They come and go at deferent times. So I don't go out for about 20 minutes after last F-35 has passed.
A major component of F-35 flyovers is their utter unpredictability. Can't they land and depart safely at a lower thrust level, and use Loring in Limestone Me., an abandoned SAC base , for full throttle manoeuvres ?
can never trust it's over since it's "unscheduled for security"--If they need special "security around take-off times"--what exactly does that say about our safety?!
you never know how many will be taking off at one time, so hard to know when it is safe to go out into my yard for enjoyment
Anywhere from 15 minutes to an hour or two depending on how loud they were and how distressing it was on that given day. Some days I can force myself to go back and do work or some thing after a half hour other days I'm fucking useless for hours
No, I endure the noise outside and in. I refuse to reschedule my day according to the whims of the F-35s.
Do to the circling back my life has to be put on hold until the fight is completed.
Yes the vibrations and piercing sound is heard well before and after the flight. Extra scary when you don't know where it's coming from
Not at all
The time inside is irrelevant. The planes are disruptive whether they keep me in 10 minutes or 20 minutes. As I stated before the planes should not be in a community such as Burlington.
The aftermath noise lasts a few minutes beyond flyocer
you don't know when it is going to end. sometimes there is a pause, then a whole other streak of planes goes over. I haven't timed this but believe it can take up an hour. Yes, confined indoors during all that.
The jet noise usually lasts for over 4 minutes with 5 jets.
IF I can get indoors! Also being indoors is not protection either!
you never know how many will be flying over at a time and at what db level. Something they should be able to control
Well, since there are multiple jets, I wait another 15 minutes after what I think was the last one.
I never know when they are going to fly by, so if I happen to be outside I have to run back inside
None.
Yes. Hearing them in the morning throws off my entire day. Not only am I stressed out about them but then I have to take the time to fill out a fucking form to complain about some thing that should be a no brainer that those planes should not be flying over the most populated area in Vermont.
I usually go back out or open the windows as soon as I notice the flight is over, although it may take from 5 min - 1 hour for me to realize, because I put headphones on inside.
Yes, because we never know when exactly the flights are going to take place
For FEAR of getting caught outside when they fly, makes me a nervous wreck. Afraid they will crash (junk that they are) bad mechanical history AND the deafening noise

I would have to stay in all morning and part of the afternoon. I risk it. It concerns me.
when I am stuck outside I need to cover my ears
Yes! Being caught under unpredictable take-offs is excruciating and putting one's fingers in one's ears useless. What do I do about my heart vibrating in my chest?
I do not know the schedule. I have planned to go on walks but had to remain inside for at least 10 minutes to wait for the F35s to pass.
When they go over I have no idea when they are done. Will it be two times, three, more?
since there are currently NO RESTRICTIONS on training flights nor are they scheduled for reasons of concern clarify that one please), there's no way to protect oneself adequately
I try to stray inside until the fly overs have stopped.
Too noisy to be outside
However long I am kept inside is irrelevant. The fact that people need to go inside is unacceptable
Today I was stuck outside during the flights.
seriously? who keeps track of flight times, other than VTANG ... i shouldn't have to post a schedule of flights (if one is even available) and work my activities around them. this is an intrusion into the peaceful enjoyment of my property, it's unhealthy and there were/are plenty of alternatives available to resolve the issue.
I am beginning a writing online on Fridays at 9:30am and can often not hear the opening response clearly because of the F-35s - so maddening.
No predicting when this terrible noise will ruin what I'm doing.
We are never sure when are they going to pass so we feel traped and scared we are going to be caught outside while they fly by. Again I feel traped in my own house.
Seems to last forever. Just when you think they are done, another one starts up.
PTSD from living here. We are adjusting our life to the POTENTIAL they will suddenly, and without warning, takeoff, blasting us with115dbl's--they need to buy people out and station staff/supporters here in the flight path!
I'm afraid to go back outside because I'm worried if that last flight was actually all of them. Then I'm worried when I do go out if they are going to be coming back and landing via the route directly over my house.
several hours per day because it is difficult to predict when they fly. there are way too many exceptions to vague schedule Vtang has announced.
I never know when its coming.

F-35 impact on your home and family in your own words if desired 103 responses

all of the above
Constant rage
I would NEVER show my house to potential buyer at any time they might be taking off or landing. I would NEVER buy a house that faces this assault every day like we now do.
VTANG has told me that they do NOT consider multiple calls from the same person---as that person is a " complainer"--so if I committed multiple assaults, only one counts? Good to know that's how this rigged system protects people---not that they should even be here, ruining VT
The noise causes moments of acute anxiety and fear when otherwise at rest in my home.
The F35s should not be stationed in a residential area. I also live in the commercial flight path which is sometimes loud but it does not interfere with all ability to function. I literally wonder every time they fly over if bombs are going to start dropping. I know this is an irrational fear but my home should not sound like a war zone. There are plenty of places in this country where these aircraft could be stationed that would not be damaging to communities.
destroyed our comfort and sense of safety. Apparently we live in the crash zone... "disposable residents" zone
Annoying and disruptive.
Y'all chose to live near an airport. This one is on you.
Again, TOTAL BULLSHIT
We are left feeling angry and helpless. It's disruptive and painful.
The F-35s cause us to enjoy our yard and home significantly less than we would were they not here. I know because we lived here when we had the F-15/16s and it was way less terrible.
it forces me to leave my home/community to get away from them to luckier communities who do not get bothered by them
I am a sound engineer and musician. The problem is beyond a nuisance.
It's absolutely unbelievable that these are allowed to fly in residential areas.
Makes me not want to live in Burlington, not just because of noise, but because excessive militarization in USA is against my moral values.
It is clear to my family that we have been knowingly selected to be exposed to indisputable health risks, cardiovascular disease, hearing less, etc. and the only alternative it to leave VT
Sad-angry-frustrated-health and well being impacted- and can't help but reflect on the people of Gaza City as they endure bombs from F16's/F35's compliments not just of Israel but USA
I spend a lot of time outside in my garden/yard and walking around town so the loud noise impacts me frequently.
My condo is worth eighty thousand dollars more than I paid for it 11 years ago.
I can’t get anything done when I hear them flying over even indoors with the windows closed. Even after words I am distracted and shaken for 10 to 15 minutes. And then put in a bad mood and anxious because I think about war and death.
The presence of F35s has had zero impact on my home and family.
The F-35s have taken the peace and quiet and enjoyment I have had in my home and neighborhood. It's been devastating.
It is very sad and frustrating because the jets distract me every day and are causing real harm across our community to people who are trying to work, learn, or take care of themselves. It has to stop. They are too loud for a residential area.
They fucking suck. You can't talk with anyone whenever they are going. Have to turn off the tv, or pause an audiobook. Forget about being on the phone.
It’s more than just a noise but the stress from worrying how it’s affecting other people with PTSD how it’s affecting domesticated and wild animals, stress from worrying how it’s affecting our war refugee population. Seriously, what fucking idiot thinks that The most populated county in Vermont of all states is a good place to fly these death machines?

It rattles my Windows and makes ot very hard to live here.
After having lived in the same apartment for over a decade, I've thought about moving specifically because the F-35 noise is so intrusive and impossible to ignore.
Sadly, ruined our life in VT
Makes me want to leave VT all together
Scares my young children, especially at bedtime!
Leahy's pollunting bastards shouldn't be in this area.
It should be illegal.
Normal contact, conversation, enjoyment of reading, listening to music, speaking via zoom are all stopped
Absolutely the worst. Literally the only reason we would ever consider moving out of Winooski. We love this town, live the school, love our neighbors, hate the jets and are not sure we can continue to live here with them ruining our home.
They are so intrusive that it can't be blocked out.
My partner and I are planning to have a child in the next two years and we really wanted to stay in Winooski because the school district is so diverse and we love our home. We are very seriously considering selling and moving in the next year because of the noise.
It ruins my quality of life daily. I absolutely despise it and wish the jets would go to a rural area. It's irresponsible for them to be here.
I love my home and wanted to stay here for a long time. If this does not stop in next couple of years, I most likely will move out of the area. I am angry and sad about this.
Blatant disregard for this community! Lying politicians don't live here. Should be accountable for lying-tampering with the basing outcome and indirectly assaulting thousands of people.
Triggers anxiety. Wakes sleeping toddler. Distracts from work. Intrusive constant reminder of war and violence.
The noise of the F-35s makes our property unlivable for several minutes, every day they fly.
The noise level is interruptive and frightening. It represents alarming indifference to the citizen's quality of life, health and safety.
Compelled to move---cost of moving- where? out of state? Being driven out of VT by politicians
I would never buy a home in the F35 flight path. We will be moving soon.
If an entity has reliable data and still proceeds to knowingly support or perp practices that cause undeniable bodily harm, isn't that a crime? If an entity deliberately poisons the environment, aren't they generally held accountable? Isn't it time, in this age of accountability, that military and crooked politicians are held up to the light?
Completely disrupts what used to be a lovely quiet place to live.
We want to move but can't afford a new house
I am still working from home with no in-person option. These flights interrupt my work, are impossible to schedule around even if I wanted to, and significantly impact my performance. This is unacceptable.
devastating mentally and emotionally
No matter what I'm doing, it forces me to pay attention to them, reminds me of those who are indebted in oil wars, bullying, systems of control and manipulation, denial of love light, and forces me to pray for their peace, global peace, and to remove themselves from my presence. If they want to be at war, don't do it with our tax dollars. Join mma or something.
this have decreased the value of my home and the enjoyment I once had
Lowers our Quality of Life and Home Value
I have to work remotely due to covid-19. The F-35 flights interrupt my meetings and class times, sometimes making it so that I cannot continue teaching.
This is just like any unwanted simple physical assault by arrogant authorities
The F-35s have absolutely reduced the value of our home. If the flights continue or ramp up, I may have to move, which I don't want to do.
My whole house shakes when the jets go by. The physical and mental stress is daily to myself and my children. We are in this home as it's the best we can afford and it was prior to the F35s. Due to financial reasons, we have to stay in this home and suffer each time the jets go by. My children's bedtime, schooling, studying, and play are negatively affected

my the sheer loudness and vibrations from the jets. I also work near the flight path and it's disruptive to myself, my fellow coworkers, and the people we service. The jets negatively affect every aspect of my life, my children's live and the effectson our health are yet to be determined but are unnecessary and could be prevented by the ceasing of the flights.

Unable to work, play, relax

Tinnitus/hearing loss

Brings me and my husband (was in the Air Force) great joy

The F-35 jets frequently interrupt my telehealth appointments with my patients.

No impact.

*adds a layer of strategic security to my home

If I knew about this assault on the senses before I moved to South Burlington, I would probably not have moved here.

Even in the NNE, the noise is so loud it makes me unhappy & anxious each time they fly.

The noise from the F35 is intrusive and offensive on every level...inside, outside and in with every activity.

The F-35 waste valuable resources. We have never needed jets to fight our battles. Jets were helpful in world wars to help other nations, but never once since then and never used to defend our land. 911 was not a nation in war with us, but a handful of extremists...who died in their attack. We do not bomb our domestic terrorist training centers! We must stop living in fear of what may happen when we are living with real threats such as pandemics, climate change, cyber attacks, disasters, domestic terrorism, racism, gun violence, police violence, hunger.... The F-35s does not help protect us against any of our real threats.

This is so invasive, and I regret that because I am not wealthy enough to buy a house and move away from the F-35 flight path, I'm forced to endure this without any ability to stop it.

The noise and the effects of the F-35 noise is not acceptable on any level!

all of the above and more!

The F-35s have ruined my sense of peace and security in my own home. It feels criminal to me.

I get highly annoyed every time I hear them. Worry about accidents and how that would affect civilians & the lake.

I’ve considered moving

In case you haven’t figured it out yet, every time I hear those fucking planes it causes anxiety and sometimes it’s so severe I just want to die. So thanks a lot military for saying you’re saving lives because your machines make me want to kill myself.

The weeks of the night flights were a nightmare!!! Seemed like those jets were constantly taking off and landing! So many times!! 5-6 times a day is horrible!

I'm concerned about all of the above, especially the quiet peace of mind, resulting in the need for me to seek out a therapist for my anxiety. I'm also anxious about the long term effects on my ears, as well as the long term devaluing of my home.

The F-35's should NOT have been based in BTV with a high residential neighborhood population. Other areas rather than Vermont were more suitable for this military plane. Thoughtless planning from our reps Leahy, Welch, Sanders, and Mayor Weinburger just to "save" 1,000 VTANG jobs, even though it effected over 6,000 families AND we later learn, the VTANG was not in jeopardy after all and would have remained with the F-35's. These "reps" did not listen to the concerns and data information which was provided of the harmful environmental and personal/medical effects of this plane from the people that have elected them years BEFORE the F-35's were to turn our beautiful Vermont into a noisy military base. Shame on them!

The constant noise is invasive.

This has to end.

Leahy's polluting bastards don't belong here.

The mental health of my family is greatly affected.

Sucks!!!! Damaged my nest egg. Who wants to live in this hell hole, soon to be ghetto.

It’s the worst

even with prices rising, these homes come in lower than other areas, because of F35's

Violates my bodily integrity in my yard.

this continued assault on my home life is wearing me down
I feel very violated and unsafe with the Jets flying over Winooski.
I hate these things with a passion. It has completely turned my life upside down and probably my future because of value of my house.
It is a daily assault on my well- being to the point of considering moving.
The Planes do not make us safer.
six of 6 checked above isn't enough?
don't know about home value impact - but would have to acquaint prospective buyers with the real experience - might lose potential buyers I would imagine
Furious and scared when these planed destroy my peace and quiet and finterrupt my business by forcing me to stop zoom meetings. . I feel invaded by own military. Makes me furious, increases heart rate. I have heart condition.
Can't rely on a day w/o F35's trashing life here and the environment, too. This is a for-profit Lockheed product draining American pockets and ruining VT life.
I'm afraid that if we ever go to sell our house that buyers will hear the jets and back out.
Living in the flight path of the airport comes with certain known issues. Noisy air traffic is expected throughout the day and sporadically at night. The F35's are a completely different level of intrusion. And, though I have always supported our military, these flights are having an adverse impact on my family
This is supposed to be a quiet place to live or has been for generations. The noise created by these planes has destroyed quality of life in rural and urban Vermont.
Makes our enjoying our property on a Saturday impossible.
premeditated, informed assault on our health and well being...perpetrator " Legacy of Lies" and cronies that all need to be held accountable as they destroy the environment with PFA's and the resident taxpayer families

OTHER (See Sheets)

F-35 night flight impact on your home and family in your own words if desired 81 responses

I have no young children but I can only imagine the impact on my neighbors who do. When multiple pairs of jets build their crescendo several times an evening

Inarticulatable rage at the magnitude of this stupidity

I can't wait for flights to be over.

GET F35's OUT OF VT NOW and hold politicians who rigged this basing accountable for the damage and suffering they knowingly cause

Usually by 8 PM I try to wind down and relax due to sleep issues. The f-35s at night disrupt my quiet relaxation time

Again, y'all chose to live near an airport. That's on you.

makes it hard to go to bed on time and go to sleep. I'm 70.

TOTAL BULLSHIT

We don't have young ones here anymore, but it is too much for my wife and I.

Yes, our entire household sets our routines based on the flights. We ensure our daughter, and all of us, will be indoors with doors and windows closed during their typical flight windows in the morning and afternoon. If we are caught outdoors, we run inside if we are close; or carry noise cancelling headphones with our daughter on her stroller or in a backpack to put those on when they fly over. Our house shakes and the sound is still so loud in our home when they go over that we all have to plug our ears anyway, but the house provides at least some shelter and reduction of exposure to the sheer volume and vibration of being outdoors. We all have an experientially-based fear/anger reaction to the planes, due to the disrespect we feel from the Guard and military for the planes even being considered appropriate to be in such a populated area, and the extremely negative affect it has on our daily lives and the lives of our neighbors who have PTSD.

Often I am out walking at that time and it is stressful and anxiety provoking.

Who wouldn't want to hear this abomination till 10pm? Worse yet, I dread the day schedule, when I won't be able to wake up and start the day begin without these F'er's, all day, between take-offs and returns an hour later x 2 rounds, each 10-12 flights.

limits our ability to enjoy our deck in the evening or go for walks.

Interveres with late afternoon nap. Late afternoon/night flights interferes with dinner, reading television, peace & quiet.

No impact

After a long day at work, I want to relax in a peaceful atmosphere at night. I have begun getting hypervigilant to the noise. I can hear them coming from a long ways away. I am getting so sensitive to the noise that I thought the streetsweeper going by was a plane and instinctively reached for the hearing protectors.

F35 night flight does not impact my home and family.

Emotional distress from being barraged with extreme noise in my home at night.

Any F35 over these homes, at extremely low altitude, blasting high decibels, polluting the air is outrageous- day or night

Totally unacceptable

I am 70- yo and go to bed at 9 pm. It is not right that they fly later than 7 pm.

Disturbs the peace! An assault on our bodies!

No additional impact relative to daytime flights. It's a huge nuisance and an imposition on my life that makes it difficult to focus on much of anything else.

My family consists of myself, my spouse, and our dog, who has also had a tough life including a fair amount of trauma. We feel terrible having exposed her to ear pain and new fear-- to the point of avoiding familiar walks and needing to sleep closer to us-- after rescuing her and doing everything we can to give her a better life. I have also been very aware of flights during our family time in the evenings, the only time we really get to see each other when we're both home from work-- and having to stop conversations repeatedly because of jet noise. It's intrusive.

Interferes with my my husband's my dogs and my bed time

No at home children. With planned post COVID visits with grandchildren planned I am fearful of how they will react

Wakes my sleeping children, gives my oldest anxiety.
the pilot's can train on simulators for this purpose along with many of the day training sessions. There is no need for the disruption and waste of fossil fuels
It wakes up children in my neighborhood EVERY time there are night runs. Parents I speak to are beyond frustrated and it's disturbing on so many levels to children and pets, never mind the effects on adults.everyone I speak to is bothered on some level by the jets. They are ruining my quality of life.
Annoying - I feel sorry for all the kids!
We are being forced to consider selling our home and leaving Hinesburg.
Disrupts naps and bedtimes every time.
I do not have children but sympathize with those who do. I do not appreciate my own sleep schedule being dictated by these planes.
Ruined this area of VT
I do not have children, but I do care for children with Autism Spectrum Disorders. The sound interferes with their sensory processing, nap times, and bedtimes.
Have to turn TV volume up to unsafe levels just to here the dialogue.
Feels like even more of a violation of our safety at night.
Practice night maneuvers SOMEWHERE ELSE, which believes they are the sound of Freedom, whatever that is.
Invasive Noise STOPS our abilities to enjoy life
just plain stressful. they hang around, hover, return - it's endless - Daytime flights bother us more, the droning on and on, the leaving us in peace only to return and harass us again.
I am worried about the health effects on me and on our pets.
It's just me. I'm my own family.
Interferes with my bedtime.
My child has experienced a trauma in the past year (unexpected loss of a sibling). She already struggles with anxiety and feeling unsafe. Home, particularly at bedtime, is where she feels safest. Extremely loud war planes flying over right at bedtime completely disrupts that fragile feeling of safety and relaxation that I'm trying to help her rebuild. Needless to say, I experienced this same trauma and am struggling with all of these issues as well. My main concern is for my child. We moved here to give her a peaceful, calm life. This is not what we expected.
I have work meetings several nights per week. Last night due to the flights I had to mute myself multiple times and missed hearing key information that was shared in the meeting.
The flights occur birth during nap and bedtime. My children cannot get the rest they need to be healthy as the flights push back or interrupt the sleep times for my children.
Ruins bike ride
None
No impact
Startling!
Have to stop speaking each time they fly over.
The flights interrupt every activity in the house or yard every time they fly over. There is no escaping the noise.
My son is 14 and suffers fear, anxiety, and aggression as a direct result of fly overs.
absolutely ridiculous that they have to do night flights for 3 weeks straight. And right at the height of bird migration
Night time is the time to unwind, which won't happen with jets flying overhead.
Interferes with my husband's and my bed time
Since I live in Richmond, the night flights are often noisy, but not dangerously so.
Disrupts time to relax from the day, phone calls, watching TV or if I decide to sleep early.
The evening flights don't have as much of an impact on me as I do not have children. But when I'm outside they're still really loud and triggering. Thankfully there's not as many people outside so I'm not as likely to have a fucking panic attack or meltdown in the presence of other people.
Although I do not have any children, the noise effects myself, my partner and my roommate detrimentally, causing personal anxiety in each of us, as well as creating a tense, unpleasant dynamic between the three of us.

Low flying, vibrating building, noise so intense you cannot read, sleep, converse or watch television. Why is it so necessary to fly so late????

They severely disrupt mine snd my dogs sleep patterns leaving me tired and lethargic throughout the day

Not only does it disturb me, but my neighbors children flip out whenever they go overhead...

My family is more irritable, frustrated, and uncomfortable because of the jet noise.

Sucks and enrages

I would like to live in Burlington, my partner insists we move due to the f35 noise. Life sucks

what could be good about F35 night flights?

We moved here so that we could have quiet. We had no idea we would be assaulted in this way with daily noise blasts--and at bedtime! In fact, as I file this report about flights at 7:50 pm (and having just completed one about the noise at 4 pm), we are being assaulted again by yet more flights, now at 9:25 pm! On the same day! It doesn't end.

We would expect peace and quiet after automobile rush hour, but the night flights just extend the damage that constant noise brings to human beings.

Why do they need to fly so late and low at night, interfering with sleep patterns, t.v. watching or just quiet, unwinding time!

When the nighttime started, I could not believe It. How much can we take, no peace, not even at night.

Awakens me during MY sleep. I have a job that I must show up for early in the morning and I need full concentration.

Being startled awake and not being able to go back to sleep is the worst part.

This incident I'm referring to did not disrupt bedtime, because it was at 4 pm.

Hate it! More distress in a time which had previously been quiet and I am concerned for all the children's bedtimes and their parents trying to help them settle in.

had to turn off the tv because couldn't hear

Disrupts my own fucking bedtime.

Interferes with our household bedtime

we have to go inside and try to avoid walking our dog during the usual flight times.

Awakens us just as we are falling asleep and sometimes even later in the evening.

Rest is impossible. The noise rips into an otherwise peaceful atmosphere and shreds it to pieces. It is the worst.

F-35 physical impact on your home in your own words if desired 85 responses

Noise
No shaking.
Windows vibrate
the vibrations knocked a clock off the wall
Have listed earlier in form. Deep resonating vibration in frame of house and windows that we never experienced with the F-16s. And we are supposedly in a sound zone that was IMPROVED by the F-35s vs F-16. TOTAL LIE!
this time? far alarm, broken glass
It's a plane... Not an earthquake generator.
House Shaking
The windows rattle
As much shaking as a garbage truck flying down the street.
Vibrated things off the shelves- broken, can't replace...like our health and exposure to F35's. No vaccine for this!
My body is standing in m vibrating home---my floors vibrating under my bare feet...I am physically vibrating along with the structure! How SICK is that that people have diliber4ately selected me for suffering.
Everything shakes, the ground, walls and the glas on windows clink
Felt shaking in my feet while standing on porch
I can definitely feel the vibrations. Vibrations like large truck driving down the street... Except that while at large truck vibrations will last 10 to 15 seconds this lasts for many minutes at a time... It is difficult to get back to the mental state I was in before this physical and psychological interruption
you can feel the vibration in your chair
Sometimes my home shakes, depending on the altitude of the jets, but it doesn't bother me and I'm not worried about the structural integrity of my home.
Window pains shake
This time is one of the first times I did not notice shaking. But usually there is shaking
Shaking house and windows
had to resituate a display of decorative glassware for fear it would shake of shelves and be destroyed
We have to straighten paintings & pictures almost daily because the vibration rattles everything around.
Windows rattle
windows rattle
I am a renter. Shakes my building and workplace.
I often feel the rumble in the floors and walls before I can 'hear' the jets. I can't imagine being able to sell this home to someone if they experience the jets flying over while looking at it.
My windows and other surfaces vibrate during the flights.
Not only do my floors vibrate, but the light fixture in my office rattles every time an F-35 flies over.
Number of crystal figurines have broken by falling due to vibration
I live in an old 1830's house
Everything shakes, including the insides. Thanks Sonic Boom!
Can definitely feel vibration in floors and windows
The planes are extra loud and rumbling today. I hate it.
Windows shake.
I'm in downtown Burlington, but the air hums like nearby machinery.
Rattles windows and vibrates floors
Things have fallen off shelves and broken
Frightening noise and some vibration
No noise cancelling can block the feeling of my damn HOUSE rumbling

the ground's moving under my feet - sad, deeply disturbing loss of my life in VT thanks to this F35 basing---makes this the worst place I've ever lived instead of a quality life in VT
Curious what continued intense vibrations are doing to the structures / mechanicals etc. as windows vibrate, things migrate off shelves, car alarms go off etc
Could feel the deck shake as I sat on it.
Rattles the storm windows
Can feel the house shake.
This will be on my next complaint form... I work and also live in the flight path.
Just a major detriment to the normal use and enjoyment of a place that we have cultivated and enjoyed for 35 years.
The Williston Community Forest, established around 2019, surely suffers as much if not more than we do- ask them.
I live in an old 1830's home which is no match for these jets
It feels like the country has gone to war.
shakes windows on back porches
Daily 110 decibels peaks over a twenty to thirty five minute timeframe two to six launch windows.
Windows rattle and the vibrations are intense enough that I am sure they are having long-term, cumulative impact on my brick face and stonework.
My whole house shakes and my body also feel it's intensity.
Excitement
Good morning! No worse than the BED chip train
There is a vibration that envelopes the atmosphere when the planes fly over.
Vibrations of walls windows floor and chair sofas being sat in
sometimes windows rattle
F-35 doesn't usually shake parts of my home. That's part of how I judged today to be much worse than usual.
Cracks in grout, shaking of objects inside
Floors, walls and windows vibrate and rattle
I can feel the vibration sitting in my home.
Windows rattled. I have a brick home with stone foundation and I am sure that vibrations are adding wear and tear to the masonry.
the F-35's don't belong in a populated area like Chittenden county.
It fucking shakes like there’s a garbage truck speeding through my neighborhood for almost 10 minutes straight. And while that doesn’t seem like a long time to psychological and physically (increase heart rate, increased blood pressure, nausea, etc.) draining impact can last for hours.
Everything rattles!!
FWW blasting in there quarry Shake my home more than 35
Our skylights were shaking visibly.
Live in a 55+ Senior complex. The windows/building vibrates with the low flying of F-35's
Shakes my apartment so hard the windows rattle if they are oriented with the jets toward my home
Rattles every window. Even dishes in the dish rack. Criminal invasion of my home
industrial vibration meters monitor noise impact/damage on equipment. I wonder what this intense shaking is doing to property. Glass rattling, pictures tilting, things vibrating off the shelf, car alarms going off...
pictures on wall sometimes rattle against the wall
Floors vibrate and chandelier rattles.
can hear vibrations inside walls (structure) and also window panes.
I feel like there is a small earth quake happening every time they fly, even with all of my windows closed inside my home.
Plants rattle on window shelves, sun catchers rattle on window, shakes building
My back porch has windows that shake when the F35s go over.
My house is in Jericho and it still rattles when they fly by
I rent but all the dishes jangle. And I can't do business in my own house.

I worry about flights disturbing friable asbestos insulation in some of these old attics.
during lower flights the older windows rattle from the pressure waves.

F-35 impact on your business in your own words if desired 65 responses

Distracted me from working on business at home.
I take a lot of Zoom classes and webinars and can't talk when the planes go over.
Frequently experience interruptions in work meetings due to noise
Interrupts all business communication when they are flying during the day.
TOTAL BULLSHIT
I don't know if my clients choose to work with others because it's annoying to try and communicate with me when we are so often interrupted, I just know it stops all communication until they pass. Depending on where the client is, sometimes right after it stops for me, we have to stop for them as they pass my client's house.
Both my wife and I own and run businesses in Winooski, Burlington, and my business also has a shop in Essex Junction. The F-35s have interrupted sales meetings, client meetings, team meetings, zoom meetings, phone calls, outdoor meetings, meetings in our offices, and work outdoors. Ironically, my wife is a former state legislator and she would have to mute herself during participation in zoom legislature events and while speaking on the "floor", etc.
I teach classes in the evenings and if my students cannot hear or their dogs are too stressed by the noise to learn I cannot provide a quality learning environment for them.
can't rely on working-talking-concentration, etc.
Hard to work when you can't hear
No impact on my business.
The F35s occasionally interrupt a business phone call, but I'm not bothered by it and so far, the people on the other end of the phone aren't bothered by it.
Currently in a training session for work and I cannot hear/understand the material because of the planes. This has been on and off for the past 30 minutes. I absolutely cannot get any work done until they're finished.
F35s interrupted my weekly departmental meeting, making me unable to participate meaningfully.
Substitute business for school.
negatively impacts counseling sessions and client safety
Again, productivity lost because I cannot take phone calls or participate in meetings with F35s flying.
about 1/2 of my team lives in the Burlington area and we lose about an hour of meetings a day to the jet noise.
Phonecalls are impossible during the flights, and I work at a job where I may need to take phonecalls at any time during normal business hours.
Work out of the house--very disturbing to be repeatedly put off course by training pilots careening overhead--can't hear, can't have a conversation, lose focus, get angry-calm down and then, they come again
I am a musician. Every flight brings my work to a standstill.
I work from home and disrupts my concentration and can't hear anything if I'm in a meeting or on a phone call
Yet again, these flights go on FOREVER. I am sitting at my desk for at least 20 minutes now because I'm waiting for these fucking planes to be done. I cannot perform my job in the meantime.
Zoom calls, any calls, have to stop as they pass.
Retired and not impacted this way
Planes started around 9:55, it's 10:05 now. Can I turn my phone back on and take customer calls yet? I don't know. I can only sit here and wait until they're finally gone and I can back to work. The F-35s reduce my productivity multiple times per day, sometimes multiple times per hour. They legitimately affect my job performance.
How long will it go on?? I've been sitting here 15 minutes waiting until I can DO MY JOB because it involves speaking with people on the phone. I should send the government a bill for the lost productivity.
I have to pause conference calls often and explain to clients what is happening. They are all out of state and are often extremely surprised that Vermont would allow this in such a populated area.
I could have stayed in NYC if I wanted noise like this.
We are extremely busy this week and I am prevented from using the phone while the planes fly overhead for I don't know how long. I lost count at 8 fly bys already. When will it end? My productivity drops to zero when they're flying

Couldn't hear members at drive up of financial institution, many members are hard of hearing to begin with and this made them frustrated and upset

It was so nice to be free of these planes for a few weeks. Now it's back to answering phone calls where you suddenly can't hear the customer because SURPRISE IT'S PLANE TIME.

When will I be able to take phone calls from customers again? I don't know! These planes go on FOREVER

was on a video call and had to stay on mute/not participate in group discussion as a result of F-35 flights. made me look bad in front of clients

I cannot perform my job when the F35s are flying.

Disrupts my chain of thought.

Have to stop conversations. Get grumpy. Frustrating

disrupts communication, focus and output

Once again, the planes are taking off for night flights and I am unable to perform my job until they are done. Yesterday this took ~15 minutes.

F-35s interrupted a webex meeting with colleagues. I was unable to participate in the meeting for a good 20 minutes because of the planes. These planes are severely affecting my productivity.

I don't own the business I work at but the jets negatively disrupt the flow of a workday for to the superfluous noise the jets make.

Outdoor yard work, so the noise interrupts my work

None

No impact

It is too early to know how this will change our business (guesthouse) but I cannot imagine wanting to stay in a guesthouse when the noise levels from the planes are as intense as they are.

Retired business not applicable

I am a psychotherapist, counseling individuals who are troubled. the roar of the warplanes is not at a therapeutic and must be apologized for again and again and again

At Taft Corners the decibel intensity can reach 110. That is insanely loud.

Work stops cannot hear or communicate with coworkers and customers.

Had to discontinue business call/meeting. Cannot concentrate and work when they fly over.

When will they end? When will I be able to take calls again? Why do the planes need to go for 10-20 minutes at a time?!

Due to working from home since March 2020, these planes are a regular nuisance to my work life and communication with my team.

I work from home because of the pandemic. Instead of getting work done I'm trying to figure out What the fuck I need to do so that I am not so stressed and I am mentally and physically able to sit down and get my work done. And guess what, if I'm not getting any work done I'm not making any money. So thanks a lot military for ruining my fucking life.

Interrupted a work call, which could have effected my career long term due to missed assignments.

Not applicable

the noise disrupts my work

Once again I am unable to perform my job functions while the F-35s are flying. This one occurred in the middle of a customer call and I could not hear anything they were saying.

concentration / phone conversation

I work from home and there have been many times I could not continue on a call or Zoom due to the excessive noise.

Horrible

Completely interrupted my work this evening. I can't believe I am subjected to this near-daily bombardment of noise. I pay way too much in city and state taxes to have my quality of life affected so negatively in my own home.

Can't tape video or record or talk to clients when these planes are roaring overhead.

I'm working from home an have to stop what I'm doing every time to cover my ears while they are passing by and lately they are flying more and more it is very unsettling, disappointing, makes me angry and not want to live here anymore even though I love my home and the location where we are.

Multiple interruptions while recording. Many hours of work have to be redone due to ruined recordings.

Impact of F-35 on your dog, cat, or other pet in your own words if desired 47 responses

No pets
Worried about pets well being. Worried about wildlife.
And mine is the cattest of all cats, and still runs scared while they are taking off, but there is no escape.
I’m worried about my gecko’s hearing in the summer when the windows need to be open (no ac) she is a small animal and cannot handle the same level of stress as a dog or cat
Pets don't care.
TOTAL BULLSHIT
N/A
As a dog trainer I have heard first-hand from many clients who live in areas of extreme noise impact that their dogs have suffered adverse impacts such a panicking when walking outside during flights which risks them getting loose and lost, hiding/shaking/panting/drooling when indoors during high noise level times, and now have underlying stress and anxiety issues that were not present prior to the F-35 flights. These clients mostly live in Winooski, South Burlington, and Colchester.
...and wildlife?
Dog anxiously barks when these noise levels are happening
How about impact on small animals; birds, deer squirrels anything living in the flight path!
My cat slept through it.
I have two dogs and they seem completely oblivious to F35 noise. Doesn't bother them at all.
I pity my pets- their exquisite hearing so much finer than humans. And, I'm aware of wildlife / environment. Data cites "noise is affecting birds ability to reproduce". There's plenty to read online. And locally, let's not forget water pollution / PFA's courtesy of VTANG, our "good neighbors"
My dog becomes visibly anxious when planes pass on a walk.
My poor cat was in the window during the flyover. She was terrified and left the window, coming to me for comfort. My cat is old and suffering from kidney disease and starting to slow down but she LOVES being in the window. The F35s are denying her this simple enjoyment
Please see my previous comments on this. My dog is a rescue and has suffered increased anxiety that has affected her behavior during and immediately after F35 encounters.
Our cat is terrified and needs to have open access to immediately run inside and sit with us.
The planes upset the neighborhood dogs, which in turn leads to more noise
We are trying to keep weight on our cat with kidney disease. It's already enough of a struggle getting to her eat, and now the planes interrupted her feeding today.
I cannot leave a window open for my cat with the F35s flying. She will blot in fear, and I worry about hearing damage.
pathetic, and then there's the wildlife
I have a service dog. The sound distracts him to a level where I am unsure he would provide an alert if one was necessary.
very stressful to both my dog and two cats
We have indoor cats and rabbits who run, hide, and show obvious distress. I am worried about the effects of the F-35 flights on my pets' health.
My dog, a puppy, hates the flights. She runs and hides.
I have cats and the cats jump down and hide under beds or couches. They will run away from the windows.
2 dogs and 2 cats - no problem
Emotional support animal sleeps through it.
My dog grew up in winooski she didn’t care. Again shame on you for your survey design.
Our cats always run inside when the planes fly over...it is frightening to them.
Pet free location
My cat runs and hides when he hears the jet noise.

My puppy gets anxious when they are flying over at night
He is visibly shaken and panicked
Can’t verbally communicate with my animals. They get really stressed out when they see how upset I am
My cat is terrified when the jets fly over!!
My dog loves the 35s
My cat was upset and panting with fear for hours afterward.
Terrified
the cats run for the house door
My dog is so frightened that he tries to hide but is so confused. It takes him over an hour to recover after they have passed.
Again I'm afraid I'll be out walking my dogs and we are going to be exposed to the crazy and deafening noise
My cat reacts with anxiety and sometimes runs and hides