

DRAFT – Interim Report of the Independent PFAS Scientific Advisory Panel for Jersey – Second Interim Report on PFAS and the Environment.

Dec 2025



Contents

Contents	2
Table of figures.....	12
1 Background.....	13
2 Introduction and approach.....	17
2.1 Types of PFAS and their chemistry	17
2.1.1 Definition and classification	17
2.1.2 Types of PFAS and their properties.....	17
2.1.3 Precursors	19
2.2 Chemistry of AFFF	20
2.2.1 PFAS Types in AFFF.....	20
2.2.2 Bioaccumulation.....	21
2.2.3 Environmental Accumulation.....	21
2.2.4 Regulatory and environmental concerns.....	21
2.3 PFAS in the natural environment and human infrastructure	22
2.3.1 Behaviour in Natural Environments.....	22
2.3.2 Interactions with Built Environments	23
2.4 Key Transport and Redistribution Processes	23
2.5 Persistence.....	23
2.6 Implications for Management.....	24
2.7 Potential routes of human exposure	25
2.7.1 Absorption of PFAS into the body.....	26
2.7.2 Distribution of PFAS in the human body.....	27
2.7.3 Metabolism	27
2.7.4 Elimination	27
2.7.5 Transmission	28
2.8 Key findings from Report 2 on the human health effects of PFAS	30
Cardiovascular Health	30
Cancer Risks	30

Immune System and Autoimmune Diseases	30
Endocrine and Metabolic Disorders.....	30
Mental Health and Wellbeing	30
Reproductive Health	31
Other Health Concerns	31
2.9 Groups at increased risk	32
2.9.1 Age.....	32
2.9.2 Additional exposure	32
2.10 Body burden and disease risk	33
2.10.1 Dose-Response Relationship.....	33
2.10.2 Evidence for Risk Reduction Through Body Burden Decrease	34
3 Testing for PFAS.....	37
3.1 How samples are taken.....	37
3.1.1 Surface water and drinking water.....	37
3.1.2 Surface sea water and sea foam	37
3.1.3 Soils and sediments.....	38
3.1.4 Air sampling.....	38
3.1.5 Wildlife tissues	38
3.2 Core laboratory methods.....	38
3.3 How sensitive are laboratory tests?	38
3.4 Special challenges for PFOS, PFHxS and PFOA.....	39
4 Context in Jersey.....	40
4.1 Waste disposal in Jersey	40
4.1.1 La Collette Energy Recovery Facility.....	40
4.1.2 La Collette Clinical Waste Incinerator	41
4.1.3 Waste Disposal Cells at La Collette	42
4.1.4 Bellozanne Valley Wastewater Treatment Works	43
5 Evidence from subject matter experts	45
5.1 Experts on PFAS and food.....	45

5.2	Presentations from experts on PFAS and food	45
5.2.1	Presentation from Subject Matter Expert Thorhallur Halldórsson	45
5.2.2	Presentation from Subject Matter Expert Leo Yeung	46
5.2.3	Presentation from Subject Matter Expert Irina Gyllenhammar	46
5.2.4	Presentation from Subject Matter Expert Ida Hallberg	47
5.3	Discussions with experts on PFAS and food	49
5.4	Experts on PFAS in non-drinking water, soil and biosolids management and PFAS destruction	50
5.5	Presentations from experts on PFAS in non-drinking water, soil and biosolids management and PFAS destruction	50
5.5.1	Presentation from Subject Matter Expert Jelena Rejanovic	50
5.5.2	Presentation from Subject Matter Expert Steven Chow	52
5.5.3	Presentation from Subject Matter Expert Linda Lee	53
5.5.4	Presentation from Subject Matter Expert Michel Hubert	54
5.6	Discussions with experts on PFAS in non-drinking water, soil and biosolids management and PFAS destruction	56
5.6.1	Wastewater remediation	56
5.6.2	Soil remediation	56
5.6.3	Biosolids	57
5.6.4	PFAS destruction	57
5.7	Expert on treatment of water in the home to reduce PFAS	58
5.8	Presentation from expert on treatment of water in the home to reduce PFAS	58
5.8.1	Presentation from Subject Matter Expert David Andrews	58
5.9	Discussion with expert on treatment of water in the home to reduce PFAS	60
6	Treatment of borehole supplies to reduce PFAS in drinking water	61
6.1	Regulatory and standard-setting context for small supplies	61
6.2	Core technologies and comparative performance in groundwater	61
6.2.1	Granular / block activated carbon (GAC/CB)	61
6.2.2	Ion-exchange resins (IX)	62
6.2.3	Reverse osmosis / nanofiltration (RO/NF)	62

6.2.4	Foam fractionation (FF) and destructive add-ons (for side-streams)	62
6.3	Design approaches for borehole and well supplies	63
6.3.1	Wellhouse point-of-entry (POE) adsorption	63
6.3.2	Membrane skids (RO/NF).....	63
6.3.3	Household-level backstops on private wells.....	63
6.4	Monitoring, operations and residuals.....	64
6.4.1	Matrix management.....	64
6.4.2	Residuals.....	64
6.5	Conclusions for borehole/well treatment	64
6.6	Key questions in options appraisal	65
7	Treatments in the home to reduce PFAS in drinking water	66
7.1	Regulatory and certification context relevant to household devices.....	66
7.2	Different technologies in use.....	66
7.2.1	Granular and block activated carbon (GAC/CB).....	66
7.2.2	Ion-exchange (IX) resins	67
7.2.3	Reverse osmosis (RO) and nanofiltration (NF).....	67
7.3	Deployment formats and engineering constraints.....	67
7.3.1	Point-of-entry (POE; whole-house).....	67
7.3.2	Under-sink point-of-use (POU; plumbed)	68
7.3.3	Worktop POU (plug-in RO and non-RO cartridges).....	68
7.3.4	Pitcher/gravity (“filter jugs”).....	69
7.4	Summary table	69
7.5	Key findings from comparative analysis	70
7.6	Unresolved issues, by technology and format.....	71
7.7	Conclusions	72
8	PFAS and food.....	73
8.1	Introduction	73
8.2	EFSA estimates of average dietary intake from food	73

8.3	PFAS concentrations in measured in foods contributing to dietary intake	74
8.4	Trends over time	75
8.5	Recent total diet intake estimates	76
8.6	Average PFAS in water contribution to total intake	77
9	Soil, biosolids and environmental water	78
9.1	Soil guidelines	78
9.2	Environmental water guidelines	80
9.3	Treatment technologies for PFAS in environmental waters and soils	80
9.3.1	Treatment technologies for PFAS in environmental waters	82
9.3.2	Treatment technologies for PFAS in soils	87
9.3.3	Conclusions	91
9.4	Biosolids management options	92
9.4.1	Land Application of biosolids	93
9.4.2	Landfilling of biosolids	94
9.4.3	Thermal treatment of biosolids	94
10	Discussion	97
10.1	Summary of expert evidence, discussions and literature review on PFAS and food	97
10.1.1	Scientific baseline and current guidance	97
10.1.2	Exposure pathways, packaging and chemicals in transition	97
10.1.3	Analytical reliability and interpretation	97
10.1.4	Swedish Market Basket findings and trends	98
10.1.5	Foods produced near hotspots: milk, beef and eggs	98
10.1.6	Jersey-relevant considerations, backyard production and comparators	99
10.1.7	Estimating dietary intake for the UK/Europe and water’s contribution	99
10.2	Panel discussions on PFAS and food	101
10.2.1	Intake accounting and the relationship with water levels	101
10.2.2	Food monitoring and uncertainty	101
10.2.3	Backyard poultry in or near contaminated areas	101
10.2.4	Freshwater fish consumption	101

10.2.5	Potential areas for recommendation on food	102
10.3	Summary of expert evidence, discussion and literature reviews on management and treatment of water not for drinking, soil and biosolids and PFAS destruction	103
10.3.1	International guidance levels for soils, environmental waters, and biosolids	103
10.3.2	Management and treatment of environmental waters	103
10.3.3	Management and treatment of soils	105
10.3.4	Management and treatment of biosolids	106
10.3.5	PFAS destruction technologies: relative strengths, weaknesses, and maturity	107
10.3.6	Key points	108
10.4	Panel discussion on management and treatment of water not for drinking, soil and biosolids and PFAS destruction	110
10.4.1	Overall approach and technology maturity	110
10.4.2	Soil use classes and potential thresholds	110
10.4.3	Non-drinking (environmental) waters levels	110
10.4.4	Treatment options for contaminated environmental waters.	111
10.4.5	Biosolids management:	111
10.4.6	Summary aims and objectives	111
10.4.7	Potential areas for recommendations on soils, environmental waters and biosolids: 112	
10.4.8	PFAS destruction technologies: summary of discussion and conclusions	112
10.4.9	Potential areas for recommendation on PFAS destruction	113
10.5	Summary of expert evidence, discussions and literature reviews on borehole and in-home water treatment	114
10.5.1	Borehole supply treatment (small groundwater supplies)	114
10.5.2	Treatment of water in the home	115
10.6	Panel discussions on borehole and in-home water treatment	119
10.6.1	Boreholes and other private supplies	119
10.6.2	Home water treatment	119
10.6.3	Potential areas for recommendation	120
11	Recommendations	121
	References	123
	Glossary	139

Appendix 1 – Minutes of Panel meetings	145
Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 4 September 2025	145
Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 25 September 2025	158
Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 4 September 2025	171
Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 25 September 2025	184
Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 15:00 on 16 October 2025	197
Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 22 October 2025	201
Draft minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 11 November 2025	211
Draft minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 18 November 2025	220
Appendix 2 – Government documents received on waste management in Jersey	231
La Collette energy recovery facility.....	231
Overview	231
Plant and Operational Description	231
Waste Inputs	232
Operational Parameters	233
Monitoring, Testing and Reporting.....	233
La Collette clinical waste incinerator	234
Overview	234
Plant Description.....	234
Waste Inputs	234

Operational Throughput	234
Operational Process	235
Waste disposal cells at La Collette reclamation site	236
12 Overview	236
Cell Engineering	236
Waste Inputs	238
Waste Acceptance Criteria.....	238
Leachate Monitoring & Management	238
Exporting Waste.....	238
Bellozanne Valley Wastewater Treatment Plant Summary.....	239
Overview	239
Inlet	239
Liquid Processing.....	239
Digester Plant.....	240
Biosolid Disposal	240
Appendix 3 – Government of Jersey sampling methodology and PFAS testing protocol	242
FOOD AND SOIL	242
TESTING METHODOLOGY	242
WATER QUALITY AND SAFETY PROGRAMME.....	242
1. INTRODUCTION	243
2. METHODOLOGY	243
2.1 SAMPLING.....	243
2.2 SAMPLE COLLECTION PROCEDURES	243
General Precautions.....	243
2.3 SOIL SAMPLING.....	244

Procedure:.....	244
Storage:.....	244
2.4 PLANT MATERIAL SAMPLING	244
Procedure:.....	244
Storage:.....	244
2.5 POTATO SAMPLING	244
Procedure:.....	244
2.6 PRODUCT OF ANIMAL ORIGIN SAMPLING	245
2.7 LABELLING AND DOCUMENTATION.....	245
2.8. TRANSPORT AND STORAGE	245
2.9. QUALITY ASSURANCE AND CONTROL.....	245
3.0 LOCATIONS.....	246
4.0 LABORATORIES USED	246
PFAS Testing Protocol – Informing Report Four by the Independent PFAS Scientific Panel.....	247
1. Rationale for Testing.....	247
2. Scope of Testing.....	248
2.1. Selection of Vegetables for PFAS Testing.....	248
2.1. Selection of Meat Products for PFAS Testing.....	248
• Beef	248
2.1. Selection of Dairy and Egg Products for PFAS Testing.....	249
• Milk.....	249
2.1. Selection of Marine Environment and Seafood for PFAS Testing.....	249
• Marine:.....	249
• Seafood:	250
• Seawater:.....	250

• Drinking Water:.....	250
• Surface and Rainwater:	250
• Groundwater:	251
2.1. Selection of Waste Processes and Soil for PFAS Testing	251
• Sewage Sludge:.....	251
• Water Treatment Process	251
• Soil:.....	251
• Leachate and Surface Water:	252
3. Methodology.....	252
3.1 Analytical Methods.....	252
• Testing Requirements:.....	252
3.2 Laboratory and Quality Assurance	252
• Chain of Custody for New Samples:	253
• Cost and Capability Review:	253
4 Data Management and Reporting.....	253
4.1 Data Aggregation.....	253
4.2 Exposure Assessment	253
4.3 Interpretation and Reporting	253
12.1 Transparency and Scientific Integrity	254
Appendix 5 – Islander input and panel responses.....	255

Table of figures

Figure 1 - Summary table of in-home PFAS water treatment options.....	69
Figure 2 - Estimate Lower Bound intakes for main food groups in EFSA report applied to UK adults.	74
Figure 3 - Average European PFAS contaminant concentration by food group, Upper and Lower Bound average from EFSA for the sum of 4 PFAS	74
Figure 4- Average UK PFAS contaminant concentration by food group 2012, for individual and sum of 4 PFAS.....	75
Figure 5- Per capita PFAS intake (ng/person per day).....	76
Figure 6- The relevant soil threshold values for PFAS in Flanders, Belgium.....	79
Figure 7- Overview of the AF-based PNEC values derived for direct toxicity in PFAS contaminated soil	79
Figure 8- Summary of technology readiness levels (TRLs).....	82
Figure 9 - Summary of PFAS treatment technologies for environmental waters.....	86
Figure 10- Summary of PFAS treatment technologies for soils.....	90

DRAFT

1 Background

Per- and polyfluoroalkyl substances (PFAS) comprise a group of over 14,000 synthetic chemicals (this total number is evolving all the time and differs in various reports) used in a wide range of consumer product and industrial applications around the world including in fire-fighting foams, in non-stick cookware, water repellents, and food packaging (Glüge et al., 2020). Their chemical stability and resistance to degradation (Cousins et al., 2020), which has led to long-term environmental contamination and the toxicological profiles of certain PFAS (*Toxicological Profile for Perfluoroalkyls*, 2021) have driven concerns regarding possible human health effects (Buck et al., 2011).

The main source of concern in Jersey relates to the historical use of PFAS-containing aqueous film-forming foams (AFFF) used in firefighting. PFAS-containing AFFFs, developed in the U.S. in the 1960s and used globally since the 1970s, have been effective in extinguishing liquid fuel fires but have been identified as a significant source of environmental contamination (Prevedouros et al., 2006). These foams were in use at Jersey Airport and its on-site training facility in the parish of Saint Peter. Groundwater near the airport and, as a consequence, some water supplies became contaminated with PFAS. In 2006, mains water was extended to the area, and therefore the initial exposure from the airport is believed to have been markedly reduced for those households that switched to using mains water, although there will be some ongoing exposure from secondary sources and recirculation of PFAS. While AFFF use and consequent exposure started some years ago; before potential environmental and human health risks from PFAS had become known; the persistence of PFAS in the environment and in the human body mean that there are still concerns today.

In response to the concerns that had been raised, a company called Arcadis were commissioned in 2018 to survey private water supplies for the presence of certain PFAS, and an Officer Technical Group (drawing its membership from several directorates across Infrastructure and Environment, Public Health, Jersey Water and others) was established by the Government in 2019 (*PFAS in Jersey* (2023)).

In 2022, a programme of blood testing was arranged for people who had regularly used borehole water supplies in the affected area as a source of drinking water and had symptoms consistent with conditions that have been associated with PFAS exposure.

In 2023, the Government of Jersey made provision, through the public health team, to commission an independent group of scientists to assess the current situation in Jersey, with regard to PFAS, and make recommendation for actions to be taken. The Independent PFAS Scientific Advisory Panel has three standing members and a standing observer from the public health team. They have regular, publicly livestreamed, meetings where they hear from subject matter experts from around the world, as well as from affected people in Jersey (experts by experience). The key issues brought to light by these contributors as well as those from the scientific literature are explored. The standing Panel members are:

- PFAS Scientific Advisory Panel Chair, Dr Steve Hajioff

Steve Hajioff is an experienced leader with over 30 years as a practicing doctor and more than two decades in leadership roles in the health sector and public health practice: including being Director of Public Health in the London Borough of Hillingdon - an area with two international airports and other environmental challenges. He has worked for a variety of organisations including the WHO, World Bank, EU, international governments, UK government departments, the Greater London Authority (where he co-led the health impact assessment of the nine mayoral strategies), several NHS bodies, and has advised BMJ, Elsevier, British Standards Institute, Reuters, and many others. He is experienced at chairing scientific panels, having chaired two high-profile guideline development groups for NICE, and also at chairing groups with a high level of political and media engagement; he chaired the Representative Body of the British Medical Association for several years and several scientific fora, regional, national, and international. Steve has also served in Chief Medical Officer roles for a variety of biotechnology businesses and has been involved in many clinical trials.

- PFAS and health expert, Dr Tony Fletcher

Tony Fletcher PhD is an environmental epidemiologist with over 40 years' work in occupational and environmental epidemiology and risk assessment, with experience of studies of exposure, biomonitoring, and health impacts such as cancer, respiratory disease, and metabolic disorders. He has been researching the health effects of PFAS – perfluorinated substances – since 2005, as a member of the C8 Science Panel which led a major investigation on potential health effects of PFOA polluted drinking water in West Virginia and Ohio. More recently he has been working in epidemiology programmes in PFAS-contaminated communities in Ronneby, Sweden and Veneto, Italy. He is currently Associate Professor at the London School of Hygiene and Tropical Medicine, where he has been since 1992, and has held jobs in the past at Public Health England, UKHSA, the International Agency for Research on Cancer (IARC) in Lyon, France, Birmingham University, the MRC Environmental Epidemiology Unit, Southampton and Aston University. He was Adjunct Research Professor in Environmental Health in the School of Public Health, Boston University, Massachusetts, and President of International Society for Environmental Epidemiology.

- PFAS and environment expert, Professor Ian Cousins

Professor Ian Cousins is Professor of Environmental Organic Chemistry at the Department of Environmental Science at Stockholm University. Professor Cousins leads a research group focusing on understanding the sources, transport, fate, and exposure of organic contaminants and is particularly well known for his research on PFAS. Professor Cousins has extensive PFAS research experience, dating back over 20 years to 1999. Some notable career highlights include being a keynote speaker at international PFAS workshops on multiple occasions and receiving several best paper awards for his research. In recent years, Ian has coordinated a large European multidisciplinary project, [PERFORCE3](#), which focused on PFAS. He was also chair of the recent international conference, [FLUOROS 2023](#), where the world's leading experts on PFAS gathered. Ian's research currently focuses on better understanding

uses of PFAS and investigating suitable alternatives, using analytical approaches to measure PFAS in consumer products and environmental samples, and investigating the transport and fate of PFAS in the environment.

- Standing observer and Group Director for Regulation, Kelly Whitehead:

Kelly Whitehead is the Group Director of Regulation for the Government of Jersey. She has worked in Jersey’s government for two decades and took on her current role in 2022. Kelly oversees regulatory areas including environmental protection and drinking water regulation. She is responsible for ensuring that regulatory frameworks protect public health and the environment and has been closely involved in the Government’s coordinated response to PFAS contamination. Kelly is a standing observer so that she can contribute to the discussion, bringing regulatory insight and knowledge of how Jersey’s systems can be used to support water quality and safety.

The panel will be producing five reports over the course of its work programme to provide best available evidence and evidence-based recommendations to the Government of Jersey, other key stakeholders like health services and Jersey Water and to wider society across Jersey and, potentially, beyond.

The five reports are:

1. An interim report on the appropriateness and feasibility of the use of therapeutic phlebotomy to lower PFAS body burden in affected individuals in Jersey.
2. A report on the current state of knowledge about the health effects of PFAS on people and an evaluation of which groups of people may be at increased risk.
3. A review of the range of interventions which may reduce PFAS body burden in those with elevated PFAS levels and the expected impacts, along with recommendations on the nature and extent of serum PFAS testing in both the affected community and the wider population of Jersey.
4. A systematic review of the technologies and methods that may be used to manage PFAS in the environment, along with key strategies for environmental monitoring.
5. An update report taking into account new and emerging evidence from the previous report areas, as well as progress made and any emergent results in the environment or population of Jersey.

All the reports will take due account of the balancing of risks and benefits and also of opportunity cost, including any potential consequences of impacts on services, and will pay particular attention to ensuring that people at greater risk are given additional consideration. The overall approach the panel will take is:

- Being led by evidence
- Working through consensus
- Involving input from experts by experience and subject matter experts
- Public involvement throughout the process
- Default to meetings being in public
- Ability to work in private where there is a need for confidentiality

- Regular engagement with key stakeholders in addition to Panel meetings
- No surprises

Each report will follow a similar process, with an initial draft scope being agreed within the panel and consulted on with stakeholders (including Islanders) before a final scope is developed. There will then be a series of systematic reviews of the available, relevant scientific literature and the consideration of evidence from subject matter experts and experts by experience. These draft reviews and meeting summaries will be shared in advance of the publicly accessible Panel meetings, where they will be discussed, and draft inferences and recommendations arrived at. A draft report will be prepared, integrating the various workstreams and will be shared with Government of Jersey through public health (the commissioners of the process) and with the public for consultation and comment. The consultation findings will be reviewed by the panel and, where appropriate, the report revised. The final report will be shared with the Government to consider the findings and launched through one or more public meetings. The panel meets normally once a month online and the public can observe and email in comments, the agenda and minutes of the meetings are publicly available on the Jersey Government website: [PFAS in Jersey \(gov.je\)](https://www.gov.je/pfas)

In order to optimise the use of time, there may be some time overlap between consecutive reports, with reports processes starting before the previous report has been finalised.

2 Introduction and approach

2.1 Types of PFAS and their chemistry

This is a summary of a presentation given by Professor Cousins at the Panel meeting on 4/3/24. Further detail is available in the minutes of the meeting.

Per- and polyfluorinated alkyl substances (PFAS) represent a group of chemically related substances used across a wide array of applications due to their unique properties. This section clarifies the terminology, chemical structure, and regulatory aspects surrounding PFAS, with an emphasis on their environmental and health implications.

2.1.1 Definition and classification

PFAS are broadly categorized based on their chemical structure:

- **Perfluorinated:** These compounds have carbon chains fully saturated with fluorine atoms, replacing all hydrogen atoms.



- **Polyfluorinated:** In these substances, not all hydrogen atoms in the carbon chain are replaced by fluorine.



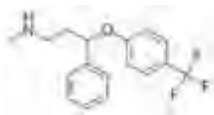
- **Alkyl Substances:** This term refers to compounds containing fully saturated chains of carbon atoms, and not rings of unsaturated carbon atoms.

There is no single globally approved definition of PFAS. The Organisation for Economic Co-operation and Development (OECD) defines PFAS as "fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (OECD, 2021). This definition encompasses substances with at least one -CF₂- or -CF₃- group, including molecules that have a ring of unsaturated carbon atoms elsewhere, expanding the number of substances defined as PFAS compared to the previous narrower definition. This broad OECD definition includes both alkyl substances and those containing rings of unsaturated carbon atoms, which can be confusing because the name "PFAS" implies that only alkyl substances should be included in the definition. The UK regulators have their own less broad definition of PFAS than that proposed by the OECD (i.e. "fluorinated substances that contain at least one fully fluorinated methyl carbon atom (without any hydrogen, chlorine, bromine or iodine atom attached to it), or two or more contiguous perfluorinated methylene groups (-CF₂-).") (Regulatory management option analysis (RMOA), 2023).

2.1.2 Types of PFAS and their properties

The extensive variety of PFAS includes compounds in various forms—solids, liquids, gases; and with diverse properties—reactive, inert, soluble, insoluble, volatile, non-volatile, mobile, immobile, and ranging from highly toxic to relatively non-toxic. Structurally, they can be long or short-chained, linear, or branched, anionic, cationic, or zwitterionic. Examples include:

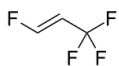
- **Fluoxetine (Prozac):** An antidepressant fitting the PFAS definition.



- **Polytetrafluoroethylene (PTFE, Teflon):** A fluoropolymer used in non-stick cookware (where n in the structure below is $\gg 1000$, i.e. there are thousands of identical repeating units of tetrafluoroethylene connected together).



- **Hydrofluoroolefin:** Employed as a refrigerant and air conditioning agent.



This diversity demonstrates the ubiquity and functional versatility of PFAS in modern society.

Research is generally focused on specific subsets of PFAS, such as:

- **Perfluoroalkyl carboxylic acids (PFCAs):** Ranging from C2 to over C20 in carbon chain length. Examples include (with 4 to 12 carbons):
 - perfluorobutanoic acid (PFBA)
 - perfluoropentanoic acid (PFPeA)
 - perfluorohexanoic acid (PFHxA)
 - perfluoroheptanoic acid (PFHpA)
 - perfluorooctanoic acid (PFOA)
 - perfluorononanoic acid (PFNA)
 - perfluorodecanoic acid (PFDA)
 - perfluoroundecanoic acid (PFUnDA)
 - perfluorododecanoic acid (PFDoDA)
- **Perfluoroalkane sulfonic acids (PFSAs):** Typically, C4, C6, C8, or C10, although other lengths are present:
 - perfluorobutanesulfonic acid (PFBS)
 - perfluorohexanesulfonic acid (PFHxS)
 - perfluorooctanesulfonic acid (PFOS)
 - perfluorodecanesulfonic acid (PFDS)

These compounds form anions when their terminal carbons in the acidic functional groups lose hydrogen atoms. They are, or were, used widely due to their effective surfactant properties, as a result of having a hydrophobic “tail” and a hydrophilic “head”. PFCAs and PFSAs belong to the group of PFAS known as perfluoroalkyl acids (PFAAs). They have been used in the manufacture of fluoropolymers like PTFE and in firefighting foams, and were also present as impurities in textiles, carpets, and food packaging materials. Much of the research has focused on these PFAS because of their widespread presence in the environment, wildlife, and humans and because they have established toxicity data and there are analytical methods available to measure them.

2.1.3 Precursors

Precursors, such as perfluoroalkyl sulfonamides and fluorotelomer alcohols, are PFAS which degrade in the environment and in organisms to form other (more stable) PFAS (usually the abovementioned PFAAs). This complicates environmental management and monitoring. For example, fluorotelomer alcohols degrade in the environment and within organisms to form PFCAs. While precursors can degrade to form PFAAs, PFAAs are highly stable and do not degrade into other PFAAs in the environment or in the human body (e.g. PFHxS cannot transform into PFOA)(Cousins et al., 2020; Prevedouros et al., 2006).

DRAFT

2.2 Chemistry of AFFF

Aqueous Film Forming Foams (AFFF) used for firefighting prominently incorporate PFAS because of the ability of these strong surfactants to spread an aqueous film over fuel fires and thus effectively extinguish the fire. Over the years, however, concerns over the bioaccumulation and environmental persistence (discussed below) of the PFAS in the AFFF have led to shifts in chemistries of AFFF.

2.2.1 PFAS Types in AFFF

Historically the PFAS-based foams containing PFSAs (especially PFOS and PFHxS) and PFCAs (notably PFOA) dominated the market. These legacy AFFF were made by the 3M Company using a process called electrochemical fluorination (ECF) and marketed under the trademark “Light Water”.

Fluorotelomer-based AFFF, made by a process called telomerisation, were also supplied by several foam manufacturers since the 1970s but had a lower market share compared to 3M. When 3M discontinued the manufacture of the Light Water AFFF in 2002, there was a shift to using fluorotelomer-based AFFF, which remained on the market, and eventually towards fluorine-free alternatives in many countries and regions; Sweden, for example. The key characteristics of PFAS-containing foams are:

- **Legacy (ECF) foams.** Historical “Light Water” type formulations contained complex mixtures of fluorinated surfactants including long-chain perfluoroalkane sulfonates, dominantly PFOS with lesser PFHxS (Backe et al., 2013). Long-chain perfluoroalkyl carboxylates such as PFOA were also often present (Guelfo & Higgins, 2013) but in lower amounts.
- **Fluorotelomer foams.** These contain complex mixtures of so-called fluorotelomer surfactants which are partially fluorinated. One of the key fluorotelomer surfactants present in these types of AFFF, 6:2 fluorotelomer sulfonate (FTS), has a partially fluorinated six-carbon chain connected to a sulfonate head. Microbial and abiotic oxidation slowly convert 6:2 FTS to PFHpA, PFHxA, PFPeA and other PFAAs (NASF, 2019). Formulations may also contain cationic or zwitterionic fluorotelomer betaines introduced for film stability (Backe et al., 2013).
- **Complex mixtures.** Analyses of commercial foams reveal up to hundreds of distinct PFAS classes, including anionic, cationic, and zwitterionic species (Backe et al., 2013). Field contamination therefore reflects overlapping generations of usage, with long-chain sulfonates from ECF foams and short-chain acids from newer foams often co-located in soil and water (ITRC, 2021). The complex mixtures of substances in AFFF are unique to a particular product. Understanding the “chemical fingerprints” of these products in environmental samples, which include the presence of specific isomers or breakdown products, is crucial for tracking and mitigating environmental contamination.

The only AFFF products which have PFOS and PFHxS as markers are Light Water AFFF products. These were initially used in the US, from 1967, and were also used in Jersey and elsewhere. The presence of those specific PFAS in Jersey, suggest that it is these products, rather than something else, that are the primary source of PFOS and PFHxS contamination. Fluorotelomer-based AFFF were on the market since the 1970s so it is possible that they were used on Jersey in parallel to Light Water AFFF, but likely in lesser amounts. Most users transitioned away from Light Water to complete reliance on fluorotelomer-based products in the early 2000s when 3M discontinued manufacture of Light Water AFFF in 2002. Some later transitioned to fluorine-free foams (3F). PFOA is a marker of both 3M Light Water AFFF products and fluorotelomer-based AFFF products. A unique marker of

fluorotelomer-based foams is 6:2 FTS. It should also be noted that the precise formulation within each of these foams may have changed over time as manufacturers seek to optimise their products.

2.2.2 Bioaccumulation

The tendency of PFOS, PFHxS and PFOA to bioaccumulate in biological tissues raises concerns about their long-term health impacts. Regulatory bodies have identified long-chain PFAAs as particularly bioaccumulative (as they bioaccumulate in humans), emphasizing the need for stringent regulatory controls for PFAAs with eight carbons and greater (i.e. with 7 or more perfluorinated carbons) and PFSAAs with six carbons and greater (i.e. with 6 or more perfluorinated carbons). So PFOA and PFCAs with longer perfluorinated carbon chains are bioaccumulative and PFHxS and PFSAAs with longer perfluorinated chains are also bioaccumulative. PFSAAs are relatively more bioaccumulative than PFCAs with equivalently long perfluorinated chains because of the special effect of the sulfonate functional group (Brunn et al., 2023; Buck et al., 2011).

2.2.3 Environmental Accumulation

The chemical stability of PFOS, PFOA, and PFHxS due to strength of the carbon-fluorine bonds leads to their persistence in the environment, posing significant challenges for remediation. Efforts to monitor and reduce environmental levels of these pollutants are ongoing, but their inert nature complicates effective degradation and removal strategies (Cousins et al., 2020; Prevedouros et al., 2006). This will be explored in more detail in Report 4.

2.2.4 Regulatory and environmental concerns

PFAS are notably persistent in the environment, which complicates their management and regulation. In response, Denmark, Germany, the Netherlands, Norway, and Sweden have proposed a REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) restriction for all PFAS meeting the OECD definition. It is recognized that PFAS have diverse properties (e.g. different toxicities), but they are all highly persistent in the environment. Additionally, there is an ongoing restriction proposal specifically targeting PFAS in firefighting foams, with a proposed 10-year phase-out, which is also currently under consideration at the European Commission.

PFAS encompass a broad and complex category of chemicals that pose significant challenges due to their persistence, bioaccumulation, and widespread use. Ongoing research and regulatory efforts aim to better understand and mitigate their health and environmental impacts. Looking forward, enhanced analytical methods and comprehensive toxicological data are increasingly important for guiding effective policy and industry practices.

2.3 PFAS in the natural environment and human infrastructure

2.3.1 Behaviour in Natural Environments

2.3.1.1 *Soil and Vadose Zone*

After use, PFAS in the spent firefighting foams infiltrate into the ground, which can consist of hard manmade surfaces (typically asphalt and concrete) or unsaturated soil. Sorption in unsaturated soil is driven by hydrophobic interactions of the fluorinated “tails” with soil organic matter and by accumulation at air-water interfaces (Guelfo & Higgins, 2013). Anionic PFAAs are electrostatically repelled by negatively charged clay minerals, yet multivalent cations, such as calcium ions, can bridge PFAS to mineral surfaces, increasing retention. Air-water interfacial sorption, especially for long-chain PFOS and PFHxS, can retard downward migration for years (Guelfo & Higgins, 2013). Sorption increases with chain length, so short-chain PFHxA and PFBS leach rapidly, whereas PFOS often remains concentrated in the top 0–50 cm, acting as a continuing source that slowly desorbs during rainfall events (Douglas et al., 2023). Several other factors, such as pH and the presence of co-contaminants are also important in controlling sorption and transport.

2.3.1.2 *Groundwater*

Once PFAS reach the saturated zone they behave as highly soluble, conservative solutes, forming plumes that may extend miles downgradient (Guelfo & Higgins, 2013). Differential mobility separates compounds by chain length (partly through differential sorption by chain length: PFBA and PFHxA form the leading edge, while PFOS and PFHxS lag nearer the source. Because natural degradation is negligible, and slow transport from unsaturated zones, plumes persist for decades; modelling suggests century-scale time frames for significant attenuation in the absence of intervention (ITRC, 2021).

Groundwater discharges to rivers and wetlands transfer PFAS to surface waters, broadening exposure pathways (Reinikainen et al., 2022).

2.3.1.3 *Surface Water, Aquatic spray and Sediments*

Stormwater runoff can carry foam residues from concrete pads, asphalt, and contaminated soil into drainage ditches and streams (Kali et al., 2025) (although a proportion can stick to the surface and slowly leach through). In open water, short chain acids remain dissolved. PFOS and PFHxS partition partly to suspended solids and, along with other longer chain PFAS, settle into sediments, creating long-term benthic reservoirs (ITRC, 2021). Aquatic foams formed during wave action can enrich PFAS by orders of magnitude, redistributing them to shorelines. Wave action can also lead to the ejection of small aerosols (or droplets known as “sea spray aerosols”) into the air which can be highly enriched with PFAS. The PFAS enriched on these aerosols can be transported long distances and potentially impact coastal areas. (Reinikainen et al., 2022; Sha et al., 2024).

2.3.1.4 *Air*

Many (but not all) AFFF-derived PFAS have negligible vapour pressure; however, spraying creates aerosols that transport PFAS locally. Additionally, volatile precursors such as fluorotelomer alcohols present in some formulations can evaporate, undergo atmospheric oxidation, and redeposit as PFAAs, contributing to regional background loads (Brunn et al., 2023).

2.3.1.5 *Biota*

Long-chain perfluoroalkane sulfonates and perfluoroalkyl carboxylates bind to blood proteins and bioaccumulate. PFOS and PFHxS display long half-lives in humans (3–8 years and 4–7 years, respectively), whereas PFHxA and PFBS are cleared within weeks to months (Li et al., 2022; Wee & Aris, 2023). Half lives can vary greatly between and within species. In aquatic food webs near AFFF sites, PFOS concentrations in fish can exceed advisory thresholds, posing dietary risks (Reinikainen et al., 2022).

2.3.2 Interactions with Built Environments

2.3.2.1 *Concrete and Asphalt*

Porous concrete absorbs PFAS-laden foam. Core samples from fire-training pads routinely contain 10^2 – 10^5 $\mu\text{g kg}^{-1}$ of PFOS and 6:2 FTS, with highest levels in the top centimetres (Douglas et al., 2023). Leaching experiments show that only a few percent of total mass is released per rainfall simulation, indicating decades-long secondary emissions. Asphalt runways also sorb PFAS; PFOS binds to the bitumen phase and can be mobilised by run-off, though initial leaching percentages are somewhat higher than for concrete (Li et al., 2024).

2.3.2.2 *Stormwater Infrastructure*

Drains, oil / water separators, and retention basins capture AFFF runoff and themselves accumulate PFAS in sediments and biofilms (Kali et al., 2025). Storm events resuspend these deposits, creating episodic pulses to downstream waters. Remediation therefore must consider physical infrastructure as an integral part of the PFAS mass balance (ITRC, 2021).

2.4 Key Transport and Redistribution Processes

- **Leaching:** Vertical migration of dissolved PFAS through soil into groundwater; rate controlled by chain length and interfacial sorption (Guelfo & Higgins, 2013).
- **Runoff:** Overland flow mobilises surface-deposited PFAS to bodies of water and into drains (Kali et al., 2025).
- **Sorption/Desorption:** Reversible binding to soils and concrete dictates long-term release; stronger for PFOS/PFHxS than for PFHxA/PFBS (Douglas et al., 2023).
- **Air–Water Interfacial Adsorption:** Major retention mechanism in unsaturated soils, particularly for long-chain PFAS (Guelfo & Higgins, 2013).
- **Precursor Transformation:** Partial fluorinated molecules such as 6:2 FTS biodegrade slowly to terminal PFAAs (NASF, 2019).
- **Aerosolisation:** Foam spray droplets generated during use of AFFF carry PFAS short distances downwind. Volatile precursors contribute to long-range deposition after atmospheric oxidation (Brunn et al., 2023).

2.5 Persistence

Fully fluorinated PFAAs (e.g., PFOS, PFHxS, PFOA) resist hydrolysis, photolysis, and microbial attack, giving environmental half-lives that exceed centuries in groundwater and sediments (Brunn et al., 2023). Precursors transform rather than mineralise, ultimately increasing the pool of persistent

acids. Consequently, AFFF plumes function like conservative tracers, and contaminated infrastructure or soil continues to release PFAS indefinitely unless physically removed or isolated (ITRC, 2021).

2.6 Implications for Management

Because natural attenuation is negligible, mitigation must focus on source removal or immobilisation. Options include excavation of contaminated soil, in-situ stabilisation (e.g., soil blending with sorbents), pump-and-treat of groundwater, and removal or surface-sealing of PFAS-laden concrete and asphalt (Douglas et al., 2023). Stormwater capture and treatment; often with granular activated carbon or ion exchange resins; may be important for preventing offsite transport (Kali et al., 2025). Knowledge of differential mobility is useful: short-chain PFAS require hydraulic containment, whereas long-chain PFAS demand strategies targeting sorbed phases in soil or hardstanding.

DRAFT

2.7 Potential routes of human exposure

The presence of organic fluorine in human blood was first detected by the dental researcher Donald Taves in the 1960s (Taves, 1968). In 2024, it is now known that virtually all humans on the planet have certain PFAS in their bodies at low microgram per litre levels (Sunderland et al., 2019). Human blood concentrations of long-chain perfluoroalkyl acids (PFAAs) such as PFOS, PFHxS and PFOA, peaked in the late 1990s/early 2000s in the general population of most countries and have declined since the 3M industrial phase-out of long-chain PFAS chemistries (the phase-out was between the years 2000 and 2002). (Sunderland et al., 2019).

For humans, exposure to PFAS occurs by three routes, namely: ingestion, inhalation, and dermal absorption, as described below. Some special exposure routes for prenatal stages and infants are discussed further down this section.

1. Ingestion exposure of PFAS for humans occurs via consumption of contaminated food, water, and other beverages. Exposure by ingestion also occurs via the intentional or inadvertent non-dietary ingestion of soil, dust, or chemical residues on surfaces or objects that are contacted via hand-to-mouth or object-to-mouth activity (especially important for young children).
2. Inhalation exposure of PFAS for humans results from breathing air that is contaminated with fine particulate matter or gas-phase volatile PFAS. Individuals can be exposed via the inhalation route during a variety of activities, both outdoors and indoors. Individuals indoors could also be exposed to outdoor air contaminants that infiltrate the indoor environment.
3. Dermal exposure of PFAS by humans results from skin contact with PFAS-containing consumer products and contaminated environmental media, including water (e.g., during bathing, washing, swimming), bottom sediments in surface waters (e.g., while wading, fishing), outdoor soil or dust (e.g., during recreational and gardening activities), and indoor dust that has settled on carpets, floors, clothing, counter tops, or other surfaces.

The relative importance of the many different PFAS exposure pathways (e.g. dietary ingestion, versus dust ingestion, versus gaseous inhalation, etc.) has been estimated in multiple studies (e.g. (Gebbink et al., 2015)) and these have been reviewed in the literature. (De Silva et al., 2021; Sunderland et al., 2019). There is general agreement that for PFOS, PFHxS and PFOA, and other long-chain PFAAs, dietary intake is the dominant exposure pathway for the general population compared to air inhalation or dermal contact (Sunderland et al., 2019). Furthermore, it is known that protein-rich foods such as eggs, meat and fish make the largest contribution to dietary exposure for the long-chain PFAAs (Vestergren et al., 2012).

In areas such as the plume area in Jersey where drinking water levels of PFAS have been substantially elevated due to contamination with AFFF, drinking water ingestion is the dominant exposure pathway for PFOS, PFHxS and PFOA (AECOM, 2016; Li et al., 2018; Xu et al., 2021). In some areas (e.g. in Oakey, Australia) where contaminated water has been used for watering livestock or irrigating crops, substantial additional exposure can be derived from consumption of local produce. (AECOM, 2016).

A further complication to understanding exposure to PFAS is that humans can be exposed to the so-called precursors, which are substances that transform to PFAAs either in organisms (including in the human body) or in the environment (Vestergren et al., 2008). Precursors are sometimes, but not

always, measured when analysing exposure media for PFAS, which means that human exposure to certain PFAS is likely underestimated. Although these precursors certainly make an additional contribution to human exposure to PFAS, the extent of this contribution, and which precursors contribute, has been debated among scientists (Vestergren et al., 2008).

Toxicokinetics is the study of the absorption, distribution, metabolism, and excretion of a chemical within an organism. Within the following sections we review the current knowledge of toxicokinetics of PFAS with particular focus on PFOS, PFHxS and PFOA. The chemical structure (e.g. chain length, functional groups, branching of the carbon chains) all impact the toxicokinetics. An exhaustive review of toxicokinetics for all PFAS is not possible here and we therefore aim to summarize the key points.

2.7.1 Absorption of PFAS into the body

The absorption behaviour of PFAS has been studied in laboratory animals (e.g., rodents and monkeys) (Gannon et al., 2011) but not typically in humans due to ethical considerations. Absorption of PFOS, PFHxS and PFOA via ingestion has been determined in animal experiments and it has been shown that 66–100% is absorbed into the body (OECD, 2002, OCA.0029.0001.0063) (Gannon et al., 2011; Kudo & Kawashima, 2003; Sundström et al., 2012). Animal studies also suggest that PFOA is easily absorbed via the lungs (Kennedy et al., 2004). Due to the high absorption of PFAS in animal studies, the absorption of PFOS, PFHxS and PFOA is typically set to 100% as a conservative assumption in human exposure modelling studies (Gebbinck et al., 2015; Trudel et al., 2008; Vestergren et al., 2008). These reported absorption efficiencies for PFAS are higher than for other well studied hydrophobic organic contaminants (such as polychlorinated biphenyls) (Schlummer et al., 1998). Given this near consensus on very high levels of absorption, these are likely to be the primary routes in the bulk of cases.

Absorption through the skin, however, is more complex. Experimental studies on dermal absorption are scarce. *In vitro* exposure studies using rat and human skin replicates conducted by Fasano et al. in 2005 have shown that PFOA can penetrate the skin, albeit with a low absorption efficiency (1.44% and 0.048% of PFOA absorbed through the rat and human skin, respectively, after 48 h of exposure) (Fasano et al., 2005). A more recent study by Franko et al. in 2012 (Franko et al., 2012) suggested that PFOA is readily absorbed by human and mouse skin, but on close examination this only occurred at unrealistically low pH (2.25) when PFOA was in its acidic neutral form. Franko et al., admitted in their study that PFOA will most likely be ionized on the skin surface. Interestingly, Franko et al. achieved similarly low absorption as in the 2005 Fasano study when PFOA was in its ionized form. These observations are consistent with the pH-partition hypothesis (Shore et al., 1957) which suggests that the passive transport of charged chemical species across biological membranes is small, owing to their poor solubility in lipids.

Abraham and Monien (Abraham & Monien, 2022) investigated the dermal absorption of $^{13}\text{C}_4$ -perfluorooctanoic acid ($^{13}\text{C}_4$ -PFOA) mixed into a sunscreen that was applied on the skin of a volunteer. The blood concentrations of $^{13}\text{C}_4$ -PFOA were monitored over 115 days after application. After application, $^{13}\text{C}_4$ -PFOA blood levels increased continuously with a maximum level measured 22 days after application. The fraction absorbed was estimated to be 1.6 % of the dose, which is still relatively low compared to ingestion and inhalation. The study of Abraham & Monien could be

considered an extreme exposure scenario given that that the contaminated sunscreen is rubbed into the skin.

Ragnarsdóttir et al (Ragnarsdóttir et al., 2024) used 3D human skin equivalent models (multilayered laboratory grown tissues that mimic the properties of normal human skin) to study the dermal absorption of 17 PFAS including PFOS, PFHxS and PFOA. Of the 17 PFAS assessed, 15 substances were shown to absorb by at least 5% of the exposure dose, which is higher than observed in the previous abovementioned studies. It is unclear, however, if the artificial skin models represent the dermal absorption of PFAS compounds behaviour of real human skin, even if the authors claim that it does.

There are few dermal contact studies for PFAS but based on the existing studies it seems reasonable to assume that dermal absorption of PFAS is relatively low compared to ingestion and inhalation absorption. In exposure modelling studies,(Gebbinck et al., 2015) it is typically assumed that dermal absorption is less than 1% for PFOS, PFHxS and PFOA based on animal experiments for PFOA and typical exposure scenarios, and these exposure models provide good estimations of human serum levels of PFAS.

2.7.2 Distribution of PFAS in the human body

As discussed above, PFAS are readily absorbed into the human body via ingestion and inhalation routes, and to a much lesser extent via the dermal route. Once absorbed, PFAS are distributed throughout the body both in the blood and into extravascular tissues (i.e. in tissues other than the blood vessels)(De Silva et al., 2021). In the tissues, PFAS bind to both phospholipids and proteins (e.g. in the blood serum to a protein called human serum albumin (HSA)) and also to fatty acid binding-proteins (FABPs)(De Silva et al., 2021). It has long been considered that the blood, liver, and kidneys are the main tissues of distribution for PFAAs in humans(De Silva et al., 2021). A recent study measured the distribution of PFAAs between liver, kidneys, lungs, spleen, brain, and the whole blood of 19 deceased adult humans(Nielsen et al., 2024). The highest extravascular tissue PFAA concentrations were in the liver, lungs, and kidneys with concentrations in the brain and spleen being much lower. PFOS was particularly high in the liver compared to other organs. PFHxS was the only PFAA that showed higher concentrations in the kidney than in the liver, while PFOA was higher in the lungs than in the liver. Extravascular PFAA tissue concentrations were generally well-correlated with those in the blood and in reasonable agreement with the partitioning predicted by theoretical models. The differing accumulation of PFAAs in various tissues has been associated with their relative binding affinities to phospholipids and proteins (e.g. HSA and FABPs)(De Silva et al., 2021). Higher binding affinities to HSA and FABPs have been observed for long-chain PFAAs compared with short-chain PFAAs(Fischer et al., 2024).

2.7.3 Metabolism

PFAAs are not chemically modified or metabolised within the human body due to their chemical inertness(Zhanyun Wang et al., 2017). However, and as mentioned above, there are precursor substances which can metabolize to form PFAAs within the human body(Vestergren et al., 2008).

2.7.4 Elimination

Some long-chain PFAAs are primarily eliminated slowly via urine(Cui et al., 2010) with others predominantly via the faeces (Andersson et al., 2025). Women have some additional elimination

pathways discussed below. Previous studies have shown relatively long human elimination half-lives (the time it takes for the amount of PFAS in the body to be reduced by 50 percent) of long-chain PFAAs. For example, average serum half-lives for PFOS, PFHxS and PFOA, of 2.9-8.5, and 2.9-7.3, 1.8-3.5 years, respectively, have been reported in different studies(Li et al., 2018; Olsen et al., 2007; Xu et al., 2020). Shorter human serum half-lives have been observed for short-chain PFAAs (e.g. perfluorobutane sulfonate (PFBS) of 44 days, and perfluoropentane sulfonate (PFPeS) of 230 days).(Xu et al., 2020) However, elimination half-lives are not only dependent on the length of the perfluoroalkyl chain. The head group (sulfonate versus carboxylate) and degree of branching in the perfluoroalkyl chain also impacts elimination rates of PFAAs.(Xu et al., 2020)

Some of the differences in elimination half-lives for individual PFAAs between studies can be due to differing exposure histories. For example, the half-lives in retired fluorochemical workers (PFOS average elimination half-life of 8.5 years)(Olsen et al., 2007) are much higher compared to residents of contaminated communities who have received historical exposure via contaminated drinking water (PFOS half-life of 2.9 years).(Xu et al., 2020) Additionally, elimination half-lives have also been reported to be highly variable between individuals and the reasons for this variability remain unknown.(Xu et al., 2020)

Women between 12.5 and 50 years old have been shown to have lower blood serum levels of PFOS than men and this is thought to be primarily because women eliminate PFOS (and other long-chain PFAAs) more rapidly than men due to their additional elimination pathway of monthly menstrual blood loss(Upson et al., 2022). Women can also eliminate PFAS from their bodies by transfer to the child to some extent, during pregnancy, childbirth, and breast feeding(Wong et al., 2014).

The long elimination half-lives of long-chain PFAAs in humans is thought to be due to their ability to be reabsorbed by organic anion transporters (OATs) in the kidneys and due to their uptake from the gut via enterohepatic circulation(Niu et al., 2023). Therefore, renal elimination/reabsorption in the kidneys is an important process in determining the elimination of PFAAs. However, the interactions between PFAAs and the renal transporters (i.e. OATs) are not fully understood(Niu et al., 2023). The active transport processes differ between different PFAAs and possibly also can explain differences in elimination between individuals. It is further possible that kidney disease can alter the expression of the renal transporters and further influence renal elimination of PFAS(Niu et al., 2023). However, little is currently known about how altered kidney function affects elimination rates of PFAS; this is an area of ongoing research.

2.7.5 Transmission

2.7.5.1 *In-utero transfer*

It has been shown that PFAS can pass the placental barrier from mother to child during pregnancy(Beesoon et al., 2011; Gützkow et al., 2012; S. Kim et al., 2011; Liu et al., 2011; Monroy et al., 2008; Pan et al., 2017). These studies have measured serum concentrations of PFAS in maternal and cord blood, or new-born blood samples directly after birth. The transplacental transfer efficiency (TTE) can be calculated for each individual mother-child pair as the ratio of foetal to maternal blood or serum concentrations, and these data have been reviewed and summarised(Winkens et al., 2017). TTEs vary significantly within and between the different studies. Strong positive correlations between maternal and foetal serum concentrations have generally been observed for PFOS, PFOA and other long-chain PFAAs. A comparison of TTEs for different PFAAs suggests a negative

relationship with the perfluoroalkyl chain-length and a slightly lower transfer efficiency for sulfonates compared to carboxylates.

2.7.5.2 Breastfeeding

PFAS have been measured in human breast milk and they are thus transmitted through lactation (Kärman et al., 2007; S.-K. Kim et al., 2011; Liu et al., 2010; Llorca et al., 2010; So et al., 2006; Sundström et al., 2011; Tao, Kannan, et al., 2008; Tao, Ma, et al., 2008; Thomsen et al., 2010; Völkel et al., 2008). Breastfeeding is therefore an additional elimination pathway for breastfeeding mothers. Breastfeeding gradually reduces the mothers' concentration of PFOA and PFOS in serum and breast milk (Fei et al., 2010; Mondal et al., 2014; Thomsen et al., 2010). For PFOA and PFOS, a common 3% reduction has been observed per month of breastfeeding, whereas for PFNA and PFHxS a 2 and 1% reduction, respectively, per month of breastfeeding has been observed (Mondal et al., 2014). This is in accordance with the finding that primiparous women have the highest loads of PFOS and PFOA in their breast milk (Fei et al., 2010; Tao, Kannan, et al., 2008).

Breastfeeding is the dominant exposure pathway for PFAS for infants who are breastfed (Mogensen et al., 2015; Verner et al., 2016). Early-life longitudinal studies have shown a consistent increasing trend of both PFOS and PFOA during the first six months of life and this has been attributed to intake via breastfeeding (Fromme et al., 2010; Gyllenhammar et al., 2016; Koponen et al., 2018; Mogensen et al., 2015). The level of exposure to an infant depends on several circumstances, principally the level of PFAS in the mother, the amount of PFAS that transfers to her breast milk, and the duration of breastfeeding (Winkens et al., 2017).

2.8 Key findings from Report 2 on the human health effects of PFAS

Cardiovascular Health

The panel found a consistent association between exposure to certain PFAS and elevated cholesterol levels, particularly low-density lipoprotein (LDL), known as "bad cholesterol." Elevated LDL levels are typically associated with increased risk of cardiovascular diseases, such as ischaemic heart disease and strokes. However, despite the increased cholesterol levels, evidence of a corresponding increase in cardiovascular diseases among PFAS-exposed populations (particularly PFOA) was less clear. The panel hypothesized that factors such as increased high-density lipoprotein (HDL) levels (good cholesterol) and indications of lower inflammation in the body might mitigate some effect of LDL on cardiovascular risk. Nevertheless, the panel took a precautionary approach; they recommended that individuals with elevated cholesterol due to PFAS exposure should follow standard management practices, including diet, exercise, and possibly lipid-lowering medications.

Cancer Risks

There is evidence suggesting a probable increase in the incidence of kidney and testicular cancers among populations exposed to certain PFAS. The panel also noted some evidence indicating an increased risk of bladder cancer, though this was less clear. In contrast, common cancers such as breast, colon, and prostate cancers did not show a significant increase in incidence across the most relevant research studies, providing some reassurance. Nevertheless, a link not having been clearly found does not mean that a link is not there. The panel noted that there were also concerns expressed by Islanders about rarer cancers and concluded that, although there is not yet evidence to give a clear answer on rare cancers, there is also insufficient evidence to rule out any potential risk from PFAS exposure.

Immune System and Autoimmune Diseases

Exposure to certain PFAS has been associated with a reduced antibody response to childhood vaccinations, which could theoretically lower the effectiveness of immunisations. While the panel was of the view that it is very likely that there is an effect on antibodies after childhood vaccination, the studies to date do not show an increase in vaccine-preventable or other infectious diseases. There was not consistent evidence linking PFAS exposure to a higher incidence of autoimmune diseases, such as rheumatoid arthritis, ulcerative colitis, or lupus. The panel suggested that enhanced public health efforts to maintain high vaccination coverage should help protect vulnerable populations, including those potentially affected by PFAS.

Endocrine and Metabolic Disorders

The evidence linking PFAS exposure to endocrine disorders, including thyroid dysfunction and metabolic issues like obesity and type 2 diabetes, was found to be inconsistent. While some studies indicated potential associations, these were not uniformly supported across different populations and settings. The panel acknowledged the complexity of these potential health effects and were of the view that further research to clarify these associations and inform public health recommendations is needed.

Mental Health and Wellbeing

The psychological impact of environmental contamination, including stress, anxiety, and depression, was identified in the scientific literature. The panel recognized that these concerns may be impacting in Islanders' lives and recommended providing mental health support to those affected by PFAS exposure. This includes access to talking therapies and other mental health services as needed.

Reproductive Health

While the only concern raised by the community was fertility, subject matter experts brought up a broader range of issues. These included potential complications like intrauterine growth retardation, reduced birth weight, high blood pressure during pregnancy, and breastfeeding challenges. Studies on birth weight are inconsistent. Some research suggested a possible reduction in birth weight associated with maternal PFAS exposure, but others not. The panel noted that the studies showing a connection often relied on measurements taken later in pregnancy, potentially introducing bias. With regard to pregnancy-associated hypertension and polycystic ovarian syndrome (PCOS). While some studies, like the C8 study, reported an association between PFAS exposure and hypertension in pregnancy and there was a report of increased PCOS cases in a high-exposure area like Ronneby, the panel did not find sufficient evidence across other studies to establish a clear link. This was also no clear evidence of reduced fertility. Overall, the panel was not persuaded that PFAS exposure been demonstrated to have impacts on most reproductive health outcomes, except for some evidence pointing to challenges with breastfeeding. They strongly recommended that mothers, even those exposed to PFAS, should breastfeed, emphasizing that the considerable benefits are likely outweigh any potential risks from PFAS transfer during breastfeeding.

Other Health Concerns

Additional health concerns explored included some gastrointestinal issues for which there was not good evidence, and changes in liver enzyme levels. The panel noted that while changes in liver enzymes were observed, they generally fell within normal ranges and were unlikely to be clinically significant or associated with poor health outcomes. The panel also looked at neurodevelopmental issues (such as speech and language delay), but the evidence in that area was also not yet clear. With regard to potential impacts on the musculoskeletal system, like osteoporosis and an increased risk of fractures the evidence was also not yet sufficiently clear. The panel was of the view that further research was needed in these areas in order to ascertain whether any risks can be corroborated across studies and what the magnitude of those risks might be.

2.9 Groups at increased risk

As discussed earlier, there are a very wide range of PFAS compounds, which seem to differ in their physiological effects, their persistence, and their route of elimination. It should be noted that patterns of exposure can be complex, and that elimination can vary from person to person.

Whilst there is not strong evidence in every area, there are indications of some groups who may potentially be more vulnerable. This may be through higher exposure risk, different patterns of elimination and different physiological effects.

2.9.1 Age

2.9.1.1 Children

Children, particularly neonates and infants, are potentially more susceptible to PFAS exposure due to their developmental stage. PFAS can cross the placental barrier, exposing the foetus during critical periods of development. Postnatally, infants can absorb PFAS through breast milk and contact with consumer products containing these chemicals (Fromme et al., 2009). Exposure during these formative years has been associated with vaccine resistance, developmental delays, and metabolic disorders (Fei et al., 2007; Grandjean et al., 2012).

2.9.1.2 Older people

While it is well-established that older people, on average, have reductions in kidney function (and the functions of some other organs and that they are more likely to have developed comorbidities, be taking medications and have accumulated risk factors), it is not clear if these have any impact on PFAS absorption, PFAS elimination or any physiological effects from PFAS exposure. Nevertheless, frailty may render certain conditions and symptoms more serious in an older person.

The elderly may experience more severe effects from PFAS exposure due to age-related decreases in renal function, which can slow the excretion of PFAS from the body. This slower clearance rate can lead to higher cumulative body burdens of PFAS. Moreover, the elderly often have multiple chronic conditions, which may be exacerbated by PFAS exposure, complicating their medical care, and adversely affecting their quality of life.

2.9.2 Additional exposure

2.9.2.1 Lived environment and diet

It is important to note that PFAS from all sources of exposure contribute to the body burden in an individual person. Consumption of water from contaminated supplies will increase levels, as will consumption of seafood which can bioconcentrate PFAS from water. Fruit and vegetables irrigated with contaminated ground water or grown in contaminated soils may also be contributory factors (Sunderland et al., 2019). A diet rich in these sources in a contaminated area could be associated with increased risk of elevated body burden.

2.9.2.2 Occupational

Workers in industries where PFAS are produced, used, or disposed of including chemical manufacturing, firefighting, and environmental cleanup, face additional potential exposure. Firefighters, for example, are exposed to PFAS through firefighting foams and gear. These occupational groups often have elevated levels of PFAS in their blood, and are associated with higher rates of some health conditions (Lau et al., 2007).

2.10 Body burden and disease risk

By the term “body burden” of PFAS is meant the amount of these substances accumulated in an individual over time. Part of this is in the blood, mainly the serum or plasma rather than the cells, part of this is spread around other organs in the body. The proportion of the total body burden residing in other parts of the body is at least as much as in the blood, but we use the serum concentration as the measure of body burden. The rate of excretion (through bladder, gut and menstrual blood loss) is proportional to the serum concentration or body burden. Therefore, with steady intake (from diet and water) the body burden increases, until the rate of excretion equals intake and the serum concentration reaches a steady state.

Epidemiological studies seek to relate the risk of disease to PFAS exposure. The exposure can be in terms of comparing an exposed population with a non-exposed one, or comparing measured or estimated degree of body burden i.e. serum concentration, with the risk of disease. Disease can be directly characterised, such as having a diagnosed cancer or thyroid disease, or a clinical marker which if affected, may indicate a risk of development into clinical disease. Examples of these clinical markers include blood pressure, antibody reactions to vaccination, cholesterol levels or thyroid hormone levels measured in blood.

For understanding and preventing disease in populations exposed to potential toxins, both the nature of the relationship - the dose-response relationship - and the reversibility of these associations are important and we discuss them here.

2.10.1 Dose-Response Relationship

The dose-response relationship (or strictly speaking the exposure-response, as the exposure may be concentration or the accumulated dose) describes how the magnitude of exposure to a chemical relates to the severity or frequency of associated adverse health effects (Eaton & Klaassen, 2008). The shape can be a simple straight line where the effect proportionally increases with dose, though whether it is straight or a curve depends on how the data are analysed – in published papers the exposure or the outcome, or both may or may not be log-transformed. So the disease risk may be reported as rising with PFAS concentration or with the log of the concentration.

Such straight-line relationships are very helpful for assessing risk as one can extrapolate the risk from one study based on a particular exposure range, to estimate the risk at higher or lower exposure levels. Sometimes the dose response relationship may indicate a threshold response, when the low exposures are not associated with any risk relative to zero exposure, although in practice it can be hard to be sure that there is a threshold. At the other end of the exposure range, the effect may flatten off: further exposure does not incrementally increase the risk further. Rarer still are non-monotonic dose response curves, where the risk may go down and then up again as the exposure changes, or even suggest a beneficial effect at low doses but harmful at high doses (Vandenberg et al., 2012). In practice, we do not see clear evidence of non-monotonic (not straight line) dose-response for PFAS. Many studies show results by dividing the population into a number of groups by increasing exposure, and then investigate if there is trend of risk increasing with exposure across these groups. All these studies should also carefully adjust in these analyses, by other risk factors to avoid having a misleading or confounded dose-response pattern.

Studies have demonstrated an exposure-dependent relationship between PFAS exposure and immunotoxic effects. Higher serum concentrations of PFAS have been associated with reduced antibody responses to vaccines in children (Blaine et al., 2024). Grandjean et al. found that a doubling of PFAS concentration corresponded to a significant decrease in antibody levels, indicating a dose-response relationship in this case between antibody levels and the logarithm of serum PFAS (Grandjean et al., 2012).

Several studies have demonstrated a positive dose-response relationship between serum PFAS levels and plasma cholesterol. Higher concentrations of the PFAS compounds perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) are associated with increased total and LDL cholesterol levels. For instance, (Nelson et al., 2010) found that elevated serum PFAS concentrations correlated with higher cholesterol in a U.S. population sample. Several studies spanning large ranges of concentration show a pattern of steep increase in relation to PFAS at lower serum concentration ranges and a shallower or levelling of the dose response relationship at higher levels (Canova et al., 2020).

Several studies have demonstrated a positive dose-response relationship between serum levels of perfluorooctanoic acid (PFOA), and the risk of cancer. For example, Barry et al. found among individuals living near a chemical plant leading to PFOA exposure there was a dose response between groups of increasing estimated serum concentrations and increased incidence of kidney and testicular cancers (Barry et al., 2013). In this case the exposure measure was a cumulative dose reflecting both serum concentrations and length of exposure.

Overall, there are many studies indicating an increasing risk in relation to higher body burdens of PFAS, although the relationship may be curved, not a simple linear straight line.

2.10.2 Evidence for Risk Reduction Through Body Burden Decrease

Past PFAS exposure has been associated with adverse health effects such as cancers. Cross sectional studies show adverse effects on clinical markers, such as raised cholesterol.

Once exposure stops, we can observe the serum levels going down, although it takes some time for the body burden to go down, given the long half-life of these PFAS. One would like to know if the associated disease risks also fall. While reducing the body burden of PFAS may reasonably be considered to reduce disease risk, there is not yet much direct evidence on the reduction of risk following the reduction of PFAS exposure. Given the PFOA and PFOS serum levels have generally fallen over the last 20 years, we may expect some studies to come which will track PFAS-related health effects over time. One study which sought to address this in the Veneto region, could not demonstrate a decrease in exposure related risk after the PFAS exposure was identified and controlled, but the post clean-up follow up was still too short (Biggeri et al., 2024).

Considering infants, as the maternal body burden goes down this would directly benefit the unborn child and infants by preventing their exposure. However, for people with past exposure, whether these disease risks disappear if exposure falls to zero is not certain.

We do know from studies of other exposures that have reduced that the associated risks do fall. The increased cancer risk resulting from exposure to certain toxins can sometimes be reduced by eliminating or minimizing the exposure, but complete reversibility is not always possible. For example, smoking cessation significantly decreases the risk of lung cancer over time; former smokers

experience a gradual risk reduction, approaching that of never-smokers after about 15 years (Peto et al., 2000). Similarly, reducing exposure to ultraviolet (UV) radiation can lower the risk of skin cancer, as DNA repair mechanisms may correct some of the damage caused by prior exposure (Armstrong & Krickler, 2001). However, for carcinogens like asbestos, the risk of mesothelioma remains elevated even after exposure stops due to irreversible changes in mesothelial cells and persistence of the fibres in the tissue (Stayner et al., 2013). Therefore, while reducing exposure to certain toxins can decrease future cancer risk, the extent of reversibility depends on the type of toxin, the duration of exposure, and the timing of intervention. It is plausible this also applies to PFAS.

For immune effects, reversibility of immunotoxicity depends on factors such as the type of toxin, exposure duration, and individual health status. For instance, immunosuppression caused by heavy metals like lead and mercury can be partially reversible upon cessation of exposure and with appropriate medical intervention (Lawrence & McCabe, 2002). Similarly, exposure to certain pesticides has been linked to immune system impairments that may improve over time after the exposure ends (Corsini et al., 2013). However, the extent of recovery can vary, and in some cases, prolonged or high-level exposure may lead to lasting immune dysfunction. Overall, reducing exposure to immunotoxic substances can facilitate the partial or full restoration of immune function. It is plausible that this also applies to PFAS.

The only direct evidence of the impact of reducing PFAS exposure are some studies of the association of cholesterol in populations where exposure had fallen and serum levels were going down. In the C8 study of a US population exposed to PFOA a group of 700 people had repeated measurements of both PFAS and cholesterol four years apart (Fitz-Simon et al., 2013). Both PFOA and PFOS declined over the survey period, and they found that there was a tendency for people with greater declines in serum PFOA or PFOS to a drop in total cholesterol and LDL, relative to those whose PFAS decreased less. If serum PFOA fell by half, the predicted fall in LDL cholesterol was 3.6% (95% confidence interval = 1.5–5.7%). The association with a decline in PFOS was even stronger, with a 5% decrease in LDL (2.5–7.4%) per halving in PFOS. A larger study in Italy also included repeat measurements of both lipids and PFAS, averaging 4 years apart, with the same direction of association but smaller decreases in cholesterol (Batzella et al., 2024). Declines in PFAS concentrations were associated with decreases in all lipids. For a natural log-decrease in PFOA, HDL-C decreased by 1.99% (95% CI: 1.28, 2.70), TC by 1.49% (95% CI: 0.88, 2.10), and LDL-C by 1.40% (95% CI: 0.45, 2.37). A natural log decrease is a reduction by a little more than a half. Overall, there was not a decrease in cholesterol in the two populations, but the individual correlations of changes in PFAS to changes in lipids is reassuring that the association of cholesterol with PFAS is reversible.

Thus, in conclusion it is plausible, given research on other exposures, that reducing body burdens will result in reduction of any PFAS associated risks, but there is no direct evidence of this for PFAS and therefore it cannot be quantified. There is however direct evidence that reducing serum PFAS results in a reduction of the impact on serum cholesterol. It is therefore reasonable to conclude there are health benefits of a fall in the PFAS body burden. However, the benefit depends on whether future risks to the exposed person are more related to current body burden/serum concentration or the cumulative exposure. In a population with past exposure that has been stopped or reduced, there would have been higher serum levels in the past and the total cumulative exposure would not be reduced by much however rapidly one reduces the body from now.

Conversely for future possible exposures to children during pregnancy and breastfeeding from maternal body burden, reducing serum levels would directly reduce that exposure to child.

DRAFT

3 Testing for PFAS

Testing (sampling and analysis) for per- and polyfluoroalkyl substances (PFAS) in the environment is challenging for four main reasons. Firstly, PFAS have an extraordinary chemical diversity. More than 14 000 PFAS moieties exist, but routine methods quantify only a few dozen; many others lack reference standards so they escape targeted detection (Z. Wang et al., 2017). Second, analytical methods need to be able to analyse parts-per-trillion (ppt) concentrations. Regulatory limits for drinking water are now moving towards the single-digit ng L^{-1} (i.e. ppt) range, demanding methods and instruments that can distinguish a handful of PFAS molecules from background contamination (Zahra et al., 2025). Third, strong matrix effects provide analytical challenges for PFAS identification and quantification. (ITRC, 2023). Matrix effects in PFAS analysis occur when components in complex environmental samples (soil, wastewater, or blood) interfere with the detection of PFAS by either suppressing or enhancing the analytical signal. This can lead to inaccurate quantification unless properly corrected using internal standards, matrix-matched calibration, or rigorous sample cleanup. Fourth, ubiquitous background contamination means that huge care must be taken to avoid contamination of samples. Fluoropolymer tubing, waterproof clothing, and even ambient laboratory air can introduce trace levels of PFAS into samples. Studies have shown that field blanks frequently contain detectable PFOS or PFOA, prompting laboratories to adopt PFAS-free materials and implement rigorous blank controls to ensure data integrity. (ITRC, 2023). Together, these factors mean that analysts must combine rigorous sampling protocols, isotope-dilution mass spectrometry, and multiple quality-control layers to produce reliable PFAS data.

3.1 How samples are taken

Because PFAS are ubiquitous outdoors and indoors, laboratories follow strict sampling rules to avoid adding contamination or losing the chemicals before they reach the instrument. Field teams avoid equipment and materials which are known to contain PFAS, and meticulously rinse all equipment (e.g., sampling tools and containers) with PFAS-free water between samples. They also collect field blanks (sealed bottles that are exposed in the field, which travel together and are analysed with the real samples) to prove the chain of custody is clean and also to determine quantification limits.

3.1.1 Surface water and drinking water

Scientists collect water samples in high-density polyethylene or polypropylene bottles (glass can adsorb PFAS). Samples are chilled, transported to the lab and analysed as soon as possible. In the lab a solid-phase extraction (SPE) cartridge is typically used to concentrate PFAS from the water and to transfer the PFAS into a solvent. The solvent is concentrated down to a few hundred microliters of solvent and a tiny fraction is injected onto the instrument for analysis. Clean-up procedures may be applied to separate PFAS from the sample matrix which can interfere with the analysis.

3.1.2 Surface sea water and sea foam

Near some coasts wind and wave action can lead to the formation of foam on the sea surface. This foam is naturally produced from the many natural surfactants present in natural organic matter present in sea water. Research over the last few years shows that foam can concentrate PFAS many thousandfold above the surrounding water concentrations; single sea-foam samples from the US Atlantic coast recently contained almost one million nanograms per litre of PFOS (Enders J, 2025). To capture foam, scientists skim it gently with a pre-cleaned stainless steel ladle into PFAS-free bottles

or plastic bags and treat it like a highly contaminated water sample (the foam rapidly collapses in sample bottles to brown-coloured water), diluting a measured portion with reagent water before applying SPE.

3.1.3 Soils and sediments

A stainless steel spade or core sampler takes at least 100 g of material to a specific depth (depending on the objectives of the study), which is stored chilled or even frozen before analysis. In the laboratory, a subsample is typically taken (e.g., 2 to 5 g are weighed), spiked with isotope-labelled standards, and then extracted with a solvent. The extract is concentration and cleaned to remove interfering matrix (e.g., humic and fulvic acids present in soil organic matter) prior to injection on an instrument for analysis.

3.1.4 Air sampling

High-volume air samplers (which are like powerful vacuum cleaners) draw hundreds of cubic metres of air through quartz fibre filters (to trap particles and particulate-bound PFAS) followed by polyurethane foam or XAD resin (to trap vapour-phase PFAS). The samples are extracted with solvent, concentrated and cleaned up prior to analysis on an instrument.

3.1.5 Wildlife tissues

Biological tissues (e.g., fish muscle, bird liver or invertebrate homogenates) are weighed, spiked with isotope labelled standards and then extracted with a solvent. The samples are extracted with solvent, concentrated and cleaned up prior to analysis on an instrument.

3.2 Core laboratory methods

Once in solvent, all sample types converge on similar analytical approaches: liquid chromatography coupled to tandem mass spectrometry (LC–MS/MS) for targeted analysis or liquid chromatography coupled to high resolution mass spectrometry for broader screening. The liquid chromatograph separates PFAS compounds based on their interactions with the column, while the mass spectrometer identifies and quantifies them. Triple-quadrupole instruments are the industry standard for targeted analysis, capable of detecting individual PFAS compounds in complex mixtures by monitoring specific ion transitions, even in the presence of thousands of other chemicals.

Each extract typically receives a set of stable isotopically labelled internal standards — PFAS compounds that are chemically similar to the targets but slightly heavier due to atoms like carbon-13 or deuterium. These internal standards mimic the behaviour of native PFAS during extraction and analysis, helping to correct for losses, matrix effects, and variability in the mass spectrometer. This approach enhances accuracy and quantification, though its effectiveness depends on how well the labelled compounds match their target analytes.

There are additional methods that are used to estimate total organic fluorine (TOF), but, given that there is not yet consensus on which the appropriate measure is, and that the methods produce very different results, they are not used widely by commercial labs.

3.3 How sensitive are laboratory tests?

- **Limit of detection (LOD)** is the smallest amount of a chemical that produces a signal distinguishable from background noise. Below the LOD the laboratory cannot reliably determine the presence of the chemical.

- **Limit of quantification (LOQ)** is higher than the LOD. It is the smallest amount the laboratory can measure with acceptable accuracy and precision (often defined as a relative standard deviation below 20 %). Between the LOD and LOQ a result is reported as “detected but not quantified.”
- **Reporting level** is the level at which an organisation views the margin of error to be sufficiently narrow for the results to be publicly reported without the risk of simple statistical variance potentially misleading the public.

Using today’s instruments and one-litre water samples, typical LODs for PFOS, PFOA and PFHxS are 1 to 2 parts per trillion (ng/L) and LOQs are roughly 3-5 ng/L. High end systems concentrating five litres of water have pushed LOQs below 0.5 ng/L, while some research groups have demonstrated part-per-quadrillion capability for PFOS in ultrapure matrices (Ackerman Grunfeld et al., 2024). In soils and wildlife tissues, matrix interferences are stronger; so realistic LOQs are 0.5 to 2 parts per billion (ng/g): still sensitive enough to flag most contaminated hotspots.

3.4 Special challenges for PFOS, PFHxS and PFOA

All three target molecules ionise well in the mass spectrometer, which helps sensitivity, but they also stick to glass and Teflon materials can be a source, so sample bottles, pipette tips and tubing must be fluoropolymer-free. PFOS and PFHxS were historically manufactured as mixtures of linear and branched isomers. Modern analytical methods either sum the isomers or employ calibration standards that reflect the specific isomeric distribution in the sample.

PFHxS is shorter and more water-soluble than PFOS, making it more difficult to trap on traditional C18 cartridges used for extraction. However, weak anion exchange (WAX) sorbents introduced in 2019 have significantly improved recovery. PFOA, while phased out in many countries, continues to cause laboratory contamination problems due its ubiquitous presence (even in laboratory solvents). Therefore, quality control steps, such as reagent blanks, are vital to identify and correct for potential false positives during sample preparation.

4 Context in Jersey

In order to triangulate the panel’s work to the context in Jersey, several documents about how liquid and solid waste are managed in Jersey were shared with panel by public utilities. These documents are appended to the report and summarised below.

4.1 Waste disposal in Jersey

This section summarises the key points relevant to PFAS management in a series of documents supplied to the Panel by public utilities in Jersey. The full text of the documents is included in Appendix 2 of this report.

4.1.1 La Collette Energy Recovery Facility

4.1.1.1 Role and regulation.

Jersey’s Energy Recovery Facility (ERF) at La Collette incinerates municipal and commercial residual waste and is regulated under the Waste Management (Jersey) Law (licence WML019), which specifies accepted waste types and emission limits to land, sea and air. The plant typically receives and processes 70,000–75,000 tonnes/year of mixed residual waste and normally generates 7.5 MW of electricity, with export to the island grid.

4.1.1.2 Process flow and core conditions.

Residual waste from parishes and commercial operators is tipped into a reinforced-concrete bunker, mixed by two grab cranes, and fed to two identical grate boilers. Combustion is maintained above 850 °C (the regulatory minimum), with a 3-hour residence time on the grates before the material drops to the ash system. Bottom ash is exported to the UK for metals recovery and use as aggregate (e.g., road foundations).

4.1.1.3 Steam cycle and power generation.

Hot flue gases produce superheated steam at up to 43 bar absolute and 397 °C, which expands through a single steam turbine directly coupled to a 4-pole generator running at 1,500 rpm, with a gross electrical capacity up to 10.24 MWe. Steam is condensed and recirculated; condensers are seawater-cooled through titanium tubes with a maximum 8 °C inlet-outlet temperature rise during normal operation to minimise ecological impact.

4.1.1.4 Flue-gas cleaning and residues.

A multi-stage flue-gas treatment line conditions emissions for compliant discharge via the stack. Urea is dosed for NO_x control; lime adjusts pH; activated carbon captures dioxins/furans, trace heavy metals and VOCs; and bag filters remove particulates. The fine particulate residue (APCR) is bagged and exported to the UK for uses such as concrete production after stringent testing.

4.1.1.5 Waste mix (unseparated residuals, 2023 composition study)

Paper & card 24.5%; plastic film 7.8%; dense plastic 9.7%; textiles 3.4%; other combustibles 22.2%; other non-combustibles 1.3%; glass 2.4%; putrescibles (biodegradable organics) 21.4%; metal 3.4%; WEEE 0.7%; potentially hazardous items 0.6%; fines 2.6%.

4.1.1.6 Throughput headroom and realistic maximum.

While the ERF can run above its typical 70–75 kt/year for short periods (subject to waste calorific value), sustained operation above that level would increase planned/unplanned maintenance, reduce availability, raise APCR/IBA arisings, increase lime/carbon/urea consumption, and heighten

logistics dependency. In short: higher peaks are feasible, but not a realistic steady-state maximum without trade-offs.

4.1.1.7 Biosolids handling capacity.

Biosolids are accepted under WML019 (Schedule 2, I7 & I8) but are not separately shown in the composition table. Current processing is 3,500 t/year (about 5% of the 75,000 t/year total). The licence limits all sludges combined to 10% of throughput, so ~7,000 t/year would likely breach the limit when municipal inputs dip. Operationally, 3,500 t/year is the stable running level; higher tonnages depress CV, making combustion control and emissions compliance more difficult. Short-term emergency uplifts might be possible, but furnace temperature and emissions would be affected. Increased recycling would also lower residual waste to the ERF, reducing headroom for biosolids.

4.1.1.8 Bunker management and outages.

Waste in the bunker is mixed continuously and, in normal operation, most daily inputs are combusted within 24-36 hours. The ERF has two six-week annual maintenance outages; during each, waste remains in the bunker, which is typically full by the end of the outage. The bunker is fully contained, and no leachate is generated.

4.1.1.9 Integration with other facilities.

The ERF is designed for a mixed-feed to maintain stable calorific value; it does not process segregated streams. Re-incineration of ERF bottom ash at the Clinical Waste Incinerator is not possible.

4.1.1.10 Compliance and reporting.

Monitoring, testing and reporting are defined in WML019 (Sections 4–5; Schedules 4–5), with all required reports submitted to the Regulator.

4.1.2 La Collette Clinical Waste Incinerator

4.1.2.1 Role and regulation.

The Clinical Waste Incinerator at La Collette disposes of healthcare wastes requiring higher combustion temperatures than the Energy Recovery Facility. It is regulated under the Waste Management (Jersey) Law with licence WML038, which defines accepted waste types and limits on airborne emissions.

4.1.2.2 Capacity and typical load.

The plant typically treats 150 tonnes/year, with a realistic maximum of 230 tonnes/year. Although the design throughput is 200 kg/h, the plant is normally operated at 180 kg/h to avoid exceedances of emission limits. Operational cycling further constrains annual output: because of the high metal and glass content in clinical waste, the plant can run up to three consecutive days before a shutdown is needed to clear large bottom-ash items. Cooling takes four days and cleaning one day, yielding an eight-day cycle.

4.1.2.3 Combustion and temperatures.

This auto-load, stepped-hearth unit uses two-stage pyrolytic gasification and combustion. The internal combustion temperature in the secondary combustion chamber is maintained above 1,100 °C. The temperature in the primary chamber is typically around 800C. Waste moves across the

stepped hearth in the primary chamber (diesel-fired ignition), is rendered to ash, then gases pass to the secondary chamber, where they are further heated, oxidised and turbulently mixed at >1,100 °C to ensure complete destruction of combustion products.

4.1.2.4 Flue-gas treatment and monitoring.

From the secondary chamber, gases travel via refractory-lined ducting where urea is injected to reduce NO_x (with a dilution fan to optimise reaction temperature). A heat exchanger (low-pressure water/glycol boiler) cools gases to 180 °C. Sodium bicarbonate and activated carbon are then dosed to neutralise acids and capture vapour-phase heavy metals and organics. The abatement plant (filter house) removes particulates and sorbents. Emissions are continuously monitored to demonstrate compliance before release. Particulate air-pollution control residues are disposed of off-island as solid waste.

4.1.2.5 Waste inputs and handling.

Accepted wastes include infectious materials, sharps, and certain medicines from the General Hospital, general practices, pharmacies, dentists, tattoo/piercing studios and nursing homes. Wastes arrive in lockable wheeled bins, are weighed, stored in refrigerated cold rooms, then auto-loaded via elevator and ram into the primary chamber. Bottom ash is quenched in a water bath and conveyed to an external skip.

4.1.3 Waste Disposal Cells at La Collette

4.1.3.1 Overview and current throughput.

The engineered containment cells at the La Collette reclamation site are operated by the Infrastructure & Environment Department for wastes that cannot be recycled, recovered or used for reclamation. They typically receive 17,000 m³/year.

4.1.3.2 Engineering and compliance.

Cells are constructed to meet Annex I of the EU Landfill Directive (1999/31/EC) for non-hazardous waste. As Jersey lacks natural clay, containment relies on a geotechnical membrane with impermeable liners to achieve the required attenuation and protect the marine environment and groundwater.

4.1.3.3 Waste inputs and annual volumes.

Accepted streams include contaminated soils from development, ash and residues from the clinical waste incinerator (CWI) and animal carcass incinerator (ACI), gas scrubbers from the sewage treatment works, and spent sandblasting material. Asbestos is placed in a separate, dedicated cell. Recent annual inputs (m³) were: ERF ash 0, ACI ash 250, CWI ash 50, soils 16,000, asbestos 1,000, other 10, total 17,310. All wastes are classified by producers under WM3 guidance and checked against the site's published waste acceptance criteria before disposal; the department requires pre-treatment where feasible to reduce hazard and/or volume.

4.1.3.4 Leachate management and monitoring.

Rainwater ingress through deposited waste generates leachate, which is collected and pumped to the sewage treatment works for safe processing, preventing releases to sea or land. When a cell is full it is sealed with a permanent cap to minimise further leachate formation. A water-quality monitoring programme (since 2011) tests leachate, groundwater and seawater for heavy metals, nitrates and organic compounds. Historically, leachate was not tested for PFAS; however, PFAS

analyses have since been conducted on selected individual cells and on combined leachate prior to discharge as trade effluent. Leachate from shredded bulky waste in Cell 34 (stored during ERF maintenance) has also been sampled.

4.1.3.5 Typical soil contaminants.

Contaminated soils reflect former land use. Common findings include domestic fuel oil/hydrocarbons (e.g., leaks from heating-oil tanks). Heavy metals and asbestos are associated with historic public or parish landfills (e.g., Esplanade/Waterfront) and private domestic burn pits.

4.1.3.6 Waste acceptance criteria.

Criteria are published on gov.je to guide producers and ensure liners are protected from chemical or physical damage. Non-compliant wastes are not accepted.

4.1.3.7 Export obligations and remaining life.

As a party to the Basel Convention, Jersey must provide adequate disposal facilities and minimise exports. At current input rates, remaining operational life of the cells is 8–10 years. Once filled, no further local capacity will exist for contaminated or hazardous wastes without an alternative solution.

4.1.4 Bellozanne Valley Wastewater Treatment Works

4.1.4.1 Overview

Bellozanne is a conventional activated-sludge works producing a compliant effluent, discharging through a marine outfall. It has a complete sludge line with pasteurisation and anaerobic digestion to generate biogas for a CHP unit, plus dewatering to produce biosolids for agricultural use where landbank allows.

4.1.4.2 Inlet and primary treatment

All flows (main works and storm tanks) are screened to remove rags/large solids, then pass through a vortex grit chamber to remove grit and other heavy, low-calorific particles. Primary settlement tanks separate solids (sludge) from liquor: heavy organics settle and are pumped to sludge treatment; fats, oils and grease (FOG) are skimmed by a rotating bridge and sent with sludge to digestion.

4.1.4.3 Liquid processing (biological treatment and disinfection)

Primary effluent enters an anoxic zone (plug-flow) for denitrification (nitrates/nitrites to nitrogen gas), then an aeration zone where air supports microbes to remove carbonaceous matter and drives nitrification (ammonia to nitrate/nitrite). Hydraulic retention in aeration is 1 hour, dependent on flow. Mixed liquor recirculation returns a portion to the anoxic zone to complete nitrogen removal. Effluent then splits to six final settlement tanks (FSTs); settled sludge is pumped off. Return activated sludge (RAS) is returned to maintain biomass; surplus activated sludge (SAS) is diverted to the sludge line (or co-settled with raw sludge). Final effluent passes a “leaf screen” and UV banks before discharge via culvert to the sea at First Tower. Final effluent, settled sewage and raw sewage are tested two to three times per week.

4.1.4.4 Sludge line (pasteurisation, digestion, energy recovery, dewatering)

SAS is thickened by drum thickener to 5–6% dry solids (DS), then combined with raw sludge and FOG in a thickened sludge tank. After a final rag screen, sludge is heated in a heat exchanger to 55 °C and pasteurised for 4 hours to destroy pathogens and condition the sludge. It is then cooled to 35 °C and

fed to anaerobic digesters with a approx. 30 -day retention time. Microbial digestion produces biogas, which is cleaned and used in CHP to supply site electricity and heat (including for pasteurisation); a supplementary boiler provides resilience during CHP maintenance. Digested sludge is dewatered by centrifuges to 25% DS (“biocake”). Sludge composition is tested daily (working days); biocake pathogens are tested quarterly.

4.1.4.5 Biosolids production and agricultural use

The works produces 6,800 m³/year of enhanced-treated biosolids. Routine analyses cover pH, bacteria, nutrients and potentially toxic elements (heavy metals). Biosolids provide N-P-K fertiliser value and are applied in line with the Water Pollution (Code of Good Agricultural Practice) (Jersey) Order 2009, the Defra Code (1996) and related guidance. Typical application rates are 2.3 m³ per vergée for arable and 3.4 m³ per vergée for grass (1 Jersey vergée = 1,798.6 m²). Applications are surface-spread on grass and ploughed to 30 cm on arable; watercourses and boreholes are avoided; each parcel receives biosolids no more than once in any rolling 12-month period. Given limited landbank, 50% of biosolids are land-applied and the remainder is sent to the La Collette Energy Recovery Facility; as biosolids are 70% water, incineration is treated as a last resort.

5 Evidence from subject matter experts

The panel met with a wide range of subject matter experts across the whole scope of the report. For ease of understanding, they have been grouped by the particular area of expertise that they shared with the panel. Where an expert met with the panel on more than one area, their biography appears

5.1 Experts on PFAS and food

Professor Thorhallur Halldórsson is from the Faculty of Food Science and Nutrition at the University of Iceland

Dr. Leo Yeung is an Associate Professor in chemistry, Örebro University, and an expert in PFAS analysis, focusing on the fate, transport, and toxicology of PFAS.

Dr. Irina Gyllenhammar is a toxicologist at the Swedish Food Agency,

Dr. Ida Hallberg is a veterinarian and researcher

5.2 Presentations from experts on PFAS and food

5.2.1 Presentation from Subject Matter Expert Thorhallur Halldórsson

PFAS are highly persistent pollutants, with long-chain variants (≥ 8 carbons; ≥ 6 for sulfonates) notable for long human elimination half-lives. They bind proteins, mimic short-chain fatty acids, are reabsorbed by the kidneys, and are excreted slowly. Despite phase-outs, they remain detectable—especially near historically contaminated sites such as airports—due to past use in firefighting foams and industrial processes. Early regulatory limits (e.g., EFSA’s 2008 TDI for PFOA at 1500 ng/kg bw/day based on rat liver effects) were later tightened drastically by national agencies using the same studies, highlighting uncertainties in rat-to-human extrapolation. Differences in toxicokinetics, particularly elimination half-lives, may make humans more vulnerable at lower doses than rodent data suggest.

EFSA’s 2018 review assessed 35 PFAS but drew firm conclusions for four (PFOS, PFOA, PFHxS, PFNA), synthesizing >200 human and numerous animal studies. Consistent associations were found with increased liver enzymes, reduced oxidative response, higher cholesterol, and lower birth weight, though effect sizes were modest and typically within normal biological variation; birth-weight changes did not translate into clinically significant outcomes such as low birth weight or SGA. The most sensitive and policy-relevant endpoint was immune function—specifically reduced post-vaccination antibody responses. Multiple human observational studies linked higher PFAS blood levels to lower antibody titres, and animal data (e.g., PFOS in mice) supported immune effects at low doses. The weight of evidence supports a causal link between PFAS exposure and immune suppression.

EFSA’s current TWI of 4.4 ng/kg bw/week for the sum of PFOS, PFOA, PFHxS, and PFNA was derived via modelling in one-year-old German infants, identifying the PFAS concentration associated with a 20% reduction in vaccine antibody response (a conservative threshold), then back-calculating maternal levels and intake, including one year of breastfeeding. This immune-based TWI is considered protective for other endpoints (cholesterol, birth weight), which tend to occur at higher exposures. EFSA did not adopt relative potency factors due to methodological issues and variability tied to intake vs circulating metrics and species half-life differences; equal potency among the four was assumed for pragmatism. Epidemiological evidence was prioritized given limitations of rodent

models; cancer data were insufficient for regulation. PFHxS shows immune effects similar to PFOS (possibly slightly lower potency), but co-exposures and limited data preclude firm distinctions; higher concentrations appear necessary for liver effects in rodents.

5.2.2 Presentation from Subject Matter Expert Leo Yeung

PFAS are fluorinated molecules whose carbon–fluorine bonds confer extreme stability and resistance to degradation. Unlike many POPs, they bind to proteins rather than fat, concentrating in blood and liver. Chain length drives behaviour: long-chain PFAS (≥ 8 carbons for carboxylates, ≥ 6 for sulfonates) bioaccumulate and persist in organisms and soils, tending to remain nearer sources, while short-chain PFAS are more mobile environmentally and biologically, clear the body faster, and travel farther. Human exposure pathways include industrial emissions, consumer products, environmental contamination, and wastewater, but food and drinking water dominate overall intake, with early-life exposure via placenta and breast milk. Multiple studies identify diet as the principal exposure route; detectable PFAS in drinking water correlate with higher serum PFOA, PFHxS, and PFOS, and seafood intake is linked to elevated PFNA and other PFAS, underscoring the need to monitor food and water.

PFAS from firefighting foams can disperse regionally and globally: compounds released could be detected ~ 60 km away, and atmospheric oxidation/rainwater transport can move PFAS to remote regions such as the Arctic. Industry has shifted from legacy PFAS (PFOS, PFHxS) toward 6:2 fluorotelomer-based substances that differ in functional groups but raise similar exposure and persistence concerns. In food systems, long-chain PFAS bind soils and enter livestock via grazing or soil/worm ingestion, transferring to meat, milk, and eggs; short-chain PFAS are more readily taken up by crops (e.g., rice, lettuce, tomatoes, cucumbers, potatoes), with residues persisting on produce surfaces even after washing. Food packaging remains a contributor: while many long-chain PFAS are phased out (e.g., via the Stockholm Convention), short-chain PFAS and side-chain fluorinated polymers remain in use and can hydrolyse or migrate—especially during microwave heating—and recycled materials may retain residues.

Analytically, the field has progressed from nanogram-level detection hampered by contamination, poor standards, and misidentification to picogram-level sensitivity with standardized methods, blanks, and internal controls. Early lab variability was high (RSD up to 250%), and some publications were withdrawn; stringent QA/QC and cautious interpretation are essential. Current guidance (e.g., FDA, EFSA) targets a few compounds, but broader surveillance of emerging short-chain PFAS and methods to quantify total PFAS—including unknowns—are needed. Policy context includes Denmark's ban on PFAS in food packaging and the EU Drinking Water Directive's 500 ng/L total PFAS limit with specified analytical approaches and TFA recovery reporting. Continued research on transport, plant uptake, and exposure assessment is critical for effective regulation and public health protection.

5.2.3 Presentation from Subject Matter Expert Irina Gyllenhammar

Key findings focus on PFAS exposure from food within Sweden's monitoring and risk-assessment framework. Food and drinking water are identified as the primary exposure sources. Sweden has applied action limits for PFAS in drinking water since 2014, which become legally binding in 2026. European benchmarks include EFSA's 2020 tolerable weekly intake (TWI) for four PFAS and the 2023 EU maximum levels for PFAS in meat, fish, and eggs.

Sweden’s long-running Market Basket (MB) Study (1999, 2005, 2010, 2015, 2022) estimates average dietary intake by purchasing foods according to national consumption patterns, homogenising them into food groups, and analysing contaminants. In 2022, with expanded PFAS testing (14 compounds), only three of 17 food groups—lean fish, fatty fish, and eggs—showed detectable PFAS; fruits, vegetables, and common meats (beef, pork, lamb, chicken) were non-detect. PFAS were detected in organic eggs but not in conventional eggs, a pattern corroborated by food control sampling.

Concentration patterns show the highest PFAS levels in fish from the Baltic Sea and Swedish lakes; lower levels occur in farmed salmon and oceanic species such as tuna. Swedish crayfish exceed levels found in imported Spanish crayfish. PFAS are present in shellfish and wild boar meat, with low levels in reindeer and liver pâté. All measured levels are below EU maximum limits. Additional control sampling confirmed the absence of PFAS in fruits, vegetables, and common meats.

Temporal trends indicate substantial declines. Estimated per-capita PFAS intake from food has fallen steadily since 1999—about 8% annually. PFAS concentrations in fish have declined by ~5% per year. These reductions align with human biomonitoring of first-time mothers in Uppsala, whose serum PFAS levels have decreased since 1996.

Exposure modelling combining national dietary surveys with 2022 MB concentrations shows most age groups remain below the EFSA TWI, though some young children (1.5 and 4 years) exceed it. When drinking water at 4 ng/L (the forthcoming Swedish limit) is included, adult exposure from water is roughly equal to that from food; at higher assumed water concentrations (e.g., 100 ng/L for 21 PFAS), water can dominate exposure. Representativeness depends on timing, food origin, and supply chains. The unexpected PFAS in organic eggs is most plausibly linked to fish-meal feed, with potential contributions from free-range soil and worm ingestion. Sweden’s archived samples support retrospective analyses to harmonise methods and validate trends.

5.2.4 Presentation from Subject Matter Expert Ida Hallberg

A project assessed PFAS exposure from animal-sourced foods produced near known Swedish contamination hotspots, focusing on beef, dairy, and small-scale (backyard) eggs against EU-regulated PFOS, PFOA, PFHxS, and PFNA. PFAS hotspots in Sweden are chiefly linked to legacy firefighting foam use rather than manufacturing. Livestock exposure differs from humans and is driven by feed, drinking water, and soil ingestion (with soil both directly ingested—especially by hens—and transferred via crops). Estimating “safe” PFAS levels in feed and water is difficult due to species physiology, exposure pathways, and compound-specific kinetics; transfer data are comparatively stronger for PFOS and sparse for other PFAS.

International precedents (Maine dairy, Belgian backyard eggs, Danish beef near a fire-training site) illustrate that food produced close to contaminated sources can reach concentrations of concern and informed the Swedish study design. Using literature-based transfer factors, theoretical maxima for PFAS in feed/water were derived to avoid exceedance of EU food thresholds; these aligned reasonably for PFOS but were uncertain for other PFAS. Real-world exposures commonly combine pathways, limiting single-route estimates.

Screening of farms within ~5 km of hotspots (milk, beef, eggs; with analyses by an academic reference laboratory) found: (1) Milk—PFAS detected in most samples but at low levels below EU action limits; no evidence of elevated contamination from local hotspots, and dairy farm drinking

water also showed no elevation. (2) Beef—PFOS was the only compound detected in meat; some samples exceeded EU thresholds. Blood PFAS in cattle varied widely; moving animals indoors did not show consistent reduction. Given relatively short PFAS half-lives in cattle (months to days), switching to clean feed/water should reduce burdens over time, though practicalities may constrain this. (3) Backyard eggs—over half of flocks near contaminated/urban areas exceeded EU thresholds, while rural flocks without known contamination showed lower levels comparable to commercial organic eggs. Backyard egg consumption near hotspots is therefore a salient individual exposure risk.

Intake modelling (aligned with national dietary approaches) indicates that high consumers of affected beef and especially backyard eggs can exceed EFSA’s TWI, underscoring the need for targeted monitoring, clear public guidance, and risk communication. Methodological notes highlight variable detection limits and the importance of stringent QA/QC; academic labs often achieve lower limits of detection, but commercial capabilities are improving. Environmental co-factors under consideration include biosolids, irrigation, and surface-water access during grazing.

DRAFT

5.3 Discussions with experts on PFAS and food

- Coastal transport: PFAS can be carried inland by sea foam; cattle near coasts have been exposed where foam settles inland. In Jersey, cattle may not graze directly on the coast, but sea foam contamination remains a concern. Sea foam sampling is technically challenging due to instability and a lack of standardised protocols; method development is underway.
- Backyard eggs: Eggs are being sampled in Jersey, but the attention to non-commercial sources is uncertain. Households using borehole water for irrigation or poultry drinking water, and keeping hens, could face elevated PFAS exposure. Evidence indicates soil and feed are more significant exposure pathways for hens than water; elevated PFAS in urban backyard eggs have been observed even with clean municipal water and without fish-based feed.
- Production system differences: Commercial egg production is highly standardised with controlled feed and water, whereas beef cattle farms (e.g., in Sweden) often rely on locally grown feed, which is more susceptible to environmental contamination. This distinction is important when comparing exposure risks across food production types.
- Sampling strategy and comparators: Jersey is sampling individual food items rather than constructing a Market Basket profile. A Swedish Market Basket identified detectable PFAS in lean fish, fatty fish, and eggs; caution is advised against assuming zero PFAS in other food groups without additional data. Robust conclusions require triangulating background measurements, data from contaminated sites, and historical datasets.
- International datasets: Access to recent food-basket data from other countries is needed to validate assumptions and support comprehensive exposure assessments. EFSA collects food sampling data from member states; many studies cited in EFSA's 2020 report are considered outdated, so newer datasets are important for accurate comparisons.
- National contributions: Germany provides a large share (reported up to 70–80%) of EFSA's food sampling data due to regulatory requirements for annual testing; the German Federal Institute for Risk Assessment (BfR) may hold recent data relevant for comparison.
- Production standardisation context: Across Europe, chicken and pork production is relatively standardised due to widespread soy-based feed, whereas cattle feed is more locally sourced and variable—an important consideration when interpreting Jersey results against international precedents.

5.4 Experts on PFAS in non-drinking water, soil and biosolids management and PFAS destruction

Jelena Rejanovic is an ICREA research professor at the Catalan Institute for Water Research in Girona, Spain. She leads a group focused on developing nanostructured materials for electrochemical water treatment and recovery systems

Steven Chow is a scientist at the Swiss Federal Institute of Aquatic Science and Technology in Zurich, Switzerland. He specialises in the fate, transport, and treatment of PFAS in water systems, and currently leads a study focused on PFAS behaviour in wastewater treatment.

Linda Lee is a professor at Purdue University with a joint appointment in agriculture and engineering. She has been researching PFAS for about 20 years, focusing on its fate, transport, and remediation. Her work includes collaborations with farmers and sanitation districts to address PFAS-related challenges.

Michel Hubert is a senior engineer at the Norwegian Geotechnical Institute (NGI) with bachelor's and master's degrees in environmental engineering. After several years in consultancy focused on groundwater modelling and pollutant transport, he completed a PhD in Norway over the past five years on the remediation of PFAS-contaminated soils. He now continues at NGI, working on PFAS contamination projects, particularly at sites impacted by aqueous film-forming foam (AFFF).

5.5 Presentations from experts on PFAS in non-drinking water, soil and biosolids management and PFAS destruction

5.5.1 Presentation from Subject Matter Expert Jelena Rejanovic

PFAS span a structurally diverse class (OECD definition) drawing intense regulatory focus in Europe (Drinking Water, Urban Wastewater, Water Framework Directives). Ultra-short chain PFAS like TFA are increasingly prioritized because they persist and are hard to remove at ultra-low limits.

5.5.1.1 *Separation (capture) technologies*

What works now:

- Granular activated carbon (GAC)
- Ion-exchange resins
- Reverse osmosis (RO)
- Foam fractionation

Performance reality: These methods remove PFAS from the water but transfer the load to residuals (spent carbon/resin, RO brines, foam concentrates) that still require treatment/disposal. Drawbacks highlighted include frequent media replacement, brine generation, energy intensity, and high O&M costs. They remain the only widely adopted and reliable solutions today, but leave an unresolved end-of-life destruction problem for PFAS-laden residuals.

5.5.1.2 *Destruction (mineralization) technologies*

Goal: Break C–F bonds and mineralize PFAS, avoiding secondary waste. Four routes were emphasized, each with scale-up and by-product challenges:

5.5.1.2.1 Electrochemical oxidation (EO)

- Mechanism: Direct/indirect oxidation at electrodes; PFAS must reach the surface (mass-transfer limits).
- Non-selectivity & by-products: In chloride-bearing waters, chlorinated by-products can form; panel noted plausibility of harmful species, particularly with aromatic PFAS precursors.
- Fluoride fate: Mostly released to the treated stream; minor incorporation in electrodes possible.
- Deployment focus: Not currently pursued for drinking water (safety/regulatory concerns). Target matrices are industrial wastewater, (at pilot stage, Landfill leachate and groundwater are at the research stage) with pre-concentration to improve energy efficiency and optional GAC polishing. Scepticism remains about any potential for commercial anodes avoiding chlorate/perchlorate.
- TRL signal: Generally early; pilots exist mainly outside drinking water.

5.5.1.2.2 Supercritical Water Oxidation (SCWO)

- Pros/cons: Strong oxidation potential but requires extreme T/P, with high energy and materials/corrosion issues. Potential to generate corrosive HF complicates continuous operation.
- TRL: Pilot/early demonstration territory.

5.5.1.2.3 Hydrothermal Alkaline Treatment (HALT)

- Pros/cons: Hydrothermal conditions with NaOH can neutralize HF—a noted advantage over SCWO. Still complex, energy-intensive, and challenging to run continuously at scale.
- TRL: Pilot/early demonstration territory.

5.5.1.2.4 Plasma oxidation

- Pros/cons: High-energy plasma can cleave C–F bonds but carries high specific energy needs and by-product control challenges.
- TRL: Early development with limited field validation.

5.5.1.3 Cross-cutting takeaways for destruction:

- Key issues are energy intensity, non-selective reaction networks, by-product formation/control, and mass-transfer limits.
- Validated destruction data (mass balance, fluoride release, by-product speciation) are essential before strong performance claims.

- According to the discussion, there are no known full-scale drinking-water deployments of PFAS destruction; field activity concentrates on industrial wastewater and impacted groundwater.

5.5.1.4 *TRL landscape & pathway to deployment*

- Many destruction approaches sit around TRL 4–5, with ambitions for TRL 7 via pilot-scale demonstrations on real waters (e.g., semiconductor wastewater, firefighting-impacted groundwater, landfill leachate).
- Progress is slowed by sector conservatism, regulatory hurdles, long validation timelines, and the need for industry partnerships.
- The pragmatic near-term architecture is capture first (separation) plus targeted destruction of concentrated residuals—provided pilots can prove energy-efficient mineralization with controlled by-products.

5.5.2 *Presentation from Subject Matter Expert Steven Chow*

Wastewater treatment plants aggregate PFAS from households, industry, and commerce. During treatment, contaminants partition: short-chain PFAS (typically <8 carbons) remain predominantly in the liquid phase, while long-chain PFAS (≥ 8 carbons) concentrate in sludge. A Swiss national survey of 21 plants found roughly 90% of measurable PFAS mass in wastewater and 10% in sludge; long-chain, bioaccumulative compounds were enriched in sludge, with PFOS partitioning about 75% to wastewater and 25% to sludge.

Many countries land-apply sewage sludge to recycle nitrogen and phosphorus, but PFAS contamination raises risks of accumulation in soils, crops, livestock, and water sources, particularly inland where treated wastewater can re-enter potable systems. Reported practices include, in the United States, approximately 60% land application, 14% incineration, and 24% landfill. Restrictions are tightening: Germany plans to phase out land application for large plants by 2032; Maine has banned land application of PFAS-contaminated sludge; Denmark has action levels for PFAS in sludge of 10–50 ppb. Switzerland banned land application in 2006 due to pathogens and heavy metals, with minimal economic impact because sludge contributed little to agricultural nutrients. Nearly all Swiss sludge now undergoes thermal treatment—primarily incineration—though there are no specific PFAS limits in sludge.

Sludge incineration is a high-temperature combustion process producing flue gas, bottom ash, and heat. Ash (inorganic) is typically landfilled; heat is recovered for energy. Incineration reduces sludge volume by over 95% but sacrifices nutrients and entails substantial capital and operating costs. Effective air-pollution control commonly includes particulate removal, acid-gas scrubbing, and activated carbon. Facilities pre-dry sludge to raise solids for efficient combustion; incinerators operate above 650 °C with energy recovery. In Switzerland, sludge is treated in dedicated incinerators, municipal waste-to-energy plants, or cement kilns; phosphorus recovery from ash becomes mandatory in 2026 (although implementation will be delayed due to technological limitations).

PFAS destruction during incineration mineralizes compounds to HF and CO₂; HF is corrosive and must be scrubbed with alkaline bases. Incomplete combustion can allow short-chain PFAS and volatile

fluorinated species to escape. Effective destruction requires temperatures above 1000 °C, residence times over 2 s, and homogeneous heating—conditions better met by cement kilns and hazardous-waste incinerators than older sludge or municipal units. Literature from Sweden and the United States indicates reductions in PFAS with residual short-chain species persisting in ash and rinse waters. A recent U.S. EPA study using advanced monitoring reported high PFAS destruction in hazardous-waste incinerators, with performance varying by facility type.

Measured stack emissions from waste-to-energy plants are reported as low; mass balances indicate major releases can occur via leachate from stored solid waste piles prior to combustion. Most PFAS mass is retained in ash or released via wastewater effluent after scrubbing; residual levels in ash are relatively low and comparable to untreated municipal sludge. Drying is the largest operating cost in sludge incineration, though dried sludge contributes heating value. Switzerland intends to maintain incineration as a sludge management policy.

5.5.3 Presentation from Subject Matter Expert Linda Lee

Wastewater treatment plants (now often termed “water resource recovery facilities”) receive PFAS from domestic, industrial, and commercial sources. PFAS either pass through to effluent or adsorb to solids that are processed into biosolids and frequently land applied. Biosolids span a wide moisture and form range (from liquid-like to dry pellets). Common processing steps—aerobic/anaerobic digestion, thermal hydrolysis, centrifugation, filtration, composting, and drying—shape handling but do little to degrade PFAS. Water removed during processing (centrate) often carries high PFAS and is recycled back into the plant, perpetuating contamination; emerging technologies are being tested on this centrate.

U.S. biosolids categories (Class A, Class B, Exceptional Quality) are defined by pathogens and metals, not PFAS. Historical reductions in metals were achieved via enforceable pretreatment at the source, offering a template for PFAS control. Reported PFAS concentrations are typically on a dry-weight basis; without correcting for water content, applied PFAS loads to land can be overestimated.

Current disposition options have material drawbacks. Landfilling is costly and recycles PFAS via leachate. Incineration faces acceptance issues due to concerns about incomplete destruction and emissions. Alternative thermal routes (pyrolysis, gasification) and chemical routes (alkaline hydrolysis, supercritical water oxidation) are being piloted but encounter corrosion, scalability, energy, and cost challenges. No single treatment is problem-free.

Domestic wastewater is becoming a larger share of PFAS input as industrial and AFFF discharges are constrained. Most domestically derived PFAS exit both in effluent and in sludge. Across multiple field sites, biosolids processing has been observed to reduce measurable PFAS by up to ~80%, likely via volatilisation rather than destruction, suggesting opportunities to capture and treat PFAS in off-gases.

Biosolids are a valuable resource—supplying nutrients, slow-release fertilisation, and soil-health benefits—but legacy PFAS from historic biosolids and compost applications remains a challenge. Paper wastes, commonly co-composted, can be substantial PFAS sources. Analytical scope strongly influences apparent PFAS loads: many studies measure only PFOS/PFOA, while unmonitored precursors often dominate mass and can transform during processing or post-application, creating the impression that PFAS are “formed” in situ.

Field evidence shows heterogeneous outcomes after land application. Long-chain PFAS tend to remain in upper soils; short-chains more readily leach, with mobility amplified in sandy soils. Atmospheric deposition near military and airport sites can exceed drinking-water limits. Runoff and tile drainage are major transport pathways; closed water bodies can accumulate PFAS, with fish burdens persisting (e.g., pond fish PFOS >1,200 ppb more than two decades after applications ceased).

Risk can be mitigated through practical management: adjust calculations to wet-weight applications; recognise that biosolids are applied on a nitrogen basis (high-N products are used at lower rates); mixing and soil incorporation dilute PFAS (often 30–100×) to sub-ppb soil levels; rotate fields and lengthen application intervals (e.g., every five years). Observations from municipal settings with typical, non-industrial biosolids show relatively low PFAS, though persistent residues and slow precursor degradation continue. Overall trends indicate declining PFAS in biosolids, with progress tied to better precursor monitoring, broader analytics, source reduction, and treatment trains rather than reliance on any single technology.

5.5.4 Presentation from Subject Matter Expert Michel Hubert

PFAS contamination in the soil–groundwater system arises from persistent, fluorinated compounds that accumulate at the air–water interface in the vadose (unsaturated) zone. Typical source areas are above the water table, notably where aqueous film-forming foam has been applied (e.g., airports and firefighting training grounds). PFAS, including precursors, migrate downward with percolating water, forming groundwater plumes that can impact drinking-water sources and surface waters. Remediation is complicated by the mix of compounds with differing properties; shorter-chain PFAS are more mobile and harder to contain.

A recent review categorises soil remediation technologies by maturity and effectiveness. Commercially used options include excavation and landfilling, engineered containment, soil washing, and stabilisation/solidification. Emerging methods under research include phytoremediation, soil leaching, and thermal desorption. Excavation and landfilling remove contamination from the site but do not destroy PFAS and raise challenges for leachate treatment and landfill acceptance. Soil washing and flushing act as separation steps that transfer PFAS from soil into a water stream requiring subsequent treatment; pilot studies report high removal for shorter-chain PFAS but lower effectiveness for long-chain compounds such as PFOS. Stabilisation and solidification aim to reduce leaching rather than remove mass; field trials, including collaborations in Sweden, show amendments like biochar can substantially reduce PFAS leaching over long timeframes.

Thermal options include desorption and high-temperature incineration. Desorption removes but does not destroy PFAS, necessitating careful capture and treatment of off-gases. Incineration at temperatures above ~1000 °C can mineralize PFAS into inert compounds (e.g., calcium fluoride) when co-processed in cement kilns, but requires robust infrastructure and continuous emissions monitoring. Phytoremediation—using plants such as hemp and sunflower—shows promise for short-chain PFAS yet entails long remediation horizons, potentially up to 50 years, and is not presently viable at large scale.

For groundwater, pump-and-treat systems extract, treat (commonly via activated carbon, ion-exchange resins, or membrane filtration), and reinject water; they are effective initially but require long-term operation due to slow PFAS release. Permeable reactive barriers, often carbon-based,

provide passive plume containment and reduction, with successful capture demonstrated under favourable geological conditions. Overall, no single method suffices; site conditions, PFAS profiles, and regulatory contexts call for tailored, multi-step treatment trains and continued innovation, particularly for persistent and mobile compounds.

DRAFT

5.6 Discussions with experts on PFAS in non-drinking water, soil and biosolids management and PFAS destruction

5.6.1 Wastewater remediation

PFAS in water arise from diffuse sources and can also be detected in rainwater at distance from point sources; elevated levels have been measured up to five miles from an airport, with attribution complicated by atmospheric mixing and contributions from clothing, wastewater treatment plants, and sea spray. For treatment, granular activated carbon (GAC) is widely used in Europe and ion-exchange (IX) resins are more common in the U.S. Both are expensive and generate secondary waste streams. GAC is often incinerated; effectiveness depends on incineration temperature and regulatory allowances. In the U.S., GAC used for potable water is typically virgin, while GAC used for remediation can be thermally regenerated by manufacturers but is generally not returned to drinking-water service. IX systems generate large volumes of regeneration brine, require periodic replacement, and are often routed to hazardous-waste incinerators, though some newer systems allow in-situ regeneration. In some applications, such as landfill leachate treatment, used GAC may be landfilled for cost reasons.

Reverse osmosis (RO) produces a PFAS-rich concentrate. Electrochemical oxidation is suitable for treating such concentrates, but high chloride can form toxic by-products (chlorate, perchlorate). Graphene-based anodes differ from traditional carbon electrodes and appear resistant to biofilm formation, although long-term performance requires pilot-scale validation. Clarifying units, referenced concentrations pertaining to water were not for solids.

Infrastructure constraints shape options in Jersey: a waste-to-energy unit operates at 850 °C and a small clinical-waste incinerator at 1100 °C; there are no cement kilns or hazardous-waste incinerators, and hazardous-waste cells have an estimated 20–30 years of capacity. Acceptance of PFAS-laden GAC, PAC, or resins is a regulatory decision; some facilities may refuse these wastes. A two-stage thermal approach (volume reduction at ~850 °C followed by higher-temperature treatment) is technically plausible, but volatile PFAS could escape the first stage if air-pollution controls are inadequate.

5.6.2 Soil remediation

PFAS at AFFF-impacted sites are highly persistent, with hydrophilic head groups and fluorinated structures leading to accumulation at the air–water interface in the vadose zone. Precursors can transform over time into other PFAS, including shorter-chain, more mobile species that are harder to contain. Available technologies span commercially used and emerging options. Excavation and landfilling remove contamination from a site but do not destroy PFAS and face limits around suitable disposal and long-term leachate risk. Engineered containment is a management option. Soil washing and flushing can be effective for certain soils and PFAS, but efficiency diminishes in high-clay or high-organic soils and transfers PFAS to a water phase that then requires treatment.

Stabilisation/solidification reduces leaching rather than removing mass; field trials and collaborations (including with SLU in Sweden) show that amendments such as biochar can significantly reduce leaching over extended periods, although long-term performance data remain limited and regulatory

acceptance may vary. Thermal desorption mobilises PFAS from soils without destroying them, requiring capture and treatment of off-gases.

For groundwater, pump-and-treat systems help contain and reduce concentrations but require long-term operation due to slow contaminant release, with applications illustrated at Oslo airport and U.S. Superfund sites. Permeable reactive barriers, often using activated carbon, provide passive plume containment and have shown significant reductions in Norwegian case studies. Both approaches must be tailored to site-specific PFAS profiles and to geological and hydrogeological conditions.

5.6.3 Biosolids

Side-chain fluorinated polymers used in paper coatings act as PFAS precursors but are difficult to quantify because of ionisation challenges in mass spectrometry. Early work indicates slow microbial degradation, and extraction can artificially cleave side chains, complicating interpretation. Recycled paper products (e.g., cereal boxes) are a significant PFAS source in paper mill sludge. Concentrations in such sludge have decreased over time, with a shift toward shorter-chain compounds like PFBS, which are more mobile but less bioaccumulative than PFOS. PFAS concentrations in biosolids are reported on a dry-weight basis, consistent with European soil guidance values. Paper-manufacture biosolids contain higher PFAS levels than those derived from municipal water or sewage treatment generally.

5.6.4 PFAS destruction

PFAS can begin to degrade at 600–800 °C, but complete mineralisation is uncertain without comprehensive monitoring. Incineration above approximately 1000 °C can mineralise PFAS to inert products when wastes are co-processed in cement kilns; these thermal approaches require robust infrastructure and continuous gas-emissions monitoring. Achieving and verifying full destruction is challenging: closing the fluorine mass balance to confirm complete mineralisation has not been performed in many scientific studies. In settings without hazardous-waste incinerators (such as Jersey), destruction routes for PFAS-laden adsorbents are constrained, and acceptance depends on facility policy and regulation. Electrochemical oxidation is applicable to concentrated aqueous streams (e.g., RO reject), but high chloride can generate chlorate and perchlorate; while graphene-based anodes appear resistant to biofouling, their long-term performance and by-product control require validation in pilot trials. Cost frequently governs whether media such as GAC are regenerated or discarded.

5.7 Expert on treatment of water in the home to reduce PFAS

David Andrews is the Acting Chief Science Officer at the Environmental Working Group (EWG), a nonprofit based in Washington, D.C. He has been with EWG for roughly 15–17 years, with over a decade focused on PFAS contamination; particularly in water; examining exposure pathways and implications for human health. He also leads work to identify policy solutions and advocate for regulatory changes to reduce overall PFAS exposure.

5.8 Presentation from expert on treatment of water in the home to reduce PFAS

5.8.1 Presentation from Subject Matter Expert David Andrews

The Environmental Working Group (EWG) is a U.S. nonprofit and nonpartisan organisation whose mission is to translate complex environmental health science into accessible information, advocate for healthier living through improved policies, and increase transparency around chemical exposures. Its work spans drinking water, food systems, consumer products, and agriculture, with a sustained emphasis on PFAS. Since the early 2000s, analysis of legal trial documents from Parkersburg, West Virginia, identified significant PFAS health risks and led to public databases and reports that informed media and regulatory bodies.

EWG compiles and analyses drinking-water quality data from public utilities across the United States and presents results against health-based standards that can differ from legal limits. Public access to these data is intended to support understanding of local contamination and the selection of effective household filtration. Household treatment options include point-of-entry (whole-home) and point-of-use systems. Testing of ten commonly available filters showed wide variability in PFAS removal: some units achieved complete removal, while others reduced concentrations by about 20%. Reverse osmosis systems and multi-stage carbon filters were identified as the most effective, typically achieving about 95–100% removal, although they have higher installation costs. Peer-reviewed studies, including work in North Carolina, reported similar patterns under real-world conditions.

Removal performance depends on PFAS chemistry. Longer-chain compounds are generally removed more effectively than shorter-chain compounds. Regular filter maintenance is critical; without timely replacement and upkeep, captured PFAS can desorb, leading to recontamination of treated water.

At the household scale, relative performance follows the underlying technology rather than the installation location. Point-of-use systems that employ reverse osmosis or multi-stage carbon achieve the highest PFAS removal (approximately 95–100% in the reported tests). Other commonly available consumer filters show a broad performance range, with some products reducing PFAS by only about 20%. Point-of-entry (whole-home) installations and point-of-use formats both rely on the treatment media and design they employ; effectiveness aligns with whether the system uses technologies such as reverse osmosis or multi-stage carbon. Simpler consumer formats, such as basic cartridge-based units and pitcher-style filter jugs within the point-of-use category, fall within the observed range and can deliver substantially lower removal where advanced media are not used and maintenance is not rigorous.

Advanced household filtration can also remove co-contaminants, including disinfection by-products and heavy metals, providing benefits beyond PFAS reduction and potentially influencing cost–benefit considerations. Certified filters are recommended, with the recognition that current certification standards do not necessarily reflect the very low concentration thresholds now regarded as health-

protective. Adhering to manufacturer maintenance guidance is essential to sustain performance over time.

DRAFT

5.9 Discussion with expert on treatment of water in the home to reduce PFAS

- General guidance on bottled water: The recommendation to avoid bottled water is a broad U.S. public-health position (e.g., concerns like microplastics), not a PFAS-specific directive.
- Reverse osmosis (RO) and remineralisation: Many RO units include remineralisation cartridges, but the literature indicates negligible impact on daily mineral intake; additional supplementation is generally unnecessary.
- RO reject water and waste handling: RO systems discharge a PFAS-containing concentrate to the wastewater stream; waste-to-drinking water ratios vary by system. Individual household inputs are small, but cumulative community-scale impacts could be meaningful. PFAS captured on carbon filters often ends up in landfill, underscoring the absence of effective disposal/destruction mechanisms for PFAS from home filtration.
- Ion exchange at different scales: Ion exchange is more common at municipal treatment scale and less available for households.
- Efficacy and certification limits: Current certifications (e.g., NSF) do not guarantee reductions to parts-per-trillion levels. Independent testing (including EWG's and academic studies) shows some filters can reduce PFAS below detection limits, potentially meeting health-based thresholds.
- Maintenance and servicing: Professional maintenance is included in cost estimates for small systems by the EPA; some companies offer installation and servicing. Clear guidance on replacement frequency tailored to contamination levels is limited, and variability in water quality complicates standard schedules.
- Performance variability across products: Certification signals some testing but does not ensure superior performance, especially given the lack of low-level standards. Real-world results vary: single-stage carbon filters achieve modest reductions, while multi-stage and RO systems perform substantially better.
- Factors affecting performance: Ambient temperature effects were not studied here; variability in household conditions, maintenance frequency, and water composition likely contribute to inconsistent outcomes.
- Consumer resources and practical recommendation: Consumer resources that compare product performance are valuable despite scale and variability constraints. For those concerned about PFAS, under-sink RO or multi-stage carbon systems are recommended as effective options with manageable maintenance when operated per manufacturer guidance. Selection should account for co-contaminants and local water quality, with RO noted as resilient across a range of contaminants.

6 Treatment of borehole supplies to reduce PFAS in drinking water

6.1 Regulatory and standard-setting context for small supplies

In April 2024 the United States Environmental Protection Agency (EPA) identified Best Available Technologies (BAT) and Small System Compliance Technologies (SSCTs) for small public water systems. These focus on granular activated carbon (GAC), ion-exchange (IX) and reverse osmosis/nanofiltration (RO/NF), and they set out indicative design and cost ranges that translate well to borehole and well applications (U.S. Environmental Protection Agency, 2024a, 2024b).

For small groundwater supplies, what ultimately matters is the concentration achieved in the treated water against the statutory limit. Certification marks on individual devices show that a product has met a performance target in a standardised laboratory challenge water; however, legal compliance is demonstrated by sampling the finished water under local conditions. In other words, certification is a useful baseline, but site-specific monitoring is the arbiter of performance (U.S. Environmental Protection Agency, 2024b). Similar approaches apply in the UK and EU.

6.2 Core technologies and comparative performance in groundwater

6.2.1 Granular / block activated carbon (GAC/CB)

6.2.1.1 Mechanism

Activated carbon removes PFAS primarily by adsorption: molecules are held on the carbon surface through a combination of hydrophobic interactions, electrical (electrostatic) effects and pore-filling within the carbon's microstructure. As a rule of thumb, the longer the PFAS molecule's fluorinated "tail", the more strongly it adsorbs. For a given carbon this typically follows PFOS > PFOA > short-chain perfluoroalkyl carboxylic acids (PFCAs). Natural organic matter in groundwater; measured as dissolved organic carbon (DOC); and other dissolved substances can compete for adsorption sites, reducing effective capacity (Appleman et al., 2014; McCleaf et al., 2017).

6.2.1.2 Performance at small scale

EPA's BAT/SSCT synthesis and numerous bench and pilot studies show that GAC performs well for long-chain PFAS when the empty-bed contact time (EBCT) is adequate. By contrast, shorter-chain compounds such as PFBA, PFPeA and PFHxA tend to pass through the bed earlier ("breakthrough"), a tendency that is accelerated when DOC is higher. To manage this, small systems typically install two vessels in series (lead-lag) and use "sentinel" monitoring to detect rising concentrations before the second vessel is affected (Pannu et al., 2023; U.S. Environmental Protection Agency, 2024b). Column studies and rapid small-scale column tests (RSSCTs) conducted on multiple groundwaters reproduce this pattern reliably, confirming that breakthrough is strongly dependent on chain length and local water chemistry (Hopkins & Knappe, 2024; McCleaf et al., 2017; Pannu et al., 2023).

6.2.1.3 Co-contaminants and pretreatment

Groundwaters with elevated iron, manganese or turbidity can foul carbon beds, while higher DOC reduces adsorption capacity. Alkalinity (e.g., bicarbonate) can also influence adsorption kinetics. For these reasons, small systems commonly include pre-filtration or oxidation upstream of the PFAS step so that the carbon bed sees cleaner water and lasts longer (U.S. Environmental Protection Agency, 2024a).

6.2.2 Ion-exchange resins (IX)

6.2.2.1 Mechanism

Anion-exchange resins remove PFAS through electrostatic attraction to positively charged functional groups (typically quaternary ammonium) and through hydrophobic partitioning into the resin matrix. Resin performance is sensitive to the resin's chemistry and structure (e.g., gel vs macroporous). Competing anions such as sulphate and bicarbonate can occupy exchange sites and reduce the effective capacity for PFAS (Chow et al., 2022; U.S. Environmental Protection Agency, 2024b).

6.2.2.2 Performance at small scale.

Parallel pilot trials and RSSCTs generally show that IX outperforms GAC for short-chain PFCAs at comparable EBCT. In practice this means longer run-lengths before breakthrough, while still achieving near-complete removal of long-chain PFAS at the start of a run. Many small systems opt for single-use resins to avoid handling brine; the trade-off is higher media cost. Where regenerable operation is chosen, the resulting PFAS-bearing brine must be managed carefully and may need polishing or destruction before disposal (Chow et al., 2022; Pannu et al., 2023; U.S. Environmental Protection Agency, 2024b).

6.2.3 Reverse osmosis / nanofiltration (RO/NF)

6.2.3.1 Mechanism

RO and tight NF are membrane separation processes. Water is pushed through thin-film composite membranes; dissolved contaminants are largely held back based on size and charge. Pre- and post-carbon stages in packaged units manage chlorine (to protect the membrane), taste and residual organics.

6.2.3.2 Performance at small scale

Packaged RO systems ("skids") routinely achieve > 90–99 % rejection across long- and many short-chain PFAS, with treated water often at or near analytical detection limits when membranes are intact and pretreatment is adequate (Appleman et al., 2014; Tow et al., 2021a). Tight NF can approach RO performance for longer chains while achieving higher water recovery, but shows greater variability for short-chain PFASs (Tow et al., 2021a). A practical consideration is the concentrate (reject) stream; commonly 15–50 % of the feed depending on the chosen recovery and fouling control; which needs a responsible management route (Tow et al., 2021a; U.S. Environmental Protection Agency, 2024a).

6.2.4 Foam fractionation (FF) and destructive add-ons (for side-streams)

Foam fractionation exploits the surfactant-like behaviour of many PFAS. Air is bubbled through water, PFAS partition into the rising foam, and the foam is skimmed off. Trials show particularly strong removal for long-chain sulphonates (often > 80–95 %), with lower capture for ultrashort and short chains (S. J. Smith et al., 2023; Y. Wang et al., 2023). At small scale, FF is best used either upstream to lower the load on GAC or IX, or applied to RO/NF concentrate so that a smaller side-stream carries most of the PFAS mass prior to disposal or destruction (S. J. Smith et al., 2023; Y. Wang et al., 2023).

Destructive technologies; including electrochemical oxidation (EO) and UV-advanced reduction processes (UV/sulphite or UV/iodide); are generally applied to these smaller side-streams (concentrates and regenerant brines) rather than the full flow. Laboratory and pilot studies are

promising, but energy demand, by-product management and scale-up for routine drinking-water use remain active research challenges (Fennell et al., 2022; Yifei Wang et al., 2023).

6.3 Design approaches for borehole and well supplies

6.3.1 Wellhouse point-of-entry (POE) adsorption

6.3.1.1 GAC trains

A typical arrangement uses two or more pressure vessels in lead–lag with sampling taps between the vessels. This set-up provides early warning of breakthrough and protects the final outlet. At small scale, EBCTs often sit in the upper single-digit to low double-digit minutes per vessel, constrained by flow and available space. Change-out triggers are usually based on a short-chain “sentinel” PFAS at conservative ng/L levels well below any regulatory limit, so that the second vessel is never compromised (Hopkins & Knappe, 2024; U.S. Environmental Protection Agency, 2024b).

6.3.1.2 IX trains

PFAS-selective strong-base resins arranged in lead–lag offer robust control of short-chain PFAS at EBCTs similar to GAC. Choosing single-use operation simplifies operation and maintenance by removing brine handling, at the expense of media cost. Regenerable systems can be cost-effective on media, but they introduce the need to collect, treat and dispose of PFAS-bearing brine responsibly (Chow et al., 2022; U.S. Environmental Protection Agency, 2024b).

6.3.1.3 Selection logic

Where the groundwater contains mostly long-chain PFAS and DOC is low, appropriately sized GAC can meet very low ng/L targets at a reasonable cost. Where short-chain PFAS are prominent, or DOC and sulphate are elevated, IX tends to deliver longer bed lives before breakthrough. In all cases, pilot testing or RSSCTs conducted on the actual groundwater are the preferred basis for selecting media and fixing bed size (Chow et al., 2022; Hopkins & Knappe, 2024; Pannu et al., 2023; U.S. Environmental Protection Agency, 2024b).

6.3.2 Membrane skids (RO/NF)

Small-system RO/NF is supplied as a compact skid with cartridge pre-filters (typically 1–5 µm), antiscalant dosing or upstream softening, and periodic clean-in-place (CIP). Typical groundwater recoveries are around 50–85 %, depending on hardness, silica and fouling tendency. Concentrate can be discharged to sewer (where permitted), stored and transferred off-site, or processed further; often using FF or IX/GAC; to reduce volume before final management. Membrane integrity is monitored with salt-rejection trends and periodic targeted PFAS analyses (Tow et al., 2021a; U.S. Environmental Protection Agency, 2024b).

6.3.3 Household-level backstops on private wells

Where a single borehole serves one property, point-of-entry adsorption or point-of-use RO at the building can add resilience. Studies on private wells show point-of-use RO consistently achieves near-detection PFAS concentrations across a broad range of compounds, while point-of-entry adsorbers work well if cartridges are replaced before short-chain breakthrough. The same influencing factors: DOC, sulphate/alkalinity, iron and manganese: apply, albeit at lower flows than community systems (Appleman et al., 2014; Herkert et al., 2020).

6.4 Monitoring, operations and residuals

Sentinel monitoring with lead/lag. For adsorption systems, inter-vessel taps allow routine measurement of early-runner PFAS (often PFHxA/PFBA) so that bed change-out happens before the finished water rises. The sampling frequency should be proportional to throughput (expressed as bed volumes) and to any upward trend seen in monitoring data (Hopkins & Knappe, 2024; U.S. Environmental Protection Agency, 2024b). For membranes, continuous conductivity or periodic salt-rejection checks alongside targeted PFAS analyses provide assurance of membrane integrity (Tow et al., 2021a).

6.4.1 Matrix management

DOC suppresses GAC performance; sulphate and bicarbonate compete on IX; and hardness, iron and manganese foul both adsorbers and membranes. As a result, many small systems incorporate pre-filtration and oxidation, and, where membranes are used, antiscalants or softening, to control the matrix and keep the PFAS step operating within design assumptions (U.S. Environmental Protection Agency, 2024a, 2024b).

6.4.2 Residuals

All capture-based processes move PFAS from water into a smaller mass of spent media or a concentrate/brine. Spent GAC may be thermally reactivated (with PFAS destruction managed by the reactivator). Single-use resins are typically disposed of as solid waste in accordance with local rules. Regenerant brines and RO/NF concentrates need their own management pathway. A growing practice is to pre-concentrate with FF, then apply EO or a UV-advanced reduction process to destroy PFAS in that smaller stream rather than tackling the full flow (Fennell et al., 2022; Yifei Wang et al., 2023; Y. Wang et al., 2023).

6.5 Conclusions for borehole/well treatment

- Separation remains the backbone. GAC, IX and RO/NF are the proven mainstays for small supplies. Conventional coagulation and media filtration do not reliably remove PFAS unless a dedicated separation step is added (Appleman et al., 2014; U.S. Environmental Protection Agency, 2024b).
- Short-chains (where relevant) set the replacement clock. Achieving single- and low double-digit ng/L targets in mixed PFAS plumes typically calls for IX tuned to short-chains (with attention to competing anions) or RO/NF with appropriate pretreatment and concentrate management. GAC is well-suited where long-chains dominate and EBCT is adequate at low DOC (Chow et al., 2022; Pannu et al., 2023; Tow et al., 2021a).
- Local pilot/RSSCT data should govern sizing. Because DOC, sulphate and alkalinity vary widely between groundwaters, “copy-and-paste” designs frequently misjudge run-lengths by orders of magnitude. Site-specific testing should be used to set EBCT, bed volumes, flux/recovery and change-out triggers with confidence (Hopkins & Knappe, 2024; U.S. Environmental Protection Agency, 2024b).
- Hybrids reduce risk and O&M. Common small-system trains include IX → GAC (to pair short-chain control with polishing of organics) and RO/NF with FF on the concentrate (to shrink the destruction/disposal problem). These combinations are increasingly documented in recent pilots and reviews (S. J. Smith et al., 2023; Tow et al., 2021a; Y. Wang et al., 2023).

6.6 Key questions in options appraisal

In deciding what technology to install, there are many questions that need to be answered for a specific site. Some of these are outlined below.

- Is the water for drinking, irrigation or a combination?
- Is the water used by more than one household?
- Is wellhouse treatment necessary or is home treatment sufficient?
- Is reducing short chain PFAS an objective?
- What co-contaminants are present that may impact PFAS removal efficiency?
- Are there other contaminants that also need to be removed?
- Are there specific issues, such as site access or space availability, that need to be factored in?
- Are there site-specific restrictions such as power usage, maintenance frequency?
- To what extent is cost a factor?
- How will residuals/waste be managed?
- Is supply security an issue?

7 Treatments in the home to reduce PFAS in drinking water

There are a range of technologies and appliance types for lowering the level of PFAS in a residential setting. This section explores the range of these technologies, their relative strengths and limitations, and any additional benefits relating to other pollutants.

7.1 Regulatory and certification context relevant to household devices

In practice, North American standards define the benchmark used worldwide. The relevant device standards are NSF/ANSI 53 (adsorptive/ion-exchange filters) and NSF/ANSI 58 (reverse osmosis). A legacy protocol, NSF/ANSI P473, verified reduction of PFOA/PFOS; in 2022 its scope was folded into 53/58 and expanded to a “Total PFAS” claim covering a multi-compound mixture with a combined treated-water limit of 20 ng/L (down from the earlier 70 ng/L criterion that applied to PFOA+PFOS alone). Certification is issued by ANSI-accredited bodies; notably NSF, IAPMO, WQA, UL, and CSA; and products are listed in public directories. (NSF International, 2024)

The U.S. EPA (2024–2025) points consumers and utilities to those certifications and notes that current device standards are being updated in light of the new federal MCLs (PFOA/PFOS at 4 ng/L; PFHxS, PFNA, HFPO-DA at 10 ng/L, plus a hazard-index approach). EPA also aggregates links to the five ANSI-accredited certifier directories. In short: device certifications validate reduction performance under standard challenge waters, while regulatory MCLs set health-based finished-water goals for systems; the two are related but distinct. (U.S. Environmental Protection Agency, 2024c, 2024d, 2025)

In the EU, the UK, and Australia, while there are regulations for PFAS in drinking water, there are no specific standards for PFAS-specific appliance performance standards.

Two implications follow. First, certification end-points (≤ 70 ng/L for PFOA/PFOS in legacy tests; ≤ 20 ng/L combined under “Total PFAS”) are performance thresholds for devices, not health limits. Second, as device certifications evolve, short-chain PFAS coverage has improved in test protocols, but field performance under diverse matrices still shows variability. (MacKeown et al., 2024)

7.2 Different technologies in use

7.2.1 Granular and block activated carbon (GAC/CB)

Mechanism. Adsorption via hydrophobic interactions, electrostatics, and pore-filling on high-surface-area carbon. Performance increases with perfluoroalkyl chain length and aromaticity; competition from dissolved organic carbon (DOC) and co-solutes reduces capacity. (Zhang et al., 2021)

Comparative performance. Multiple studies report higher removal for long-chain PFAS (e.g., PFOS, PFOA) than for short-chain species (e.g., PFBS, PFBA). Equilibrium and column studies consistently show chain-length-dependent sorption (PFOS > PFOA > PFBS > PFBA). Breakthrough of short-chain acids can occur early at realistic empty-bed contact times (EBCT), particularly at elevated DOC. (Zhang et al., 2021)

Household evidence. In a national assessment of POU devices, activated-carbon systems reduced PFAS variably; long-chain compounds were attenuated more reliably than short-chains, while RO reduced broader suites to near or below detection. (Herkert et al., 2020) A 2024 controlled evaluation of pitcher-type carbon/IX cartridges across two waters (Σ_{75} PFAS = 13 and 56 ng/L) found

wide variability among designs and rapid capacity loss for some configurations, underscoring the importance of contact time and media dosage in gravity formats. (Teymoorian et al., 2024)

Co-contaminants. Carbon is effective for many organic micropollutants (e.g., VOCs, some “401” compounds) and for taste/odour, but has little effect on inorganics such as nitrate or fluoride. (U.S. Environmental Protection Agency, 2024c)

7.2.2 Ion-exchange (IX) resins

Mechanism. Strong-base or specialized resins exchange counter-anions and adsorb PFAS via electrostatic and hydrophobic interactions; quaternary ammonium functional groups and matrix hydrophobicity strongly influence selectivity. (Chow et al., 2022)

Comparative performance. Pilot and column studies often show longer breakthrough times and higher capacities for IX than GAC under PFAS-impacted waters, including scenarios dominated by short-chain PFCAs, though resin chemistry matters. Structure selectivity work suggests tailored long-chain amine resins can improve uptake across PFAS classes. (Chow et al., 2022)

Household relevance. In POU cartridges, IX is commonly blended with carbon to widen the spectrum. Field/bench evidence indicates improved short-chain control relative to GAC alone, but exhaustion can still be rapid when influent concentrations or DOC are high. (Chow et al., 2022)

Co-contaminants. IX can target some anionic species, but selectivity for common inorganics is limited; pairing with carbon is typical to address organics not well retained by IX. (Chow et al., 2022)

7.2.3 Reverse osmosis (RO) and nanofiltration (NF)

Mechanism. Size- and charge-based exclusion through thin-film composite membranes; pre-post-carbon stages in consumer units primarily handle chlorine, organics, and taste. (Tow et al., 2021b)

Comparative performance. Point of use (POU)/under-sink RO frequently achieves > 90–99 % rejection across long- and many short-chain PFAS, with treated water at or near instrument detection in lab/field tests. NF performance is more membrane-dependent (reported ≈ 70–99 %); “tighter” NF/RO improves short-chain rejection at the cost of flux. (Mulhern et al., 2021; Tow et al., 2021b)

Household evidence. In a cross-sectional POU study, RO was the most consistent technology across PFAS spanning legacy and emerging compounds; two-stage/RO configurations reduced PFAS (including HFPO-DA) by ≥ 94 % (study-specific conditions). A 2024/2025 synthesis similarly found average POU removals > 90 % for RO. (Herkert et al., 2020)

Co-contaminants and trade-offs. RO reduces dissolved inorganics (e.g., nitrate, fluoride, arsenic), but generates a concentrate stream; typical residential recoveries are on the order of 20–45 %, varying by design. Membrane scale/clogging risk rises with hardness and particulates; prefiltration is standard. (Tow et al., 2021b)

7.3 Deployment formats and engineering constraints

7.3.1 Point-of-entry (POE; whole-house)

Typical technologies. Large-bed GAC/CB systems, sometimes with IX media; RO is rarely deployed at whole-house flow because of recovery/pressure constraints.

Relative PFAS performance. POE carbon/IX can attenuate long-chain PFAS effectively and; in optimized beds; control selected short-chains, but breakthrough behaviour depends strongly on influent composition, DOC, and EBCT. Certified POE offerings historically referenced the PFOA/PFOS protocol (≤ 70 ng/L), with fewer publicly documented POE “Total PFAS” certifications to date. Verification sampling to detect onset of breakthrough is central at POE scale. (Kucharzyk et al., 2017)

Operational constraints. High volumetric throughput reduces contact times; media change-out is driven by loading (ng of PFAS per g of media), not merely by months of use. Waste management of spent beds (PFAS-laden carbon/resin) and safe handling are additional considerations. (Chow et al., 2022)

Co-contaminants. POE carbon commonly targets chlorine/chloramine and some VOCs; pairing with softening/iron-manganese control is routine for non-PFAS objectives. (Concawe, 2020)

7.3.2 Under-sink point-of-use (POU; plumbed)

Typical technologies

- Composite CB/IX cartridges
- RO with pre-/post-carbon polishing.

Relative PFAS performance.

- **CB/IX:** Reliable for long-chain species; short-chain performance is medium-to-high but more sensitive to EBCT and matrix chemistry (DOC, sulphate, bicarbonate). Peer-reviewed pilot work shows IX > GAC for many cases, particularly short-chains, with longer breakthrough times in parallel columns. (Chow et al., 2022)
- **RO:** High rejection of both long- and many short-chains, often producing permeate near detection at the tap; performance depends on membrane integrity and pre-treatment. (Tow et al., 2021b)

Operational constraints.

- **CB/IX:** Cartridges sized for hundreds–thousands of litres typically; replacement triggers should reflect both volume and time because adsorption is capacity-limited and susceptible to fouling.
- **RO:** Separate lifetimes for prefilters (months) and membranes (1–2 years are commonly reported in technical literature); permeate recovery can be 20–45 %. (Tow et al., 2021b)

Co-contaminants. CB/IX excels for organics/lead (when certified under 53/401), while RO additionally addresses dissolved inorganics (nitrate, fluoride, arsenic). (U.S. Environmental Protection Agency, 2024c)

7.3.3 Worktop POU (plug-in RO and non-RO cartridges)

Typical technologies

- **Plug-in RO** with internal reservoirs
- **non-RO** counter units using CB/IX.

Relative PFAS performance.

- **Worktop RO** mirrors under-sink RO in membrane rejection, with the advantage of no plumbing
- **non-RO** countertop cartridges show PFAS performance similar to under-sink CB/IX provided contact time is adequate.

Comparative household studies consistently place RO at the high end of PFAS removal under mixed influent. (Herkert et al., 2020)

Operational constraints.

- Worktop RO designs manage concentrate internally but still discharge periodic flush volumes;
- non-RO designs depend critically on flow control (contact time). (Tow et al., 2021b)

7.3.4 Pitcher/gravity (“filter jugs”)

Typical technologies. Carbon blocks and/or blended CB + IX in gravity flow.

Relative PFAS performance. Pitchers can reduce PFOA/PFOS and some short-chains, but performance is highly variable among designs, with faster exhaustion under high TDS/DOC waters. A 2024 evaluation across two waters showed compound-specific removal spanning from near-complete for some long-chains to modest for several short-chains; and with rapid declines in some configurations as capacity was consumed. (Teymoorian et al., 2024)

Operational constraints. Low head pressure limits EBCT and mass transfer; tens–hundreds of litres per cartridge are typical order-of-magnitude capacities in the literature and public health summaries, with change-outs required to sustain certified performance. (U.S. Environmental Protection Agency, 2024c)

7.4 Summary table

Figure 1 - Summary table of in-home PFAS water treatment options

Deployment format	Dominant household technology	Mechanistic strength vs PFAS	Typical relative performance (long-chain → short-chain)	Major operational constraints	Co-contaminant profile (typical)
POE (whole-house)	Large-bed GAC/CB, sometimes IX	Adsorption with EBCT-dependent capacity; IX improves anionic selectivity	High → medium (GAC/CB); high with IX for some short-chains; breakthrough governed by loading and DOC	High flow lowers contact time; media change-out driven by ng PFAS /g verification sampling critical	Organics (VOC/T&O) via carbon; minerals largely unchanged
Under-sink POU (non-RO)	Composite CB/IX	Adsorption/ion-exchange; better	High → medium; IX improves short-	Capacity-limited; hundreds–thousands of litres	Lead/VOCs (when 53/401); little

Deployment format	Dominant household technology	Mechanistic strength vs PFAS	Typical relative performance (long-chain → short-chain)	Major operational constraints	Co-contaminant profile (typical)
		residence time than pitchers	chain control vs GAC alone	typical order of magnitude; performance sensitive to DOC	effect on nitrate/fluoride
Under-sink POU (RO)	RO + pre/post carbon	Size/charge exclusion across TFC membrane	Very high → high across many PFAS (including HFPO-DA), often near MDLs	Concentrate stream (20–45 % recovery), membrane scaling/fouling; periodic filter/membrane replacement	Broad inorganic and organic reduction (nitrate, fluoride, arsenic; with carbon polishing)
Worktop POU (RO)	RO	Same as above	Very high → high	Internal reservoir; periodic flushes; electrical needs	Similar to under-sink RO
Worktop POU (non-RO)	CB/IX	Adsorption/IX with controlled flow	High → medium (design-dependent)	Cartridge capacity; design-specific flow control	Organics and some metals; not salts
Pitcher/gravity	CB or CB + IX	Low-pressure adsorption; short contact times	Moderate → variable; best on long-chains; short-chains often lower and degrade with use	Tens–hundreds of litres order of magnitude; rapid performance decline possible	Taste/odour; some organics; minimal effect on inorganics

7.5 Key findings from comparative analysis

- Chain-length dependence is fundamental. Carbon sorption favours long-chain PFASs/PFCAs (PFOS, PFOA, PFNA) over short-chains (PFBS, PFBA); early carbon column work and subsequent equilibrium studies report consistent isotherm trends and faster short-chain breakthrough at realistic empty bed contact times (EBCTs). (Yu et al., 2009)
- IX generally outperforms GAC for short-chains. A 441-day parallel pilot demonstrated longer run times and higher short-chain PFCA removal with strong-base IX resins than GAC under groundwater conditions; resin chemistry and water matrix (e.g., sulphate) modulate selectivity. (Chow et al., 2022)
- RO is the most broadly effective single technology at POU scale. Multiple syntheses and field campaigns find > 90–99 % rejection across PFAS suites, including many short-chains, with permeate often near the method detection limits when membranes are intact and pretreatment is adequate. NF can approach RO performance with tight membranes but is more variable for short-chains. (Tow et al., 2021b)

- Pitcher performance is design-specific and can degrade quickly. Gravity cartridges show wider variance across brands/models and rapid capacity loss in some cases; studies that tracked removal across dozens of PFAS in real tap waters document divergent outcomes across products in the same water, emphasizing the centrality of media mass and flow control. (Teymoorian et al., 2024)
- Field vs. bench. Cross-sectional sampling of households (multiple U.S. states) found RO consistently reduced PFAS to near or below detection, whereas carbon-based POU performance ranged from moderate to high and depended on water chemistry and compound class. Longitudinal monitoring of carbon POU on private wells showed initial high removal followed by compound-specific breakthrough, reinforcing the need to link replacement intervals to exposure rather than elapsed time alone. (Herkert et al., 2020)
- Certification targets vs. MCLs. Devices certified to legacy PFOA/PFOS criteria must achieve ≤ 70 ng/L under a 1 500 ng/L challenge; “Total PFAS” devices must achieve ≤ 20 ng/L combined under a 2 160 ng/L mixture. These thresholds are not identical to 2024 EPA MCLs, which are lower for some compounds (e.g., PFOA/PFOS at 4 ng/L). Accordingly, even a certified device may produce effluent below the certification threshold but above an MCL in challenging matrices—or below MCLs in favourable matrices—depending on design and maintenance. (Washington State Department of Health, 2025)

7.6 Unresolved issues, by technology and format

- **Short-chains and ultrashort-chains.** While RO/NF can substantially reject C2–C6 acids and sulphonates under optimized conditions, the most mobile ultrashort-chains remain analytically and operationally challenging. Adsorption requires long EBCT and tailored sorbents; recent material science (e.g., specialized IX and advanced adsorbents) shows promise but limited household validation.
- **Matrix effects.** DOC and competing anions (sulfate, bicarbonate) reduce IX capacities and impede GAC sorption; hardness and colloids impact RO via scaling and fouling, increasing the need for pretreatment and maintenance.
- **By-products and integrity.** Thin-film composite membranes can contain fluorinated materials; a 2024 analysis cautioned about potential PFAS leaching from certain membrane constructions, though operational significance at POU scale remains under investigation. (Sadia et al., 2024)
- **Residue management.** All capture-based methods (GAC, AIX, RO/NF) transfer PFAS to a spent medium or concentrate requiring disposal. Household guidance typically directs spent cartridges to solid waste; POE operations may require managed disposal or regeneration with brine waste handling. (Concawe, 2020)
- **Certification scope vs. real-world mixtures.** The seven-analyte “Total PFAS” mixture does not encompass all field-relevant PFAS (e.g., precursors); nor do certification waters always reflect local DOC/ionic strength. As a result, certified performance is a necessary but not sufficient indicator of field removal for every mixture. (Washington State Department of Health, 2025)

7.7 Conclusions

- **Mechanism dictates selectivity.** GAC/CB provide robust adsorption for long-chain PFAS but are matrix-limited for short-chains; IX improves short-chain retention but remains capacity-limited. RO most consistently reduces broad PFAS suites (including many short-chains) to low ng/L levels, with a concentrate-stream trade-off.
- **Format governs contact time and reliability.** Under-sink plumbed systems (CB/IX or RO) achieve better residence times and control than pitchers, which show wide variability and faster exhaustion. Countertop RO offers RO-level rejection without plumbing but with reservoir/flush considerations. POE carbon/IX can protect all taps but requires careful sizing and verification monitoring for breakthrough. (Teymoorian et al., 2024)
- **Certification end-points and MCLs are not the same.** Devices meeting ≤ 20 ng/L combined (“Total PFAS”) or ≤ 70 ng/L (legacy PFOA/PFOS) under standardized challenges may or may not deliver ≤ 4 – 10 ng/L under site-specific conditions; nonetheless, certifications provide comparable, audited baselines for performance claims. (Washington State Department of Health, 2025).
- **There is no domestic technology that is certified to reduce PFAS to the levels the panel has recommended for Jersey.** This, of course, does not mean that the appliances are not capable of such a reduction.

8 PFAS and food

8.1 Introduction

In this chapter the likely baseline intake of PFAS from food is estimated. There are no data collected for total dietary intake in Jersey, so data collected in the UK and other European countries are used. The usual method for estimating total dietary intake, involves both measuring PFAS in representative samples of food items and collecting data from dietary surveys of data on food sales to estimate the intake from average diets, along with upper and lower estimates. The contributions from each food group (e.g. the average weight of eggs or fish that is eaten, along with the measured concentrations in these foods) can be assessed and the daily or weekly intake for each PFAS can be calculated.

Collecting detailed measurements from thousands of food sample is expensive and is only done intermittently, the last survey for PFAS across UK foods being in 2012 (Fernandes A, 2012). Unfortunately, there are no more recent data for the UK on total dietary PFAS intake so we have had to make estimates from European averages, drawing on these relatively old UK data and trends observed in other countries. The estimates are therefore necessarily uncertain but we believe of the right order of magnitude. Three further sources of uncertainty are 1) individual variability: the wide variability in both peoples dietary choices and the concentrations measured in different food samples, so we have to rely on averages; 2) time trends: much of the data is rather out of date and only a few countries regularly repeat these surveys to reveal changes over time; and 3) limits of detection: each laboratory has a minimum concentration which can be detected and whether the values below the limit of detection are assumed to be zero or close to the limit has an substantial effect on the summed or averaged PFAS concentration estimates.

8.2 EFSA estimates of average dietary intake from food

We start with the European average measurements of PFAS in food assembled by EFSA, then compare with more recent measurements. EFSA summarised data from many European analyses of food samples and based their assessment on samples collected between 2007 and 2016 (EFSA et al., 2020). After some quality control there were 69433 analytical results with most provided by Germany, France and the UK. Many results were below the limit of detection (LOD) or limit of quantification (LOQ) for specific PFAS and they explain different ways of dealing with these low values. All laboratories have an LOD (and it varies between lab results) and the results are expressed as lower bound (LB) assuming all the values below LOD are zero and upper bound (UB) assuming all the below LOD values are at the LOD. The true result will lie somewhere in between the sometimes wide range of values between LB and UB. So for example for PFOS in milk the LB is 0.001 ng/g and the UB is 0.14 ng/, and for herrings the LB and UB were 0.32 and 0.62 ng/g respectively.

The EFSA report summarises in detail the range and average levels of various PFAS in multiple foodstuffs. The daily intake were estimated by applying those concentrations to the average amounts of each food consumed, collected in dietary surveys (for the UK the national diet surveys of 2008-2011). It is expressed as ng of PFAS per day per kilogram of body weight. Applying these approaches they estimated average intake for adults of the 4 PFAS, and the European averages for adults were in the range 0.92 (LB) to 15.9 (UB) ng/kg/day. For the UK the equivalent two figures were 0.62 (LB) and 13.8 (UB) ng/kg/day.

Figure 2 - Estimate Lower Bound intakes for main food groups in EFSA report applied to UK adults

Food group	PFHxS ng/kg/day	PFNA ng/kg/day	PFOA ng/kg/day	PFOS ng/kg/day	sum4 ng/kg/day	%
Alcoholic beverages	0.020	0.000	0.036	0.000	0.056	9.1
Drinking water	0.017	0.001	0.013	0.006	0.037	5.9
Eggs and egg products	0.000	0.000	0.011	0.027	0.037	6.0
Fish and other seafood	0.001	0.006	0.039	0.260	0.306	49.5
Fruit and fruit products	0.028	0.014	0.011	0.033	0.085	13.8
Meat and meat products	0.000	0.001	0.016	0.044	0.061	9.9
Milk and dairy products	0.000	0.000	0.002	0.002	0.004	0.6
Other foods	0.000	0.000	0.003	0.001	0.004	0.7
Starchy roots and tubers	0.000	0.000	0.005	0.004	0.010	1.6
Vegetables and vegetable products	0.000	0.001	0.011	0.005	0.017	2.8
Total	0.067	0.023	0.145	0.382	0.617	100

Estimates of intake mainly used the LB results and for the LB estimates contributions were presented by food group with 49% from fish and seafood, 13% from fruit and fruit products, 10% from meat and 6% from drinking water. The average drinking water concentrations used to make these estimates were low, with LB values of PFHxS 1.8, PFOA 1.3, PFOS 0.6 and PFNA 0.08 ng/L. These values are lower than expected in the UK, so the total estimate is considered as mainly reflecting dietary intake.

8.3 PFAS concentrations in measured in foods contributing to dietary intake

The concentrations in foods that they use to make these estimates can be to an extent compared to the measurements made in the UK dietary contaminant survey of 2012. Categories do not easily correspond, and the dates of sampling do not exactly match (2012 in UK, 2007 to 2020 in EFSA with 40% of samples between 2016 and 2020). Furthermore the LB EFSA estimate is pulled down by a large number of below LOD estimates in the European dataset. **Error! Reference source not found.** summarises the Upper and Lower bound average European contaminant level for the sum of 4 PFAS, and Table 3 the TDS results for the UK in 2012 (EFSA et al., 2020; Fernandes A, 2012).

Figure 3 - Average European PFAS contaminant concentration by food group, Upper and Lower Bound average from EFSA for the sum of 4 PFAS

EFSA data Food group	Sum 4 LB µg/kg	Sum 4 UB µg/kg
Alcoholic beverages	0.016	0.028
Drinking water	0.004	0.012
Eggs and egg products	0.374	0.712
Fish and other seafood	1.799	3.785
Fruit and fruit products	0.069	0.842
Meat and meat products	0.068	0.545
Milk and dairy products	0.001	0.437
Starchy roots and tubers	0.008	2.507
Vegetables and vegetable products	0.010	0.520

Figure 4- Average UK PFAS contaminant concentration by food group 2012, for individual and sum of 4 PFAS

UK TDS Food group	PFOA µg/kg	PFNA µg/kg	PFHxSH µg/kg	PFOS µg/kg	Sum4 µg/kg
Bread	0.54	0.73	0.07	0.10	1.44
Cereals	0.37	0.37	0.12	0.09	0.95
Carcass Meat	0.17	0.18	0.13	0.22	0.70
Offal	0.62	0.44	1.30	2.66	5.02
Meat products	0.20	0.22	0.23	0.17	0.82
Poultry	0.21	0.23	0.25	0.16	0.85
Fish	1.51	0.60	2.41	0.96	5.48
Fats and Oils	<0.05	0.42	0.22	0.15	0.79
Eggs	0.11	0.21	0.10	0.31	0.73
Sugars and Preserves	0.48	1.21	0.16	0.08	1.93
Green Vegetables	0.22	0.25	0.17	0.10	0.74
Potatoes	0.12	0.12	0.07	0.05	0.36
Other Vegetables	0.18	0.17	0.10	0.04	0.49
Canned Vegetables	0.20	0.15	0.03	0.03	0.41
Fresh Fruit	0.20	1.10	0.18	0.07	1.55
Fruit products	0.17	0.17	0.08	0.02	0.44
Milk	0.03	0.01	0.02	0.05	0.11
Milk and Dairy	0.08	0.08	0.06	0.06	0.28
Nuts	0.54	0.72	0.09	0.10	1.45

For those categories where comparisons can be made, the UK measurements were higher in most cases than LB averages which are used to estimate the likely intake by EFSA. The largest contribution was estimated to come from fish intake, and the concentration for UK was 3 times the LB average for Europe, for eggs it was twice as high and for fruit products it was 6 fold higher. So to estimate likely intake around 2012, we can take the EFSA LB estimate and multiply by 2 and 6 to provide a range of plausible intake estimates. Applying these factors, instead of 0.62 ng/kg/day, the estimated intake around 2012 in the UK would have been potentially 1.2 to 3.6 ng/kg/day.

8.4 Trends over time

There have been significant declines in measured levels in food samples. In the UK 2012 TDS study it is noted that compared to the earlier Total Diet Study with samples collected in 2004, the range of concentrations of observed in the potato group in 0.03-0.85 µg/kg in 2012 compared to 1-10 µg/kg in 2004 (Fernandes A, 2012).

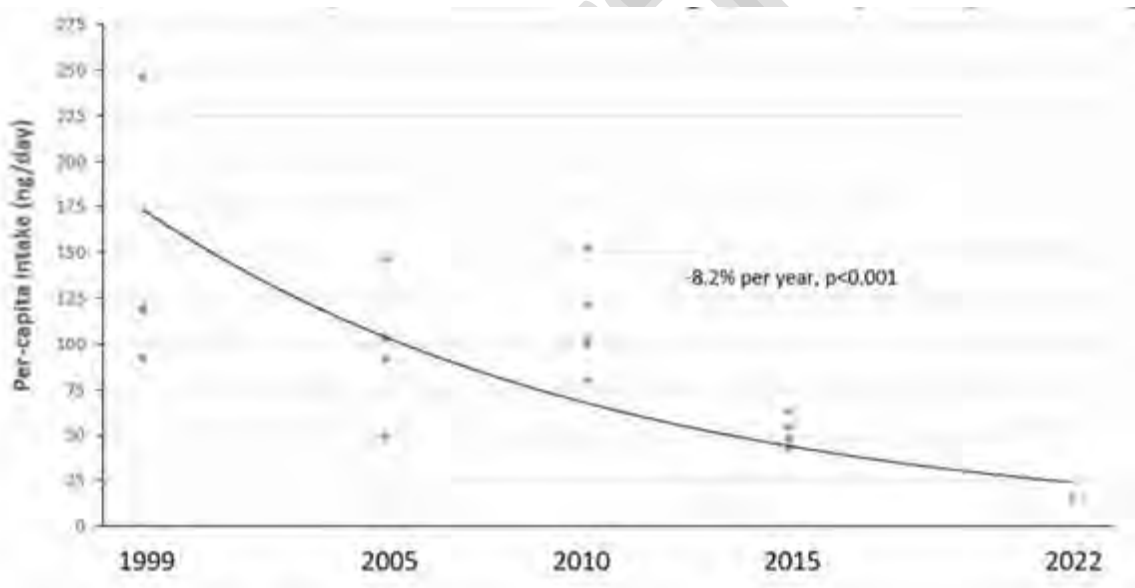
Within the UK a clue to trends can be seen in the fish data as a recent report has detailed measurements in a wide range of fish species (FERA, 2025). There is no aggregate estimate for fish overall but taking some of the results for species with the most measurements and then taking the average level of PFAS, we find the following: for the sum of 4 PFAS average concentrations were 0.46 µg/kg for Sardines, 0.65 for Crab and 0.63 for Cod. These compare to the overall fish average reported for in 2012 of 5.48 µg/kg suggesting a 10 fold reduction.

Another specific fish category of interest is lobster with four results averaging 0.75 µg/kg. There are no values for oysters but a recent paper assessing PFAS marine contamination near Portsmouth including analyses of 3 oyster samples (Ford & Ginley, 2024). All values were below the limit of detection (0.1 for most PFAS) except for one PFOA result of 0.19 µg/kg.

German data on eggs allow a comparison from 2018-22 to 2024 during which average PFAS levels fell from 0.29 to 0.06 µg/kg, a 5 fold reduction (BFR, 2025).

Swedish data on time trends over a 20 year period show declines, and comparing the difference between 2010 and 2022, the sum of PFAS fell from about 110 to 15 ng/person/day a 7 to 8 fold reduction, illustrated in the following figure (Livsmedelsverket, 2024). For the EFSA-4, the intake in 2022 was reported as 7.5 ng/day.

Figure 5- Per capita PFAS intake (ng/person per day)



8.5 Recent total diet intake estimates

Two European countries have presented recent estimated of total dietary intake from PFAS for the EFSA-4.

Germany in the MEAL study report an estimated total intake of 0.9 ng/kg/week from all food items together (<https://m.bfr-meal-studie.de/microsite/en/meal-homepage.html> reported in a presentation at BFR October 2025).

The Swedish food basket study report an average intake of 7.5 ng/day (Livsmedelsverket, 2024). The range of food categories that contributed to this decline has reduced. In the 2015 survey PFAS was measured in a wide range of food categories: Meat, Eggs, Cereals, Pastries, Sweets, Milk and Dairy Products, Fats, Oils. The repeat survey of 2022 only found PFOA, PFOS, PFHxS or PFNA in Lean and Fatty Fish, and Eggs, with all other food categories below detection limits.

In a recent report on the intake of PFAS in the Netherlands, the intake in the most recent assessment based on food samples analysed in 2022 was compared with an earlier assessment based on samples collected in 2009. They report that the total intake from food in 2022 for the sum of 16 PFAS

was 40% lower than the sum of 4 PFAS in the earlier assessment so not simply comparable. The EFSA 4 accounted for about a 1/3 of the total intake from 16 PFAS so an approximate estimate for the reduction between the two surveys would be a 5-fold drop.

Although there are no recent UK data, the average intake can be estimated from the general trends. From the results summarised and discussed above, we can estimate the intake from UK food around 2012 as being 1.2 to 3.6 ng/kg/day. The expectation is that the intake would have fallen by 5 to 10 fold from which would estimate the food intake now in the range 0.1 to 0.7 ng/kg/day from food. However these adjustment factors are uncertain.

The reported dietary intake of PFAS from Germany and Sweden suggest 0.1 ng/kg/day, or a little over, consistent with the UK estimate. We can therefore be reasonably confident that food intake would be expected to be 0.1 to 0.2 ng/kg/day for adults in the UK, or per week 0.7 to 1.4 ng/kg/week.

8.6 Average PFAS in water contribution to total intake

In the UK COT commentary on the EFSA document they cite estimates provided by the DWI (UKCOT, 2022) reflecting recent typical average levels of PFOA and PFOS in groundwater derived drinking water was generally up to 5 ng/L and surface water derived drinking water up to 10 ng/L. If the water concentration of 5 ng/L for each is taken as the typical average water concentration then the intake (assuming 1.5L and 75kg) would be 1.4 ng/kg/week.

Water intake at a level of 4 ng/L would therefore be equivalent to 0.5 ng/kg/week.

The estimates here of average dietary intake (0.7 to 1.4) and water (1.4 ng/kg/week) are together less than the EFSA guidance value of 4.4 ng/kg/week. They are similar magnitudes of contribution. In the past the dietary contribution was significantly higher and would have therefore been more important than the water contribution. These reasonable estimates for an average UK or European are however subject to uncertainty, and for Jersey in particular we need to compare measured concentrations in water and key local food items to establish if we expect different general average levels of PFAS intake.

9 Soil, biosolids and environmental water

9.1 Soil guidelines

PFAS soil screening levels vary not only by jurisdiction but also by treatment goal, whether the aim is to protect human health through direct contact, prevent leaching to groundwater, guide land use decisions, or trigger site remediation. These thresholds are shaped by different exposure assumptions, regulatory philosophies, and technical constraints, resulting in wide variation across and within countries.

International soil guidelines for PFAS vary widely, with only a handful of countries publishing formal threshold values. The most comprehensive global overview is provided by the Interstate Technology and Regulatory Council (ITRC) (<https://pfas-1.itrcweb.org/fact-sheets/>), which compiles screening levels from the United States, Canada, Australia, and selected European countries. In the U.S., the Environmental Protection Agency (EPA) has published soil screening levels for direct contact exposure, including 0.019 µg/kg for PFOS and 6.3 µg/kg for PFOA, based on ingestion, dermal contact, and dust inhalation under residential exposure scenarios. The EPA has also derived soil-to-groundwater migration values, such as 0.030 µg/kg and 0.061 µg/kg for PFOS and PFOA, respectively to protect drinking water sources from leaching. However, their practical enforceability should be questioned as many of these values fall below typical background soil concentrations of <1 µg/kg (Brusseau et al., 2020; Söregård et al., 2022; Washington et al., 2019) and analytical detection limits. At the state level, guidance varies significantly. Washington State has adopted one of the most stringent residential soil screening levels for PFOS at 0.046 µg/kg, and an even lower saturated zone soil-to-groundwater protection value of 0.003 µg/kg, reflecting a highly precautionary approach to groundwater protection. Again, the enforceability of such low guidelines is highly questionable. Other states vary widely depending on the PFAS and the protection goal.

Canada and Australia have proposed national guidelines, with PFOS thresholds as low as 9 µg/kg in Australia for residential land use and 10 µg/kg in Canada for protection of leaching to groundwater. In Europe, only four countries, Belgium, Denmark, the Netherlands, and Norway, currently have formal soil values for PFAS, highlighting a significant regulatory gap across the EU. Denmark and the Netherlands provide screening levels used in site assessments and permitting, with the Netherlands setting relatively high thresholds of 1100 µg/kg for PFOA and 110 µg/kg for PFOS. Norway, by contrast, has adopted more precautionary values, with residential screening levels of 13 µg/kg for PFOA and 2.3 µg/kg for PFOS, as reported in the ITRC table.

In Europe, Belgium, particularly the Flemish Region under OVAM (Openbare Vlaamse Afvalstoffenmaatschappij, or Public Waste Agency of Flanders), stands out with the most detailed and operational framework. (OVAM, 2025) It sets remediation values for PFOS and PFOA as low as 3.8 and 2.5 µg/kg dry weight, respectively, for nature land use. Belgium's approach has evolved in response to high-profile contamination cases, notably the Oosterweel project. The soil remediation values for PFOS and PFOA, with specific thresholds for natural land use are outlined in Figure 6, below. These values are primarily based on human health risk and derived from the EFSA tolerable weekly intake (TWI) published in 2020. As we have used the EFSA guidelines as the basis for our recommendations for drinking water guidelines on Jersey, the Flemish soil guidelines seem particularly relevant. These thresholds sit only slightly above typical background levels: for PFOS, the Flemish background value is 1.5 µg/kg dw, and for PFOA, 1.0 µg/kg dw (OVAM, 2025), which is consistent with the literature. (Brusseau et al., 2020; Söregård et al., 2022; Washington et al., 2019) All soils contain PFAS due to ambient atmospheric deposition. (Johansson et al., 2018)

Figure 6- The relevant soil threshold values for PFAS in Flanders, Belgium

Threshold	Remediation value for nature land use (µg/kg dry weight)	Target value (µg/kg dry weight)	Background value (µg/kg dry weight)
PFOS (total)	3.8	3	1.5
PFOA (total)	2.5	2	1
Sum measured PFAS*	-	8	-

*"Sum measured PFAS" refers to the total concentration of individually quantified PFAS compounds included in the Flemish analytical protocol, typically measured using targeted LC-MS/MS methods. This sum includes substances such as PFOS, PFOA, PFBS, PFHxS, and other regulated PFAS listed in OVAM guidance.

In addition to human health-based criteria, ecotoxicological thresholds have been developed. The lowest values were derived for nature and agricultural land uses. For PFOS and PFOA, the soil remediation values are 3 and 7 µg/kg dw, respectively. These Flemish thresholds are informed by earlier work from the National Institute for Public Health and the Environment in the Netherlands (RIVM),(RIVM, 2017, 2020) which emphasized that the values are based on indirect ecological effects, particularly secondary poisoning.

For direct ecotoxicity, RIVM proposed higher thresholds: 16 µg/kg dw for PFOS and 500 µg/kg dw for PFOA. Using the Assessment Factor (AF)-approach tailored to the Blokkersdijk site, alternative direct ecotoxicity thresholds were calculated; 10 µg/kg dw for PFOS and 46 µg/kg dw for PFOA (see Figure 7). The calculated values serve as a useful first-tier screening tool for risk assessment. In the context of environmental risk assessment, especially for PFAS-contaminated soil, Tier 1 risk assessment refers to the initial, conservative screening phase used to determine whether a site may pose a potential risk to human health or the environment. It is the first step in a tiered or phased approach to risk assessment and decision-making.

Figure 7- Overview of the AF-based PNEC values derived for direct toxicity in PFAS contaminated soil

Threshold (µg/kg dw)	AF-based PNEC _{soil} *
PFBS	1000
PFHxS	10
PFHpS	No data
PFOS	10
PFBA	No data
PFHxA	>20
PFHpA	10
PFOA	46
PFNA	10
PFBSA	No data
MePFBSA	No data
EtPFOSAA	No data
6:2 FTS	No data

* Based on soil ecotoxicity data

Although PFAS soil thresholds have been established in a few European countries, applying them in practice remains challenging. Belgium's framework is the most operational, with clear values and

integration into permitting and remediation workflows. In contrast, Denmark’s site-specific approach and Norway’s background-based trigger require expert judgment and local adaptation. Across all cases, effective implementation depends on reliable analytical methods, clear land use definitions, and the ability of regulatory authorities to interpret data and enforce decisions. Therefore, these thresholds are useful as first-tier screening tools but not sufficient on their own for comprehensive risk management. Also, it is important to establish the background soil levels on Jersey to determine the feasibility of introducing stringent soil guidelines.

Soil threshold values can be affected ongoing inputs from secondary sources such as sewage sludge (or biosolids). Biosolids applied to agricultural land can introduce PFAS at levels of concern, potentially elevating soil concentrations over time and undermining the effectiveness of existing thresholds. The following section explores how biosolids can contribute to PFAS accumulation in soil, with implications for crop uptake, groundwater contamination, and long-term regulatory control.

9.2 Environmental water guidelines

The European Union has set Environmental Quality Standards (EQS) for PFOS in surface waters that are based on human health protection through fish consumption (EU, 2008). Because PFOS bioaccumulates strongly in aquatic food webs, the critical exposure pathway is human dietary intake. The annual average EQS of 0.65 ng/L was calculated to ensure that PFOS concentrations in fish remain below levels that would pose risks to consumers. Monitoring data show that this EQS for PFOS is frequently exceeded across Europe (51–60% of rivers, 11–35% of lakes, and 47–100% of transitional and coastal waters) (European Environment Agency, 2024). Moreover, PFOS levels in rainwater are often close to or above this threshold, making compliance particularly challenging even in areas without significant local sources (Cousins et al., 2022).

The EU has further proposed a broader EQS for the sum of 24 PFAS compounds, expressed as 4.4 ng/L (PFOA equivalents) in both surface water and groundwater (European Commission, 2022). The scientific basis for the PFAS-24 EQS lies in evidence of cumulative exposure and mixture toxicity. The 24 substances were chosen because they are the most frequently detected and well-studied PFAS in European waters. The scientific foundation for this new EQS is the EFSA tolerable weekly intake (TWI) of 4.4 ng/kg body weight per week. Countries in Europe rely on the EU-wide EQS for PFOS and sum of 24 PFAS. Compliance to this EQS for the sum 24 PFAS is also very challenging given the prevalence of PFAS in populated regions.

9.3 Treatment technologies for PFAS in environmental waters and soils

Treatment technologies aimed at rendering water suitable for human consumption were addressed separately and earlier in this report, reflecting their prioritization by the Government of Jersey. In this section, the focus shifts to treatment technologies applicable to other water types; namely wastewater, surface water, and groundwater, which are collectively referred to as “environmental waters,” as well as to soils contaminated with PFAS. These technologies leverage the physical and chemical properties of contaminants to immobilize, separate, or destroy them. However, the distinctive characteristics of PFAS, particularly their extreme persistence and high mobility in both soils and water, render many conventional treatment methods ineffective. A range of specialized technologies is available, which may be deployed either *ex situ* (e.g., by extracting and treating contaminated groundwater) or *in situ* (e.g., by injecting sorptive materials directly into subsurface soils). Selecting an appropriate treatment approach requires a comprehensive understanding of site-

specific contamination, a review of proven technological options, and the use of monitoring tools to track progress and ensure regulatory compliance.

At a PFAS-contaminated site, a so-called conceptual site model (CSM) is essential for justifying the chosen treatment approach. A PFAS-focused CSM integrates multiple layers of site-specific information to understand and manage contamination. A CSM typically covers:

- Sources of PFAS: Identifies where PFAS originated (e.g., firefighting foam, industrial discharge).
- Contaminant types: Details which PFAS compounds are present, including precursors and breakdown products.
- Transport mechanisms: Explains how PFAS moves through soil, groundwater, and surface water.
- Exposure pathways: Maps how humans or ecosystems might come into contact with PFAS (e.g., drinking water, food chain).
- Geological and hydrological context: Describes subsurface conditions that affect PFAS mobility, such as aquifer properties, pH, and redox conditions.
- Receptor locations: Highlights sensitive areas such as residential zones, water wells, or ecological habitats.

Many treatment technologies have limited capacity and uncertain effectiveness. The selection of a treatment technology for PFAS is influenced by several factors:

- PFAS Properties: PFAS are defined by strong carbon-fluorine bonds, which contribute to their chemical stability and resistance to degradation. Their behavior is influenced by ionic states (anionic, cationic, or zwitterionic), functional groups (e.g., carboxylates and sulfonates), perfluoroalkyl chain length and branching, acidity, etc. These characteristics directly affect how PFAS interact with environmental media and respond to treatment technologies.
- Environmental Conditions: PFAS behavior in the environment is influenced by a range of factors, including natural processes and interactions with co-contaminants such as petroleum hydrocarbons, organic matter, and minerals. These interactions can increase PFAS mobility, alter partitioning behavior, and facilitate the transformation of precursor compounds into more stable and persistent perfluoroalkyl acids (PFAAs). Environmental conditions, particularly redox potential, pH, total organic carbon, and competing anions, play a critical role in determining PFAS distribution, degradation pathways, and the overall effectiveness of treatment technologies. Understanding these site-specific variables is essential for designing and implementing successful remediation strategies.
- Community Input: Stakeholder engagement is critical in remedy selection. Community members often weigh trade-offs between cost, level of cleanup, long-term effectiveness, and the acceptability of residual contamination. Transparent communication and inclusive decision-making help build trust and support for remediation strategies.
- Technology Suitability: The effectiveness of PFAS treatment technologies depends heavily on site-specific conditions and the nature of the waste stream. For example, sorption methods such as granular activated carbon (GAC) and ion exchange (IX) media are well-suited for treating large volumes of water with low PFAS concentrations (as well as low organic matter

content and co-contaminants). In contrast, destructive technologies are more appropriate for small volumes of high-concentration liquids.

Below we divide the treatment technologies broadly into those for 1) treating PFAS in environmental waters (primarily contaminated wastewaters, surface waters and groundwater) and 2) those for treating PFAS in soils. We have ordered the treatment technologies, starting with those treatment technologies with the highest technology readiness levels (TRLs) and then finishing the sections with the emerging treatment technologies which are some years from implementation. The TRL Scale (Levels 1–9) is described in Figure 8.

Figure 8- Summary of technology readiness levels (TRLs)

TRL	Description	Stage
1	Basic principles observed	Early research
2	Concept formulated	Hypothesis stage
3	Experimental proof of concept	Lab validation
4	Technology validated in lab	Bench-scale testing
5	Technology validated in relevant environment	Simulated field conditions
6	Prototype demonstrated in relevant environment	Pilot-scale testing
7	System prototype in operational environment	Field demonstration
8	System completed and qualified	Full-scale implementation
9	Proven in operational use	Commercial deployment

For example, granular activated carbon (GAC) for PFAS removal from water is typically TRL 9, while electrochemical oxidation, described by one of the subject matter experts, is TRL 5–7 depending on the specific application.

9.3.1 Treatment technologies for PFAS in environmental waters

9.3.1.1 Sorption technologies

Sorption technologies are used both ex situ and in situ to treat PFAS-contaminated environmental waters. Ex situ setups may employ multiple sorption media types in series to enhance removal efficiency. The two main types of sorption technologies used for drinking water treatment (GAC and IX) can also be used for treatment of PFAS in environmental waters. However, most full-scale GAC and IX systems focus on treating PFOA and PFOS in drinking water, with limited data on other PFAS or different water sources. (Tshangana et al., 2025) Treating groundwater from areas such as fire training zones often requires more complex pretreatment (e.g. surface active foam fractionation (SAFF)) and frequent media replacement due to higher contaminant levels, leading to increased operational costs. As is the case for drinking water treatment, designing an effective sorption treatment system for PFAS-contaminated environmental waters involves lab and pilot testing to determine parameters like bed depth, contact time, media consumption rate, and breakthrough projections. Tests should use site-specific water to account for local geochemistry. As previously discussed, membrane filtration technologies such as nanofiltration and reverse osmosis are highly

effective for removing PFAS from drinking water. However, they are less effective for environmental waters impacted by PFAS, such as surface or groundwater, which often contain organic matter and other contaminants that foul membranes and reduce performance.(Tshangana et al., 2025) Managing the concentrated waste stream also becomes more complex, making these systems less practical for large-scale environmental remediation.

Injectable colloidal activated carbon (CAC) is a passive in situ treatment designed to immobilize PFAS in contaminated groundwater and prevent its migration toward sensitive receptors such as drinking water wells or surface water bodies.(Carey et al., 2022) The fine carbon particles are injected directly into aquifer flux zones, where they bind PFAS quickly and effectively, outperforming traditional GAC in sorption kinetics. CAC has been successfully applied at multiple sites globally, showing long-term effectiveness, often reducing PFAS to non-detect levels for years.(Carey et al., 2022; McGregor, 2018) Its performance depends on site-specific factors such as PFAS type, contaminant flux, and aquifer conditions. Compared to pump-and-treat systems (i.e., groundwater pumped up and treated ex-situ), CAC offers a more sustainable solution with minimal energy use and a significantly lower carbon footprint, making it well-suited for treating PFAS in natural groundwater systems.(Carey et al., 2022; McGregor, 2018)

Several emerging sorption technologies show promise for treating PFAS-contaminated environmental waters, particularly groundwater. Polymer-coated sand, using cyclodextrin-based polymers, offers high selectivity and mechanical stability, with strong performance for PFOA and PFOS and excellent regenerability.(Badruddoza et al., 2017) Surface-modified clays and zeolites use ion exchange and hydrophobic interactions to remove PFAS, including short- and long-chain variants, and have demonstrated resistance to fouling in complex groundwater matrices.(Han et al., 2019) Biochar, derived from biomass, is a low-cost, carbon-rich material with good affinity for organic contaminants, though its performance and consistency vary across batches.(Inyang & Dickenson, 2017) Hydrogels and fluorogels are especially effective for short-chain PFAS due to their high selectivity and rapid sorption kinetics, and some formulations can be regenerated for reuse.(Kumarasamy et al., 2020) While most of these technologies are still in early stages or pilot testing, they offer promising alternatives to conventional media for in situ or ex situ treatment of PFAS in environmental waters.

9.3.1.2 Interface-driven separation technologies for PFAS in environmental waters

Beyond sorption, a growing class of PFAS treatment technologies focuses on separating and concentrating contaminants from environmental waters, such as groundwater, landfill leachate, and wastewater, before destruction. These interface-driven separation technologies rely on physical or chemical boundaries to isolate PFAS efficiently, especially in complex water matrices where conventional adsorptive methods like GAC, ion exchange, and membranes may struggle.

SAFF is one of the most promising approaches for PFAS-impacted environmental waters.(We et al., 2024) It uses air bubbles to lift PFAS to the surface and concentrate them in foam. Unlike GAC, IX, and membrane technologies, SAFF performs well in the presence of organic matter and co-contaminants and thus requires minimal pre-treatment. However, concerns remain about airborne PFAS emissions during operation and the need for safe foamate disposal or destruction. Despite these challenges, SAFF has demonstrated strong performance in field applications and is gaining traction as a scalable solution.

Precipitation, coagulation, and flocculation are conventional separation methods that use chemical or electrochemical coagulants to form solids that capture PFAS through co-precipitation. (Lin et al., 2015) These methods have shown success in bench-scale studies (particularly electrocoagulation (Lin et al., 2015)) but face challenges in full-scale deployment due to variability in performance and the need for careful quality control. They are best suited as pre-treatment steps to reduce PFAS mass before applying more advanced destruction technologies. The solid waste generated requires proper disposal, and specialty coagulants for PFAS applications are still under evaluation.

Water aggregation and separation (WAS) is an emerging technology developed at the Colorado School of Mines that isolates PFAS at the gas–water interface, similar in principle to SAFF (personal communication from Professor Chris Higgins at Colorado School of Mines, US). WAS is designed to concentrate PFAS from dilute water streams, reducing the volume of contaminated waste and making downstream destruction more efficient. Though still under development, WAS offers a low-energy, scalable pathway for PFAS separation and is being explored as part of integrated treatment trains. Its reliance on interfacial behaviour makes it particularly well-suited for environmental waters with complex chemistries. While WAS itself is not yet formally published, its principles align with recent findings from Schrama et al. (2024) (Schrama et al., 2024) on PFAS behaviour at interfaces and light-driven degradation.

9.3.1.3 Destruction technologies for PFAS in environmental waters

Although many PFAS destruction technologies were originally developed for treating concentrated waste streams and complex environmental waters, several are now being explored for application in drinking water treatment. This reflects growing regulatory pressure to achieve complete PFAS removal and minimize residual waste. However, compared to mature sorption technologies such as GAC and IX, which operate at TRL 8–9 and are widely deployed in drinking water systems, most destruction technologies remain at lower TRLs (typically TRL 3–7). Their use in potable water treatment is therefore limited to lab-scale pilot studies. The following section reviews these emerging destruction technologies, highlighting their mechanisms, performance, and potential roles in future integrated treatment trains.

Redox manipulation involves chemical oxidation or reduction to break PFAS molecular bonds with some promising bench-scale and limited field results. (Nzeribe et al., 2019). However, complete defluorination is rarely achieved and transformation products may persist. Ozone-based systems use ozone combined with other oxidants like hydrogen peroxide or persulfate to generate reactive radicals that can degrade PFAS. (Thomas et al., 2020) Bench and limited field-scale studies show promising PFAS reductions, but the exact degradation mechanisms remain unclear. Sorption may also contribute to observed reductions. While effective as a polishing step, more research is needed to confirm full PFAS destruction and by-product formation. Catalyzed hydrogen peroxide (CHP)-based systems rely on hydrogen peroxide and metal catalysts to produce hydroxyl radicals that partially transform PFAS precursors into stable PFCAs. (Bruton & Sedlak, 2017) Some systems also generate superoxide and hydroperoxide, which have shown potential to mineralize PFOA in bench tests. However, field-scale effectiveness is limited, and transformation often stops at intermediate compounds, making CHP more suitable for partial degradation or precursor treatment. Activated persulfate uses chemical activation (via heat, pH, or metals) to generate sulfate and hydroxyl radicals that degrade PFAS. (Bruton & Sedlak, 2017) Under acidic conditions, sulfate radicals can fully mineralize PFCAs like PFOA through decarboxylation and HF elimination, but PFOS and other PFASs

remain largely unreactive. At high pH, hydroxyl radicals transform PFAS precursors into stable PFCAs. While effective for certain PFAS, especially under acidic conditions, its broader applicability is limited by incomplete degradation and variable reactivity.

Sonochemical oxidation uses high-frequency ultrasound to create cavitation bubbles that generate extreme heat, pressure, and free radicals, leading to rapid PFAS breakdown.(Gole et al., 2018) Bench and field-scale studies show >90% defluorination of PFOA and PFOS, with mineralization to fluoride, sulfate, and carbon dioxide. It's considered one of the most effective PFAS destruction methods, especially for groundwater, and can be enhanced by combining with persulfate for synergistic effects.(Lei et al., 2020)

Photolysis/photochemical oxidation uses UV or vacuum UV light, often combined with catalysts like TiO₂ or persulfate, to generate reactive radicals that break PFAS bonds.(S. Wang et al., 2017) While direct photolysis is limited due to PFAS' low light absorption, photochemical oxidation can degrade PFAS through radical-driven reactions. It's most effective under controlled conditions and can mineralize PFAS into shorter chains, fluoride, and carbon dioxide. Emerging methods like porous media photocatalysts and boron nitride may enhance performance, but field-scale validation is still limited.

Electrochemical treatment uses anodic oxidation to degrade PFAS directly at the electrode or indirectly via radicals formed in solution.(Sanne J. Smith et al., 2023) Boron-doped diamond electrodes are most commonly used due to their durability and effectiveness.(Sanne J. Smith et al., 2023) Bench and pilot studies show strong PFAS removal, including short- and long-chain compounds and precursors, with fluoride release as a byproduct.(Sanne J. Smith et al., 2023) It's suitable for treating concentrated PFAS waste and is being explored for in situ use. Managing byproducts like perchlorate and optimizing operating conditions are key to successful application.

Solvated electron-based advanced reduction processes use activation techniques such as ultraviolet light, ultrasound, or chemical reductants to generate hydrated electrons, highly reactive species capable of cleaving the strong carbon-fluorine bonds.(Cui et al., 2020) They are effective for PFOS and PFOA under controlled laboratory conditions. However, the presence of oxygen and other radical scavengers can significantly reduce treatment efficiency. Despite these challenges, recent studies have reported high defluorination rates in short time periods, highlighting the potential of this technology for high-performance PFAS degradation.

Plasma technology employs electrical discharges to create reactive species that rapidly degrade PFAS in water.(Stratton et al., 2017) Nonthermal plasma is preferred for water treatment due to lower energy demands. It can achieve up to 90% PFAS degradation in short timeframes and is unaffected by co-contaminants. Plasma technology is also considered environmentally friendly and suitable for a diversity of environmental waters.

Zero-valent iron (ZVI)/doped-ZVI is an in situ reductive technology that removes PFAS through surface-mediated reactions.(Arvaniti et al., 2015) Nanoscale ZVI offers enhanced reactivity and injectability. It has been proven effective for PFOS degradation, with fluoride release confirming breakdown. Surface coatings such as Mg-aminoclay can improve performance.

Alkaline metal reduction uses alkali metals and catalysts such as vitamin B12 to chemically reduce PFAS, particularly branched PFOS isomers.(Zenobio et al., 2020) Bimetallic nNiFeO particles

supported on activated carbon have demonstrated transformation of both linear- and branched-PFOS isomers, achieving 94% PFOS transformation at 50°C. (Zenobio et al., 2020) Transformation byproducts detected in the particle extracts indicate defluorination and desulfonation pathways.

High-energy electron beam (eBeam) applies ionizing radiation to generate reactive species that degrade PFAS in water and soil without added chemicals. (Wang et al., 2016) Bench studies show up to 95% defluorination of PFOA and PFOS, with effectiveness influenced by water chemistry and dose. (Wang et al., 2016) It's a promising ex situ technology for concentrated PFAS waste streams.

Supercritical water oxidation (SCWO) uses high temperature and pressure to destroy PFAS and co-contaminants in complex aqueous waste. (McDonough et al., 2022; Scheitlin et al., 2023) Effective for both carboxylic and sulfonic PFAS at $\geq 450^{\circ}\text{C}$ and $\geq 575^{\circ}\text{C}$, respectively. (Scheitlin et al., 2023) SCWO is well-suited for industrial-scale applications and has shown consistent performance across varied waste matrices.

Microbial and fungal degradation of PFAS is possible for some polyfluorinated compounds and precursors, but PFOA and PFOS remain highly resistant. (Idris & Erasmus, 2024; Liu & Avendano, 2013) Recent studies show partial defluorination using specific bacteria and enzymes, though transformation often leads to persistent byproducts. Research is ongoing to identify effective strains and conditions for broader PFAS biodegradation.

Alkaline hydrothermal reaction, also known as HALT (Hydrothermal Alkaline Treatment), is a high-temperature, high-pressure, and high-pH process designed to chemically destroy PFAS, particularly stubborn compounds like PFOS. (Wu et al., 2019) The method breaks PFAS down into harmless end products such as fluoride and carbonate salts. It has shown impressive results, achieving over 90% degradation in various water types, and even exceeding 99% in continuous flow systems. Although it typically requires longer treatment times, (Pinkard et al., 2023) HALT is emerging as a powerful option for concentrated PFAS waste and is being explored for broader use in environmental water remediation.

Figure 9 - Summary of PFAS treatment technologies for environmental waters

Technology Category	Example Methods	TRL Range	Primary Function
Sorption	Granular Activated Carbon (GAC), Ion Exchange (IX), Colloidal Activated Carbon (CAC)	8–9	Separation/Immobilization
Emerging Sorbents	Polymer-Coated Sand, Surface-Modified Clays, Biochar, Fluorogels	4–6	Separation/Immobilization
Membrane Filtration	Nanofiltration, Reverse Osmosis	8–9	Separation
Interface-Driven Separation	Foam Fractionation, Water Aggregation and Separation (WAS), Electrocoagulation	6–8	Separation/Concentration
Chemical Oxidation	Ozone-Based Systems, Catalyzed Hydrogen Peroxide (CHP), Activated Persulfate	5–7	Partial Destruction

Advanced Oxidation	Sonolysis, Photochemical Oxidation	6–7	Destruction
Electrochemical Treatment	Boron-Doped Diamond Electrodes	5–7	Destruction
Advanced Reduction	Solvated Electrons, Alkaline Hydrothermal Treatment (HALT)	3–5	Destruction
Plasma Technology	Nonthermal Plasma Systems	5–7	Destruction
Radiation-Based Treatment	High-Energy Electron Beam (eBeam)	5–7	Destruction
Supercritical Oxidation	Supercritical Water Oxidation (SCWO)	6–8	Destruction
Biodegradation	Microbial/Fungal Processes	1–3	Partial Transformation

9.3.2 Treatment technologies for PFAS in soils

PFAS-contaminated soils present unique challenges due to their complex composition and the persistent nature of these compounds. PFAS-contaminated soils can be treated using a limited number of technologies, primarily applied ex situ. These include excavation and disposal, soil washing, sorption/stabilization, phytoremediation, thermal treatment and electrokinetic remediation.

9.3.2.1 Excavation and disposal

Excavation and disposal is a proven method for managing a wide range of contaminated soils including PFAS-contaminated soils, involving the removal of impacted material and its transport to a permitted landfill, followed by backfilling with clean soil. While this approach effectively eliminates the source of contamination, it does not destroy PFAS and may contribute to PFAS in landfill leachate. Stabilizing agents can be added prior to disposal to reduce leachability, and in some cases, soils may be treated on site using sorption or thermal methods before reuse or disposal.

This method is widely implemented but faces challenges due to evolving regulations and limited landfill acceptance of PFAS waste. Disposal in unlined or improperly lined landfills should be avoided to prevent environmental release. Sustainability concerns include emissions from excavation and transport, resource use for backfill, and community impacts such as traffic and noise. (Söderqvist et al., 2015) Despite its high cost, excavation and disposal can be a permanent and viable solution for smaller volumes of contaminated soil.

9.3.2.2 Soil washing

Soil washing is a field-implemented, ex situ treatment technology that removes PFAS from soil through physical separation and chemical extraction. It targets the finer soil fractions, such as clays and silts, where PFAS tend to accumulate due to higher organic carbon content and stronger hydrophobic interactions. (Quinnan et al., 2022) The process uses water or surfactant-based wash solutions to separate fine and coarse particles, transferring PFAS from the solid phase into the liquid phase for follow-up treatment or disposal.

Mechanical separation tools like vibratory screens, trommels, and hydrocyclones help isolate the PFAS-rich fine fraction, which is then managed separately. Coarser fractions, such as sands and gravels, often meet cleanup goals and can be reused or returned to the site. Field demonstrations

have shown PFOS removal efficiencies of 94–99% in coarse fractions and up to 89% in finer soils, with total soil volume reductions exceeding 90%.(Quinnan et al., 2022)

Design considerations include soil grain size distribution, moisture content, and PFAS concentration variability. Soils with high clay content or inconsistent feed conditions may require preprocessing. Optimal particle sizes range from 0.25–2 mm, while soils with more than 50% fines may be less viable for treatment. Wash solution treatment, retention time, and throughput must be carefully managed to ensure efficiency.

Although energy-intensive, soil washing can reduce the need for off-site disposal and allow reuse of treated soils if regulatory criteria are met. The wash solution can be recycled, but the fine fraction that fails cleanup standards must be disposed of properly. Soil washing offers a scalable and effective option for reducing PFAS mass in contaminated soils, especially when particle size separation is feasible.

9.3.2.3 Sorption and stabilization/solidification

Sorption and stabilization/solidification are field-implemented techniques used to immobilize PFAS in contaminated soils and reduce leaching to groundwater and surface water.(Söregård et al., 2020) These methods involve mixing PFAS-binding amendments, such as powdered activated carbon, carbon-mineral blends, surface-modified clays, or cementitious binders, into the soil either in situ or ex situ.(Söregård et al., 2020) In situ mixing is performed with standard construction equipment, while ex situ treatment may use pug mills or similar systems. When applied correctly, these amendments form a low-permeability matrix that restricts PFAS mobility and minimizes environmental transport.(Söregård et al., 2020)

While effective at immobilization, these technologies do not destroy PFAS and may limit future treatment options, particularly in situ. Stabilized soils may be difficult to re-treat and could require excavation for further remediation. Additionally, erosion in flood-prone areas poses a risk of off-site transport. Environmental factors such as soil pH, organic content, ionic strength, and co-contaminants influence sorption performance. High organic content can reduce effectiveness, while low pH and the presence of polyvalent cations may improve PFAS binding. Long-term stability has been demonstrated through simulated aging tests, and reductions in PFAS uptake by plants and earthworms have also been observed.

To ensure success, site-specific treatability testing is essential to determine the appropriate amendment type, dose, and delivery method and post-treatment testing is also needed. These technologies offer a practical, scalable solution for managing PFAS in soil source zones, especially when long-term containment is the primary objective.

9.3.2.4 Phytoremediation

Phytoremediation has emerged as a promising, low-cost strategy for managing PFAS-contaminated soils, particularly in settings where conventional remediation methods are impractical or prohibitively expensive.(Mayakaduwege et al., 2022; Naveed et al., 2024) Its appeal lies not only in its energy efficiency and environmental friendliness but also in its potential for community engagement and aesthetic integration into landscapes. While phytoremediation has demonstrated moderate success with other contaminant classes, its application to PFAS is still in early stages, with growing interest from researchers, regulators alike.

The primary mechanism of interest for PFAS is phytoextraction, wherein plants take up PFAS via the roots and transfer them to the above-ground plant parts (shoots and leaves), which can then be harvested and removed from the site. Other phytoremediation pathways (i.e., phytostabilization, rhizodegradation, and phytovolatilization) are less relevant for PFAS due to their chemical stability and resistance to degradation). A wide range of plant species have shown the ability to accumulate PFAS, though uptake varies significantly depending on both the plant and the specific PFAS. (Mayakaduwege et al., 2022; Naveed et al., 2024)

Bioaccumulation factors (BAFs) are a key determinant of phytoremediation effectiveness and vary between the specific plant species and PFAS. Shorter-chain PFAS with 3-4 perfluoroalkyl carbons have BAFs around 10, indicating relatively high uptake potential, whereas longer-chain PFAS (e.g., PFOA and PFOS, with 7-8 perfluoroalkyl carbons) typically show BAFs closer to 1, reflecting limited translocation into plant tissues. (Lesmeister et al., 2021) These differences underscore the importance of selecting appropriate plant species and targeting specific PFAS profiles. Moreover, soil characteristics, including pH, organic matter content, and moisture, play a critical role in PFAS mobility and plant uptake. (Mayakaduwege et al., 2022; Naveed et al., 2024)

A recent field-scale trial at the former Loring Air Force Base in Maine demonstrated the potential of fiber hemp (*Cannabis sativa*) for PFAS phytoextraction. (Nason et al., 2024) The study found that hemp absorbed 10 PFAS compounds, with higher accumulation in leaves than stems and greater uptake of short-chain PFCAs than PFSAs. The ChinMa hemp variety showed the most robust growth and removal efficiency, extracting approximately 1.4 mg of PFAS from soil and achieving up to 2% removal in the most successful plot. This removal achieved in one growing season was only in the localized root zone and not the entire contaminated area and most PFAS removed were the shorter-chain PFAS. Post-harvest hydrothermal liquefaction (HTL) of hemp biomass degraded nearly all carboxylic acids and reduced extractable organic fluorine, offering a viable pathway for PFAS destruction. (Nason et al., 2024)

Despite its advantages, phytoremediation of PFAS is constrained by slow remediation rates of longer-chain PFAS. At typical biomass harvest rates of 5 metric tons dry weight per hectare per year, estimated timeframes for meaningful PFAS removal range from 50 to 500 years. (Cornelissen et al., 2025) However, the identification and deployment of hyperaccumulator crops with elevated BAFs could reduce remediation times, for shorter-chain PFAS at least.

9.3.2.5 Thermal treatment

The only destruction technologies available for PFAS in soils, sediments and solid wastes are various thermal treatments which encompass a range of high-temperature processes. (Longendyke et al., 2022) These include incineration, pyrolysis, and gasification, each varying in temperature, mechanism, and maturity. Ex situ thermal destruction (e.g., incineration) has been tested at temperatures up to 1100°C and shown to be effective, achieving PFOS removal rates above 99%. (Longendyke et al., 2022) While in situ thermal treatment has not yet been field-demonstrated, bench-scale results suggest it may be feasible. (Kang et al., 2023)

Incineration, a subset of thermal treatment, uses combustion with heat and oxygen to mineralize PFAS in solids and liquids. It is a mature technology applied to various hazardous wastes, though its effectiveness for PFAS is still under investigation. Recent studies have documented destruction efficiencies exceeding 99% for certain PFAS, (Longendyke et al., 2022) but the specific conditions

required for complete breakdown remain unclear (e.g. is the 850°C for 2 seconds typically used in municipal solid waste incineration sufficient?).

All thermal processes face similar challenges: achieving uniform heating, managing air emissions, and controlling hazardous by-products such as hydrogen fluoride. Off-gas treatment systems such as scrubbers are essential for safe operation. Pyrolysis and gasification, typically used for energy recovery, are now being evaluated for PFAS destruction but remain in early development.

Thermal treatment is energy-intensive and costly, with sustainability concerns tied to fuel use, transportation, and air emissions. Nonetheless, it offers one of the few pathways for permanent PFAS destruction and may be viable for smaller volumes of highly contaminated soil, sediments and biosolids, especially when other technologies fall short. Ongoing research is focused on optimizing process parameters and understanding environmental risks to support broader implementation.

9.3.2.6 *Electrokinetic remediation*

Electrokinetic remediation (EKR) is an emerging in-situ technology that applies a low-voltage electric field across contaminated soils to mobilize ionic PFAS compounds toward electrodes for capture or degradation. (Niarchos et al., 2022) It is particularly promising for shorter-chain PFAS, but removal of longer-chain PFAS is a more challenging. Combining EKR with other techniques (e.g., stabilisation) could potentially increase removal efficiency of longer-chain PFAS. While still at a low TRL for PFAS, bench-scale studies have demonstrated measurable removal and defluorination under optimized conditions. Challenges remain in scaling the technology and managing energy inputs, but EKR offers a potentially viable pathway for in-situ treatment of PFAS in source zone soils.

Figure 10- Summary of PFAS treatment technologies for soils

Technology Category	Example Methods	TRL Range	Primary Function
Excavation and Disposal	Identification of hotspots followed by physical excavation, disposal in landfills and in some cases thermal treatment ex-situ	9	Physical removal of contaminated soil followed by disposal/destruction
Soil Washing	Physical excavation followed by soil washing with mechanical separation and chemical extraction	7-8	Remove PFAS-rich fine particles and reduce disposal volume
Sorption and Stabilisation	Sorption/stabilisation in situ with activated carbon, modified clays, cementitious binders	8-9	Reduce PFAS leachability and mobility
Phytoremediation	Planting hyperaccumulating crops in contaminated soils, harvesting crops followed by thermal treatment	4-5	Harvesting removes PFAS taken up into stems/leaves from root zone in soils
Thermal Treatment	Incineration, pyrolysis, gasification (usually ex-situ but some in-situ methods have been tested at lab-scale)	6-8	Permanently destroy PFAS through high-temperature processes

Electrokinetic remediation	Low-voltage electric field applied to mobilize PFAS through soil toward electrodes.	3–4	Destruction not effective for longer-chain PFAS
----------------------------	---	-----	---

9.3.3 Conclusions

The PFAS treatment technologies reviewed here span a wide range of TRLs, reflecting their maturity, field validation, and suitability for different environmental media (Figure 9, Figure 10). In both environmental waters and contaminated soils, treatment selection depends on site-specific factors such as PFAS type, concentration, co-contaminants, and regulatory goals. This review may not have been exhaustive as developing new treatment technologies for PFAS is a vibrant area of research that attracts a lot of funding.

In environmental waters, including groundwater, surface water, and landfill leachate, several high-TRL technologies are widely deployed. GAC and IX are mature (TRL 8–9), field-proven methods. While effective, their performance can be impacted by complex water chemistries and the presence of co-contaminants. Foam fractionation and colloidal activated carbon (CAC) also operate at high TRLs and are particularly well-suited for environmental waters, offering efficient PFAS removal with minimal pre-treatment and strong field validation.

Emerging adsorbents, such as surface-modified clays, polymer-coated sand, and biochar, are in the pilot or lab-scale phase (TRL 4–6). These materials show promise but require further demonstration to support full-scale deployment. Destructive technologies, including electrochemical oxidation, sonolysis, plasma, supercritical water oxidation (SCWO), and high-energy electron beam (eBeam), have demonstrated high PFAS degradation in controlled settings and are advancing toward pilot-scale use (TRL 5–7). Advanced reduction processes such as solvated electrons and alkaline hydrothermal treatment remain in early development (TRL 3–5), offering potential for both in situ and ex situ applications. Biodegradation is the least mature (TRL 1–3), with limited and inconsistent results to date.

In PFAS-contaminated soils, treatment options are more limited and primarily applied ex situ, with varying levels of maturity. Excavation and disposal is a fully field-implemented solution (TRL 9), widely used to remove source zones. While effective at eliminating contamination from the site, it does not destroy PFAS and may contribute to landfill leachate. Stabilizing agents can be added prior to disposal to reduce leachability, and in some cases, soils may be treated on site using sorption or thermal methods before reuse or disposal.

Sorption and stabilization/solidification is also field-implemented (TRL 8–9), using amendments such as activated carbon or modified clays to immobilize PFAS and reduce leaching. While effective for containment, these methods do not destroy PFAS and may limit future treatment options, particularly in situ. Soil washing is a field-demonstrated technology (TRL 7–8) that separates PFAS-rich fine particles from reusable coarse fractions, reducing disposal volumes and enabling more targeted treatment. Removal efficiencies for PFOS and other PFAS compounds have exceeded 90% in coarse fractions, with total volume reductions over 90%.

Phytoremediation of PFAS-contaminated soils is currently at TRL 4–5: it has been validated at the lab-scale and in small-scale field experiments, but not yet widely deployed or optimized for full-scale

remediation. Phytoremediation has been shown to be a promising technology for shorter-chain PFAS, but even hyperaccumulating crops would take decades to remove longer-chain PFAS from soils.

Thermal treatment, including desorption, incineration, pyrolysis, and gasification, ranges from pilot-scale to field-demonstrated (TRL 6–8), depending on the method. While thermal treatments are already used to treat PFAS wastes (e.g., incineration) they have a TRL of 8 because of uncertainties regarding their effectiveness for totally destroying PFAS. These high-temperature processes offer one of the few potential pathways for permanent PFAS destruction, with removal rates >99%. However, they are energy-intensive and require careful management of emissions and by-products such as hydrogen fluoride. Other destruction technologies although promising have TRLs typically of 7 or less and cannot therefore be currently implemented on Jersey. SCWO has a TRL of 8 but is also energy intensive. Other in situ soil treatments such as electrokinetic remediation remain at a low TRL of 3-4.

Across both water and soil applications, site-specific evaluation and sustainability considerations are critical to ensure effective and responsible remediation. While several technologies are ready for deployment, many others are still evolving. Continued research, pilot testing, and regulatory alignment will be essential to advancing PFAS treatment and achieving long-term environmental protection. As PFAS regulations evolve, especially for short-chain compounds and precursors, treatment selection must remain adaptive. Technologies with scalable deployment and proven field performance will be critical for meeting emerging standards and stakeholder expectations.

9.4 Biosolids management options

Sewage sludge or biosolids are a waste product from municipal wastewater treatment plants (WWTPs) and are known to be contaminated with PFAS.(Lenka et al., 2021) WWTPs are not primary sources of PFAS, but instead receive PFAS from diverse domestic, commercial, and industrial sources. PFAS enter WWTPs via influent wastewater and during treatment are redistributed across multiple environmental media; including treated effluent, air emissions, the untreated sewage sludge, and the biosolids. The composition and concentration of PFAS in these outputs reflect influent characteristics, treatment processes, and the presence of precursors that may transform during treatment.(Lenka et al., 2021)

PFAS in the WWTP influent originate from both point and diffuse sources. While industrial discharges historically dominated PFAS loading, recent studies suggest that domestic sources now contribute substantially, often primarily, to PFAS concentrations in municipal systems(Thompson et al., 2022). These domestic sources include; laundry effluent from treated textiles, food packaging waste, personal care products and household cleaners, human excretion of PFAS and drinking water contaminated with PFAS.

WWTPs also receive PFAS via landfill leachate, industrial pretreatment discharges, and stormwater inflows. The influent PFAS profile includes both terminal perfluoroalkyl acids (PFAAs) and a wide range of precursors such as fluorotelomer sulfonates, polyfluoroalkyl phosphate esters (PAPs and diPAPs), and sulfonamides. Precursors may be more prevalent than the perfluoroalkyl acids in contemporary wastewater.(Thompson et al., 2023) These precursors can undergo biotic and abiotic transformation during treatment, contributing to the formation of persistent PFAAs in effluent and biosolids.(Lenka et al., 2021)

Conventional WWTP processes, including primary sedimentation, activated sludge, and secondary clarification, are not designed to remove PFAS. PFAAs such as PFOA, PFOS, and PFBS are frequently detected in treated effluent, often at concentrations ranging from tens to hundreds of ng/L. (Lenka et al., 2021) Treatment may increase PFAA concentrations via precursor oxidation. (Müller et al., 2023) Advanced technologies such as granular activated carbon (GAC), reverse osmosis (RO), and ion exchange resins show promise but are costly, energy-intensive, and variably effective, particularly for short-chain PFAS. (Alsadik et al., 2025)

Partitioning behaviour during treatment results in significant PFAS accumulation in solids. Sludge, scum, and septage contain elevated concentrations of both PFAAs and precursors. These solids are typically stabilized through anaerobic digestion, then dewatered to produce sewage sludge (biosolids), which are managed via land application, landfilling, or thermal treatment (e.g., waste-to-energy plants, cement kilns, or pyrolysis). Anaerobic digestion does not effectively degrade PFAS; instead, it may concentrate PFAS in solids and facilitate precursor transformation. (Lakshminarasimman et al., 2021) Each management option presents potential for PFAS release. Land application can result in PFAS leaching to groundwater, runoff to surface water, and uptake by plants and soil organisms. Landfilling and composting may lead to PFAS release via leachate, which is often treated at WWTPs, creating a feedback loop. Thermal treatments are being studied due to concerns about incomplete combustion and byproduct formation.

PFAS in biosolids include both terminal perfluoroalkyl acids (e.g., PFOS, PFOA) and precursors such as diPAPs, fluorotelomer sulfonates, and sulfonamides. (Zhou et al., 2024) These compounds originate from domestic and industrial sources and can persist through treatment. Studies have reported PFOS concentrations in biosolids ranging from 0.02–601 µg/kg and PFOA from <0.01–2440 µg/kg. (Zhou et al., 2024) Transformation of precursors to PFAAs has been observed in land-applied biosolids, (Washington et al., 2010) although some precursors remain in soils for decades. (Washington et al., 2019)

Given the persistence of PFAS in biosolids and their potential for environmental release, the method of sludge management plays a critical role in determining exposure pathways and long-term risks. The following sections examine key disposal and treatment options, beginning with land application.

9.4.1 Land Application of biosolids

Land application of biosolids is, potentially a major PFAS release pathway, particularly industrially-derived biosolids. PFAS can leach to groundwater or run off to surface water, with fate influenced by soil properties, infiltration rates, climate, and application practices. Elevated PFAS concentrations have been observed in water bodies near fields receiving biosolids from industrially impacted WWTPs. (Washington et al., 2010) Municipal biosolids may pose lower relative risks, but still contribute to environmental loading. (Gottschall et al., 2017) PFAS mobility is enhanced in areas with high infiltration or shallow groundwater, and short-chain PFAS are particularly mobile in soils and groundwater.

PFAS in biosolids-amended soils can be taken up by plants and soil organisms, potentially entering the food chain. Uptake is compound- and crop-specific, with short-chain PFAS exhibiting higher bioaccumulation factors (BAFs) than long-chain analogues. Blaine et al. (Blaine et al., 2013; Blaine, Rich, Sedlacko, Hundal, et al., 2014; Blaine, Rich, Sedlacko, Hyland, et al., 2014) reported BAFs ranging from 0.1 to 10 in edible crops. Livestock fed silage from biosolids-treated fields have shown

elevated tissue PFAS levels.(Lindstrom et al., 2011) However, some studies found no detectable PFAS in grain grown on biosolids-treated plots.(Gottschall et al., 2017) Importantly, the PFAS concentration in the biosolids is a key factor in controlling the potential for contamination of groundwater and the agricultural food chain.

Applying biosolids to agricultural soil can increase PFOS concentrations above natural background levels and, over time, may challenge existing soil thresholds. To estimate this effect, consider a typical land application rate of 5 metric tons of biosolids per hectare. If the biosolids contain 25% solids (a common value for dewatered sludge) and PFOS at 50 µg/kg dry weight, this equates to 1,250 kg of dry matter and a total PFOS input of 0.0625 grams. Assuming uniform mixing into the top 15 cm of soil with a bulk density of 1.4 g/cm³ (yielding approximately 2.1 million kg of soil per hectare), the resulting increase in soil PFOS concentration would be around 0.03 µg/kg dry weight. While this is well below the Flemish background value for PFOS (1.5 µg/kg dw), repeated applications or higher PFOS concentrations in biosolids could lead to cumulative buildup, potentially exceeding screening thresholds over time.

9.4.2 Landfilling of biosolids

Landfilling of biosolids can contribute to PFAS release via leachate, which is often routed to wastewater treatment plants (WWTPs) or discharged to surface water. PFAS concentrations in landfill leachate typically range from nanograms to hundreds of micrograms per litre,(Sabba et al., 2025) and conventional leachate treatment is largely ineffective at removing these compounds. Liner failures or aging infrastructure can further exacerbate environmental releases. Landfilling of biosolids is not considered a viable option on Jersey given the shortage of landfills on the island.

9.4.3 Thermal treatment of biosolids

Incineration is currently used for a minority of biosolids, primarily in urban areas with limited land application capacity. While it offers benefits such as volume reduction, pathogen destruction, and energy recovery, its role in PFAS management is under increasing scrutiny. PFAS compounds are thermally stable and require high temperatures, typically above 850°C,(Weitz et al., 2024) for complete destruction. In practice, incineration may not fully mineralize all PFAS, especially some small gaseous PFAS. Incomplete combustion can result in the formation of transformation products, including volatile fluorinated compounds and hydrogen fluoride (HF), which pose additional environmental and health risks. Stack emissions, fly ash, and bottom ash may retain residual PFAS, complicating disposal and air quality management.

Research is ongoing to evaluate the efficacy of incineration and to characterize PFAS emissions profiles under various operating conditions. A 2023 study by Björklund et al.(Björklund et al., 2023) investigated PFAS emissions during incineration of municipal solid waste (MSW) amended with 5–8 wt % biosolids in a Swedish waste-to-energy plant. PFAS were detected in all examined residues, with short-chain PFCAs (C4–C7) being most abundant. Total extractable PFAS levels were higher in biosolid-amended MSW than in standard MSWI, with estimated annual releases of 47 g and 13 g, respectively. Notably, PFAS were detected in flue gas for the first time (4.0–5.6 ng/m³), underscoring that high-temperature incineration does not guarantee complete PFAS degradation. In 2024, Björklund et al. (Björklund et al., 2024) extended this work by investigating PFAS fate in the in-house process-water treatment (PWT) system of the same waste to energy plant. Sampling across five locations over five days revealed that nine of eleven target PFAS were consistently present, with

concentrations varying due to waste fuel composition. PFAS levels were highest in foam (130 times that of treated water) though the mass flow was lower. The condensate scrubber was identified as a key transfer step, increasing PFAS mass flow in the PWT sixfold after condensate addition. The study concluded that the existing PWT configuration was not effective at removing PFAS, despite potential for targeted improvements. Most recently, Johansson et al. (Johansson et al., 2024) investigated PFAS emissions from bottom ash at Swedish municipal solid waste incineration (MSWI) sites. Sampling ash from facilities representing 70% of Sweden’s incineration capacity, the researchers found that PFAS concentrations were low, typically in the nanogram-per-gram ($\mu\text{g}/\text{kg}$) range, with PFBA, PFBS, and PFHxA most frequently detected. However, measurements of extractable organofluorine (EOF) revealed that unidentified fluorinated compounds were present at higher levels than the sum of known PFAS, suggesting that conventional targeted analysis may underestimate total PFAS-like content. Leaching tests showed limited PFAS mobility from bottom ash under standard conditions, indicating a low risk to groundwater when ash is properly managed. Collectively, these studies suggest that while bottom ash may pose limited risk under controlled conditions, flue gas, process water, and residues from sludge-enhanced incineration represent more significant emission pathways. The presence of unidentified EOF across waste streams highlights the need for broader monitoring and precautionary management, especially when residues are reused or landfilled without containment. There is a waste to energy management plant on Jersey, and if biosolids are incinerated there, monitoring of the waste streams for PFAS is recommended.

To address the limitations of conventional incineration and to provide alternative management options, several emerging thermal and chemical technologies are being explored. Cement kilns, for example, operate at temperatures up to $1,450^{\circ}\text{C}$ and offer long residence times, making them promising for PFAS destruction. They are widely used in Switzerland for the treatment of biosolids. Co-processing biosolids in kilns may achieve near-complete fluorine mineralization, but concerns remain about volatilization, emissions control, and regulatory oversight. There are no cement kilns on Jersey so this is not a viable management option.

Pyrolysis, which involves heating biosolids in the absence of oxygen (typically $400\text{--}900^{\circ}\text{C}$), produces three main products: a solid product called biochar, a py-liquid that consists of aqueous phase and non-aqueous phase liquid, and py-gas. The biochar serves as a carbon-sequestering soil amendment, while py-gas can be used for on-site energy recovery. The py-liquid is a potentially hazardous complex mixture. Although pyrolysis can reduce PFAS in solids, it does not fully destroy them; instead, PFAS may partition into the py-liquid, which requires further treatment, e.g. by catalysis or thermal oxidation, to mitigate environmental risks. The fate of PFAS in py-gas remains poorly understood, representing a key knowledge gap. Moisture content in biosolids significantly affects the energy balance of pyrolysis, making the process more viable for utilities that already produce dried biosolids. Gasification, operating at even higher temperatures ($800\text{--}1200^{\circ}\text{C}$) than pyrolysis with controlled oxygen or steam, shows potential for PFAS breakdown given the higher operating temperatures, though it remains technically complex and capital-intensive. (Winchell et al., 2022) Neither pyrolysis nor gasification facilities are currently available on Jersey. While technically feasible, installation at the wastewater treatment plant would require substantial capital investment and careful consideration of operational needs, regulatory requirements, and long-term cost-effectiveness. (Winchell et al., 2022)

In summary, while incineration and emerging thermal technologies offer potential pathways for PFAS destruction in biosolids, none are yet universally accepted or proven for PFAS. Continued research, technology refinement, and regulatory alignment are essential to ensure safe, effective, and scalable solutions. The choice of treatment method must consider PFAS speciation, operational feasibility, environmental trade-offs, and long-term liability.

DRAFT

10 Discussion

10.1 Summary of expert evidence, discussions and literature review on PFAS and food

10.1.1 Scientific baseline and current guidance

PFAS are highly persistent contaminants. Long-chain moieties bind to proteins, mimic short-chain fatty acids, undergo renal and gut reabsorption and are eliminated slowly, leading to long human half-lives.

EFSA reviewed 35 PFAS in 2018 and concluded that regulatory guidance should focus on four—PFOS, PFOA, PFHxS and PFNA—supported by more than 200 human studies and numerous animal studies. Reported human associations include reduced antibody response following vaccination, increased liver enzymes, altered oxidative response, elevated cholesterol and lower birthweight. Effect sizes were generally modest and often within normal ranges, but the most sensitive, policy-relevant endpoint selected was reduced antibody response following vaccination. EFSA's 2020 tolerable weekly intake (TWI) of 4.4 ng/kg body weight for the sum of PFOS, PFOA, PFHxS and PFNA was derived by modelling the PFAS concentration linked to a 20% reduction in post-vaccination antibody response in one-year-old infants, and back-calculating maternal intake (including a year of breastfeeding). This immune-based TWI is considered protective for other endpoints that occur at higher exposures. EFSA did not adopt relative potency factors between PFAS because of methodological limitations and species/kinetic differences, and treated the four compounds as equally potent for practical purposes.

10.1.2 Exposure pathways, packaging and chemicals in transition

Food and drinking water remain the principal exposure routes for the general population. Chain length strongly influences behaviour and exposure: long-chains bioaccumulate and tend to remain nearer sources; short-chains are more mobile in the environment and clear the body more quickly.

In food systems, long-chain PFAS bind strongly to soils and can enter livestock through grazing and direct soil ingestion, transferring into meat, milk and eggs. Short-chain PFAS are more readily taken up by plants (e.g., rice, lettuce, tomatoes, cucumbers, potatoes), and residues can persist on produce surfaces even after washing.

Food-contact materials remain relevant. Many long-chains have been phased out, but short-chains and side-chain fluorinated polymers are still used in packaging and can migrate into food, particularly when packaging is heated in microwaves. Recycled packaging may retain residual PFAS.

10.1.3 Analytical reliability and interpretation

Analytical capability has improved markedly over 25 years. Early studies suffered from contamination of instruments and labware, lack of standards, misidentification and high inter-laboratory variability; relative standard deviations of up to 250% were documented and at least one publication was withdrawn due to misidentification. Today, detection limits have fallen from nanograms to picograms per gram, and standardised methods, blanks and internal standards are routine. Even so, rigorous contamination control, careful handling of non-detects (lower- versus upper-bound assumptions), and attention to chromatographic interferences and ion suppression/enhancement remain essential, especially for short-chains and precursors.

10.1.4 Swedish Market Basket findings and trends

Sweden’s Market Basket (MB) Study—conducted in 1999, 2005, 2010, 2015 and 2022—purchases foods according to national consumption patterns, pools them into food groups and analyses them for contaminants. In 2022, with expanded PFAS coverage (14 compounds) and additional item-specific sampling, detectable PFAS were confined to three of 17 food groups: lean fish, fatty fish and eggs. Fruits, vegetables and common meats (beef, pork, lamb, chicken) were below detection. PFAS were present in organic eggs but much less in conventional eggs, a pattern corroborated by a food-control programme. Highest concentrations were in fish from the Baltic Sea and Swedish lakes; farmed salmon and oceanic fish (e.g., tuna) were lower. Swedish crayfish exceeded imported Spanish crayfish, and PFAS were also detected in shellfish and wild boar meat, with low levels in reindeer and liver pâté. All results were below EU maximum levels. Additional control sampling confirmed the absence of PFAS in fruits, vegetables and common meats.

Time trends are clearly downward. Estimated per-capita dietary PFAS intake has fallen by about 8% per year since 1999, while fish concentrations have declined by roughly 5% per year. These trends mirror decreasing serum PFAS concentrations in first-time mothers in Uppsala since 1996. Exposure modelling that combines national dietary surveys with 2022 concentrations in the MB study shows most age groups below EFSA’s TWI, though some young children (around 1.5 and 4 years old) exceed it. When drinking water is included at 4 ng/L (the forthcoming Swedish limit), water contributes about as much as food in adults; at higher water concentrations, water can dominate.

10.1.5 Foods produced near hotspots: milk, beef and eggs

A Swedish project assessed PFAS in animal-sourced foods produced near known contaminated sites, focusing on beef, dairy and small-scale (backyard) eggs, and benchmarking against EU maximum levels for PFOS, PFOA, PFHxS and PFNA. Estimating “safe” PFAS in animal feed and water is difficult because of species-specific physiology, exposure routes and variation across compounds; transfer data are stronger for PFOS and sparse for other PFAS.

Milk contained PFAS in most samples but at low levels below action limits; dairy-farm drinking water showed no elevation, and no clear hotspot signal was observed, suggesting background contributions. In beef, PFOS was the only PFAS detected in meat; some samples exceeded EU thresholds. Blood PFAS in cattle varied widely and did not consistently decline when animals were moved indoors. Given relatively short half-lives in cattle (months or days), switching to clean feed and water should reduce burdens over time, although practical constraints may slow improvement. Backyard eggs near contaminated and urban areas were most frequently elevated: more than half of sampled flocks exceeded EU thresholds, whereas rural flocks away from known contamination showed lower levels similar to commercial organic eggs. Intake modelling indicates that heavy consumers of such eggs—and, to a lesser extent, self-produced beef in affected areas—can exceed EFSA’s TWI. Targeted monitoring, guidance and risk communication are therefore warranted for specific households.

International case studies (a dairy farm in Maine with biosolid-related contamination, backyard hen eggs near PFAS industries in Belgium, and beef exposure downstream of a fire-training site in Denmark) illustrate that foods produced close to contaminated sources can reach concentrations of concern and provided useful context for the Swedish work.

10.1.6 Jersey-relevant considerations, backyard production and comparators

Three practical points matter in Jersey. First, PFAS can be transported inland via sea spray; cattle near coasts may have been exposed where sea spray settles inland. While this is a global issue, as an island nation, Jersey may be more affected. Sampling is technically difficult and there are no standardised protocols.

Second, backyard egg production requires specific attention. Households that use borehole water for irrigation or poultry drinking water ; or whose soil or groundwater is contaminated from being in the plume; and who keep hens, could face elevated exposure. International evidence indicates that soil and feed are often more significant exposure routes for hens than water; elevated PFAS in urban backyard eggs have been observed even where municipal water is clean and owners report no fish-meal feed.

Third, sampling and comparators need to be aligned. Because there is no established food basket for Jersey, individual items that are tested are complemented with recent international datasets. Recent food-basket data from other countries will strengthen comparisons; much data used in EFSA's 2020 report are now dated. Germany contributes a large share of EFSA food-sampling data due to annual testing, and national authorities may hold recent datasets. Production systems also matter: chicken and pork are relatively standardised across Europe (soy-based feeds), whereas cattle feeds are more locally variable—another reason to make like-for-like comparisons.

10.1.7 Estimating dietary intake for the UK/Europe and water's contribution

EFSA's dietary intake estimates (largely 2007–2016 measurements applied to national consumption surveys) handle many non-detects by reporting lower-bound (non-detects as zero) and upper-bound (non-detects at the detection limit) values. For UK adults, the daily sum-of-four intake was estimated as 0.62 ng/kg/day (lower-bound) and 13.8 ng/kg/day (upper-bound). In lower-bound estimates, fish/seafood dominated intake, followed by fruit, meat and drinking water (noting EFSA's assumed water concentrations were low for the UK at the time).

Where categories align, the UK 2012 Total Diet Study showed higher concentrations than European lower-bound averages—about three-fold for fish, roughly two-fold for eggs and around six-fold for fruit products. Scaling EFSA's UK lower-bound estimate by those factors gives a plausible 2012 UK adult intake of 1.2–3.6 ng/kg/day (sum of PFOS, PFOA, PFHxS, PFNA). Multiple lines of evidence indicate subsequent declines: UK potatoes fell from roughly 1–10 µg/kg (2004) to 0.03–0.85 µg/kg (2012); more recent UK fish means for sardines, crab and cod are about an order of magnitude below the 2012 Total Diet Study average; German egg averages fell five-fold between 2018–2022 and 2024; Sweden's MB shows a seven- to eight-fold fall in dietary intake from 2010 to 2022 (EFSA-4 intake in 2022 around 7.5 ng/day). Taken together, the document proposes that present-day UK adult dietary intake is in the range 0.1–0.7 ng/kg/day, with a central estimate near 0.1–0.2 ng/kg/day (0.7–1.4 ng/kg/week), acknowledging clear uncertainty.

For drinking water, UK commentary on the EFSA report cites average concentrations up to about 5 ng/L each for PFOA and PFOS in groundwater-derived supplies and up to about 10 ng/L in surface-water supplies. Using 5 ng/L for each of PFOS and PFOA, with 1.5 L/day ingestion and a 75-kg adult, yields roughly 1.4 ng/kg/week from water; at 4 ng/L the contribution is about 0.5 ng/kg/week. Combining the dietary estimate above (0.7–1.4 ng/kg/week) with a typical water contribution (0.5–1.4 ng/kg/week) suggests that total weekly intake for a typical adult remains below EFSA's TWI, and

that diet and water are now of similar magnitude for many people. Individual behaviours—such as high consumption of locally caught fish or frequent consumption of backyard eggs near hotspots—can materially alter personal exposure.

DRAFT

10.2 Panel discussions on PFAS and food

10.2.1 Intake accounting and the relationship with water levels

The discussion adopted a pragmatic “intake budgeting” approach against EFSA’s tolerable weekly intake (TWI) of 4.4 ng/kg/week for the sum of four PFAS. Using the worked examples, drinking water at 10 ng/L contributes about 1.4 ng/kg/week, leaving roughly 3 ng/kg/week available for food while remaining within the TWI. At the future target of 4 ng/L, the water contribution drops to about 0.6 ng/kg/week, increasing the margin for food to around 3.8 ng/kg/week. Earlier assumptions that water contributes only a small fraction of total intake compared with food are no longer reliable because food contributions have declined over time. The sum of current water and modelled food levels are both comfortably below the TWI. On this basis, the drinking water guideline of 4 ng/L does not need to be revised; taking likely levels in food into account, that limit does not risk breaching EFSA’s threshold.

10.2.2 Food monitoring and uncertainty

The operational test is the performance of the composite food basket relative to the intake budget. Provided total dietary exposure remains below about 3 ng/kg/week at current water levels (10 ng/L) and about 3.8 ng/kg/week at the future water target (4 ng/L), there is no need to revise drinking water recommendations. That said, average intake estimates carry uncertainty due to variability in measured food concentrations and limited sample sizes. To validate assumptions, local Jersey measurements should be benchmarked against UK averages for similar categories; particularly locally produced eggs, fish, meat and milk; to confirm alignment or highlight any category that disproportionately contributes to intake. While particular items might warrant scrutiny if they dominate exposure, the current evidence does not identify clear outliers; emphasis should therefore remain on managing the overall basket against the agreed budget.

10.2.3 Backyard poultry in or near contaminated areas

Backyard chickens kept in contaminated areas were identified as a notable risk unless birds are housed indoors and fed uncontaminated commercial feed. Free-ranging hens foraging on contaminated soils are likely to ingest PFAS via soil and earthworms, creating an efficient pathway into eggs. It was also noted that organic eggs can sometimes contain higher PFAS levels because fish meal in organic feed introduces an additional source, higher in practice than non-organic feed. This counterintuitive pattern underscores the complexity of exposure pathways and supports a precautionary stance on non-commercial egg production where contamination is suspected.

10.2.4 Freshwater fish consumption

Freshwater fish were recognised as a potential major source of PFAS exposure in some settings; advisories elsewhere suggest a single fish could equate to months of exposure from drinking water at 40 ng/L. Jersey, however, does not produce freshwater fish for consumption. Local ponds are used for recreational angling and most clubs operate no-kill policies, so consumers primarily obtain any freshwater fish from imports, mainly the UK. Formal consumption recommendations are therefore unnecessary at present, but public information should explain PFAS risks in freshwater fish, particularly biomagnification in predatory species such as pike. Existing UK food basket data have not shown high PFAS in freshwater fish, plausibly reflecting the predominance of farmed rather than wild-caught products, but this should be confirmed through further analysis before any guidance on frequency is considered.

10.2.5 Potential areas for recommendation on food

1. **Retain the 4 ng/L water guideline.** On the agreed intake budgets (3.0 ng/kg/week at 10 ng/L; 3.8 ng/kg/week at 4 ng/L), likely present food exposures leave sufficient headroom within the EFSA TWI.
2. **Backyard eggs:** precautionary stance. In areas with suspected ground or water contamination, discourage free-range backyard production unless birds are indoors on clean commercial feed.
3. **Freshwater fish:** inform rather than restrict. Provide clear information on predatory species and biomagnification, note the no-kill nature of local angling, and review UK data before considering any frequency guidance.

DRAFT

10.3 Summary of expert evidence, discussion and literature reviews on management and treatment of water not for drinking, soil and biosolids and PFAS destruction

10.3.1 International guidance levels for soils, environmental waters, and biosolids

Guidance values and regulatory expectations for PFAS vary widely by jurisdiction and by medium (soil, water, biosolids). They are set for different objectives (e.g., protecting groundwater via leaching controls, direct contact, food-chain protection) and reflect different analytical capabilities and policy choices. As such, they should be treated as screening tools that trigger proportionate, evidence-based management rather than as absolute dictates in every case.

10.3.1.1 Soils.

Across Europe and elsewhere, soil guidance typically aims to prevent unacceptable leaching to groundwater and to manage direct human and ecological exposure around known sources (e.g., airports and firefighting training grounds where AFFF was used). Because PFAS occur as mixtures with varying mobility (short chains are generally more mobile), soil values are often accompanied by site-specific assessments. The practical message is that local background levels, land use, and hydrogeology matter: where numbers approach background or analytical limits, decision-making leans on lines of evidence beyond a single screening value.

10.3.1.2 Environmental waters.

Drinking water standards in Europe are tightening under instruments such as the Drinking Water Directive, with increasing attention to ultra-short-chain PFAS as analytical methods improve. For non-drinking environmental waters, management often focuses on surveillance and control at sources and pathways, because PFAS are now detected broadly, including in rainwater far from obvious point sources. Atmospheric deposition (from everyday consumer sources, wastewater treatment, and sea spray) complicates simple attribution to a single emitter.

10.3.1.3 Biosolids.

Jurisdictions are diverging in their stance. Denmark has action levels for PFAS in sludge (10–50 ppb) and Germany plans to phase out land application for large plants. Switzerland banned land application of sludge in 2006 (originally driven by pathogens/metals), which has led to near-universal thermal treatment. In the United States, biosolids categories are defined by pathogens and metals rather than PFAS. An important accounting point is that reported concentrations are on a dry-weight basis; unless corrected for the moisture and nitrogen-based application rates that actually determine how much biosolids are land-applied, risk can be over- or under-estimated. Paper-related precursors (e.g., side-chain fluorinated polymers used in coatings) have been implicated as notable contributors to sludge PFAS, with an observed shift over time towards shorter-chain species in some paper-mill sludges.

10.3.2 Management and treatment of environmental waters

10.3.2.1 Where PFAS appears and how it partitions.

PFAS enter environmental waters via domestic, commercial and industrial use, landfill leachate, and atmospheric deposition. In municipal wastewater treatment, shorter-chain PFAS preferentially remain in the liquid phase, whereas longer-chain species tend to partition to sludge. In surface waters and rainfall, detection is increasingly common, including at distances from obvious point sources, underscoring diffuse inputs.

10.3.2.2 Separation technologies (capture) and their roles.

Technology Readiness Levels (TRLs) are a common shorthand for maturity: TRL 1 denotes basic concept; TRL 9 denotes full-scale, proven operation. Below we provide indicative TRLs (where available) and summarise strengths, weaknesses and mitigations.

- **Granular activated carbon (GAC) — TRL 9 (commercial).**
 - *Strengths:* Proven, relatively straightforward to design and run; effective on long-chain PFAS; co-benefits for organic contaminants and taste/odour.
 - *Weaknesses:* Earlier breakthrough for short-chains; capacity decreases with higher dissolved organic carbon (DOC), iron/manganese and turbidity.
 - *Mitigations:* Lead–lag vessels with inter-bed sampling; conservative contact times; simple pretreatment (particulates, iron/manganese control, DOC reduction) to extend run length.
 - *Residuals:* Spent carbon requiring reactivation or disposal.
- **Ion exchange (IX) — TRL 9 (commercial).**
 - *Strengths:* Often superior to GAC for short-chain acids at comparable contact time; compact vessels; long run lengths in short-chain-dominated waters.
 - *Weaknesses:* Competition from sulphate/bicarbonate; spent resin management; if regenerated, PFAS-bearing brine must be handled.
 - *Mitigations:* Match resin chemistry to the matrix; arrange lead–lag staging; where regeneration is impractical, select single-use resins and plan disposal.
 - *Residuals:* Spent resin or regenerant brine.
- **Reverse osmosis / tight nanofiltration (RO/NF) — TRL 9 (commercial).**
 - *Strengths:* Broad, high rejection across PFAS suites (including many short-chains) and strong co-benefits for inorganics.
 - *Weaknesses:* Produces a PFAS-rich concentrate; sensitive to fouling/scaling; requires pretreatment and routine integrity checks. Energy intensive
 - *Mitigations:* Cartridge prefiltration; softening/antiscalant where appropriate; conservative recovery with planned, lawful concentrate disposal.
 - *Residuals:* Concentrate stream (and periodic cleaning wastes).
- **Foam fractionation (FF, including SAFF) — TRL ~7–8 (piloted/early deployments).**
 - *Strengths:* Exploits PFAS surfactancy to concentrate mass into a small foamate stream; can reduce load to downstream GAC/IX or treat RO/NF concentrate. Low energy requirements.
 - *Weaknesses:* Performance is compound- and matrix-dependent (long-chain sulfonates concentrate best); foamate still requires destruction/disposal.

- *Mitigations:* Integrate as a pre-concentrator ahead of a reliable destruction pathway; monitor surfactant interferences.
- *Residuals:* Foamate requiring treatment.

10.3.2.3 *In situ groundwater immobilisation.*

- **Colloidal activated carbon (CAC) barriers — TRL ~7–8 (field-demonstrated).**
 - *Strengths:* Injected sorbents immobilise PFAS in the aquifer, reducing dissolved concentrations and plume migration without continuous pumping. Low cost.
 - *Weaknesses:* Performance depends on hydrogeology and PFAS flux; placement quality is critical. Eventually becomes saturated.
 - *Mitigations:* Site-specific treatability testing; staged injections; performance monitoring.
 - *Residuals:* None ex situ; long-term monitoring remains necessary.

10.3.2.4 *Groundwater polishing.*

- **Pump-and-treat — TRL 9 (commercial).**
 - Extraction and above-ground treatment via GAC/IX/membranes can rapidly reduce concentrations, but long-term operation is common due to slow release from soils and vadose-zone storage. The cost and environmental impact of pumping may require consideration.

10.3.3 Management and treatment of soils

PFAS released at ground surface (notably from AFFF) percolate into the vadose zone and accumulate at the air–water interface; precursors can transform over time into other PFAS, including shorter-chain species that are more mobile. This argues for tailored, site-specific treatment trains that respect both the PFAS profile and the hydrogeology.

10.3.3.1 *Field-implemented options with higher maturity.*

- **Excavation and off-site disposal — TRL 9 (commercial).**
 - Removes source mass decisively and is widely understood by regulators and contractors. It does not destroy PFAS and transfers responsibility to disposal facilities and leachate treatment. Sustainability and local traffic impacts should be weighed.
- **Stabilisation/solidification and sorptive amendments — TRL 8–9 (commercial/field-proven).**
 - In situ and ex situ mixing with sorbents (e.g., activated carbon, biochar, mineral blends) and binders reduces leaching without removing mass. Field trials show durable reductions in leachability. The approach can preserve existing landforms and reduce off-site transport but may constrain future excavation or redevelopment.
- **Soil washing/flushing — TRL 8–9 (commercial/field-proven where soils are amenable).**

- Physical separation and chemical washing of soils can strip PFAS into a liquid stream for follow-on treatment, reducing the volume requiring disposal. Performance drops in fine-grained, organic-rich soils; the wash water becomes the new focus for separation and destruction.

10.3.3.2 *Emerging/conditional options.*

- **Thermal desorption — TRL ~6–8 (pilot to commercial, PFAS-specific).**
 - Volatilises PFAS from soil for off-gas capture and treatment; relocates rather than destroys PFAS, so destruction steps downstream are essential.
- **Phytoremediation — TRL ~3–5 (early field use, long horizons).**
 - Plant uptake (e.g., for shorter-chain PFAS) can be helpful over long periods, but timescales can extend to decades; best viewed as a supplementary measure rather than a primary remedy.

10.3.4 Management and treatment of biosolids

Wastewater plants aggregate PFAS; conventional processes do not destroy them. A fraction partitions into biosolids, with side-streams (centrate) often carrying elevated PFAS back to headworks. Biosolids range from liquid to dried pellets. Reported concentrations are dry-weight; actual land-application loads depend on moisture and nitrogen-based application rates. Higher-nitrogen products (even with higher concentrations) may be applied at lower mass, yielding lower total PFAS loadings than lower-nitrogen products.

- **Land application**
 - *Benefits:* Nutrients, slow-release fertilisation and soil-health gains.
 - *Risks:* Leaching and runoff to waters; accumulation of long-chains in upper soils; mobility of short-chains (amplified in sandy soils); uptake into certain food chains; and atmospheric deposition confounding local source attribution.
 - *Risk reduction measures:* Wet-weight load calculations, field rotation, extended intervals between applications, and source control upstream (e.g., intercepting industrially influenced sludges) all reduce risk.
- **Landfilling.**
 - Practical for limited volumes, but transfers risk to leachate, which often returns to the wastewater works, creating a loop. Space constraints and long-term liability must be considered. It should be noted that appropriate landfilling facilities do not exist in Jersey.
- **Waste-to-energy, dedicated sludge lines, co-processing — TRL 9 (commercial).**
 - Incineration reduces volume by >95% and destroys pathogens. PFAS destruction depends on achieving sufficiently high temperature, residence time and mixing, with acid gas scrubbing to handle HF. Measured stack emissions in some studies have been low, but residual short-chains can appear in ash and process waters; significant movement can occur via pre-combustion waste handling and leachates. Facility type matters: hazardous-waste incinerators and cement kilns more readily meet the thermal envelope for mineralisation than older municipal lines.

- *Practical constraints:* Availability, capital and operating costs, acceptance policies and liability concerns. Some jurisdictions mandate phosphorus recovery from ash, shaping future operations.

10.3.5 PFAS destruction technologies: relative strengths, weaknesses, and maturity

Separation is mature and widely deployable, but it moves PFAS into residuals (spent media, brines, concentrates, foamates, process waters). Destruction seeks to break C–F bonds and mineralise PFAS, ideally to carbon dioxide and fluoride. Core challenges recur across methods: energy intensity, non-selective reaction networks (by-products), and mass-transfer limits. Credible claims require fluoride balances and by-product speciation, ideally on real-world matrices.

- **Thermal destruction (high-temperature incineration and co-processing) — TRL 8–9 (operational, facility-dependent).**
 - *Strengths:* Scalable infrastructure; when the thermal envelope is achieved (temperature, residence time, mixing), mineralisation is possible; cement kilns and hazardous-waste incinerators are more likely to sustain these conditions.
 - *Weaknesses:* Energy-intensive; HF needs scrubbing; risk of incomplete destruction and short-chain/volatile emissions if sub-optimal; ash and process waters still require control; facility acceptance and liability concerns.
 - *Best use:* Solids and concentrated streams (e.g., PFAS-laden media and dried biosolids), with continuous emissions control and mass-balance checks.
- **Electrochemical oxidation (EO) — TRL ~4–7 (from lab/pilot to early demonstrations; specific projects at TRL 4–5 aiming for 7).**
 - *Strengths:* Modular; can target concentrated aqueous streams (e.g., RO reject); capable of degrading a range of short- and long-chains under suitable conditions.
 - *Weaknesses:* Non-selective oxidation; in chloride-rich matrices, formation of chlorate/perchlorate and other by-products is a risk; electrode fouling and mass-transfer limitations must be addressed. Graphene-based anodes differ from traditional carbon and appear resistant to biofilm formation, but long-term performance awaits pilot-scale validation.
 - *Best use:* As a polishing/destruction step on RO/FF concentrates with active by-product monitoring and chemistry management.
- **Supercritical water oxidation (SCWO) — TRL ~6–7 (pilot/early demonstration).**
 - *Strengths:* Powerful oxidation for difficult aqueous wastes.
 - *Weaknesses:* High temperature/pressure; materials and corrosion challenges (including HF); continuous operation and energy management remain difficult.
 - *Best use:* High-strength concentrates and specific industrial streams where the infrastructure exists.
- **Hydrothermal alkaline treatment (HALT) — TRL ~5–7 (pilot/early demonstration).**
 - *Strengths:* Hydrothermal conditions with alkali can neutralise HF and drive defluorination.
 - *Weaknesses:* Energy intensive; longer residence times; scale-up and reliability for continuous operation still in development.
 - *Best use:* Concentrated aqueous streams, potentially as part of a treatment train following concentration.

- **Plasma — TRL ~5–6 (early pilots).**
 - *Strengths:* Rapid degradation reported across matrices; potential resilience to co-contaminants compared with some wet-chemistry routes.
 - *Weaknesses:* Energy per unit PFAS destroyed can be high; by-product control and full mass balances need further evidence at scale.
 - *Best use:* Smaller volumes/concentrates with strong monitoring.
- **Sonolysis (high-frequency ultrasound) — TRL ~5–6 (bench to field pilot).**
 - *Strengths:* Demonstrated defluorination of PFOA/PFOS in pilots; can be synergistic with oxidants.
 - *Weaknesses:* Energy-intensive; scale-up is non-trivial; sensitive to matrix effects; rigorous mass-balance accounting is needed.
 - *Best use:* Concentrated streams as a targeted destruction step.
- **Photochemical/advanced oxidation (UV/VUV, ozone-based, activated persulphate, catalysed peroxide) — TRL ~3–6 (lab to pilot).**
 - *Strengths:* Well-understood radical chemistry; useful for precursor transformation and polishing when paired with separation.
 - *Weaknesses:* Complete mineralisation is variable (sulphonates are often recalcitrant); co-contaminants can quench reactions; sorption can be misinterpreted as destruction.
 - *Best use:* As a polishing or precursor-management step within a broader train.
- **Advanced reduction (solvated electrons) and radiation (e-beam) — TRL ~3–5 (early).**
 - *Strengths:* Direct C–F scission demonstrated in controlled settings; fast kinetics possible.
 - *Weaknesses:* Sensitivity to oxygen and scavengers; energy/dose management; limited field data.
 - *Best use:* Research and targeted pilots on small, high-strength streams.
- **Biological routes — TRL ~1–3 (early research).**
 - *Strengths:* Potentially low energy and compatible with existing infrastructure for precursor management.
 - *Weaknesses:* Terminal PFAAs resist biodegradation; partial defluorination with persistent by-products is common; highly compound-specific.
 - *Best use:* Exploratory research; not ready for primary destruction.

10.3.6 Key points

- Across all soil and groundwater remedies, site investigations should identify where PFAS mass resides (vadose interface, fines, groundwater). Treatability testing (bench or pilot) informs selection and sizing. Long-term performance monitoring (including checks for precursor transformation and short-chain mobility) is a core part of any management plan.
- Every capture process creates PFAS-bearing residuals; every destruction route creates its own wastes (e.g., scrubber liquors).
- Acceptance of PFAS-bearing residuals (spent carbon, IX, powders, concentrates) is as much about liability and permitting as it is about chemistry. There may be limited high-temperature routes and finite hazardous-waste cell capacity. Two-stage thermal concepts (volume reduction at moderate temperature, then final destruction at higher temperature)

can be viable where air-pollution controls prevent intermediate releases, but feasibility turns on local infrastructure and regulation.

- **Water:** In environmental waters, GAC, IX and RO/NF are the workhorses (TRL 9). Foam fractionation (TRL ~7–8) is valuable for pre-concentration. In situ CAC and PRBs (TRL ~7–8) can cut plume impacts without long-running pump-and-treat. Concentrates and foamates are the proper targets for destruction.
- **Soil:** For immediate risk reduction, excavation (TRL 9) or stabilisation (TRL 8–9) are decisive. Where soils allow, washing (TRL 8–9) can greatly reduce disposal volumes. Thermal desorption (TRL ~6–8) and high-temperature destruction (TRL 8–9, facility-dependent) are powerful but infrastructure-intensive. Phytoremediation (TRL ~3–5) is supplementary and long-horizon.
- **Biosolids:** Correct dry-weight concentrations to wet-weight applications and nitrogen-based dosing, rotate fields, and lengthen intervals to manage accumulation. Where land application is constrained or unacceptable, thermal routes (TRL 9) provide volume reduction and pathogen control, but they demand robust emissions control and downstream management of ash and process waters. Segregating industrially influenced sludges (e.g., paper-mill streams) from ordinary municipal biosolids can materially reduce risk.
- **Destruction:** Where destruction is pursued, match method to stream: thermal (TRL 8–9) for solids and dried residues; electrochemical (TRL ~4–7), SCWO/HALT (TRL ~5–7), plasma/sonolysis (TRL ~5–6) for concentrates. Require fluoride accounting and by-product monitoring. If by-products or mass balance are uncertain, treat the step as transformation/polishing and keep separation as the primary control.

10.4 Panel discussion on management and treatment of water not for drinking, soil and biosolids and PFAS destruction

10.4.1 Overall approach and technology maturity.

Interventions should prioritise high-TRL (Technology Readiness Level 8–9) separation and containment solutions that are demonstrably operational today. Cost is the principal drawback and ultimately a policy choice. On soils, two mature options exist:

- **soil washing:** which can be effective but is capital-intensive and generally requires a dedicated plant. It is not in widespread use.
- **immobilisation:** using sorbents, which is cheaper, widely used internationally, and reduces PFAS availability in soils and groundwater but necessitates ongoing monitoring and periodic media replacement.

For groundwater, pump-and-treat remains effective but expensive because of extended pumping durations and subsequent treatment demands (typically granular activated carbon or ion exchange). In-situ destruction is not yet viable; contaminated soil or water must be removed for treatment.

10.4.2 Soil use classes and potential thresholds

A structured framework was adopted to align soil decisions with land use and exposure pathways, mostly drawing on Flemish guidance as the most practical and comprehensive basis, but also Swedish guidance. Any thresholds are to be applied to the sum of four key PFAS associated with AFFF contamination, for simplicity and consistency with water recommendations:

- **Agricultural land:** a threshold in the 3-4 µg/kg range was discussed, to protect food-chain receptors; this sits above typical background (approximately 0.1-1 µg/kg) and is intended to be precautionary yet workable. 4 µg/kg is where the final consensus landed.
- **Water-protection (sensitive) zones:** although a stricter 1 µg/kg was discussed, the conclusion was to apply the agricultural threshold of 4 µg/kg in line with the Flemish recommendation.
- **Land for human habitation and industrial land:** The Flemish guidance recommends 8 µg/kg, reflecting fewer exposure pathways than agriculture; livestock-driven biomagnification underpins the tighter agricultural value.
- **Other land:** A pragmatic discussion about 20 µg/kg (Flemish guidance has no recommendation), as a trigger for source investigation.

10.4.3 Non-drinking (environmental) waters levels

Existing European surface-water EQS values (for example, at sub-ng/L levels) are impractical, as ambient inputs (including rainwater) can easily exceed them. The panel supports investigative trigger levels designed to identify and prioritise sources:

- **Surface waters:** a 10 ng/L trigger (sum of four PFAS) to prompt source investigation.
- **Groundwater:** the same 10 ng/L investigative trigger is appropriate **except** where the source is used for human consumption, which will be handled under drinking-water provisions discussed earlier.

Recent trend data indicate declining averages in surface waters.

10.4.4 Treatment options for contaminated environmental waters.

There is no single universal solution; site conditions dictate the mix. The default emphasis is on high-TRL capture technologies:

- **Granular activated carbon (GAC)** and **ion exchange (IX)** as proven workhorses.
- **Foam fractionation** as a mature pre-concentration step in appropriate matrices.
- **Membranes (nanofiltration/reverse osmosis)** are primarily suited to drinking-water applications; their energy intensity constrains broad environmental deployment.

In practice, bespoke treatment trains combining these technologies are common, with continuous operation at hotspots feasible where logistics, cost and permitting align.

10.4.5 Biosolids management:

Three management pathways were considered:

- restrict application to certain land types
- allow application only where resulting soil concentrations remain below the relevant threshold for that land class
- pursue destruction of biosolids. Landfilling is not viable locally.

The preferred interim approach is to apply according to the PFAS tolerance of a particular land type, coupled with a programme of monitoring to track soil PFAS accumulation and inform future decisions. This balances agronomic and carbon footprint benefits with exposure control and is adaptable as data improve. The monitoring programme should:

- Confirm that post-application soils remain below the land-class threshold (as set out above).
- Track multi-year trends to identify any cumulative build-up, with triggers for management review.
- Provide the evidence base for planning potential destruction options if and when they become practical and proportionate.

Practical constraints are acknowledged: limited land availability and enforcement challenges locally, and the reality that biosolids are presently applied to both agricultural and non-agricultural land. Destruction technologies (e.g., pyrolysis, gasification) were recognised as potential future tools but carry significant capital needs and uncertainties (emissions control, occupational exposure), which are especially salient given the proximity of the wastewater treatment site to populated areas. These options merit continued evaluation, not immediate deployment.

10.4.6 Summary aims and objectives

The panel is making recommendations in order to help to:

- Reduce food-chain exposure risk by setting thresholds for agricultural and human habitation area soils to be considered contaminated.
- Direct investigations areas of potential water contamination on the basis of trigger levels.

- Keep biosolids use within safe bounds, while collecting data to inform any later transition to destruction technologies if warranted.

10.4.7 Potential areas for recommendations on soils, environmental waters and biosolids:

1. **Recommend Flemish based soil thresholds are considered as targets**, with totals applied to the sum of four AFFF-relevant PFAS, differentiated by land use as above.
2. **Consider an 20µg/kg trigger** for source investigation in other land
3. **Use 10 ng/L investigative triggers** (sum of four) for **surface waters and groundwater** not used for human consumption, to drive **source identification and prioritisation**.
4. **Prioritise high-TRL treatments where treatments are needed** for soils, groundwater and non-drinking waters: soil washing and immobilisation for soils; pump-and-treat with GAC/IX for plumes; and GAC/IX/foam fractionation as principal water treatments.
5. **Manage biosolids by outcome**: apply only where soils remain below thresholds, backed by monitoring; keep destruction as a future option pending resolution of energy/carbon footprint, cost, emissions and siting uncertainties.

10.4.8 PFAS destruction technologies: summary of discussion and conclusions

The panel adopted a clear stance on technology maturity: only destruction options at Technology Readiness Level (TRL) 8-9 are acceptable for implementation. Anything below this threshold remains experimental and lacks the operational proof required for dependable results at scale. While many offerings are marketed as solutions, the group agreed that the bar should mirror that used for medicines; credible, real-world trials before adoption; so that policy rests on demonstrated performance rather than a promise.

Within that frame, thermal destruction is the only option considered mature enough today. Breaking the carbon-fluorine bond demands very high energy; around 1,100 °C is cited for complete destruction, whereas waste-to-energy incineration at 850 °C has shown reasonable effectiveness in some studies. The evidence indicates incineration does not eliminate PFAS entirely, but achieves approximately 99.9% destruction, leaving trace amounts in ash and associated wastewater streams. This residual risk underscores that thermal treatment is not perfect, yet it is currently the only consistently validated route to near-total breakdown. Proposals to re-incinerate ash at higher temperature were viewed as untested (TRL 1–2) and impractical in Jersey given limited capacity in the clinical-waste incinerator.

On landfill or hazardous-waste storage, the group drew a strict distinction between containment and destruction. Landfill does not destroy PFAS; it locks them into a long-term management problem. Modern facilities capture leachate for specialised treatment, but volatile PFAS can still diffuse to air, and indefinite stewardship is required. As a result, landfill (or hazardous-waste storage) should be reserved for small-volume residues such as incinerator ash, not for bulk materials like contaminated soils or biosolids. Capacity constraints in Jersey further reinforce this hierarchy and the need to avoid filling scarce hazardous-waste cells with high-volume PFAS wastes.

The panel also considered waste-stream specifics. Spent granular activated carbon (GAC) was seen as relatively straightforward: it is combustible, generally carries lower PFAS loadings, and arises in small volumes, making treatment in a municipal waste-to-energy plant a feasible route. By contrast, reject streams from reverse osmosis (RO) or nanofiltration (NF) are non-combustible, so disposal choices must be accounted for upfront when planning water-treatment trains. This disposal perspective should inform technology selection: choosing capture methods without a viable end-of-life pathway simply shifts the problem downstream. For any large-scale destruction of biosolids or contaminated soil, the panel noted that additional infrastructure may be required..

10.4.9 Potential areas for recommendation on PFAS destruction

1. **Apply a TRL 8-9 appetite for destruction.** Only technologies proven reliable in operational settings should be implemented.
2. **Use high-temperature incineration as the primary destruction route.** Expect near-complete (~99.9%) destruction with trace residues in ash and process waters; recognise that 850 °C is effective but not absolute, and 1,100 °C is the benchmark for complete destruction.
3. **Treat landfill as last-resort containment.** Reserve hazardous-waste capacity for small-volume residues (e.g., ash), not bulk soils or biosolids.
4. **Plan for end-of-life at the design stage.** Prefer capture options with viable disposal pathways: **GAC** is combustible and small-volume; RO/NF rejectate is non-combustible and must be planned for accordingly.
5. **Use soil washing for hotspots where feasible; contain lower-risk areas.** In the absence of dedicated plant, prioritise hotspots for active treatment and rely on containment only where justified.
6. **Do not recommend untested escalation steps.** Re-incineration of ash or other secondary treatments are below the TRL threshold and impractical locally.
7. **Track emerging methods but defer deployment.** Options like supercritical water oxidation remain promising yet immature; revisit only when TRL and local feasibility improve.

10.5 Summary of expert evidence, discussions and literature reviews on borehole and in-home water treatment

10.5.1 Borehole supply treatment (small groundwater supplies)

For small borehole and well supplies, the goal is to reduce PFAS reliably to very low finished-water targets using compact, serviceable systems. Three separation approaches dominate: granular activated carbon (GAC), ion exchange (IX), and reverse osmosis/tight nanofiltration (RO/NF). Performance depends on the site's PFAS mixture (especially the balance of short- vs long-chain species) and the raw water chemistry.

10.5.1.1 GAC – strengths, weaknesses, mitigations.

- **Strengths:** Proven, simple to operate, strong attenuation of long-chain PFAS, broad polishing of organics, and taste/odour improvement.
- **Weaknesses:** Earlier breakthrough for short-chains; capacity loss when dissolved organic carbon (DOC), iron/manganese, or turbidity are elevated.
- **Mitigations:** Lead-lag vessels with a “sentinel” sample point between beds; conservative empty-bed contact time (EBCT); straightforward pretreatment (particulate removal, iron/manganese control, DOC reduction) to keep the carbon clean and extend run length.

10.5.1.2 IX resins – strengths, weaknesses, mitigations.

- **Strengths:** Generally better short-chain control than GAC at similar EBCTs; compact vessels; longer run lengths where short-chains dominate.
- **Weaknesses:** Competition from common anions (e.g., sulphate, bicarbonate); end-of-life management (single-use disposal vs regeneration brines).
- **Mitigations:** Match resin chemistry to the matrix; arrange lead–lag vessels; choose single-use media where brine handling is impractical, or, if regenerating, plan a responsible route for PFAS-bearing brine.

10.5.1.3 RO/NF – strengths, weaknesses, mitigations.

- **Strengths:** Broad, high removal across PFAS suites (including many short-chains) and co-benefits for inorganics.
- **Weaknesses:** Produces a PFAS-rich concentrate (typically 15–50% of feed); membrane fouling/scaling risk; needs pretreatment and periodic cleaning/membrane replacement. Loss of water.
- **Mitigations:** Cartridge prefiltration; softening/antiscalant where appropriate; recovery set to the fouling tendency; routine integrity checks; planned management of the concentrate (sewering if allowed, hauling, or volume reduction).

10.5.1.4 Hybrid/side-stream options.

Foam fractionation can lower PFAS loading ahead of GAC/IX or shrink RO/NF concentrate volumes. Where used, destructive steps (e.g., electrochemical) are best targeted at these smaller, PFAS-rich side streams.

10.5.1.5 *Design, operation, and residuals.*

Small systems typically use lead-lag adsorption with inter-vessel sampling so change-out precedes breakthrough; EBCT is set using pilot or RSSCT data on the actual groundwater. RO/NF skids come with prefilters and integrity checks. All options transfer PFAS to residuals (spent carbon/resin, brines, concentrate), so disposal or treatment routes need to be planned from the outset; in some settings, residuals logistics become the binding constraint.

10.5.1.6 *In summary*

GAC, IX, and RO/NF are the workhorses. Where short-chains dominate, IX or RO/NF usually sustains performance longer than GAC. Conservative sizing, basic pretreatment, verification monitoring, and (where helpful) hybrid trains reduce risk and operating burden.

10.5.2 Treatment of water in the home

Consumer devices are typically certified under standards for adsorptive/IX filters and for RO. These certifications confirm performance under standardised challenge waters but are not the same as local health-based limits; real-world outcomes still depend on the household's water chemistry, the PFAS mixture, and maintenance discipline.

10.5.2.1 *Technology overview — relative strengths, weaknesses, and mitigations.*

10.5.2.1.1 *Activated carbon (granular or carbon block).*

- Strengths: Reliable attenuation of long-chain PFAS; broad organic polishing; improves taste and odour.
- Weaknesses: Variable short-chain removal; faster capacity loss with higher DOC and at higher flows.
- Mitigations: Larger media mass; slower flow/higher contact time; replace by litres treated (not just calendar time).

10.5.2.1.2 *Ion exchange (often blended with carbon in point-of-use cartridges).*

- Strengths: Better short-chain control than carbon alone; compact cartridges.
- Weaknesses: Capacity can be consumed quickly when influent PFAS or DOC are high; some designs are sensitive to competing anions.
- Mitigations: Choose PFAS-specific cartridges; track throughput; replace proactively.

10.5.2.1.3 *Reverse osmosis (or tight NF).*

- Strengths: Most consistent broad-spectrum PFAS reduction at the tap; also reduces many inorganic co-contaminants.
- Weaknesses: Generates a reject stream; needs prefilters and periodic membrane replacement.
- Mitigations: Follow maintenance schedules; protect the membrane with prefiltration; plan for concentrate discharge.

Certification signals audited testing but does not guarantee parts-per-trillion outcomes in every home. Field experience consistently shows wide variability among single-stage carbon devices, while

multi-stage carbon/IX and RO tend to perform substantially better: provided cartridges and membranes are replaced on time and contact time is preserved.

10.5.2.2 *Relative effectiveness by deployment level*

10.5.2.2.1 Whole-home (point-of-entry, POE)

- What it can include.
 - Large-bed activated carbon or carbon + ion-exchange (IX) trains (single or multistage in lead–lag).
 - Whole-home RO/NF (less common but feasible), typically with prefiltration, a permeate tank/booster pump, and post-carbon polishing.
- Effectiveness.
 - Multistage carbon/IX (e.g., IX→GAC or GAC→IX in lead–lag) improves control of both long- and short-chain PFAS versus single-media systems and extends run length.
 - POE RO/NF provides broad, consistent PFAS reduction across suites (including many short-chains) at every outlet, with added benefits for salts and metals.
- Benefits.
 - Multistage carbon/IX: House-wide coverage; robust for variable household flows when beds are generously sized; straightforward operation; taste/odour polishing.
 - POE RO/NF: Highest, most uniform whole-home PFAS reduction (drinking, cooking, bathing, laundry); useful where short-chains dominate or influent levels vary; co-benefits for other contaminants.
- Weaknesses.
 - Multistage carbon/IX: Short-chain breakthrough risk at high instantaneous flows if contact time is tight; multiple vessels increase footprint and cost; spent media must be managed.
 - POE RO/NF: Produces a concentrate (reject) stream that must be discharged properly; lower recovery increases wastewater volume; requires pretreatment (scaling/fouling control), storage/pressurisation, and periodic membrane service; higher capital and space demands than single-media POE.
- Mitigations.
 - Multistage carbon/IX: Use lead–lag staging with inter-bed sampling; size for conservative EBCT; add pretreatment (iron/manganese/particulate management and DOC reduction); set replacement triggers on sentinel short-chains well below any target.
 - POE RO/NF: Provide cartridge prefiltration and, where needed, softening/antiscalant; design for appropriate recovery with a validated concentrate disposal route; include permeate storage and booster pumping to stabilise pressure/flow; add a post-carbon polish; plan scheduled membrane maintenance. Where practical, partial POE (for example, RO/NF on cold lines or a dedicated manifold) can reduce load and waste while still covering critical outlets.

10.5.2.2.2 Under-sink point-of-use (POU, one tap — plumbed)

- Effectiveness.
 - Under-sink RO consistently delivers the highest reductions across broad PFAS suites (often to near detection when membranes are intact).
 - Composite carbon/IX cartridges reliably reduce long-chains and perform moderately to well on short-chains, but are sensitive to DOC and flow/contact time.
- Benefits.
 - Targets the drinking/cooking tap where most ingestion occurs; RO also reduces many inorganic co-contaminants.
- Weaknesses.
 - RO produces a reject stream and needs periodic prefilter/membrane replacement; carbon/IX cartridges are capacity-limited and can exhaust quickly when influent PFAS are elevated.
- Mitigations.
 - For RO: keep prefilters and membranes on schedule. For carbon/IX: use PFAS-oriented designs, track litres treated, and replace proactively.

10.5.2.2.3 Worktop/countertop (plug-in RO and non-RO)

- Effectiveness.
 - Plug-in RO units with reservoirs can achieve reductions comparable to under-sink RO without plumbing changes. Non-RO countertop devices using carbon or carbon/IX can perform similarly to under-sink cartridges if contact time and media mass are sufficient; results are design-dependent.
- Benefits.
 - Flexible installation and portability—useful for renters or where plumbing changes are impractical.
- Weaknesses.
 - RO units still generate reject water; non-RO designs can decline faster with heavy use or inadequate contact time.
- Mitigations.
 - Choose designs with validated performance; obey cartridge change-out volumes; ensure flow control that preserves contact time.

10.5.2.2.4 Pitcher/gravity “filter jugs” (single-stage)

- Effectiveness.
 - Can reduce PFOA/PFOS and some short-chains, but performance varies widely by brand/design and often declines quickly; gravity flow limits contact time and capacity.
- Benefits.
 - Lowest upfront cost and simplest to deploy.
- Weaknesses.

- Generally the weakest and fastest-declining short-chain removal; small capacities (typically tens to a few hundred litres per cartridge); highly sensitive to DOC and throughput.
- Mitigations.
 - Replace cartridges based on litres treated (not just time); choose models with higher media mass and controlled flow; where possible, verify performance periodically.

10.5.2.3 *Choosing among in-home options.*

- For highest and most consistent reductions at the drinking tap, under-sink RO (and plug-in worktop RO) are the strongest options when maintained.
- Well-designed multi-stage carbon/IX units can perform strongly with careful cartridge management.
- Whole-home carbon/IX delivers house-wide benefits but requires conservative sizing and verification to control short-chain breakthrough at high flows.
- Single-stage filter jugs provide incremental, variable reduction at low cost but demand especially diligent replacement to sustain performance.

10.5.2.4 *Key considerations*

Every separation process transfers PFAS to residuals: spent carbon/resin, RO/NF concentrate, or regenerant brine. In settings with limited disposal options, residuals management can dominate feasibility and cost. Define disposal, reactivation, regeneration, or side-stream volume-reduction routes before committing to a train.

Certification verifies performance under standardised lab challenges; achieving very low, health-based targets in the home still depends on matching technology to local water composition and on disciplined maintenance and verification.

Whether the solution is GAC, IX, RO/NF, or a hybrid, performance hinges on sticking to replacement and cleaning intervals set by actual water use/quality; not just the calendar. For homeowners, clear, volume-based change-out triggers and simple upkeep routines are the best mitigations against performance decline

Combinations (e.g., IX to GAC, or RO/NF with foam fractionation on the concentrate) can extend run length, reduce residual volumes, and improve robustness. At POE scale, multistage carbon/IX increases resilience to high flows; where feasible, POE RO/NF provides the most uniform whole-home reduction but requires thoughtful recovery, storage/pressurisation, and concentrate handling.

10.6 Panel discussions on borehole and in-home water treatment

10.6.1 Boreholes and other private supplies

The panel framed recommendations for private supplies as advisory, not mandatory, because boreholes lie outside Jersey’s statutory drinking-water regime and there is no legal mechanism for enforcement or liability assignment.

- For **multi-household boreholes**, an aspirational target aligned with mains water; currently 4 ng/L (sum of four PFAS) with an additional threshold of 10ng/L for the sum of a larger group of PFAS; was judged appropriate, provided it is clearly signposted as guidance. The panel stressed proportionality: shaving concentrations from, for example, 5 ng/L to 4 ng/L could impose disproportionate costs on owners and users with negligible benefit. Any disputes would, in practice, be civil matters between households and borehole owners.
- For **single-household boreholes** and wells, the panel did not support a formal numerical threshold. In the absence of statutory obligations, decisions should rest with guidance rather than prescriptive rules. A hypothetical concern; that discharging contaminated borehole water to sewer could introduce PFAS into municipal treatment; was considered. With no licensing system for private supplies and limited data on connections, contributions from such discharges were judged minimal and not a regulatory priority.

On treatment technologies, the panel rejected one-size-fits-all prescriptions. Interventions should be case-by-case, reflecting source water chemistry, PFAS levels and the capacity and reliability of the supply. The group endorsed high-TRL (mature) options already in the market; granular activated carbon (GAC), ion exchange resins, reverse osmosis (RO) and nanofiltration; noting that RO generally offers the highest PFAS removal in a compact footprint. However, RO brings energy use and wastewater generation; if a borehole comfortably meets demand, RO is practicable, but if ~20% wastage would jeopardise supply, alternatives (GAC/IX/NF) may be more proportionate.

10.6.2 Home water treatment

For in-home treatment (under-sink systems, countertop/worktop units, filter jugs), the panel chose to offer general guidance, not product endorsements. Expert reviews and prior discussions indicate that multi-stage systems are highly effective at PFAS removal, whereas single-stage carbon jugs are comparatively inefficient. The panel highlighted real-world performance as the crucial differentiator. Laboratory testing by the Environmental Working Group (EWG) showed strong results for some countertop devices, but a North Carolina field survey found that some jug filters underperformed relative to lab conditions, possibly due to inconsistent cartridge replacement and variable usage. Fixed under-sink installations tend to deliver more consistent outcomes, particularly when maintained correctly.

The panel chose to signpost households to helpful resources which review a number of brands (though not all); specifically, the EWG report and the North Carolina field study; rather than endorse brands or specific models. Guidance should emphasise maintenance discipline (timely cartridge changes, correct storage and adherence to manufacturer instructions) and transparently explain trade-offs, including RO water wastage, which may matter during periods of scarcity. The panel did not recommend blanket connection to mains water at this stage.

10.6.3 Potential areas for recommendation

1. **Multi-household boreholes:** Adopt an advisory target aligned with mains water, with clear messaging on cost–proportionality.
2. **Single-household boreholes:** offer information-based guidance so households can choose proportionate measures.
3. **Private-supply treatment:** Guidance should discuss the pros and cons of different technologies so that households can make appropriate choices
4. **In-home treatment:** If considered, favour multi-stage over single-stage jugs for robust PFAS removal; underscore the maintenance required to sustain performance.
5. **Guidance should:** Direct Islanders to the EWG report and the North Carolina field study; explain trade-offs (especially RO wastage) in plain language.

11 Recommendations

The panel recommends that:

1. **Agricultural land and sensitive land such as water abstraction areas should not be considered to be PFAS affected unless they contain a sum of four PFAS (PFOS, PFOA, PFHxS, PFNA) that exceeds 4 µg/kg dry weight.**
2. **Residential, recreational and industrial land should not be considered to be PFAS affected unless they contain a sum of four PFAS (PFOS, PFOA, PFHxS, PFNA) that exceeds 8 µg/kg dry matter.**
3. **If land other than agricultural, sensitive, residential, recreational or industrial has or a sum of four PFAS (PFOS, PFOA, PFHxS, PFNA) that exceeds 20 µg/kg dry matter, the source of contamination should be identified and remediation considered.**
4. **Where land meets the relevant threshold for being PFAS affected, a risk assessment should be undertaken to clarify appropriate land management and usage, testing and retesting schedules of land or any products from that land, and any further source investigation or remediation.**
5. **If surface or ground waters that are not to be used for drinking water production are found to have a sum of four PFAS (PFOS, PFOA, PFHxS, PFNA) that exceeds 10 ng/L, the source of that contamination should be identified and mitigation considered.**
6. **When treating water or soil or when destroying PFAS-contaminated materials, only interventions with a technology readiness level (TRL) of 8 or above should be considered. Those include soil washing and immobilisation for soils; pump-and-treat with GAC/IX for plumes; and GAC/IX (and foam fractionation/RO/NF depending on setting) as principal water treatments and thermal destruction of resulting concentrates.**
7. **For all interventions, plan for end of life and total PFAS pathway at the design stage.**
8. **Biosolids should only be applied to land when the level of PFAS in that land is below the contamination threshold for that particular land type and will not be raised above that threshold by the application of biosolids.**
9. **Consideration should be given to the longer-term management of biosolids using destruction technologies. It is likely that this will require additional infrastructure.**
10. **Use incineration as the primary PFAS destruction route for contaminated activated carbon or ion exchange resins.**
11. **Use hazardous waste landfill solely as last resort containment for small volumes, such as post-incineration ash, and not bulk soils or biosolids**
12. **Soil washing may be appropriate for contamination hotspots; for lower contamination areas, containment should be considered when appropriate**
13. **Where a borehole or a well supplies drinking water to multiple premises, the owner of the supply should consider applying a standard of 4 ng/L for the simple sum of four PFAS (PFOS, PFOA, PFHxS, PFNA) and/or 10 ng/L for the sum of forty-eight measurable PFAS.**
14. **For a borehole or well that supplies a single household, public authorities should make available information on different potential treatment options that the owner may wish to consider. That information should include the relative strengths and weaknesses and the necessary maintenance.**

- 15. If a household is considering in-home water treatment for PFAS, generally speaking, multistage processes are more effective and efficient than single stage filter jugs (although more expensive). It is important to adhere to the maintenance and replacement schedules of any given product.**
- 16. Public authorities should make available information on the strengths and weaknesses of in home treatment options; drawing on reports such as that of the Environmental Working Group and the North Carolina field study.**

DRAFT

References

- Abraham, K., & Monien, B. H. (2022). Transdermal absorption of ¹³C₄-perfluorooctanoic acid (¹³C₄-PFOA) from a sunscreen in a male volunteer – What could be the contribution of cosmetics to the internal exposure of perfluoroalkyl substances (PFAS)? *Environment International*, 169, 107549. <https://doi.org/10.1016/j.envint.2022.107549>
- Ackerman Grunfeld, D., Gilbert, D., Hou, J., Jones, A. M., Lee, M. J., Kibbey, T. C. G., & O’Carroll, D. M. (2024). Underestimated burden of per- and polyfluoroalkyl substances in global surface waters and groundwaters. *Nature Geoscience*, 17(4), 340–346. <https://doi.org/10.1038/s41561-024-01402-8>
- AECOM. (2016). *Stage 2C Environmental Investigation - Human Health Risk Assessment, Army Aviation Centre Oakey 01/09/2016*. <https://publications.aecom.com/pfas/solutions/pfas-contamination-investigation>
- Alsadik, A., Akintunde, O. O., Habibi, H. R., & Achari, G. (2025). PFAS in water environments: recent progress and challenges in monitoring, toxicity, treatment technologies, and post-treatment toxicity. *ENVIRONMENTAL SYSTEMS RESEARCH*, 14(1), Article 18. <https://doi.org/10.1186/s40068-025-00411-9>
- Andersson, A. G., Fletcher, T., Xu, Y., Kärrman, A., Pineda, D., Nilsson, C. A., Lindh, C. H., Jakobsson, K., & Li, Y. (2025). The relative importance of fecal and urinary excretion of perfluorooctane sulfonic acid and perfluorooctanoic acid after high exposure - An observational study in Ronneby, Sweden. *Environ Res*, 285(Pt 3), 122487. <https://doi.org/10.1016/j.envres.2025.122487>
- Appleman, T. D., Higgins, C. P., Quiñones, O., Vanderford, B. J., Kolstad, C., Zeigler-Holady, J. C., & Dickenson, E. R. V. (2014). Treatment of poly- and perfluoroalkyl substances in U.S. full-scale water treatment systems. *Water Research*, 51, 246–255. <https://doi.org/10.1016/j.watres.2013.10.067>
- Armstrong, B. K., & Kricker, A. (2001). The epidemiology of UV induced skin cancer. *J Photochem Photobiol B*, 63(1-3), 8–18. [https://doi.org/10.1016/s1011-1344\(01\)00198-1](https://doi.org/10.1016/s1011-1344(01)00198-1)
- Arvaniti, O. S., Hwang, Y., Andersen, H. R., Stasinakis, A. S., Thomaidis, N. S., & Aloupi, M. (2015). Reductive degradation of perfluorinated compounds in water using Mg-aminoclay coated nanoscale zero valent iron. *Chemical Engineering Journal*, 262, 133–139. <https://doi.org/10.1016/j.cej.2014.09.079>
- Backe, W. J., Day, T. C., & Field, J. A. (2013). Zwitterionic, cationic, and anionic fluorinated chemicals in aqueous film forming foam formulations and groundwater from U.S. military bases by nonaqueous large-volume injection HPLC-MS/MS. *Environ Sci Technol*, 47(10), 5226–5234. <https://doi.org/10.1021/es3034999>
- Badruddoza, A. Z. M., Bhattarai, B., & Suri, R. P. S. (2017). Environmentally Friendly β-Cyclodextrin-Ionic Liquid Polyurethane-Modified Magnetic Sorbent for the Removal of PFOA, PFOS, and Cr(VI) from Water. *ACS Sustainable Chemistry & Engineering*, 5(10), 9223–9232. <https://doi.org/10.1021/acssuschemeng.7b02186>
- Barry, V., Winqvist, A., & Steenland, K. (2013). Perfluorooctanoic acid (PFOA) exposures and incident cancers among adults living near a chemical plant. *Environ Health Perspect*, 121(11-12), 1313–1318. <https://doi.org/10.1289/ehp.1306615>
- Batzella, E., Fletcher, T., Pitter, G., da Re, F., Russo, F., di Nisio, A., & Canova, C. (2024). Decreases in serum PFAS are associated with decreases in serum lipids: A longitudinal study on a highly exposed population. *Sci Total Environ*, 954, 176227. <https://doi.org/10.1016/j.scitotenv.2024.176227>

- Beesoon, S., Webster Glenys, M., Shoeib, M., Harner, T., Benskin Jonathan, P., & Martin Jonathan, W. (2011). Isomer Profiles of Perfluorochemicals in Matched Maternal, Cord, and House Dust Samples: Manufacturing Sources and Transplacental Transfer. *Environmental Health Perspectives*, 119(11), 1659–1664. <https://doi.org/10.1289/ehp.1003265>
- BFR. (2025). *Weniger PFAS in Hühnereiern aus Boden- und Freilandhaltung – Eier und Eiprodukte tragen aber weiterhin zur Gesamtexposition bei. (Lower levels of PFAS in barn and free-range eggs – however, eggs and egg products still contribute to overall exposure.) Statement No. 043/2025. Federal Institute for Risk Assessment.* <https://www.bfr.bund.de/stellungnahme/weniger-pfas-in-huehnereiern-aus-boden-und-freilandhaltung-eier-und-eiprodukte-tragen-aber-weiterhin-zur-gesamtexposition-bei/>
- Biggeri, A., Stoppa, G., Facciolo, L., Fin, G., Mancini, S., Manno, V., Minelli, G., Zamagni, F., Zamboni, M., Catelan, D., & Bucchi, L. (2024). All-cause, cardiovascular disease and cancer mortality in the population of a large Italian area contaminated by perfluoroalkyl and polyfluoroalkyl substances (1980-2018). *Environ Health*, 23(1), 42. <https://doi.org/10.1186/s12940-024-01074-2>
- Björklund, S., Carlund, A., Weidemann, E., & Jansson, S. (2024). Occurrence and mass flow rate of PFAS in a Waste-to-Energy water treatment process. *Waste Management*, 190, 169–173. <https://doi.org/https://doi.org/10.1016/j.wasman.2024.09.020>
- Björklund, S., Weidemann, E., & Jansson, S. (2023). Emission of Per- and Polyfluoroalkyl Substances from a Waste-to-Energy Plant—Occurrence in Ashes, Treated Process Water, and First Observation in Flue Gas. *Environmental Science & Technology*, 57(27), 10089–10095. <https://doi.org/10.1021/acs.est.2c08960>
- Blaine, A. C., Rich, C. D., Hundal, L. S., Lau, C., Mills, M. A., Harris, K. M., & Higgins, C. P. (2013). Uptake of Perfluoroalkyl Acids into Edible Crops via Land Applied Biosolids: Field and Greenhouse Studies. *Environmental Science & Technology*, 47(24), 14062–14069. <https://doi.org/10.1021/es403094q>
- Blaine, A. C., Rich, C. D., Sedlacko, E. M., Hundal, L. S., Kumar, K., Lau, C., Mills, M. A., Harris, K. M., & Higgins, C. P. (2014). Perfluoroalkyl Acid Distribution in Various Plant Compartments of Edible Crops Grown in Biosolids-Amended soils. *Environmental Science & Technology*, 48(14), 7858–7865. <https://doi.org/10.1021/es500016s>
- Blaine, A. C., Rich, C. D., Sedlacko, E. M., Hyland, K. C., Stushnoff, C., Dickenson, E. R. V., & Higgins, C. P. (2014). Perfluoroalkyl Acid Uptake in Lettuce (*Lactuca sativa*) and Strawberry (*Fragaria ananassa*) Irrigated with Reclaimed Water. *Environmental Science & Technology*, 48(24), 14361–14368. <https://doi.org/10.1021/es504150h>
- Bline, A. P., DeWitt, J. C., Kwiatkowski, C. F., Pelch, K. E., Reade, A., & Varshavsky, J. R. (2024). Public Health Risks of PFAS-Related Immunotoxicity Are Real. *Curr Environ Health Rep*, 11(2), 118–127. <https://doi.org/10.1007/s40572-024-00441-y>
- Brunn, H., Arnold, G., Körner, W., Rippen, G., Steinhäuser, K. G., & Valentin, I. (2023). PFAS: forever chemicals—persistent, bioaccumulative and mobile. Reviewing the status and the need for their phase out and remediation of contaminated sites. *Environmental Sciences Europe*, 35(1), 20. <https://doi.org/10.1186/s12302-023-00721-8>
- Brusseau, M. L., Anderson, R. H., & Guo, B. (2020). PFAS concentrations in soils: Background levels versus contaminated sites. *Science of The Total Environment*, 740, 140017. <https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.140017>
- Bruton, T. A., & Sedlak, D. L. (2017). Treatment of Aqueous Film-Forming Foam by Heat-Activated Persulfate Under Conditions Representative of In Situ Chemical Oxidation. *Environmental Science & Technology*, 51(23), 13878–13885. <https://doi.org/10.1021/acs.est.7b03969>

- Buck, R., Franklin, J., Berger, U., Conder, J., Cousins, I., de Voogt, P., Jensen, A., Kannan, K., Mabury, S., & van Leeuwen, S. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integr Environ Assess Manag*, 513–541.
- Canova, C., Barbieri, G., Zare Jeddi, M., Gion, M., Fabricio, A., Daprà, F., Russo, F., Fletcher, T., & Pitter, G. (2020). Associations between perfluoroalkyl substances and lipid profile in a highly exposed young adult population in the Veneto Region. *Environment International*, 145, 106117. <https://doi.org/https://doi.org/10.1016/j.envint.2020.106117>
- Carey, G. R., Hakimabadi, S. G., Singh, M., McGregor, R., Woodfield, C., Van Geel, P. J., & Pham, A. L.-T. (2022). Longevity of colloidal activated carbon for in situ PFAS remediation at AFFF-contaminated airport sites. *Remediation Journal*, 33(1), 3–23. <https://doi.org/https://doi.org/10.1002/rem.21741>
- Chow, S. J., Croll, H. C., Ojeda, N., Klamerus, J., Capelle, R., Oppenheimer, J., Jacangelo, J. G., Schwab, K. J., & Prasse, C. (2022). Comparative investigation of PFAS adsorption onto activated carbon and anion exchange resins during long-term operation of a pilot treatment plant. *Water Res*, 226, 119198. <https://doi.org/10.1016/j.watres.2022.119198>
- Concawe. (2020). https://www.concawe.eu/wp-content/uploads/Rpt_20-14.pdf. https://www.concawe.eu/wp-content/uploads/Rpt_20-14.pdf
- Cornelissen, G., Briels, N., Bucheli, T. D., Estoppey, N., Gredelj, A., Hagemann, N., Lerch, S., Lotz, S., Rasse, D., Schmidt, H.-P., Sørmo, E., & Arp, H. P. H. (2025). A Virtuous Cycle of Phytoremediation, Pyrolysis, and Biochar Applications toward Safe PFAS Levels in Soil, Feed, and Food. *Journal of Agricultural and Food Chemistry*, 73(6), 3283–3285. <https://doi.org/10.1021/acs.jafc.5c00651>
- Corsini, E., Sokooti, M., Galli, C. L., Moretto, A., & Colosio, C. (2013). Pesticide induced immunotoxicity in humans: a comprehensive review of the existing evidence. *Toxicology*, 307, 123–135. <https://doi.org/10.1016/j.tox.2012.10.009>
- Cousins, I. T., DeWitt, J. C., Glüge, J., Goldenman, G., Herzke, D., Lohmann, R., Ng, C. A., Scheringer, M., & Wang, Z. (2020). The high persistence of PFAS is sufficient for their management as a chemical class. *Environ. Sci.: Processes Impacts*, 22(12), 2307–2312.
- Cousins, I. T., Johansson, J. H., Salter, M. E., Sha, B., & Scheringer, M. (2022). Outside the Safe Operating Space of a New Planetary Boundary for Per- and Polyfluoroalkyl Substances (PFAS). *Environmental Science & Technology*, 56(16), 11172–11179. <https://doi.org/10.1021/acs.est.2c02765>
- Cui, J., Gao, P., & Deng, Y. (2020). Destruction of Per- and Polyfluoroalkyl Substances (PFAS) with Advanced Reduction Processes (ARPs): A Critical Review. *Environmental Science & Technology*, 54(7), 3752–3766. <https://doi.org/10.1021/acs.est.9b05565>
- Cui, L., Liao, C.-y., Zhou, Q.-f., Xia, T.-m., Yun, Z.-j., & Jiang, G.-b. (2010). Excretion of PFOA and PFOS in Male Rats During a Subchronic Exposure. *Archives of Environmental Contamination and Toxicology*, 58(1), 205–213. <https://doi.org/10.1007/s00244-009-9336-5>
- De Silva, A. O., Armitage, J. M., Bruton, T. A., Dassuncao, C., Heiger-Bernays, W., Hu, X. C., Kärrman, A., Kelly, B., Ng, C., Robuck, A., Sun, M., Webster, T. F., & Sunderland, E. M. (2021). PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding. *Environmental Toxicology and Chemistry*, 40(3), 631–657. <https://doi.org/https://doi.org/10.1002/etc.4935>
- Douglas, G. B., Vanderzalm, J. L., Williams, M., Kirby, J. K., Kookana, R. S., Bastow, T. P., Bauer, M., Bowles, K. C., Skuse, D., & Davis, G. B. (2023). PFAS contaminated asphalt and concrete - Knowledge gaps for future research and management. *Science of The Total Environment*, 887, 164025. <https://doi.org/https://doi.org/10.1016/j.scitotenv.2023.164025>

- Eaton, D., & Klaassen, C. D. (2008). Principles of toxicology in Casarett and Doull's Toxicology: The Basis Science of Poisons. *Principles of Toxicology, Casarett and Doull's Toxicology: The Basic Science of Poisons.*, 11–43.
- EFSA, Schrenk, D., Bignami, M., Bodin, L., Chipman, J. K., Del Mazo, J., Grasl-Kraupp, B., Hogstrand, C., Hoogenboom, L. R., Leblanc, J. C., Nebbia, C. S., Nielsen, E., Ntzani, E., Petersen, A., Sand, S., Vleminckx, C., Wallace, H., Barregard, L., Ceccatelli, S.,...Schwerdtle, T. (2020). Risk to human health related to the presence of perfluoroalkyl substances in food. *EFSA J*, 18(9), e06223. <https://doi.org/10.2903/j.efsa.2020.6223>
- Enders J, W. R., Donovan E, Phelps D, Campbell G, May K, Baker E. (2025). Detection and Quantitation of Per- and Polyfluoroalkyl Substances in Sea Foam and the Corresponding Sea Water (Preprint). *ChemRxiv*. <https://doi.org/doi:10.26434/chemrxiv-2025-bhqg0>
- EU. (2008). *Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council*. EUR-Lex. <https://eur-lex.europa.eu/eli/dir/2008/105>
- European Commission. (2022). *COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT REPORT Accompanying the document Proposal for a Directive of the European Parliament and of the Council amending Directive 2000/60/EC establishing a framework for Community action in the field of water policy, Directive 2006/118/EC on the protection of groundwater against pollution and deterioration and Directive 2008/105/EC on environmental quality standards in the field of water policy*. Retrieved 26/11 from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2022%3A0540%3AFIN>
- European Environment Agency. (2024). *PFAS pollution in European waters*. EU. Retrieved 26/11 from <https://www.eea.europa.eu/en/analysis/publications/pfas-pollution-in-european-waters>
- Fasano, W. J., Kennedy, G. L., Szostek, B., Farrar, D. G., Ward, R. J., Haroun, L., & Hinderliter, P. M. (2005). Penetration of Ammonium Perfluorooctanoate Through Rat and Human Skin In Vitro. *Drug and Chemical Toxicology*, 28(1), 79–90. <https://doi.org/10.1081/DCT-39707>
- Fei, C., McLaughlin, J. K., Lipworth, L., & Olsen, J. (2010). Maternal concentrations of perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA) and duration of breastfeeding. *Scandinavian Journal of Work, Environment & Health*(5), 413–421. <https://doi.org/10.5271/sjweh.2908>
- Fei, C., McLaughlin, J. K., Tarone, R. E., & Olsen, J. (2007). Perfluorinated chemicals and fetal growth: a study within the Danish National Birth Cohort. *Environ Health Perspect*, 115(11), 1677–1682. <https://doi.org/10.1289/ehp.10506>
- Fennell, B. D., Mezyk, S. P., & McKay, G. (2022). Critical Review of UV-Advanced Reduction Processes for the Treatment of Chemical Contaminants in Water. *ACS Environ Au*, 2(3), 178–205. <https://doi.org/10.1021/acsenvironau.1c00042>
- FERA. (2025). *Contaminants monitoring programme for wild caught fish, crustaceans and cephalopods*. (FSA Research and Evidence, Issue. <https://doi.org/10.46756/001c.127617>
- Fernandes A, R. M., Smith F and Holland M (2012). *Organic Environmental Contaminants in the 2012 Total Diet Study Samples Report to the Food Standards Agency Fera Report FD 12/04*. <https://www.food.gov.uk/sites/default/files/media/document/research-report-total-diet-study.pdf>
- Fischer, F. C., Ludtke, S., Thackray, C., Pickard, H. M., Haque, F., Dassuncao, C., Endo, S., Schaidler, L., & Sunderland, E. M. (2024). Binding of Per- and Polyfluoroalkyl Substances (PFAS) to Serum

- Proteins: Implications for Toxicokinetics in Humans. *Environmental Science & Technology*, 58(2), 1055–1063. <https://doi.org/10.1021/acs.est.3c07415>
- Fitz-Simon, N., Fletcher, T., & Luster, M. I. (2013). Reductions in Serum Lipids with a 4-year Decline in Serum Perfluorooctanoic Acid and Perfluorooctanesulfonic Acid (vol 24, pg 569, 2013). *Epidemiology*, 24(6), 941–941. <https://doi.org/10.1097/EDE.0b013e3182a55cf8>
- Ford, A. T., & Ginley, F. (2024). Insights into PFAS contaminants before and after sewage discharges into a marine protected harbour. *Chemosphere*, 366, 143526. <https://doi.org/10.1016/j.chemosphere.2024.143526>
- Franco, J., Meade, B. J., Frasch, H. F., Barbero, A. M., & Anderson, S. E. (2012). Dermal Penetration Potential of Perfluorooctanoic Acid (PFOA) in Human and Mouse Skin. *Journal of Toxicology and Environmental Health, Part A*, 75(1), 50–62, OCA.0025.0001.0938. <https://doi.org/10.1080/15287394.2011.615108>
- Fromme, H., Mosch, C., Morovitz, M., Alba-Alejandre, I., Boehmer, S., Kiranoglu, M., Faber, F., Hannibal, I., Genzel-Boroviczény, O., Koletzko, B., & Völkel, W. (2010). Pre- and Postnatal Exposure to Perfluorinated Compounds (PFCs). *Environmental Science & Technology*, 44(18), 7123–7129. <https://doi.org/10.1021/es101184f>
- Fromme, H., Tittlemier, S. A., Völkel, W., Wilhelm, M., & Twardella, D. (2009). Perfluorinated compounds--exposure assessment for the general population in Western countries. *Int J Hyg Environ Health*, 212(3), 239–270. <https://doi.org/10.1016/j.ijheh.2008.04.007>
- Gannon, S. A., Johnson, T., Nabb, D. L., Serex, T. L., Buck, R. C., & Loveless, S. E. (2011). Absorption, distribution, metabolism, and excretion of 1-C-14 -perfluorohexanoate (C-14 -PFHx) in rats and mice [Article]. *Toxicology*, 283(1), 55–62. <https://doi.org/10.1016/j.tox.2011.02.004>
- Gebbink, W. A., Berger, U., & Cousins, I. T. (2015). Estimating human exposure to PFOS isomers and PFCA homologues: The relative importance of direct and indirect (precursor) exposure. *Environment International*, 74, 160–169. <https://doi.org/10.1016/j.envint.2014.10.013>
- Glüge, J., Scheringer, M., Cousins, I. T., DeWitt, J. C., Goldenman, G., Herzke, D., Lohmann, R., Ng, C. A., Trier, X., & Wang, Z. (2020). An overview of the uses of per- and polyfluoroalkyl substances (PFAS). *Environ. Sci.: Processes Impacts*, 22(12), 2345–2373.
- Gole, V. L., Sierra-Alvarez, R., Peng, H., Giesy, J. P., Deymier, P., & Keswani, M. (2018). Sono-chemical treatment of per- and poly-fluoroalkyl compounds in aqueous film-forming foams by use of a large-scale multi-transducer dual-frequency based acoustic reactor. *Ultrasonics Sonochemistry*, 45, 213–222. <https://doi.org/https://doi.org/10.1016/j.ultsonch.2018.02.014>
- Gottschall, N., Topp, E., Edwards, M., Payne, M., Kleywegt, S., & Lapen, D. R. (2017). Brominated flame retardants and perfluoroalkyl acids in groundwater, tile drainage, soil, and crop grain following a high application of municipal biosolids to a field. *Science of The Total Environment*, 574, 1345–1359. <https://doi.org/https://doi.org/10.1016/j.scitotenv.2016.08.044>
- Grandjean, P., Andersen, E. W., Budtz-Jørgensen, E., Nielsen, F., Mølbak, K., Weihe, P., & Heilmann, C. (2012). Serum vaccine antibody concentrations in children exposed to perfluorinated compounds. *Jama*, 307(4), 391–397. <https://doi.org/10.1001/jama.2011.2034>
- Guelfo, J. L., & Higgins, C. P. (2013). Subsurface transport potential of perfluoroalkyl acids at aqueous film-forming foam (AFFF)-impacted sites. *Environ Sci Technol*, 47(9), 4164–4171. <https://doi.org/10.1021/es3048043>
- Gützkow, K. B., Haug, L. S., Thomsen, C., Sabaredzovic, A., Becher, G., & Brunborg, G. (2012). Placental transfer of perfluorinated compounds is selective – A Norwegian Mother and Child sub-cohort study. *International Journal of Hygiene and Environmental Health*, 215(2), 216–219. <https://doi.org/https://doi.org/10.1016/j.ijheh.2011.08.011>

- Gyllenhammar, I., Benskin, J. P., Lignell, S., Kärsrud, A.-S., Sandblom, O., & Glynn, A. (2016). *Temporal trends of poly- and perfluoroalkyl substances (PFASs) in serum from children at 4, 8, and 12 years of age, in Uppsala 2008-2015*. <http://urn.kb.se/resolve?urn=urn:nbn:se:naturvardsverket:diva-6707>
- Han, H., Rafiq, M. K., Zhou, T., Xu, R., Mašek, O., & Li, X. (2019). A critical review of clay-based composites with enhanced adsorption performance for metal and organic pollutants. *Journal of Hazardous Materials*, 369, 780–796. <https://doi.org/https://doi.org/10.1016/j.jhazmat.2019.02.003>
- Herkert, N. J., Merrill, J., Peters, C., Bollinger, D., Zhang, S., Hoffman, K., Ferguson, P. L., Knappe, D. R. U., & Stapleton, H. M. (2020). Assessing the Effectiveness of Point-of-Use Residential Drinking Water Filters for Perfluoroalkyl Substances (PFASs). *Environmental Science & Technology Letters*, 7(3), 178–184. <https://doi.org/10.1021/acs.estlett.0c00004>
- Hopkins, Z. R., & Knappe, D. R. U. (2024). Predicting per- and polyfluoroalkyl substances removal in pilot-scale granular activated carbon adsorbers from rapid small-scale column tests. *Awwa Water Science*, 6(2), e1369. <https://doi.org/https://doi.org/10.1002/aws2.1369>
- Idris, O. A., & Erasmus, M. (2024). Degradation pathways of perfluoroalkyl and polyfluoroalkyl compounds: Removal in water and soil using fungi and plant-based remediation. *Environmental Advances*, 18, 100598. <https://doi.org/https://doi.org/10.1016/j.envadv.2024.100598>
- Inyang, M., & Dickenson, E. R. V. (2017). The use of carbon adsorbents for the removal of perfluoroalkyl acids from potable reuse systems. *Chemosphere*, 184, 168–175. <https://doi.org/10.1016/j.chemosphere.2017.05.161>
- ITRC. (2021). *Technical and Regulatory Guidance (Sections 3 & 5) (Per- and Polyfluoroalkyl Substances, Issue*. <https://pfas-1.itrcweb.org/wp-content/uploads/2022/03/PFAS-Full-PDF-December-2021-Update.pdf>
- ITRC. (2023). *11 Sampling and analysis*. ITRC. Retrieved 02/06 from <https://pfas-1.itrcweb.org/11-sampling-and-analytical-methods/>
- Johansson, J. H., Bolinius, D., Strandberg, J., Yang, J.-J., Benskin, J. P., & Awad, R. (2024). Emission of Perfluoroalkyl Acids and Unidentified Organofluorine from Swedish Municipal Waste Incineration Plants. *Environmental Science & Technology Letters*, 11(12), 1377–1383. <https://doi.org/10.1021/acs.estlett.4c00819>
- Johansson, J. H., Shi, Y., Salter, M., & Cousins, I. T. (2018). Spatial variation in the atmospheric deposition of perfluoroalkyl acids: source elucidation through analysis of isomer patterns [10.1039/C8EM00102B]. *Environmental Science: Processes & Impacts*, 20(7), 997–1006. <https://doi.org/10.1039/C8EM00102B>
- Kali, S. E., Österlund, H., Viklander, M., & Blecken, G.-T. (2025). Stormwater discharges affect PFAS occurrence, concentrations, and spatial distribution in water and bottom sediment of urban streams. *Water Research*, 271, 122973. <https://doi.org/https://doi.org/10.1016/j.watres.2024.122973>
- Kang, Y.-G., Birch, Q. T., Nadagouda, M. N., & Dionysiou, D. D. (2023). Advanced destruction technologies for PFAS in soils: Progress and challenges. *Current Opinion in Environmental Science & Health*, 33, 100459. <https://doi.org/https://doi.org/10.1016/j.coesh.2023.100459>
- Kärman, A., Ericson, I., van Bavel, B., Darnerud Per, O., Aune, M., Glynn, A., Lignell, S., & Lindström, G. (2007). Exposure of Perfluorinated Chemicals through Lactation: Levels of Matched Human Milk and Serum and a Temporal Trend, 1996–2004, in Sweden. *Environmental Health Perspectives*, 115(2), 226–230. <https://doi.org/10.1289/ehp.9491>

- Kennedy, G. L., Butenhoff, J. L., Olsen, G. W., O'Connor, J. C., Seacat, A. M., Perkins, R. G., Biegel, L. B., Murphy, S. R., & Farrar, D. G. (2004). The toxicology of perfluorooctanoate [Review]. *Critical Reviews in Toxicology*, 34(4), 351–384. <https://doi.org/10.1080/10408440490464705>
- Kim, S.-K., Lee, K. T., Kang, C. S., Tao, L., Kannan, K., Kim, K.-R., Kim, C.-K., Lee, J. S., Park, P. S., Yoo, Y. W., Ha, J. Y., Shin, Y.-S., & Lee, J.-H. (2011). Distribution of perfluorochemicals between sera and milk from the same mothers and implications for prenatal and postnatal exposures. *Environmental Pollution*, 159(1), 169–174. <https://doi.org/https://doi.org/10.1016/j.envpol.2010.09.008>
- Kim, S., Choi, K., Ji, K., Seo, J., Kho, Y., Park, J., Kim, S., Park, S., Hwang, I., Jeon, J., Yang, H., & Giesy, J. P. (2011). Trans-Placental Transfer of Thirteen Perfluorinated Compounds and Relations with Fetal Thyroid Hormones. *Environmental Science & Technology*, 45(17), 7465–7472. <https://doi.org/10.1021/es202408a>
- Koponen, J., Winkens, K., Airaksinen, R., Berger, U., Vestergren, R., Cousins, I. T., Karvonen, A. M., Pekkanen, J., & Kiviranta, H. (2018). Longitudinal trends of per- and polyfluoroalkyl substances in children's serum. *Environment International*, 121, 591–599. <https://doi.org/https://doi.org/10.1016/j.envint.2018.09.006>
- Kucharzyk, K. H., Darlington, R., Benotti, M., Deeb, R., & Hawley, E. (2017). Novel treatment technologies for PFAS compounds: A critical review. *Journal of Environmental Management*, 204, 757–764. <https://doi.org/https://doi.org/10.1016/j.jenvman.2017.08.016>
- Kudo, N., & Kawashima, Y. (2003). TOXICITY AND TOXICOKINETICS OF PERFLUOROOCANOIC ACID IN HUMANS AND ANIMALS. *The Journal of Toxicological Sciences*, 28(2), 49–57. <https://doi.org/10.2131/jts.28.49>
- Kumarasamy, E., Manning, I. M., Collins, L. B., Coronell, O., & Leibfarth, F. A. (2020). Ionic Fluorogels for Remediation of Per- and Polyfluorinated Alkyl Substances from Water. *ACS Central Science*, 6(4), 487–492. <https://doi.org/10.1021/acscentsci.9b01224>
- Lakshminarasimman, N., Gewurtz, S. B., Parker, W. J., & Smyth, S. A. (2021). Removal and formation of perfluoroalkyl substances in Canadian sludge treatment systems - A mass balance approach. *Science of The Total Environment*, 754, Article 142431. <https://doi.org/10.1016/j.scitotenv.2020.142431>
- Lau, C., Anitole, K., Hodes, C., Lai, D., Pfahles-Hutchens, A., & Seed, J. (2007). Perfluoroalkyl acids: a review of monitoring and toxicological findings. *Toxicol Sci*, 99(2), 366–394. <https://doi.org/10.1093/toxsci/kfm128>
- Lawrence, D. A., & McCabe, M. J., Jr. (2002). Immunomodulation by metals. *Int Immunopharmacol*, 2(2-3), 293–302. [https://doi.org/10.1016/s1567-5769\(01\)00180-1](https://doi.org/10.1016/s1567-5769(01)00180-1)
- Lei, Y.-J., Tian, Y., Sobhani, Z., Naidu, R., & Fang, C. (2020). Synergistic degradation of PFAS in water and soil by dual-frequency ultrasonic activated persulfate. *Chemical Engineering Journal*, 388, 124215. <https://doi.org/https://doi.org/10.1016/j.cej.2020.124215>
- Lenka, S. P., Kah, M., & Padhye, L. P. (2021). A review of the occurrence, transformation, and removal of poly- and perfluoroalkyl substances (PFAS) in wastewater treatment plants. *Water Research*, 199, Article 117187. <https://doi.org/10.1016/j.watres.2021.117187>
- Lesmeister, L., Lange, F. T., Breuer, J., Biegel-Engler, A., Giese, E., & Scheurer, M. (2021). Extending the knowledge about PFAS bioaccumulation factors for agricultural plants – A review. *Science of The Total Environment*, 766, 142640. <https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.142640>
- Li, Y., Andersson, A., Xu, Y., Pineda, D., Nilsson, C. A., Lindh, C. H., Jakobsson, K., & Fletcher, T. (2022). Determinants of serum half-lives for linear and branched perfluoroalkyl substances after long-term high exposure-A study in Ronneby, Sweden. *Environ Int*, 163, 107198. <https://doi.org/10.1016/j.envint.2022.107198>

- Li, Y., Fletcher, T., Mucs, D., Scott, K., Lindh, C. H., Tallving, P., & Jakobsson, K. (2018). Half-lives of PFOS, PFHxS and PFOA after end of exposure to contaminated drinking water. *Occupational and Environmental Medicine*, 75(1), 46–51. <https://doi.org/10.1136/oemed-2017-104651>
- Li, Y., Key, T. A., Vo, P. H. N., Porman, S., Thapalia, A., McDonough, J. T., Fiorenza, S., Barnes, C. M., Mueller, J. F., & Thai, P. K. (2024). Distribution and release of PFAS from AFFF-impacted asphalt: How does it compare to concrete? *J Hazard Mater*, 466, 133627. <https://doi.org/10.1016/j.jhazmat.2024.133627>
- Lin, H., Wang, Y., Niu, J., Yue, Z., & Huang, Q. (2015). Efficient Sorption and Removal of Perfluoroalkyl Acids (PFAAs) from Aqueous Solution by Metal Hydroxides Generated in Situ by Electrocoagulation. *Environmental Science & Technology*, 49(17), 10562–10569. <https://doi.org/10.1021/acs.est.5b02092>
- Lindstrom, A. B., Strynar, M. J., Delinsky, A. D., Nakayama, S. F., McMillan, L., Libelo, E. L., Neill, M., & Thomas, L. (2011). Application of WWTP Biosolids and Resulting Perfluorinated Compound Contamination of Surface and Well Water in Decatur, Alabama, USA. *Environmental Science & Technology*, 45(19), 8015–8021. <https://doi.org/10.1021/es1039425>
- Liu, J., Li, J., Liu, Y., Chan, H. M., Zhao, Y., Cai, Z., & Wu, Y. (2011). Comparison on gestation and lactation exposure of perfluorinated compounds for newborns. *Environment International*, 37(7), 1206–1212. <https://doi.org/https://doi.org/10.1016/j.envint.2011.05.001>
- Liu, J., Li, J., Zhao, Y., Wang, Y., Zhang, L., & Wu, Y. (2010). The occurrence of perfluorinated alkyl compounds in human milk from different regions of China. *Environment International*, 36(5), 433–438. <https://doi.org/https://doi.org/10.1016/j.envint.2010.03.004>
- Liu, J. X., & Avendano, S. M. (2013). Microbial degradation of polyfluoroalkyl chemicals in the environment: A review [Review]. *Environment International*, 61, 98–114, OCA.0025.0001.1076. <https://doi.org/10.1016/j.envint.2013.08.022>
- Livsmedelverket. (2024). *The Swedish Market Basket Study 2022. Per capita-based analyses of nutrients and toxic compounds in market baskets and assessment of benefit or risk.* <https://www.livsmedelverket.se/globalassets/publikationsdatabas/rapporter/2024/l-2024-nr-08-swedish-market-basket-study-2022.pdf>
- Llorca, M., Farré, M., Picó, Y., Teijón, M. L., Álvarez, J. G., & Barceló, D. (2010). Infant exposure of perfluorinated compounds: Levels in breast milk and commercial baby food. *Environment International*, 36(6), 584–592. <https://doi.org/https://doi.org/10.1016/j.envint.2010.04.016>
- Longendyke, G. K., Katel, S., & Wang, Y. (2022). PFAS fate and destruction mechanisms during thermal treatment: a comprehensive review [10.1039/D1EM00465D]. *Environmental Science: Processes & Impacts*, 24(2), 196–208. <https://doi.org/10.1039/D1EM00465D>
- Mackeown, H., Magi, E., Di Carro, M., & Benedetti, B. (2024). Removal of perfluoroalkyl and polyfluoroalkyl substances from tap water by means of point-of-use treatment: A review. *Science of The Total Environment*, 954, 176764. <https://doi.org/https://doi.org/10.1016/j.scitotenv.2024.176764>
- Mayakaduwege, S., Ekanayake, A., Kurwadkar, S., Rajapaksha, A. U., & Vithanage, M. (2022). Phytoremediation prospects of per- and polyfluoroalkyl substances: A review. *Environmental Research*, 212, 113311. <https://doi.org/https://doi.org/10.1016/j.envres.2022.113311>
- McCleaf, P., Englund, S., Östlund, A., Lindegren, K., Wiberg, K., & Ahrens, L. (2017). Removal efficiency of multiple poly- and perfluoroalkyl substances (PFASs) in drinking water using granular activated carbon (GAC) and anion exchange (AE) column tests. *Water Res*, 120, 77–87. <https://doi.org/10.1016/j.watres.2017.04.057>
- McDonough, J. T., Kirby, J., Bellona, C., Quinnan, J. A., Welty, N., Follin, J., & Liberty, K. (2022). Validation of supercritical water oxidation to destroy perfluoroalkyl acids. *Remediation-the*

- Journal of Environmental Cleanup Costs Technologies & Techniques*, 32(1-2), 75–90, Article 21711. <https://doi.org/10.1002/rem.21711>
- McGregor, R. (2018). In Situ treatment of PFAS-impacted groundwater using colloidal activated Carbon. *Remediation-the Journal of Environmental Cleanup Costs Technologies & Techniques*, 28(3), 33–41. <https://doi.org/10.1002/rem.21558>
- Mlüler, V., Kindness, A., & Feldmann, J. (2023). Fluorine mass balance analysis of PFAS in communal waters at a wastewater plant from Austria. *Water Research*, 244, Article 120501. <https://doi.org/10.1016/j.watres.2023.120501>
- Mogensen, U. B., Grandjean, P., Nielsen, F., Weihe, P., & Budtz-Jørgensen, E. (2015). Breastfeeding as an Exposure Pathway for Perfluorinated Alkylates. *Environ Sci Technol*, 49(17), 10466–10473. <https://doi.org/10.1021/acs.est.5b02237>
- Mondal, D., Weldon Rosana, H., Armstrong Ben, G., Gibson Lorna, J., Lopez-Espinosa, M.-J., Shin, H.-M., & Fletcher, T. (2014). Breastfeeding: A Potential Excretion Route for Mothers and Implications for Infant Exposure to Perfluoroalkyl Acids. *Environmental Health Perspectives*, 122(2), 187–192. <https://doi.org/10.1289/ehp.1306613>
- Monroy, R., Morrison, K., Teo, K., Atkinson, S., Kubwabo, C., Stewart, B., & Foster, W. G. (2008). Serum levels of perfluoroalkyl compounds in human maternal and umbilical cord blood samples. *Environmental Research*, 108(1), 56–62. <https://doi.org/https://doi.org/10.1016/j.envres.2008.06.001>
- Mulhern, R., Bynum, N., Liyanapatirana, C., DeStefano, N. J., Knappe, D. R. U., & MacDonald Gibson, J. (2021). Longitudinal assessment of point-of-use carbon filters for removal of per- and polyfluoroalkyl substances from private well water. *Awwa Water Science*, 3(6), e1262. <https://doi.org/https://doi.org/10.1002/aws2.1262>
- NASF. (2019). *Summary of Toxicology Studies on 6:2 FTS and Technical Support Documents*. <https://cswab.org/wp-content/uploads/2019/11/6-2-FTS-Summary-Toxicology-Technical-Support-Documents-NASF-March-2019.pdf>
- Nason, S. L., Thomas, S., Stanley, C., Silliboy, R., Blumenthal, M., Zhang, W., Liang, Y., Jones, J. P., Zuverza-Mena, N., White, J. C., Haynes, C. L., Vasiliou, V., Timko, M. P., & Berger, B. W. (2024). A comprehensive trial on PFAS remediation: hemp phytoextraction and PFAS degradation in harvested plants [10.1039/D3VA00340J]. *Environmental Science: Advances*, 3(2), 304–313. <https://doi.org/10.1039/D3VA00340J>
- Naveed, S., Oladoye, P. O., Kadhom, M., Oladipo, M. E., Alli, Y. A., & Anjum, N. (2024). The potential of phytoremediation technology as a panacea for per- and poly-fluoroalkyl substances-contaminated soil. *Chemical Papers*, 78(4), 2079–2099. <https://doi.org/10.1007/s11696-023-03246-9>
- Nelson, J. W., Hatch, E. E., & Webster, T. F. (2010). Exposure to polyfluoroalkyl chemicals and cholesterol, body weight, and insulin resistance in the general U.S. population. *Environ Health Perspect*, 118(2), 197–202. <https://doi.org/10.1289/ehp.0901165>
- Niarchos, G., Söregård, M., Fagerlund, F., & Ahrens, L. (2022). Electrokinetic remediation for removal of per- and polyfluoroalkyl substances (PFASs) from contaminated soil. *Chemosphere*, 291, 133041. <https://doi.org/https://doi.org/10.1016/j.chemosphere.2021.133041>
- Nielsen, F., Fischer, F. C., Leth, P. M., & Grandjean, P. (2024). Occurrence of Major Perfluorinated Alkylate Substances in Human Blood and Target Organs. *Environmental Science & Technology*, 58(1), 143–149. <https://doi.org/10.1021/acs.est.3c06499>
- Niu, S., Cao, Y., Chen, R., Bedi, M., Sanders, A. P., Ducatman, A., & Ng, C. (2023). A State-of-the-Science Review of Interactions of Per- and Polyfluoroalkyl Substances (PFAS) with Renal

- Transporters in Health and Disease: Implications for Population Variability in PFAS Toxicokinetics. *Environ Health Perspect*, 131(7), 76002. <https://doi.org/10.1289/ehp11885>
- NSF International. *PFAS in drinking water (consumer resource)*. Retrieved 22/9 from <https://www.nsf.org/consumer-resources/articles/pfas-drinking-water> (NSF)
- NSF International. (2024). *Forever chemicals and the advancement of filtration standards*. <https://www.nsf.org/knowledge-library/forever-chemicals-advancement-filtration-standards> (NSF)
- Nzeribe, N., Crimi, M., Thagard, S. M., & Holsen, T. M. (2019). Physico-Chemical Processes for the Treatment of Per- And Polyfluoroalkyl Substances (PFAS): A review Blossom. *Critical Reviews in Environmental Science and Technology*, 49(10), 866–915. <https://doi.org/10.1080/10643389.2018.1542916>
- OECD. (2002, OCA.0029.0001.0063). *Cooperation on existing chemicals: Hazard assessment of perfluorooctane sulfonate (PFOS) and its salts, env/jm/rd(2002)17/final*.
- OECD. (2021). *Reconciling Terminology of the Universe of Per-and Polyfluoroalkyl Substances: Recommendations and Practical Guidance*. Organisation for Economic Co-operation and Development
- Olsen, G. W., Burris, J. M., Ehresman, D. J., Froehlich, J. W., Seacat, A. M., Butenhoff, J. L., & Zobel, L. R. (2007). Half-life of serum elimination of perfluorooctanesulfonate, perfluorohexanesulfonate, and perfluorooctanoate in retired fluorochemical production workers. *Environmental Health Perspectives*, 115(9), 1298–1305, OCA.0032.0001.0018. <https://doi.org/10.1289/ehp.10009>
- OVAM. (2025). *Informatie over richtinggevende toetsingswaarden voor bodemonderzoek en sanering voor PFAS: Aanvulling bij Basisinformatie voor risico-evaluaties. Publicatiedatum: 1 juli 2025. Openbare Vlaamse Afvalstoffenmaatschappij (OVAM), Mechelen, België*. <https://ovam.vlaanderen.be>.
- Pan, Y., Zhu, Y., Zheng, T., Cui, Q., Buka, S. L., Zhang, B., Guo, Y., Xia, W., Yeung, L. W. Y., Li, Y., Zhou, A., Qiu, L., Liu, H., Jiang, M., Wu, C., Xu, S., & Dai, J. (2017). Novel Chlorinated Polyfluorinated Ether Sulfonates and Legacy Per-/Polyfluoroalkyl Substances: Placental Transfer and Relationship with Serum Albumin and Glomerular Filtration Rate. *Environmental Science & Technology*, 51(1), 634–644. <https://doi.org/10.1021/acs.est.6b04590>
- Pannu, M. W., Chang, J., Medina, R., Grieco, S. A., Hwang, M., & Plumlee, M. H. (2023). Comparing PFAS removal across multiple groundwaters for eight GACs and alternative adsorbent. *Awwa Water Science*, 5(3), e1345. <https://doi.org/https://doi.org/10.1002/aws2.1345>
- Peto, R., Darby, S., Deo, H., Silcocks, P., Whitley, E., & Doll, R. (2000). Smoking, smoking cessation, and lung cancer in the UK since 1950: combination of national statistics with two case-control studies. *BMJ*, 321(7257), 323–329. <https://doi.org/10.1136/bmj.321.7257.323>
- PFAS in Jersey. (2023). <https://www.gov.je/Environment/ProtectingEnvironment/Water/Pages/PFAS.aspx>
- Pinkard, B. R., Austin, C., Purohit, A. L., Li, J., & Novosselov, I. V. (2023). Destruction of PFAS in AFFF-impacted fire training pit water, with a continuous hydrothermal alkaline treatment reactor. *Chemosphere*, 314, 137681. <https://doi.org/https://doi.org/10.1016/j.chemosphere.2022.137681>
- Prevedouros, K., Cousins, I. T., Buck, R. C., & Korzeniowski, S. H. (2006). Sources, Fate and Transport of Perfluorocarboxylates. *Environmental Science & Technology*, 40(1), 32–44.
- Quinnan, J., Morrell, C., Nagle, N., & Maynard, K. G. (2022). Ex situ soil washing to remove PFAS adsorbed to soils from source zones. *Remediation-the Journal of Environmental Cleanup Costs Technologies & Techniques*, 32(3), 151–166. <https://doi.org/10.1002/rem.21727>

- Ragnarsdóttir, O., Abou-Elwafa Abdallah, M., & Harrad, S. (2024). Dermal bioavailability of perfluoroalkyl substances using in vitro 3D human skin equivalent models. *Environment International*, 188, 108772. <https://doi.org/https://doi.org/10.1016/j.envint.2024.108772>
- Regulatory management option analysis (RMOA). (2023). Health and Safety Executive. Retrieved 1/8 from <https://www.hse.gov.uk/REACH/rmoa.htm>
- Reinikainen, J., Perkola, N., Äystö, L., & Sorvari, J. (2022). The occurrence, distribution, and risks of PFAS at AFFF-impacted sites in Finland. *Sci Total Environ*, 829, 154237. <https://doi.org/10.1016/j.scitotenv.2022.154237>
- RIVM. (2017). *RIVM (Rijksinstituut voor Volksgezondheid en Milieu). (2017) Report. Risicogrenzen PFOA voor grond en grondwater.* <https://rivm.openrepository.com/bitstream/handle/10029/622062/2018-0060.pdf?sequence=1&isAllowed=y>.
- RIVM. (2020). *RIVM (Rijksinstituut voor Volksgezondheid en Milieu) Report. Ecotoxicologische risicogrenzen voor PFOS in bodem en grondwater.* www.rivm.nl/bibliotheek/rapporten/2020-0085.pdf.
- Sabba, F., Kassar, C., Zeng, T., Mallick, S. P., Downing, L., & McNamara, P. (2025). PFAS in landfill leachate: Practical considerations for treatment and characterization. *Journal of Hazardous Materials*, 481, Article 136685. <https://doi.org/10.1016/j.jhazmat.2024.136685>
- Sadia, M., ter Laak, T. L., Cornelissen, E. R., & van Wezel, A. P. (2024). Exploring Perfluoroalkyl and Polyfluoroalkyl Substance Presence and Potential Leaching from Reverse Osmosis Membranes: Implications for Drinking Water Treatment. *Environmental Science & Technology*, 58(35), 15799–15806. <https://doi.org/10.1021/acs.est.4c04743>
- Scheitlin, C. G., Dasu, K., Rosansky, S., Dejarme, L. E., Siriwardena, D., Thorn, J., Mullins, L., Haggerty, I., Shqau, K., & Stowe, J. (2023). Application of Supercritical Water Oxidation to Effectively Destroy Per- and Polyfluoroalkyl Substances in Aqueous Matrices. *Acs Es&T Water*, 3(8), 2053–2062. <https://doi.org/10.1021/acsestwater.2c00548>
- Schlummer, M., Moser, G. A., & McLachlan, M. S. (1998). Digestive tract absorption of PCDD/Fs, PCBs, and HCB in humans: mass balances and mechanistic considerations. *Toxicol Appl Pharmacol*, 152(1), 128–137. <https://doi.org/10.1006/taap.1998.8487>
- Schrama, F. R. A., Massimi, S. E., Dooley, M. R., Trewyn, B. G., Vyas, S., & Richards, R. M. (2024). Light-driven interfaces for PFAS detection and destruction [10.1039/D4LF00171K]. *RSC Applied Interfaces*, 1(5), 833–845. <https://doi.org/10.1039/D4LF00171K>
- Sha, B., Johansson, J. H., Salter, M. E., Blichner, S. M., & Cousins, I. T. (2024). Constraining global transport of perfluoroalkyl acids on sea spray aerosol using field measurements. *Science Advances*, 10(14), ead11026. <https://doi.org/doi:10.1126/sciadv.adl1026>
- Shore, P. A., Brodie, B. B., & Hogben, C. A. (1957). The gastric secretion of drugs: a pH partition hypothesis [Article]. *The Journal of pharmacology and experimental therapeutics*, 119(3), 361–369.
- Smith, S. J., Lauria, M., Ahrens, L., McCleaf, P., Hollman, P., Bjälkefur Seroka, S., Hamers, T., Arp, H. P. H., & Wiberg, K. (2023). Electrochemical Oxidation for Treatment of PFAS in Contaminated Water and Fractionated Foam—A Pilot-Scale Study. *Acs Es&T Water*, 3(4), 1201–1211. <https://doi.org/10.1021/acsestwater.2c00660>
- Smith, S. J., Lewis, J., Wiberg, K., Wall, E., & Ahrens, L. (2023). Foam fractionation for removal of per- and polyfluoroalkyl substances: Towards closing the mass balance. *Sci Total Environ*, 871, 162050. <https://doi.org/10.1016/j.scitotenv.2023.162050>
- So, M. K., Yamashita, N., Taniyasu, S., Jiang, Q., Giesy, J. P., Chen, K., & Lam, P. K. S. (2006). Health Risks in Infants Associated with Exposure to Perfluorinated Compounds in Human Breast

- Milk from Zhoushan, China. *Environmental Science & Technology*, 40(9), 2924–2929.
<https://doi.org/10.1021/es060031f>
- Söderqvist, T., Brinkhoff, P., Norberg, T., Rosén, L., Back, P.-E., & Norrman, J. (2015). Cost-benefit analysis as a part of sustainability assessment of remediation alternatives for contaminated land. *Journal of Environmental Management*, 157, 267–278.
<https://doi.org/https://doi.org/10.1016/j.jenvman.2015.04.024>
- Söregård, M., Kikuchi, J., Wiberg, K., & Ahrens, L. (2022). Spatial distribution and load of per- and polyfluoroalkyl substances (PFAS) in background soils in Sweden. *Chemosphere*, 295, 133944. <https://doi.org/https://doi.org/10.1016/j.chemosphere.2022.133944>
- Söregård, M., Östblom, E., Köhler, S., & Ahrens, L. (2020). Adsorption behavior of per- and polyfluoroalkyl substances (PFASs) to 44 inorganic and organic sorbents and use of dyes as proxies for PFAS sorption. *Journal of Environmental Chemical Engineering*, 8(3), 103744.
<https://doi.org/https://doi.org/10.1016/j.jece.2020.103744>
- Stayner, L., Welch, L. S., & Lemen, R. (2013). The worldwide pandemic of asbestos-related diseases. *Annu Rev Public Health*, 34, 205–216. <https://doi.org/10.1146/annurev-publhealth-031811-124704>
- Stratton, G. R., Dai, F., Bellona, C. L., Holsen, T. M., Dickenson, E. R. V., & Mededovic Thagard, S. (2017). Plasma-Based Water Treatment: Efficient Transformation of Perfluoroalkyl Substances in Prepared Solutions and Contaminated Groundwater. *Environmental Science & Technology*, 51(3), 1643–1648. <https://doi.org/10.1021/acs.est.6b04215>
- Sunderland, E. M., Hu, X. C., Dassuncao, C., Tokranov, A. K., Wagner, C. C., & Allen, J. G. (2019). A review of the pathways of human exposure to poly- and perfluoroalkyl substances (PFASs) and present understanding of health effects. *Journal of Exposure Science & Environmental Epidemiology*, 29(2), 131–147. <https://doi.org/10.1038/s41370-018-0094-1>
- Sundström, M., Chang, S.-C., Noker, P. E., Gorman, G. S., Hart, J. A., Ehresman, D. J., Bergman, Å., & Butenhoff, J. L. (2012). Comparative pharmacokinetics of perfluorohexanesulfonate (PFHxS) in rats, mice, and monkeys. *Reproductive Toxicology*, 33(4), 441–451.
<https://doi.org/https://doi.org/10.1016/j.reprotox.2011.07.004>
- Sundström, M., Ehresman, D. J., Bignert, A., Butenhoff, J. L., Olsen, G. W., Chang, S.-C., & Bergman, Å. (2011). A temporal trend study (1972–2008) of perfluorooctanesulfonate, perfluorohexanesulfonate, and perfluorooctanoate in pooled human milk samples from Stockholm, Sweden. *Environment International*, 37(1), 178–183.
<https://doi.org/https://doi.org/10.1016/j.envint.2010.08.014>
- Tao, L., Kannan, K., Wong, C. M., Arcaro, K. F., & Butenhoff, J. L. (2008). Perfluorinated Compounds in Human Milk from Massachusetts, U.S.A. *Environmental Science & Technology*, 42(8), 3096–3101. <https://doi.org/10.1021/es702789k>
- Tao, L., Ma, J., Kunisue, T., Libelo, E. L., Tanabe, S., & Kannan, K. (2008). Perfluorinated Compounds in Human Breast Milk from Several Asian Countries, and in Infant Formula and Dairy Milk from the United States. *Environmental Science & Technology*, 42(22), 8597–8602.
<https://doi.org/10.1021/es801875v>
- Taves, D. R. (1968). EVIDENCE THAT THERE ARE 2 FORMS OF FLUORIDE IN HUMAN SERUM. *Nature*, 217(5133), 1050–&. <https://doi.org/10.1038/2171050b0>
- Teymoorian, T., Dinh, Q. T., Barbeau, B., & Sauvé, S. (2024). Performance of pitcher-type POU filters for the removal of 75 PFAS from drinking water: comparing different water sources [Original Research]. *Frontiers in Environmental Chemistry*, Volume 5 - 2024.
<https://doi.org/10.3389/fenvc.2024.1376079>
- Thomas, R., Jenkins, K., Landale, B., Trigger, G., Holsen, T. M., Dore, S., Pope, D., & Wasielewski, J. (2020). Evaluation of PFAS treatment technology: Alkaline ozonation. *Remediation-the*

- Journal of Environmental Cleanup Costs Technologies & Techniques*, 30(3), 27–37.
<https://doi.org/10.1002/rem.21654>
- Thompson, J. T., Robey, N. M., Tolaymat, T. M., Bowden, J. A., Solo-Gabriele, H. M., & Townsend, T. G. (2023). Underestimation of Per- and Polyfluoroalkyl Substances in Biosolids: Precursor Transformation During Conventional Treatment. *Environmental Science & Technology*.
<https://doi.org/10.1021/acs.est.2c06189>
- Thompson, K. A., Mortazavian, S., Gonzalez, D. J., Bott, C., Hooper, J., Schaefer, C. E., & Dickenson, E. R. V. (2022). *Poly- and Perfluoroalkyl Substances in Municipal Wastewater Treatment Plants in the United States: Seasonal Patterns and Meta-Analysis of Long-Term Trends and Average Concentrations* (Figshare).
<https://doi.org/https://doi.org/10.1021/acsestwater.1c00377.s002>
- Thomsen, C., Haug, L. S., Stigum, H., Frøshaug, M., Broadwell, S. L., & Becher, G. (2010). Changes in Concentrations of Perfluorinated Compounds, Polybrominated Diphenyl Ethers, and Polychlorinated Biphenyls in Norwegian Breast-Milk during Twelve Months of Lactation. *Environmental Science & Technology*, 44(24), 9550–9556.
<https://doi.org/10.1021/es1021922>
- Tow, E. W., Ersan, M. S., Kum, S., Lee, T., Speth, T. F., Owen, C., Bellona, C., Nadagouda, M. N., Mikelonis, A. M., Westerhoff, P., Mysore, C., Frenkel, V. S., Desilva, V., Walker, W. S., Safulko, A. K., & Ladner, D. A. (2021a). Managing and treating per- and polyfluoroalkyl substances (PFAS) in membrane concentrates. *Awwa Water Science*, 3(5), Article e1233.
<https://doi.org/10.1002/aws2.1233>
- Tow, E. W., Ersan, M. S., Kum, S., Lee, T., Speth, T. F., Owen, C., Bellona, C., Nadagouda, M. N., Mikelonis, A. M., Westerhoff, P., Mysore, C., Frenkel, V. S., deSilva, V., Walker, W. S., Safulko, A. K., & Ladner, D. A. (2021b). Managing and treating per- and polyfluoroalkyl substances (PFAS) in membrane concentrates. *AWWA Water Sci*, 3(5), 1–23.
<https://doi.org/10.1002/aws2.1233>
- Toxicological Profile for Perfluoroalkyls*. (2021).
<https://www.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=1117&tid=237>
- Trudel, D., Horowitz, L., Wormuth, M., Scheringer, M., Cousins, I. T., & Hungerbühler, K. (2008). Estimating consumer exposure to PFOS and PFOA [Review]. *Risk Analysis*, 28(2), 251–269, KCA.0028.0001.0029. <https://doi.org/10.1111/j.1539-6924.2008.01017.x>
- Tshangana, C. S., Nhlengethwa, S. T., Glass, S., Denison, S., Kuvarega, A. T., Nkambule, T. T. I., Mamba, B. B., Alvarez, P. J. J., & Muleja, A. A. (2025). Technology status to treat PFAS-contaminated water and limiting factors for their effective full-scale application. *npj Clean Water*, 8(1), 41. <https://doi.org/10.1038/s41545-025-00457-3>
- U.S. Environmental Protection Agency. (2024a). *2024 Technologies and Costs for Removing Per- and Polyfluoroalkyl Substances (PFAS) from Drinking Water*. (815R24012). Washington DC, Retrieved from <https://downloads.regulations.gov/EPA-HQ-OW-2022-0114-3742/content.pdf>
- U.S. Environmental Protection Agency. (2024b). *Best Available Technologies and Small System Compliance Technologies for*
- Per- and Polyfluoroalkyl Substances (PFAS) in Drinking Water*. (815R24011). Washington, DC 20460: EPA Retrieved from https://www.epa.gov/system/files/documents/2024-04/2024-final-pfas-bat-ssct_final-508.pdf
- U.S. Environmental Protection Agency. (2024c). *Identifying drinking water filters certified to reduce PFAS*. U.S. Environmental Protection Agency. Retrieved 22/9 from

- <https://www.epa.gov/water-research/identifying-drinking-water-filters-certified-reduce-pfas>
- U.S. Environmental Protection Agency. (2024d). *Water filters: Fact sheet (lists ANSI-accredited PFAS certifiers)*. <https://www.epa.gov/system/files/documents/2024-04/water-filter-fact-sheet.pdf>
- U.S. Environmental Protection Agency. (2025). *PFAS—SDWA regulation overview*. Retrieved 22/9 from <https://www.epa.gov/sdwa/and-polyfluoroalkyl-substances-pfas>
- UKCOT. (2022). *Statement on the EFSA Opinion on the risks to human health related to the presence of perfluoroalkyl substances in food. Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment*. https://cot.food.gov.uk/sites/default/files/2022-11/COT%20PFAS%20%20Statement%20on%20EFSA%20Opinion_2022_04.22%20Acc%20V0.pdf
- Upton, K., Shearston, J. A., & Kioumourtzoglou, M. A. (2022). An Epidemiologic Review of Menstrual Blood Loss as an Excretion Route for Per- and Polyfluoroalkyl Substances. *Curr Environ Health Rep*, 9(1), 29–37. <https://doi.org/10.1007/s40572-022-00332-0>
- Vandenberg, L. N., Colborn, T., Hayes, T. B., Heindel, J. J., Jacobs, D. R., Jr., Lee, D.-H., Shioda, T., Soto, A. M., vom Saal, F. S., Welshons, W. V., Zoeller, R. T., & Myers, J. P. (2012). Hormones and Endocrine-Disrupting Chemicals: Low-Dose Effects and Nonmonotonic Dose Responses. *Endocrine Reviews*, 33(3), 378–455. <https://doi.org/10.1210/er.2011-1050>
- Verner, M.-A., Ngueta, G., Jensen, E. T., Fromme, H., Völkel, W., Nygaard, U. C., Granum, B., & Longnecker, M. P. (2016). A Simple Pharmacokinetic Model of Prenatal and Postnatal Exposure to Perfluoroalkyl Substances (PFASs). *Environmental Science & Technology*, 50(2), 978–986. <https://doi.org/10.1021/acs.est.5b04399>
- Vestergren, R., Berger, U., Glynn, A., & Cousins, I. T. (2012). Dietary exposure to perfluoroalkyl acids for the Swedish population in 1999, 2005 and 2010 [Article]. *Environment International*, 49, 120–127. <https://doi.org/10.1016/j.envint.2012.08.016>
- Vestergren, R., Cousins, I. T., Trudel, D., Wormuth, M., & Scheringer, M. (2008). Estimating the contribution of precursor compounds in consumer exposure to PFOS and PFOA. *Chemosphere*, 73(10), 1617–1624. <https://doi.org/10.1016/j.chemosphere.2008.08.011>
- Völkel, W., Genzel-Boroviczeny, O., Demmelmair, H., Gebauer, C., Koletzko, B., Twardella, D., Raab, U., & Fromme, H. (2008). Perfluorooctane sulphonate (PFOS) and perfluorooctanoic acid (PFOA) in human breast milk: Results of a pilot study. *International Journal of Hygiene and Environmental Health*, 211(3), 440–446. <https://doi.org/https://doi.org/10.1016/j.ijheh.2007.07.024>
- Wang, L., Batchelor, B., Pillai, S. D., & Botlaguduru, V. S. V. (2016). Electron beam treatment for potable water reuse: Removal of bromate and perfluorooctanoic acid. *Chemical Engineering Journal*, 302, 58–68. <https://doi.org/https://doi.org/10.1016/j.cej.2016.05.034>
- Wang, S., Yang, Q., Chen, F., Sun, J., Luo, K., Yao, F., Wang, X., Wang, D., Li, X., & Zeng, G. (2017). Photocatalytic degradation of perfluorooctanoic acid and perfluorooctane sulfonate in water: A critical review. *Chemical Engineering Journal*, 328, 927–942. <https://doi.org/https://doi.org/10.1016/j.cej.2017.07.076>
- Wang, Y., Ji, Y., Li, K., & Huang, Q. (2023). Foam fractionation and electrochemical oxidation for the treatment of per- and polyfluoroalkyl substances (PFAS) in environmental water samples. *Chemosphere*, 339, 139615. <https://doi.org/https://doi.org/10.1016/j.chemosphere.2023.139615>
- Wang, Y., Ji, Y., Tishchenko, V., & Huang, Q. (2023). Removing per- and polyfluoroalkyl substances (PFAS) in water by foam fractionation. *Chemosphere*, 311(Pt 2), 137004. <https://doi.org/10.1016/j.chemosphere.2022.137004>

- Wang, Z., DeWitt, J. C., Higgins, C. P., & Cousins, I. T. (2017). A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)? *Environmental Science & Technology*, 51(5), 2508–2518. <https://doi.org/10.1021/acs.est.6b04806>
- Wang, Z., DeWitt, J. C., Higgins, C. P., & Cousins, I. T. (2017). A Never-Ending Story of Per- and Polyfluoroalkyl Substances (PFASs)? *Environ Sci Technol*, 51(5), 2508–2518. <https://doi.org/10.1021/acs.est.6b04806>
- Washington, J. W., Rankin, K., Libelo, E. L., Lynch, D. G., & Cyterski, M. (2019). Determining global background soil PFAS loads and the fluorotelomer-based polymer degradation rates that can account for these loads. *Science of The Total Environment*, 651, 2444–2449. <https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.10.071>
- Washington, J. W., Yoo, H., Ellington, J. J., Jenkins, T. M., & Libelo, E. L. (2010). Concentrations, Distribution, and Persistence of Perfluoroalkylates in Sludge-Applied Soils near Decatur, Alabama, USA. *Environmental Science & Technology*, 44(22), 8390–8396. <https://doi.org/10.1021/es1003846>
- Washington State Department of Health. (2025). *PFAS Point-Of-Use Filter Options*. <https://doh.wa.gov/sites/default/files/2025-07/331-713.pdf>
- We, A. C. E., Zamyadi, A., Stickland, A. D., O, C. B., & Freguia, S. (2024). A review of foam fractionation for the removal of per- and polyfluoroalkyl substances (PFAS) from aqueous matrices. *Journal of Hazardous Materials*, 465, Article 133182. <https://doi.org/10.1016/j.jhazmat.2023.133182>
- Wee, S. Y., & Aris, A. Z. (2023). Revisiting the “forever chemicals”, PFOA and PFOS exposure in drinking water. *npj Clean Water*, 6(1), 57. <https://doi.org/10.1038/s41545-023-00274-6>
- Weitz, K., Kantner, D., Kessler, A., Key, H., Larson, J., Bodnar, W., Parvathikar, S., Davis, L., Robey, N., Taylor, P., De la Cruz, F., Tolaymat, T., Weber, N., Linak, W., Krug, J., & Phelps, L. (2024). Review of per- and poly-fluoroalkyl treatment in combustion-based thermal waste systems in the United States. *Science of The Total Environment*, 932, 172658. <https://doi.org/https://doi.org/10.1016/j.scitotenv.2024.172658>
- Winchell, L. J., Ross, J. J., Brose, D. A., Pluth, T. B., Fonoll, X., Norton, J. W., & Bell, K. Y. (2022). Pyrolysis and gasification at water resource recovery facilities: Status of the industry. *WATER ENVIRONMENT RESEARCH*, 94(3), Article e10701. <https://doi.org/10.1002/wer.10701>
- Winkens, K., Vestergren, R., Berger, U., & Cousins, I. T. (2017). Early life exposure to per- and polyfluoroalkyl substances (PFASs): A critical review. *Emerging Contaminants*, 3(2), 55–68. <https://doi.org/https://doi.org/10.1016/j.emcon.2017.05.001>
- Wong, F., MacLeod, M., Mueller, J. F., & Cousins, I. T. (2014). Enhanced Elimination of Perfluorooctane Sulfonic Acid by Menstruating Women: Evidence from Population-Based Pharmacokinetic Modeling. *Environmental Science & Technology*, 48(15), 8807–8814. <https://doi.org/10.1021/es500796y>
- Wu, B., Hao, S., Choi, Y., Higgins, C. P., Deeb, R., & Strathmann, T. J. (2019). Rapid Destruction and Defluorination of Perfluorooctanesulfonate by Alkaline Hydrothermal Reaction. *Environmental Science & Technology Letters*, 6(10), 630–636. <https://doi.org/10.1021/acs.estlett.9b00506>
- Xu, Y., Fletcher, T., Pineda, D., Lindh Christian, H., Nilsson, C., Glynn, A., Vogs, C., Norström, K., Lilja, K., Jakobsson, K., & Li, Y. (2020). Serum Half-Lives for Short- and Long-Chain Perfluoroalkyl Acids after Ceasing Exposure from Drinking Water Contaminated by Firefighting Foam. *Environmental Health Perspectives*, 128(7), 077004. <https://doi.org/10.1289/EHP6785>
- Xu, Y., Nielsen, C., Li, Y., Hammarstrand, S., Andersson, E. M., Li, H., Olsson, D. S., Engström, K., Pineda, D., Lindh, C. H., Fletcher, T., & Jakobsson, K. (2021). Serum perfluoroalkyl substances in residents following long-term drinking water contamination from firefighting foam in

- Ronneby, Sweden. *Environment International*, 147, 106333.
<https://doi.org/https://doi.org/10.1016/j.envint.2020.106333>
- Yu, Q., Zhang, R., Deng, S., Huang, J., & Yu, G. (2009). Sorption of perfluorooctane sulfonate and perfluorooctanoate on activated carbons and resin: Kinetic and isotherm study. *Water Research*, 43(4), 1150–1158. <https://doi.org/https://doi.org/10.1016/j.watres.2008.12.001>
- Zahra, Z., Song, M., Habib, Z., & Ikram, S. (2025). Advances in per- and polyfluoroalkyl substances (PFAS) detection and removal techniques from drinking water, their limitations, and future outlooks. *Emerging Contaminants*, 11(1), 100434.
<https://doi.org/https://doi.org/10.1016/j.emcon.2024.100434>
- Zenobio, J. E., Modiri-Gharehveran, M., de Perre, C., Vecitis, C. D., & Lee, L. S. (2020). Reductive transformation of perfluorooctanesulfonate by nNiFeO-Activated carbon. *Journal of Hazardous Materials*, 397, 122782.
<https://doi.org/https://doi.org/10.1016/j.jhazmat.2020.122782>
- Zhang, D., He, Q., Wang, M., Zhang, W., & Liang, Y. (2021). Sorption of perfluoroalkylated substances (PFASs) onto granular activated carbon and biochar. *Environ Technol*, 42(12), 1798–1809.
<https://doi.org/10.1080/09593330.2019.1680744>
- Zhou, T., Li, X., Liu, H., Dong, S. M., Zhang, Z. H., Wang, Z. Y., Li, J. B., Nghiem, L. D., Khan, S. J., & Wang, Q. L. (2024). Occurrence, fate, and remediation for per-and polyfluoroalkyl substances (PFAS) in sewage sludge: A comprehensive review. *Journal of Hazardous Materials*, 466, Article 133637. <https://doi.org/10.1016/j.jhazmat.2024.133637>

Glossary

AFFF	aqueous film-forming foams; used in firefighting, particularly where liquid fuel may be involved. Can contain PFAS.
ALT (Alanine Aminotransferase)	An enzyme found in the liver and blood, often measured to assess liver health
anaemia	a condition where there is a lower-than-normal number of healthy blood cells. This can reduce oxygen availability and lead to shortness of breath and fatigue.
anionic	Refers to PFAS molecules that carry a negative charge in aqueous solutions. Anionic PFAS compounds are commonly found in industrial applications and consumer products, often as surfactants due to their ability to lower surface tension
apheresis	A process separating specific components from blood (like plasma or cells), then returning the remainder to the donor or patient.
aplastic Anaemia	A serious condition where the body stops producing enough new blood cells, leading to fatigue, infections, and bleeding risks.
ATSDR (Agency for Toxic Substances and Disease Registry)	A federal public health agency within the United States Department of Health and Human Services. The ATSDR is responsible for assessing the health effects of exposure to hazardous substances and providing guidance on preventing or reducing harmful exposures. It conducts public health assessments, health consultations, and studies to evaluate the impact of environmental contaminants on human health, offering recommendations and support to communities, health professionals, and policymakers
attributable risk	The difference in the rate of a condition between an exposed population and an unexposed population, attributable to a specific risk factor
autoimmune diseases	Conditions where the immune system mistakenly attacks the body's own cells
beneficence	Acting in the best interest of others, especially in healthcare, by promoting well-being, preventing harm, and ensuring positive outcomes for patients or communities.
bile acid sequestrants	Medications that bind bile acids in the gut, promoting excretion of certain substances (including lipids or pollutants, like PFAS) to lower blood levels.
bioaccumulative, bioaccumulation	The accumulation of substances, such as pesticides or chemicals, in an organism over time
biological plausibility	The logical relationship between a cause and an effect based on existing biological or medical knowledge
BMJ	British Medical Journal.
body burden	describes the amount of chemicals in the human body.
bwt	Bodyweight.
C8	the name given to the surfactant PFOA in some commercial contexts, the name deriving from it having an 8-carbon length structure. Fluorosurfactants known as C8. It is also the name given to a research study and remediation programme of a contamination incident in the United States of America
cationic	Refers to PFAS molecules that carry a positive charge. These cationic PFAS compounds are less common than anionic ones but can be used in specific industrial applications, such as coatings and textile treatments, where they help bind the PFAS to surfaces

causality (Causal relationship)	The relationship between cause and effect, where one event (the cause) directly influences another event (the effect)
causation	The action of causing something; a relationship where one event causes another
CDC	Centers for Disease Control, a national public health body in the US.
cerebrovascular disease	Disorders affecting the blood vessels in the brain, which can lead to strokes
chance association	A relationship between two variables that occurs randomly rather than through a causal link
Cholestyramine	A bile acid sequestrant that binds bile acids in the intestines, used to lower cholesterol or remove certain contaminants.
Colesevelam	A newer bile acid sequestrant that helps lower cholesterol levels and can remove specific toxins or pollutants in the digestive tract.
Colestipol	Another bile acid sequestrant medication, reducing cholesterol or unwanted substances in the gut by binding bile acids.
community advisory boards	Groups of local stakeholders who offer guidance, feedback, and support to ensure research or interventions align with community interests.
confounding (confounding bias)	A distortion in the perceived relationship between an exposure and an outcome caused by a third variable that is associated with both the exposure and the outcome
cost effectiveness	A measure of whether an intervention's benefits justify its financial cost, helping compare different strategies for achieving the best outcomes with limited resources.
c-reactive protein (CRP)	A substance produced by the liver in response to inflammation, used as a marker in blood tests
data triangulation	The use of multiple data sources or methods to validate research findings and ensure accuracy
decile groups	Statistical divisions that split a population into ten equal parts, often used in data analysis to compare different groups
degradation	The breakdown or decay of substances
dose-response	Describes how varying levels of exposure to a substance relate to changes in magnitude or frequency of an observed effect.
dyslipidaemia	An abnormal level of lipids (fats), like cholesterol or triglycerides, in the blood, potentially increasing cardiovascular disease risk.
Ecological fallacy	The error of making inferences about individuals based on aggregate data for a group
EFSA (European Food Safety Authority)	An agency of the European Union that provides independent scientific advice on food-related risks
EMA	The European Medicines Agency, which evaluates and supervises medicines within the European Union to ensure their quality and safety.
endometriosis	A condition where tissue similar to the lining inside the uterus grows outside of it, causing pain and potential fertility issues
endometrium	The mucous membrane lining the uterus, which thickens during the menstrual cycle
enterohepatic circulation	The circulation of substances from the liver to the bile, absorbed by the intestine, and returned to the liver
EPA	Environmental Protection Agency, the federal agency in the US responsible for protecting the environment.

EQ5D-5L	European 5 dimension, 5 level, quality of life assessment. A commonly used tool to assess health related quality of life.
EU	European Union
experts by experience	Individuals who provide expertise based on personal experiences rather than formal qualifications
exposure media	The different environments (e.g., air, water, soil) through which individuals can be exposed to substances
FDA	Food and Drug Administration, the regulator of medicines in the US.
FDA	The Food and Drug Administration, a U.S. agency regulating food, drugs, medical devices, and related public health measures.
gastrooesophageal reflux	A condition where stomach acid frequently flows back into the tube connecting the mouth and stomach, causing heartburn
Gen X	Refers to a specific type of PFAS developed as a replacement for older, longer-chain PFAS chemicals. The term "Gen X" in this context is used both to describe the chemical process and the resulting products, which are marketed as having a shorter environmental persistence and potentially lower toxicity compared to traditional PFAS like PFOA and PFOS. However, concerns remain about the environmental and health impacts of these substances.
GMP	Good Manufacturing Practice, guidelines ensuring products are consistently produced and controlled to quality standards.
gut microbiome	The community of microorganisms living in the digestive tracts of humans and other animals
haematoma	localised collection of blood outside blood vessels.
haemodialysis	A procedure using a machine to filter wastes, salts, and excess fluid from the blood when kidneys cannot perform adequately
haemolytic Anaemia	Occurs when red blood cells are destroyed faster than they can be made, leading to fatigue, jaundice, and other health issues.
half-life	the time it takes for the concentration of a substance in the body or in the environment to reduce to half its initial value
HBM	Human Biomonitoring Committee of the German Environmental Agency.
herd immunity	The resistance to the spread of a contagious disease within a population, achieved when a high proportion of individuals are immune
high-density lipoprotein (HDL)	Known as "good" cholesterol, it helps remove other forms of cholesterol from the bloodstream
hypotension	Low blood pressure, where the force of the blood pumping through the arteries is below normal, possibly causing dizziness or fainting.
IARC (International Agency for Research on Cancer)	An agency of the World Health Organization that conducts and coordinates research on the causes of cancer
immunosuppression	The reduction of the activation or efficacy of the immune system, which can occur naturally or be induced by medication or disease
immunotoxic	Refers to a substance that harms the immune system, potentially reducing the body's ability to fight infections or maintain normal immune function.
information bias	Bias arising from measurement errors or misclassification in the data collection process
intrauterine growth retardation	A condition where a foetus is smaller than expected for the number of weeks of pregnancy, due to various factors

ischaemic heart disease	A condition characterized by reduced blood supply to the heart, often due to clogged arteries
Kg	Kilograms.
leiomyoma	A benign smooth muscle tumour, often found in the uterus (uterine fibroids)
log	Short for “logarithm,” a mathematical function indicating how many times a base number must be multiplied by itself to reach a specific value.
log-transformed	A mathematical operation converting data by applying the logarithm function, often used to handle skewed distributions or stabilize variance in statistical analysis.
low density lipoprotein (LDL)	A type of cholesterol known as “bad” cholesterol because high levels can lead to plaque buildup in arteries
mean	a statistical average where all values are added up and divided by the number of readings.
median	a statistical measure where the middle value of a list of findings is used.
MeFOSAA	N-Methylperfluorooctanesulfonamidoacetic acid.
mesothelioma	A rare and aggressive cancer of the lining of the lungs or abdomen, often linked to asbestos exposure.
MHRA	The Medicines and Healthcare products Regulatory Agency, responsible for overseeing the safety and efficacy of medical products in the UK.
millilitre (ml)	one thousandth of a litre.
ml/y	millilitre per year.
monotonic dose response	A relationship in which increases in exposure consistently lead to either increasing or decreasing effects, without reversing direction. A straight-line relationship.
moral injury	Psychological distress resulting from actions that violate one’s moral or ethical code
nanogram (ng)	one billionth of a gram.
natural log-decrease	A reduction measured using the natural logarithm (base e), often applied in studies to describe exponential declines or half-life processes.
nephrotic Syndrome	A kidney disorder causing the body to lose excess protein in the urine, leading to swelling, low protein levels, and other complications.
neurodevelopment	The process of brain development, often focusing on growth and maturation from birth through adolescence
ng/ml	nanogram per millilitre.
NHANES	The National Health and Nutrition Examination Survey in the United States, which collects data on health and nutrition from a representative population sample.
NHS	National Health Service.
NICE	The National Institute of Health and Care Excellence, the national clinical guidelines organisation in England.
non-maleficence	The duty to “do no harm,” requiring healthcare providers and researchers to avoid causing injury or suffering
non-monotonic dose response	A relationship in which increases in exposure do not consistently lead to either increasing or decreasing effects, without reversing direction. The dose response is a curve or may have multiple phases.
OECD	The Organisation for Economic Cooperation and Development, an international organisation comprising the countries with advanced economies.
osteoporosis	A condition characterized by weakened bones, increasing the risk of fractures

PCOS (Polycystic Ovary Syndrome)	A hormonal disorder causing enlarged ovaries with small cysts on the outer edges
PFAS	per- and polyfluoroalkyl substances.
PFCAs	perfluoroalkyl carboxylic acids or perfluoroalkyl carboxylate.
PFDA	perfluorodecanoic acid.
PFHpS	perfluoroheptane sulfonic acid.
PFHxS	perfluorohexane sulfonic acid.
PFNA	perfluorononanoic acid.
PFOA	perfluorooctanoic acid.
PFOS	perfluorooctane sulfonic acid.
PFPeS	perfluoropentane sulfonic acid.
PFSAs	perfluoroalkane sulfonic acids or perfluoroalkane sulfonates.
PFUnDA	perfluoroundecanoic acid.
plasma	the liquid portion of the blood.
plasmapheresis	A procedure that filters out plasma (where certain substances reside) from a patient's blood, returning blood cells to the body.
plume	the geographical area over which a contaminant spreads. In the context of this report, it is interpreted broadly, to mean the area where contamination is likely, and not just to relate to the known dispersion of the contaminant
primiparous	Referring to a woman who has given birth for the first time
Probenecid	A medication increasing urinary excretion of certain compounds, historically used to manage gout and sometimes investigated for pollutant removal.
Psyllium husk	A natural soluble fibre often used to improve digestion and lower cholesterol, possibly aiding in excreting certain substances.
PTFE (Polytetrafluoroethylene)	A synthetic fluoropolymer, commonly known by the brand name Teflon™, used in non-stick cookware and other products
REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals)	A European Union regulation governing the use of chemicals to protect human health and the environment
reliability	The consistency and stability of a measurement or test over time
renal calculi	Also known as kidney stones, these are hard deposits of minerals and salts forming in the kidneys, potentially causing pain.
reverse causality	A situation where the direction of cause and effect is opposite to what is presumed
rheumatoid disease	Refers to autoimmune conditions like rheumatoid arthritis, where chronic inflammation affects joints and other parts of the body
risk factors	Characteristics or variables associated with an increased risk of a disease or condition
saturated	Refers to organic compounds where all the carbon atoms are fully bonded with hydrogen and fluorine atoms, with no double or triple bonds present. Their saturated nature contributes to their stability and low reactivity under normal conditions.

saturation Point	The level above which a further increase in the level of PFAS does not lead to any additional increase in risk of a particular health condition. This may apply in some instances but is not yet proven.
Scotchgard	a waterproofing and stain proofing treatment developed by 3M.
selection bias	A type of bias caused by the non-random selection of participants, leading to unrepresentative samples
serum	the liquid that is left when blood has clotted, often used for doing medical tests.
somatisation	The manifestation of psychological distress through physical symptoms
specificity	The extent to which a particular exposure leads to a specific outcome, used to help establish causal relationships
systemic lupus erythematosus (SLE)	A chronic autoimmune disease affecting multiple organ systems, including the skin, joints, and kidneys
Teflon	A brand name for PTFE, known for its non-stick properties
temporality	The timing of exposure relative to the occurrence of an outcome, important in establishing causality
therapeutic phlebotomy	withdrawal of blood to prevent or cure disease.
threshold response	A dose-response pattern where no effect is observed until a certain exposure level (the threshold) is reached, after which effects appear.
total risk	The overall risk of an outcome occurring in a population or study group, encompassing all possible contributing factors
toxicokinetics	The study of how a substance enters, moves through, and exits the body
toxicologist	A scientist who studies the effects of chemicals on living organisms
UK	United Kingdom.
validity	The extent to which a measurement or test accurately represents the concept it is intended to measure
venesection	taking blood
Volume of Distribution (Vd)	the theoretical volume into which an amount chemical or drug would be dispersed to result in the observed concentration in serum or plasma. Usually expressed in volume per body weight ml/kg.
WHO	World Health Organization, the United Nations agency devoted to health and health protection.
zwitterionic	Molecules with both positive and negative charges but are overall electrically neutral

Appendix 1 – Minutes of Panel meetings

Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 4 September 2025

Panel Members present: Professor Ian Cousins – PFAS and Environment member (temporary chair)

Dr Tony Fletcher – PFAS and Health member

In attendance: Standing Observer (Regulation) - Kelly Whitehead - Group Director of Regulation, Infrastructure and Environment Department

Various Subject Matter Experts

Programme support team from I&E

Welcome:

Ian Cousins opened the session, noting the absence of the usual chair, Steve Hajioff, who was unwell and unable to attend. Despite Steve's illness, the decision was made to proceed with the meeting, given the presence of invited subject matter experts who had generously allocated their time to present. However, Ian informed attendees that the agenda would be slightly reduced to accommodate the circumstances. Specifically, reviewing the agenda, matters arising and other business would be deferred to the next panel meeting, when it is hoped that Steve will be well enough to resume his role as chair.

Introductions

Dr Tony Fletcher, PFAS and Health Panel Member: Environmental Epidemiologist at the London School of Hygiene and Tropical Medicine, working on PFAS since 2006 and member of the panel with experience of epidemiological studies on the health effects of PFAS in contaminated communities in West Virginia in the United States, in the Veneto region, in Italy, and in Ronneby, and is the health expert on the panel.

Professor Ian Cousins, PFAS and Environment Panel Member: A Professor in Environmental Chemistry at Stockholm University, an expert on PFAS, appointed as the environmental expert on this Panel and whose expertise on PFAS is on the sources, transport, fate, and exposure of PFAS.

Kelly Whitehead, Group Director for Regulation in the in the Infrastructure and Environment Department, leading on the Water Quality and Safety Programme, coordinating Government's response.

Declaration of Interests

- No new interests declared.

Presentation from Subject Matter Expert Thorhallur Halldórsson

Professor Thorhallur Halldórsson, from the Faculty of Food Science and Nutrition at the University of Iceland, opened his presentation by outlining the scope of his talk: the adverse health effects of PFAS (per- and polyfluoroalkyl substances), with a particular focus on the conclusions drawn in the European Food Safety Authority (EFSA) 2020 opinion. To provide context, he offered a historical overview of how public health authorities and regulatory agencies approached PFAS prior to 2020. He clarified that although he contributed to EFSA opinions in 2018 and 2020, the views expressed were his own and not representative of EFSA.

Halldórsson described PFAS as highly persistent environmental pollutants, characterised by their resistance to degradation. He focused on long-chain PFAS, defined by having more than eight carbon atoms (or six for sulfonates), which are particularly concerning due to their long elimination half-lives in humans. These compounds bind to proteins and mimic short-chain fatty acids, leading to reabsorption by the kidneys and slow excretion. Despite being phased out, long-chain PFAS remain detectable in the environment, especially near contaminated sites such as airports, due to their historical use in firefighting foams and industrial processes.

The presentation then shifted to the regulatory journey of PFAS, particularly PFOA and PFOS. Halldórsson highlighted EFSA's evolving stance, beginning with a 2008 tolerable daily intake (TDI) of 1500 ng/kg body weight for PFOA, based on increased liver weight in rats. Over time, other agencies such as the Dutch and Danish environmental authorities drastically reduced these values—sometimes by factors of 100—using the same studies. This discrepancy raised questions about the reliability of animal models, particularly rats, in predicting human toxicity. He suggested that differences in toxicokinetic, especially elimination half-lives, may explain why humans are more vulnerable to PFAS accumulation at lower doses.

Halldórsson detailed EFSA's 2018 opinion, which reviewed 35 PFAS compounds but found sufficient evidence to draw conclusions on only four: PFOS, PFOA, PFHxS, and PFNA. The review encompassed over 200 human studies and numerous animal studies. Key health outcomes identified included increased liver enzymes, reduced oxidative response, elevated cholesterol levels, and lower birth weight. While these associations were consistent across studies, the effect sizes were modest and often within normal biological variation. For example, the reduction in birth weight was comparable to changes seen with variations in maternal nutrition and did not result in clinically significant outcomes like low birth weight or small-for-gestational-age infants.

The most critical and sensitive endpoint identified was the impact of PFAS on the immune system, particularly reduced antibody response following vaccination. Halldórsson explained that PFAS, due to their structural similarity to fatty acids, may interfere with immune modulation. Multiple human observational studies showed a consistent association between PFAS blood concentrations and reduced antibody titres post-vaccination. Supporting evidence from animal studies, including a 2005 mouse study on PFOS, confirmed this effect at low doses. Although variability exists in experimental setups and species used, the overall weight of evidence supported a causal relationship between PFAS exposure and immune suppression.

To establish the current TWI of 4.4 ng/kg body weight for the sum of PFOS, PFOA, PFHxS, and PFNA, EFSA used a modelling approach based on data from one-year-old German infants. These infants had both PFAS and antibody concentrations measured, allowing researchers to estimate the PFAS level associated with a 20% reduction in antibody response—a conservative threshold. The model back-calculated maternal PFAS concentrations that would result in this infant exposure level after one year of breastfeeding. This led to the derivation of the intake value that is now used as the health-based guidance level.

In closing, Halldórsson emphasised that the immune system endpoint is both sensitive and scientifically justified for regulatory purposes. He acknowledged that other endpoints—such as cholesterol, liver enzymes, mammary gland development, and birth weight—are also relevant but less critical. He cautioned against overinterpreting associations with severe disease outcomes, which typically occur at much higher PFAS concentrations. Halldórsson reflected on the challenges of PFAS risk assessment, noting that discrepancies between rodent and human data are not uncommon in toxicology. He expressed confidence in the robustness of human observational studies, which have been instrumental in shaping current regulatory standards.

Panel Discussion and Clarifications

Tony Fletcher opened the discussion by asking whether the tolerable weekly intake (TWI) set by EFSA for PFAS was also protective against other health endpoints such as cholesterol and birth weight. Professor Halldórsson confirmed that while the TWI was primarily based on immune system effects, it would likely be protective against other endpoints as well. However, if the TWI had been based on cholesterol or birth weight alone, the values would have been slightly higher, indicating those effects occur at higher exposure levels.

Tony then raised the issue of the relative potency factor (RPF) approach used by RIVM, which assigns different potencies to PFAS compounds like PFNA. Halldórsson explained that EFSA did not adopt this method because it was developed later and remains problematic. He noted that potency estimates vary significantly depending on whether they are based on intake or circulating concentrations, due to differences in elimination half-lives between rodents and humans. He emphasised that EFSA assumed equal potency among the four PFAS due to lack of robust comparative data and expressed scepticism about the scientific reliability of the RPF approach in its current form.

Ian Cousins asked about criticisms of EFSA's reliance on human epidemiological studies, referencing Australia's decision to disregard such data and set much higher PFAS limits. Halldórsson acknowledged that historically, epidemiological data were underutilised in setting health guidelines. However, he argued that the toxicological community in Europe has increasingly recognised the limitations of rodent models, especially due to differences in elimination half-lives. He defended EFSA's approach, stating that human data provide better predictions of relevant exposure levels, even if uncertainty factors are not strictly scientific. He criticised the dismissal of human studies without offering scientifically sound alternatives, especially when setting higher thresholds.

Ian asked why cancer was not considered a regulatory endpoint in EFSA's opinion. Halldórsson responded that while cancer was reviewed, the rodent studies were inconclusive, and human data—such as those from the C8 study—were not robust enough to support regulation. He acknowledged that PFAS may have immune-related mechanisms that could theoretically link to cancer, but the

evidence was insufficient. He contrasted EFSA's cautious approach with the U.S. stance, which assumes no safe level and bases drinking water guidelines on what is technically achievable. Halldórsson disagreed with the "no safe level" concept, suggesting that some safe threshold likely exists, though he admitted this was a personal view.

Tony noted that EFSA's 2018 review concluded that only PFOS and PFOA had sufficient data to set health-based guidance values. He asked whether PFHxS, which is of particular concern due to its use in firefighting foams, showed any distinct effects in the 2020 assessment. Halldórsson replied that PFHxS appeared to have similar immune effects to PFOS, though possibly with slightly lower potency. However, he cautioned that the available human studies often involved co-exposure to multiple PFAS, making it difficult to isolate PFHxS effects. Rodent studies suggested that higher concentrations of PFHxS were needed to produce liver effects, but the data were not strong enough to draw firm conclusions.

Presentation from Subject Matter Expert Leo Yeung

Dr. Leo Yeung began by introducing his academic background and long-standing research on PFAS, which spans his master's, PhD, postdoctoral work, and current collaborations with Swedish government agencies. His focus is on analytical techniques for characterising PFAS in food and environmental samples. He aimed to provide an academic perspective on PFAS in food.

Yeung explained the chemical structure of PFAS, particularly PFOS, noting its similarity to fatty acids but with hydrogen atoms replaced by fluorine. This substitution results in a highly stable molecule due to the strength of the carbon-fluorine bond, making PFAS resistant to degradation. He distinguished between fully fluorinated and partially fluorinated compounds; the former being referred to as perfluoroalkyl substances. PFAS are widely used in consumer products for their ability to repel water and oil, and their persistence in harsh environments such as firefighting applications.

Unlike other persistent organic pollutants (POPs), PFAS do not accumulate in fatty tissues but bind to proteins, concentrating in blood and liver. Yeung cited studies from 2006 and beyond that confirmed this pattern in chickens and fish. He emphasised the importance of chain length: long-chain PFAS (e.g., more than seven fluorinated carbons for carboxylic acids or six for sulfonates) tend to bioaccumulate and persist in the body, while short-chain PFAS are more mobile and are excreted more rapidly. This also affects their environmental mobility, with long-chain PFAS remaining near the source and short-chain PFAS traveling further.

Yeung outlined the various pathways through which humans are exposed to PFAS, including industrial emissions, consumer product use, environmental contamination, and wastewater treatment. He emphasised that food and drinking water are the primary exposure routes, with breast milk and placental transfer contributing to early-life exposure. He referenced studies showing that 40% of PFAS exposure research focuses on food and 30% on water, highlighting the significance of dietary intake.

He presented findings from studies that identified dietary ingestion as the predominant exposure pathway, followed by indoor dust and air. One study showed that detectable PFAS concentrations in drinking water were directly associated with serum levels of PFOA, PFHxS, and PFOS. Seafood

consumption was linked to elevated levels of PFNA and other PFAS. These findings underscore the importance of monitoring food and water sources for PFAS contamination.

Using a case study from Japan, Yeung illustrated how PFAS from firefighting foams can disperse regionally and globally. He described how compounds released near Tokyo travelled over 60 kilometres to Tsukuba, where he conducted postdoctoral research. These compounds can undergo transformation through oxidation or rainwater transport, reaching distant ecosystems such as the Arctic. Long-chain PFAS tend to remain nearer the source, while short-chain PFAS can travel extensively depending on environmental conditions.

Yeung explained the shift from legacy PFAS like PFOS and PFHxS to newer compounds such as 6:2 fluorotelomer-based substances. These newer compounds share structural similarities but differ in functional groups and environmental behaviour. He noted that these compounds are increasingly detected in firefighting foams and other applications, raising concerns about their relevance to human exposure and environmental persistence.

He described how PFAS accumulate in various food sources, including fish, livestock, and crops. Long-chain PFAS bind to soil particles and are ingested by animals through grazing or feeding on contaminated soil and worms. These compounds are then transferred to meat, milk, and eggs. Short-chain PFAS, on the other hand, are more likely to be taken up by plants. Studies in Japan showed that rice and vegetables like lettuce, tomatoes, cucumbers, and potatoes absorb short-chain PFAS through root systems. Notably, PFAS contamination was found on potato skins even after washing, indicating persistent surface binding.

Yeung addressed the role of food packaging materials in PFAS exposure. He explained that PFAS can migrate from packaging into food, especially when heated in microwaves. While long-chain PFAS have been phased out due to regulatory bans, short-chain compounds and side-chain fluorinated polymers are still used. These materials can hydrolyse and release PFAS into food, contributing to overall exposure. He emphasised the importance of considering packaging materials in exposure assessments and noted that recycled packaging may retain residual PFAS.

Yeung reviewed the evolution of PFAS analytical methods over the past 25 years. Early studies faced challenges due to instrument contamination, lack of standards, and poor sensitivity. He showed examples of chromatographic interference and contamination from instrument components and sample vials. Over time, improvements in instrumentation, standardisation, and quality control have enabled detection limits to drop from nanograms to picograms per gram. He stressed the importance of rigorous contamination control during sample collection and preparation.

He cited a 2006 study that revealed significant variability in PFAS measurements across laboratories, with relative standard deviations reaching up to 250%. This was attributed to inconsistent methods and lack of standards. A 2008 publication was withdrawn due to misidentification of PFAS compounds, highlighting the need for accurate transitions and separation techniques. Today, standardised methods and internal controls help mitigate ion suppression and signal enhancement, improving data reliability.

Yeung referenced technical guidance documents from the FDA and EFSA, which outline detection requirements for PFAS in food and feed. While current regulations focus on four main compounds, he advocated for broader monitoring of emerging short-chain PFAS. In Sweden, his team analyses up

to 20 PFAS compounds, facing challenges with chromatographic interference and lack of standards for newer substances. He emphasised the need for methods to quantify total PFAS exposure, including unknown compounds.

Following the presentation, panel members raised questions about analytical methods, food packaging, and PFAS migration in plants. Yeung clarified that while long-chain PFAS are generally less mobile, they can still travel several kilometres in groundwater. He also explained that short-chain PFAS are more efficiently transported within plants, though long-chain compounds can occasionally be detected in above-ground parts. The panel discussed the importance of accurate data, the role of blanks in analysis, and the need for robust quality assurance to avoid contamination and misreporting.

Panel Discussion and Clarifications

Ian Cousins opened the discussion by commending Yeung for the depth of his analytical overview, particularly the historical evolution of PFAS detection methods. He emphasised the importance of blanks in analytical procedures to prevent contamination and noted that early PFAS studies often suffered from false positives due to inadequate detection limits and poor control measures. Yeung agreed and added that early data were often skewed due to the lack of mass-labelled standards, which led to both over- and underestimation of PFAS levels. He stressed that with the availability of better standards and techniques, current data are far more reliable.

Ian then shared an example from Germany, where a study had significantly overreported PFAS levels due to intermittent blank contamination. Upon reanalysis, the actual concentrations were found to be 50 to 100 times lower than initially reported. This highlighted the critical need for stringent quality control and the importance of interpreting literature data cautiously.

Tony Fletcher raised a question about food packaging, asking whether it still posed a risk for long-chain PFAS exposure given recent regulatory changes. Yeung responded that long-chain PFAS have largely been phased out due to international conventions like the Stockholm Convention. However, he cautioned that short-chain PFAS and side-chain fluorinated substances are still used in packaging materials and may migrate into food, especially when heated. He also noted that recycled packaging materials could retain residual PFAS, posing an additional exposure risk.

The panel discussed the broader industry trend toward eliminating PFAS from food contact materials, with Ian citing Denmark's complete ban on all PFAS in food packaging. However, he and Yeung agreed that while long-chain PFAS are mostly phased out, short-chain variants and precursors remain a concern due to their potential to degrade into harmful substances.

Tony then asked about the European Union's delay in implementing a total fluorine standard for drinking water, questioning whether consensus had been reached on analytical methods. Yeung explained that the EU Drinking Water Directive sets a limit of 500 ng/L for total PFAS and offers three recommended methods for compliance. He noted that labs are also required to report trifluoroacetic acid (TFA) recovery, although how TFA data will be used remains under discussion.

Ian offered a clarification regarding PFAS mobility, noting that long-chain compounds can travel several kilometres in groundwater, contrary to the assumption that they remain localised. He cited the example of Jersey, where PFAS from a fire training ground migrated through groundwater,

demonstrating that even long-chain PFAS can pose regional contamination risks. Yeung acknowledged the correction and agreed that environmental transport mechanisms must be considered carefully.

The discussion then turned to PFAS migration in plants. Tony asked whether long-chain PFAS could migrate beyond plant roots, referencing data on leafy vegetables. Yeung explained that short-chain PFAS are more efficiently transported within plants due to their mobility and potential for active transport mechanisms. While long-chain PFAS are generally retained in soil or root tissues, they can occasionally be detected in above-ground parts like stems and leaves. Ian confirmed this, noting that although long-chain PFAS are less mobile, they are not entirely immobile and can appear in plant tissues under certain conditions.

The panel concluded with consensus on the importance of continued research into PFAS transport, exposure pathways, and analytical improvements. There was strong agreement that high-quality data, robust standards, and careful interpretation are essential for effective regulation and public health protection.

Presentation from Subject Matter Expert Irina Gyllenhammar

Dr. Irina Gyllenhammar, a toxicologist at the Swedish Food Agency, presented an overview of PFAS exposure through food, with a focus on Sweden’s national monitoring and risk assessment efforts. She began by outlining the regulatory context, noting that both food and drinking water are the primary sources of PFAS exposure. Sweden has had action limits for PFAS in drinking water since 2014, and from 2026, these will become legally binding. She also referenced the 2020 EFSA risk assessment, which established a tolerable weekly intake (TWI) for four PFAS compounds, and the 2023 EU regulation that introduced maximum levels for PFAS in meat, fish, and eggs.

Gyllenhammar described the Swedish Market Basket Study (MB), a long-term surveillance programme designed to estimate the average dietary intake of nutrients and contaminants. The study involves purchasing food from supermarkets based on national consumption statistics, homogenising it into food groups, and analysing it for various substances. Since 1999, five MB studies have been conducted (1999, 2005, 2010, 2015, and 2022), allowing for temporal trend analysis.

In the 2022 study, with additional funding from the Swedish Environmental Protection Agency, the agency expanded PFAS testing to include more specific food samples. Analysis was conducted by Dr. Leo Yeung’s team at Örebro University, covering 14 PFAS compounds. Among 17 food groups, only three—lean fish, fatty fish, and eggs—had detectable PFAS levels. Other food groups, including fruits, vegetables, beef, pork, lamb, and chicken, showed no detectable PFAS. Notably, PFAS was found in organic eggs but not in conventional eggs, a pattern also confirmed by the agency’s food control programme.

The highest PFAS concentrations were found in fish from the Baltic Sea and Swedish lakes, with lower levels in farmed salmon and oceanic fish like tuna. Swedish crayfish had higher PFAS levels than imported crayfish from Spain. PFAS was also detected in shellfish and wild boar meat, with low levels in reindeer and moose liver pâté. However, all levels were below EU maximum limits. The agency found no PFAS in fruits, vegetables, or common meats, and confirmed these findings through additional food control sampling.

Gyllenhammar presented data showing a clear downward trend in PFAS exposure from food over time. The per capita intake of PFAS has decreased steadily since 1999, with an estimated annual reduction of 8%. Concentrations in fish have also declined by approximately 5% per year, suggesting a broader environmental reduction in PFAS contamination. These trends were mirrored in human biomonitoring data from first-time mothers in Uppsala, where serum PFAS levels have also declined since 1996.

Using national dietary surveys and PFAS concentration data from the 2022 MB study, the agency calculated PFAS intake across different age groups. Most of the population had intake levels below the EFSA TWI, but some young children (1.5 and 4 years old) exceeded the threshold. When drinking water was included in the exposure model—assuming a concentration of 4 ng/L (the upcoming Swedish limit)—the contribution from water was roughly equal to that from food in adults. A separate model using a higher drinking water limit of 100 ng/L for 21 PFAS compounds showed that water could become the dominant exposure source under such conditions.

Panel Discussion and Clarifications

Ian Cousins praised the clarity of the presentation and confirmed that the most recent Market Basket report is available in English. Tony Fletcher raised two questions: first, whether the observed decline in PFAS levels in sea fish was surprising, given the persistence of PFAS in oceans. Gyllenhammar acknowledged the complexity of oceanic trends and noted that fish included in the MB study may not fully represent open ocean species. Ian added that trends in ocean PFAS levels are inconsistent, with clearer declines observed in coastal regions and human serum data.

Tony's second question concerned the representativeness of the Swedish MB study for other countries. Gyllenhammar noted that while few countries conduct full MB studies, many monitor individual food items. She emphasised that sampling time is critical for comparisons, as PFAS levels have declined over time. Ian agreed and highlighted the importance of considering food origin and supply chains.

The panel also discussed the unexpected presence of PFAS in organic eggs. Gyllenhammar attributed this to the use of fish meal in organic poultry feed, a hypothesis supported by Danish studies. Tony

suggested that free-range behaviour and worm and soil ingestion might also contribute, as seen in Dutch data, but Gyllenhammar maintained that feed was the more likely source.

Tony then referenced the UK's 2012 Total Diet Study, which showed much higher PFAS levels in fish than current Swedish data. He questioned whether Sweden's observed 5% annual decline could be applied retrospectively to UK data. Ian and Gyllenhammar agreed that analytical comparability and methodological differences must be considered. Gyllenhammar confirmed that Sweden has archived samples from past MB studies and that PFAS analysis began in 2015, allowing for retrospective validation using modern methods.

Finally, Tony questioned whether this data fitted the assumption that food is the dominant PFAS exposure source, noting that in Sweden, drinking water at the 4 ng/L limit contributed about half of adult intake. Gyllenhammar explained that this varies by region and water source, and that Sweden uses a lower-bound approach (setting non-detects to zero), which may underestimate total intake. She acknowledged that using a middle-bound approach would yield higher estimates but could overstate risk.

Presentation from Subject Matter Expert Ida Hallberg

Dr. Ida Hallberg, a veterinarian and researcher, opened her presentation by introducing the scope of her work on PFAS contamination in animal-sourced food products near known contaminated sites in Sweden. The project was funded by the Swedish Environmental Protection Agency and involved collaboration with the Swedish Food Agency and Örebro University. The primary aim was to assess the risk of PFAS exposure through food produced in proximity to contaminated areas, focusing on beef, dairy cattle, and small-scale egg production. The study concentrated on the four PFAS compounds regulated by EU maximum levels, allowing for direct comparison with established thresholds.

Hallberg provided a schematic overview of PFAS circulation in the environment, emphasising that even in countries without PFAS manufacturing industries, contamination can occur through legacy uses—particularly firefighting foams. She explained that livestock exposure differs from human exposure, with feed, drinking water, and soil ingestion being the primary routes. Soil plays a dual role: animals may ingest it directly (especially hens), and PFAS can transfer from soil to crops consumed by livestock. She noted that while other exposure routes exist, they are less relevant due to controlled animal husbandry practices.

To contextualise the Swedish situation, Hallberg presented three international case studies:

1. **Maine, USA** – A dairy farm used biosolids from a nearby PFAS-producing industry as fertiliser for decades, resulting in milk contamination. The case led to severe consequences for the farmer and prompted the Maine government to develop PFAS monitoring strategies and food safety regulations.

2. **Belgium** – Eggs from backyard hens near PFAS industries showed elevated PFAS levels, with concentrations decreasing with distance from the source. Further sampling revealed additional hotspots and raised concerns about small-scale production near industrial zones.
3. **Denmark** – Beef cattle grazing downstream from a fire training site were exposed via contaminated grass and water. The meat was consumed by members of a cattle association, highlighting the risk of concentrated exposure in specific populations.

These cases underscored the importance of monitoring food production near contaminated sites and informed the design of the Swedish study.

Hallberg explained that in Sweden, PFAS hotspots are primarily linked to firefighting foam use rather than industrial production. She emphasised the difficulty of estimating safe PFAS levels in feed and water due to species-specific physiology, exposure routes, and compound properties. Milk and beef were identified as particularly sensitive due to high feed and water intake—lactating cows, for example, may consume over 100 litres of water daily. While PFOS transfer data are relatively robust, data for other PFAS remain uncertain, complicating risk assessments.

The team attempted to calculate theoretical maximum PFAS levels in feed and water that would not result in food exceeding EU thresholds. These calculations were based on published literature and transfer rates from feed to food products. For PFOS, estimates aligned with studies from Germany, but for other PFAS, data were sparse and uncertain. The team concluded that cattle grazing on contaminated land could produce food exceeding EU thresholds, especially when exposed to both contaminated feed and water. They also noted that real-world exposure is often a combination of sources, making single-pathway estimates insufficient.

The team conducted a screening study involving farms within close proximity of known PFAS hotspots, focusing on milk, beef, and eggs. Farms were selected regardless of water plume direction to maintain anonymity. Analysis was conducted by Dr. Leo Yeung's lab at Örebro University. Samples included blood and muscle tissue from cattle, milk from dairy cows, and eggs from backyard hens. The study aimed to identify PFAS levels in food products and assess whether they exceeded EU thresholds.

PFAS was detected in most milk samples but at low levels, below EU action limits. No clear evidence of contamination from local hotspots was found, and drinking water samples from dairy farms also showed no elevated PFAS levels. The team concluded that milk contamination was minimal and likely reflected background environmental levels rather than localised exposure.

Blood and muscle tissue were sampled from cattle within 5 km of hotspots. PFOS was the only compound detected in meat, with some samples exceeding EU thresholds. Blood PFAS levels varied widely, and no consistent reduction was observed after cattle were moved indoors. The team is planning further studies to better understand blood-to-muscle transfer dynamics. They noted that PFAS half-lives in cattle are relatively short (months or days), suggesting that switching to clean feed and water could reduce contamination over time, though practical implementation may be challenging.

Backyard flocks near contaminated and urban areas were sampled. Over half of the flocks had PFAS levels above EU thresholds. Eggs from rural areas without known contamination had lower PFAS

levels, similar to those found in commercial organic eggs. The team concluded that backyard egg production near contaminated sites poses a significant exposure risk, especially for individuals who consume large quantities of their own eggs.

Using the same intake estimation model as Dr. Irina Gyllenhammar, the team assessed consumer risk based on PFAS levels found in beef and eggs. They concluded that individuals consuming large quantities of these products—such as backyard hen owners or farmers consuming their own meat—may exceed EFSA’s tolerable weekly intake. This highlights the need for targeted monitoring, public awareness, and risk communication in affected communities.

Panel Discussion and Clarifications

Ian Cousins praised the clarity and relevance of the presentation, especially for regions like Jersey, where firefighting foam use has raised similar concerns. He acknowledged the importance of understanding food contamination pathways and the implications for local populations.

Tony Fletcher asked whether contamination was confirmed through environmental sampling or inferred from proximity to hotspots. Hallberg clarified that while drinking water samples were available for dairy farms, full environmental data for other sites were still being processed. She noted that surface water access during grazing may be a significant exposure route for cattle.

Tony also queried the variation in detection limits for PFOS and PFOA in milk. Dr. Leo Yeung explained that contamination during sample handling can affect detection limits, and different compounds pose different analytical challenges. Ian added that academic labs often achieve lower detection limits than commercial labs, though commercial capabilities are improving.

Further discussion explored the role of biosolids, irrigation practices, and surface water in livestock exposure. Ian clarified that while PFOA is present in firefighting foam, it is typically at lower levels than PFOS and PFHxS. Tony emphasised the value of individual sample data for triangulating between background levels, contaminated sites, and historical datasets. He expressed interest in collaborating on future analyses and projections, particularly in comparing trends across regions and time periods.

Final Discussion with Subject Matter Experts

Ian Cousins invited general reflections on the day’s presentations and discussions. He explained that the team in Jersey is collecting samples from a range of locally significant food items, including potatoes, vegetables, milk, eggs, and milk products. These commodities are both consumed locally and exported, making them important for public health and economic reasons. Halldórsson asked whether seafood had been sampled, given the proximity of contaminated sites to coastal areas. Ian confirmed that seafood sampling is planned, likely to occur in autumn when wave action may stir up PFAS-containing sea foam, which is known to be a problematic matrix for analysis.

Halldórsson referenced a case from Denmark where cattle grazing near the coast were exposed to PFAS coming from sea foam, which had settled inland from the shoreline. Ian acknowledged the relevance of this example and noted that while Jersey's cattle may not graze directly on the coast, sea foam contamination is a concern. He explained that sampling sea foam is technically challenging due to its unstable nature and lack of standardised protocols, but efforts are underway to develop suitable methods.

Ian raised the issue of backyard egg production, noting that while eggs are being sampled in Jersey, it is unclear how much attention is being given to non-commercial sources. He emphasised that individuals who use borehole water for irrigation or poultry drinking water, and who also keep hens, could be at risk of elevated PFAS exposure. Hallberg agreed, adding that in her research, soil and feed appeared to be more significant exposure pathways for hens than water. She noted that even in urban areas with clean municipal water, eggs from backyard hens had elevated PFAS levels, despite owners reporting no use of fish-based feed.

Hallberg elaborated on the differences between commercial and backyard egg production. Commercial operations are highly standardised, with controlled feed and water sources. In contrast, beef cattle farms—particularly in Sweden—tend to use locally grown feed, which may be more susceptible to environmental contamination. This distinction is important when assessing PFAS exposure risks across different types of food production.

Ian noted that Jersey's approach differs from Sweden's Market Basket Study, as Jersey is sampling individual food items rather than compiling a representative dietary profile. He asked whether this assumption—that supermarket food in Jersey is comparable to that in Sweden or the UK—is valid. Tony responded by pointing out that the Swedish Market Basket identified only three food groups with detectable PFAS: lean fish, fatty fish, and eggs. Jersey is sampling all three, but Tony cautioned against assuming zero PFAS in all other food groups without further data.

Tony emphasised the importance of accessing recent food basket data from other countries to validate assumptions and ensure comprehensive exposure assessments. He mentioned that EFSA has a programme for collecting food sampling data from member states and that he is in the process of requesting access to these datasets. He noted that many of the studies cited in EFSA's 2020 report are outdated, and newer data would be essential for accurate comparisons.

Halldórsson added that Germany contributes a significant proportion of food sampling data to EFSA—up to 70–80%—due to regulatory requirements mandating annual testing. He suggested contacting the German Federal Institute for Risk Assessment (BfR), which may have recent data. He also noted that chicken and pork production is relatively standardised across Europe due to the widespread use of soy-based feed, whereas cattle feed tends to be more locally sourced and variable.

Ian concluded the discussion by thanking all participants for their contributions and presentations. He expressed interest in maintaining contact with the panel members for future advice and collaboration as the Jersey PFAS investigation progresses. Tony reiterated the importance of triangulating data from background levels, contaminated sites, and historical datasets to ensure robust conclusions. The discussion ended with a shared understanding of the complexity of PFAS exposure and the need for continued research and data sharing.

Any other business

No other business was raised by the panel.

Date of next meeting

Thursday 25th September 2025. It will be held 10am - 1pm online.

The Chair thanked everyone for their contributions, those watching the meeting and those offering support throughout the whole process.

A reminder to the public that this meeting has been recorded, and the video will be available online on request by emailing the Regulation Enquiries mailbox on RegulationEnquiries@gov.je. This will take a couple of days to make sure the observers are anonymised.

There being no further business, the meeting was closed.

To note that the Panel can be emailed via PFASpanel@gov.je.

Details of meeting dates and times can be found at [PFAS in Jersey \(gov.je\)](https://www.gov.je/PFAS)

Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 25 September 2025

Panel Members present: Dr Steve Hajioff – Independent Chair
Dr Tony Fletcher – PFAS and Health member
Professor Ian Cousins – PFAS and Environment member

In attendance: Standing Observer (Regulation) - Kelly Whitehead - Group Director of Regulation, Infrastructure and Environment Department
Various Subject Matter Experts
Programme support team from I&E

Welcome:

The Chair welcomed everyone to the Panel meeting and reminded people the meeting was being recorded.

Introductions

The Chair and Panel members introduced themselves.

Dr Steve Hajioff, Independent Panel Chair: A retired Director of Public Health from an area of London with two major international airports and a variety of other environmental hazards and challenges, with 35 years in clinical medicine. An expert on translating science into policy, he has worked with Nice, the Greater London Authority, the EU, WHO and World Bank, several UK government departments and several international governments. Dr Hajioff has also worked extensively in the pharmaceutical industry.

Dr Tony Fletcher, PFAS and Health Panel Member: Environmental Epidemiologist at the London School of Hygiene and Tropical Medicine, working on PFAS since 2006 and member of the panel with experience of epidemiological studies on the health effects of PFAS in contaminated communities in West Virginia in the United States, in the Veneto region, in Italy, and in Ronneby, and is the health expert on the panel.

Professor Ian Cousins, PFAS and Environment Panel Member: A Professor in Environmental Chemistry at Stockholm University, an expert on PFAS, appointed as the environmental expert on this Panel and whose expertise on PFAS is on the sources, transport, fate, and exposure of PFAS.

Kelly Whitehead, Group Director for Regulation in the in the Infrastructure and Environment Department, leading on the Water Quality and Safety Programme, coordinating Government's response.

Declaration of Interests

- No new interests declared.

Minutes

- Minutes from 24 July 2025 meeting approved as a true and accurate record by the panel.

Matters Arising

- Nothing to report

Additional Findings Since the Last Meeting

Steve Hajioff began by referencing a recent public meeting held a few weeks prior, which was not a formal panel session but rather a presentation of the panel's third report. This report focused on PFAS testing in the human population, the consequences of PFAS exposure, and potential interventions to reduce PFAS levels in the body. The meeting also included the government's response to the report. Steve noted that the discussions during this public meeting were in-depth and, at times, heated, prompting the need for clarification on certain points.

One major concern raised was the panel's recommendation of the drug Colesevelam for certain population groups, despite the published research at the time focusing on Cholestyramine. Although both drugs belong to the same pharmacological class, they are not identical, and this discrepancy caused discomfort among some community members. Steve outlined three key reasons for the panel's recommendation of Colesevelam over Cholestyramine:

1. **Forthcoming Research:** At the time of the recommendation, the panel was aware of ongoing research involving Colesevelam that had not yet been published. This research has since been released, and the panel intends to update Report 3 to reflect this and provide traceability to the relevant study.
2. **Tolerability and Side Effects:** Colesevelam is significantly better tolerated than Cholestyramine, which often causes patients to discontinue use after only a few doses due to adverse effects. The panel believed that recommending a drug with fewer side effects would result in better outcomes for affected individuals.
3. **Pharmacological Class Considerations:** In clinical practice, it is common to prescribe drugs within the same class based on shared mechanisms of action. Steve explained that this is standard behaviour in medicine, citing examples such as the substitution of ampicillin with amoxicillin due to convenience, despite differences in trial data. Since Colesevelam and Cholestyramine belong to the same class, the panel deemed it appropriate to recommend Colesevelam.

Steve confirmed that these justifications would be incorporated into the updated version of Report 3, which he hoped to complete in the coming days. He invited Ian Cousins and Tony Fletcher to add any further points. Tony contributed an important clarification regarding

ethical concerns. He confirmed that the Colesevelam trial conducted in Sweden had received full ethical approval and had been properly scrutinised. He emphasised that Colesevelam is not a novel drug—it has been used and trialled extensively for other purposes, such as lowering cholesterol, and is considered safe.

Steve reiterated that the recent study focused specifically on Colesevelam’s application in reducing PFAS levels, but the drug itself is well-established. He then asked if there were any other developments in the PFAS field since the last meeting.

Tony shared that he had recently attended the International Society of Biological Monitoring meeting in Milan, which focused on biomonitoring in environmental and occupational settings. At this event, Axel—the lead author of the Colesevelam trial—presented the study, and Tony summarised the conclusions of Report 3. The audience was receptive, and no challenging questions were raised. However, one occupational specialist cautioned against using the drug as a substitute for controlling PFAS exposure at the source. Tony reassured the individual that the panel prioritises reducing exposure and that the drug is intended only for those already exposed, to help manage body burden.

Subject Matter Experts Introductions

Jelena Rejanovic is an ICREA research professor at the Catalan Institute for Water Research in Girona, Spain. She leads a group focused on developing nanostructured materials for electrochemical water treatment and recovery systems. She included a brief introduction about herself for the livestream audience and expressed hope that the evidence she prepared for the session would be useful.

Steven Chow is a scientist at the Swiss Federal Institute of Aquatic Science and Technology in Zurich, Switzerland. He specialises in the fate, transport, and treatment of PFAS in water systems, and currently leads a study focused on PFAS behaviour in wastewater treatment. Originally from the United States, he has a background in applied PFAS treatment in drinking water.

Linda Lee is a professor at Purdue University with a joint appointment in agriculture and engineering. She has been researching PFAS for about 20 years, focusing on its fate, transport, and remediation. Her work includes collaborations with farmers and sanitation districts to address PFAS-related challenges.

Presentation from Subject Matter Expert Jelena Rejanovic

Jelena Rejanovic, delivered a comprehensive presentation on PFAS treatment technologies, particularly focusing on electrochemical water treatment and resource recovery systems. She began with a brief personal and institutional introduction, outlining her academic journey from Serbia to Spain and Australia, and her current leadership of a research group at ICRA. The institute, though relatively small with around 120 staff, conducts research across the entire continental water cycle, including conventional and next-generation water and wastewater treatment technologies.

Jelena provided an overview of PFAS (per- and polyfluoroalkyl substances), referencing the broad OECD definition and highlighting the structural diversity of PFAS compounds. She noted the increasing regulatory attention and public concern surrounding PFAS contamination, particularly in Europe, where directives such as the Drinking Water Directive, Urban Wastewater Directive, and Water Framework Directive set stringent limits and monitoring requirements. She emphasised the challenge posed by ultra-short chain PFAS like trifluoroacetic acid (TFA), recently added to the European Council's priority list due to its extreme persistence and difficulty of removal.

The presentation then shifted to available PFAS removal technologies, which she categorised into separation and destruction methods. Mature separation technologies include granular activated carbon (GAC), ion exchange resins, reverse osmosis, and foam fractionation. While effective, these methods generate PFAS-laden residuals requiring further treatment and are associated with high operational costs. Jelena detailed the limitations of each, such as frequent replacement needs, brine generation, and energy-intensive processes.

She then explored destruction technologies, including electrochemical oxidation, supercritical water oxidation (SCWO), hydrothermal alkaline treatment, and plasma oxidation. These methods aim to break down PFAS molecules but face significant challenges, particularly high energy consumption and the formation of toxic byproducts. Using electrochemical oxidation as a case study, she explained the technical bottlenecks, such as non-selective oxidation leading to chlorinated byproducts and mass transfer limitations due to the need for PFAS molecules to interact directly with electrode surfaces.

To address these issues, Jelena's group developed a novel graphene sponge electrode under the European Research Council's "Electrochem4Water" project. This material showed promise in avoiding toxic byproduct formation while effectively degrading contaminants. The team secured patents in the US and Europe and progressed to developing scalable reactors and system-integrated units under the "Forever Water" project, funded by the European Innovation Council. Collaborating with partners in Germany, France, and Spain, they aim to validate their technology through pilot trials treating PFAS-contaminated wastewater from semiconductor manufacturing, groundwater affected by firefighting activities, and landfill leachate.

Jelena emphasised the difficulty of scaling up PFAS destruction technologies from lab to market, citing the long timelines, regulatory hurdles, and lack of industry partnerships typical in the conservative water sector. She illustrated the concept of Technology Readiness Levels (TRLs), noting that her team's technology is currently at TRL 4–5, with the goal of reaching TRL 7 for commercial deployment. She also discussed the formation of a spin-off company to support commercialisation and compared her group's approach to other PFAS destruction technologies, many of which rely on commercial anodes and are still in early development stages.

In closing, Jelena reflected on the broader challenges facing PFAS remediation: the extreme persistence of PFAS compounds, the need to meet ultra-low concentration limits, and the difficulty of bridging the gap between innovative lab research and real-world application. She highlighted the importance of pilot-scale trials and industry collaboration to demonstrate the value of new technologies and cautioned against overpromising results without validated destruction data. Her presentation concluded with acknowledgements to her research team

and an invitation for further discussion, noting that she had intentionally kept the technical depth moderate for the panel audience.

Discussion

Following Jelena's presentation, the panel engaged in a technical and exploratory discussion on the implications and challenges of PFAS destruction technologies, particularly electrochemical oxidation. Steve initiated the conversation by asking whether the presence of chloride ions in electrochemical oxidation systems could lead to the formation of new, potentially harmful compounds when interacting with fluorinated organics. Jelena responded that such reactions could occur, especially if the PFAS molecules have aromatic structures, which are highly reactive with chlorine. She noted that while this is theoretically plausible, it has not yet been thoroughly investigated in the literature.

Tony then raised a related concern about the fate of fluoride released during PFAS breakdown. Jelena explained that fluoride is typically present in trace concentrations and, in some cases, may be incorporated into the electrode material without affecting performance. However, most fluoride is released into the treated water stream. She emphasised that electrochemical processes are inherently non-selective, with multiple reactions occurring simultaneously, making it difficult to control byproduct formation.

Steve followed up with a question about hydrothermal alkaline treatment (HALT), asking whether sodium hydroxide used in the process effectively neutralises hydrofluoric acid, a toxic byproduct. Jelena confirmed that this is indeed one of HALT's advantages over supercritical water oxidation (SCWO), which requires extreme conditions and can generate corrosive HF. However, she cautioned that both technologies are complex and energy-intensive, and may not be suitable for continuous, scalable operation.

Ian then shifted the discussion to the broader application of destruction technologies. He asked whether the ultimate goal was to integrate electrochemical oxidation into drinking water treatment plants as a replacement for conventional methods like granular activated carbon (GAC). Jelena clarified that her team is not currently testing their technology on drinking water due to safety concerns and regulatory constraints. Instead, they are focusing on contaminated groundwater and industrial wastewater. She explained that their system integration approach involves pre-concentration of PFAS to improve energy efficiency, with the potential to add GAC as a polishing step if needed.

Ian further noted that, to his knowledge, no PFAS destruction technologies are currently deployed in drinking water treatment globally. Jelena agreed, stating that despite significant investment and commercial interest, she is unaware of any full-scale implementation for drinking water. She speculated that some companies may be piloting systems for industrial wastewater, which poses lower risks, but expressed scepticism about the effectiveness of commercial anodes in avoiding toxic byproducts like chlorate and perchlorate.

The conversation concluded with a reflection on the maturity of available technologies. Jelena reiterated that absorption methods, such as GAC and ion exchange resins, remain the only widely adopted and reliable solutions. Ian agreed and raised a final question about the best methods for destroying PFAS-contaminated absorption materials. Jelena acknowledged the importance of this issue but suggested it be addressed later in the plenary session, as others on the panel may have insights to contribute.

Presentation from Subject Matter Expert Steven Chow

Steven Chow, presented on the fate and transport of PFAS in wastewater systems, with a particular focus on sludge management and incineration practices in Switzerland. He began by contextualising PFAS contamination within wastewater treatment plants, which act as aggregate sources due to inputs from households, industry, and commerce. These contaminants settle into sewage sludge—a byproduct of wastewater treatment—which is often land-applied in many countries to recycle nutrients like nitrogen and phosphorus. However, PFAS contamination poses risks of accumulation in soil, crops, livestock, and water sources, especially in inland regions where treated wastewater may enter potable water systems.

Steven explained that PFAS partitioning occurs during wastewater treatment: short-chain PFAS (typically fewer than eight carbon atoms) tend to remain in the liquid phase, while long-chain PFAS (eight or more carbon atoms) accumulate in sludge. In a Swiss national study of 21 wastewater treatment plants, approximately 90% of measurable PFAS mass was found in the wastewater, and 10% in the sludge—though the sludge contained more bioaccumulative long-chain compounds like PFOS, which was found to partition 75% into wastewater and 25% into sludge.

He then discussed the widespread practice of land application of sludge, particularly in the United States, where 60% of sludge is land-applied, 14% incinerated, and 24% landfilled. While this method is cost-effective and supports nutrient recycling, it raises concerns about contaminants such as heavy metals, pathogens, pharmaceuticals, microplastics, and PFAS. Several countries have begun restricting land application due to PFAS risks. For example, Germany plans to phase out land application for large treatment plants by 2032, and U.S. states like Maine have banned PFAS-contaminated sludge from being land-applied. Denmark has introduced action levels for PFAS in sludge ranging from 10 to 50 ppb.

Switzerland presents a unique case, having banned land application of sludge since 2006 due to concerns over pathogens and heavy metals. The economic impact was minimal, as only a small fraction of nitrogen and phosphorus from sludge was used in agriculture. Today, nearly all Swiss sludge undergoes thermal treatment, primarily incineration, although there are no specific PFAS limits in sludge.

Steven provided a detailed overview of sludge incineration, describing it as a high-temperature combustion process that produces flue gas, bottom ash, and heat. The ash, containing inorganic materials, is typically landfilled, while the heat is recovered for energy. Incineration reduces sludge volume by over 95% but also results in nutrient loss and requires significant capital and operating costs. Effective pollution control—particularly for flue gas—is essential, often involving particle removal, acid gas scrubbers, and activated carbon filters.

He described the operational flow of a sludge incineration facility, emphasising the need for pre-drying sludge to increase solids content for efficient combustion. Incinerators operate at temperatures above 650°C, with air pollution controls and energy recovery systems in place. In Switzerland, sludge is treated in dedicated incinerators, municipal waste-to-energy plants, or cement kilns. Zurich, for example, has a centralised sludge facility co-located with its

wastewater plant. Starting in 2026, Switzerland will mandate phosphorus recovery from incineration ash.

Regarding PFAS destruction, Steven explained that successful incineration breaks PFAS into HF gas and CO₂. HF is corrosive and must be scrubbed using alkaline bases. Incomplete combustion can result in short-chain PFAS and volatile fluorinated compounds escaping into the air. Effective PFAS destruction requires high temperatures (above 1000°C), sufficient residence time (over 2 seconds), and homogeneous heating. Cement kilns and hazardous waste incinerators meet these criteria better than older sludge or municipal waste incinerators.

He reviewed literature from Sweden and the U.S. showing that while incineration can reduce PFAS, residual short-chain PFAS often remain in ash and rinse water. A recent USEPA study using advanced monitoring confirmed high PFAS destruction in hazardous waste incinerators but cautioned that performance varies by facility type.

Steven concluded by discussing the broader implications of sludge management. He emphasized that incineration may offer high destruction of long-chain PFAS but could increase short-chain PFAS, requiring careful risk assessment. The USEPA recommends high-temperature treatment but acknowledges no current method is ideal. He stressed the importance of considering PFAS precursors, other pollutants, and the need for upstream source reduction.

Finally, he highlighted emerging sludge treatment technologies, including supercritical water oxidation and gasification/pyrolysis. These offer potential advantages such as carbon sequestration and energy recovery but remain costly and underdeveloped at scale. Steven ended his presentation by inviting questions from the panel.

Discussion

Following Steven's presentation on PFAS fate and sludge incineration, the panel engaged in a technical discussion focused on the feasibility and implications of thermal treatment options, particularly in the context of Jersey's infrastructure. Steve (Hajioff) opened the floor for questions, prompting Ian Cousins to note that Jersey has a waste-to-energy incinerator but lacks other thermal treatment facilities such as cement kilns or hazardous waste incinerators. Kelly Whitehead confirmed this, explaining that Jersey operates two incineration facilities: a waste-to-energy plant burning at 850°C and a small clinical waste incinerator operating at 1100°C. However, there are no dedicated hazardous waste incinerators, and the island's hazardous waste containment cells have limited capacity—estimated at only 20 to 30 years under current usage.

Steve (Hajioff) posed a follow-up question to Steven (Chow), asking whether it would be technically feasible to use a two-stage incineration process: first reducing sludge volume at a lower temperature (e.g., 850°C), followed by complete PFAS destruction in a higher-temperature facility (e.g., 1100°C). Steven (Chow) found the idea intriguing and plausible, noting that while the ash produced has no energy value, the concept of staged treatment could be viable depending on how the waste is mixed and managed.

Ian added that one of the Swedish researchers involved in PFAS incineration studies had been invited to the meeting. He referenced a study that performed a mass balance on PFAS at a waste-to-energy facility, noting that while volatile PFAS compounds were not measured, the detected levels of PFAS in emissions were low. Interestingly, the study found that the largest environmental emission source was not the incinerator itself but the leachate from stored solid waste piles prior to combustion, which contaminated nearby streams.

Steven (Chow) agreed, stating that most PFAS emissions from incineration appear to be minimal and that the majority of PFAS mass is either retained in ash or released via wastewater effluent. He emphasised that while PFAS are not completely destroyed, the residual levels in ash are relatively low and comparable to those found in untreated municipal sludge. Importantly, incineration achieves a 95% reduction in sludge volume, making the remaining waste more manageable for disposal or export.

Tony raised concerns about incineration temperature, noting that previous discussions had suggested 850°C might be sufficient, but recent comments implied that temperatures above 1000°C may be necessary for complete PFAS destruction. He questioned whether sludge could be cost-effectively added to waste-to-energy streams, given its organic content and potential calorific value. Steven (Chow) responded that the most significant cost in sludge incineration is the drying process. Sludge must be actively dried to increase its solids content before incineration, which adds to operational costs. However, once dried, sludge does contribute to the heating value of the process.

Steven (Chow) cautioned against overinterpreting trace PFAS findings in research studies, noting that comprehensive mass balance data for PFAS in municipal incinerators is still lacking. He added that the Swiss government has no plans to change its policy of incinerating sludge, viewing it as a less problematic exposure pathway compared to land application.

Tony then returned to the topic of land application, asking whether Switzerland had concerns about the loss of organic matter in agricultural soils due to the removal of sewage sludge from the fertiliser stream. Steven (Chow) acknowledged that maintaining soil organic matter is a general agricultural concern but explained that the contribution of sewage sludge to soil nutrients in Switzerland was minimal. Farmers often rely on manure and composting for soil amendment, which more than compensates for the absence of sewage sludge.

Presentation from Subject Matter Expert Linda Lee

Linda Lee, delivered a comprehensive presentation on PFAS in biosolids, drawing from over two decades of research and numerous field sites across the United States. Linda focused specifically on the fate of PFAS during biosolids processing and after land application. She began by emphasising that wastewater treatment plants—now often referred to in the U.S. as “water resource recovery facilities”—receive PFAS from a wide range of sources, including domestic, industrial, and commercial inputs. These compounds either remain in the effluent or adsorb to solids, which are then processed into biosolids and often land-applied.

Linda explained that biosolids vary widely in moisture content and physical form, ranging from liquid-like materials to dry, pelletised solids. The treatment processes used—such as

anaerobic or aerobic digestion, thermal hydrolysis, centrifugation, filtration, composting, and drying—affect the final form and handling of biosolids but do little to degrade PFAS. In fact, water removed during processing (centrate) often contains high PFAS concentrations and is recycled back into the treatment plant, perpetuating contamination. Some emerging technologies are being tested on this centrate to break the cycle.

In the U.S., biosolids are classified as Class A, Class B, or Exceptional Quality (EQ), based on pathogen and metal content—not PFAS. Linda noted that regulatory success in reducing metals in biosolids came from enforcing pretreatment requirements (prior to discharge into wastewater treatment plants), a model that could inform PFAS management. She also highlighted that PFAS concentrations in biosolids are reported on a dry weight basis, which can make levels appear deceptively high given the low solids content.

Linda reviewed the limitations of current disposal options. Landfilling is increasingly costly and perpetuates PFAS cycling via leachate. Incineration is not widely accepted in the U.S. due to concerns about incomplete destruction and emissions. Alternative thermal treatments like pyrolysis and gasification are being piloted but face technical and economic challenges. She emphasized that no treatment method is problem-free, and even promising technologies like alkaline hydrolysis and supercritical water oxidation face issues such as equipment corrosion and scalability.

A key theme in Linda's presentation was the growing contribution of domestic wastewater to PFAS loads, especially as industrial and AFFF (aqueous film-forming foam) discharges are more tightly regulated. She noted that most PFAS from domestic sources exit both in the effluent and the sludge. Her research coupled to others research in the past few years has shown that biosolids processing can reduce PFAS concentrations by up to 80%, likely due to volatilisation rather than degradation. This opens the possibility of capturing and treating PFAS in off-gas streams.

Linda warned against assuming that biosolids are the only source of PFAS in composted materials, noting that paper waste—a common compost input—contains high PFAS levels. She stressed the value of biosolids as a resource, citing their nutrient content, slow-release fertilisation properties, and ability to improve soil health and productivity. However, she acknowledged that legacy PFAS contamination from historic biosolids and compost applications remains a major challenge.

She presented data from her research showing wide variability in PFAS concentrations across biosolids samples, driven by input sources and analytical scope. Many studies only measure a few compounds like PFOS and PFOA, missing the majority of PFAS mass, which often consists of unmonitored precursors. These precursors can transform into the more commonly regulated PFAS during treatment or after land application, creating the illusion that PFAS are being “created” in the process.

Linda reviewed state-level regulatory responses in the U.S., ranging from interim strategies to outright bans on biosolids use. She criticised the narrow focus on PFOS and PFOA in some regulations, arguing that many precursors are being overlooked. She also highlighted the problem of industrially impacted biosolids, which include several types of industries, but she noted in particular paper mills which have been overlooked. Paper mill wastes can contain extremely high PFAS levels and have been linked to contamination of farmland and water supplies.

She presented several case studies illustrating PFAS behaviour after land application. In one long-term disposal site, biosolids increased soil organic carbon significantly, but PFAS—especially long-chain compounds—remained in the upper soil layers, while short-chain PFAS leached into groundwater. Another site showed how soil type affects PFAS mobility, with sandy soils allowing deeper leaching. She also discussed atmospheric deposition of PFAS, noting that rainwater near military and airport sites in the U.S. has exceeded drinking water limits for PFOS.

Linda emphasised the importance of considering runoff and tile drainage as major PFAS transport pathways. She shared data showing high PFAS loads in runoff following heavy rainfall and noted that closed water bodies like ponds can accumulate PFAS, posing risks to wildlife and livestock. In one case, fish in a pond near a former biosolids application site had PFOS levels exceeding 1,200 ppb, more than 2 decades after application had ceased.

Despite these concerns, Linda concluded on a cautiously optimistic note. In her own county in Indiana, extensive well testing near biosolids application sites showed low PFAS levels, suggesting that with proper management, risks can be minimised. She reiterated that PFAS concentrations in biosolids are generally decreasing and that innovation in treatment technologies is ongoing. However, she stressed the need for better monitoring of precursors, more comprehensive analytical methods, and a shift toward source reduction and treatment trains rather than reliance on any single solution.

Discussion

Steve Hajioff opened the discussion by highlighting a key insight from her talk: the importance of distinguishing between PFAS concentrations reported on a dry weight basis versus the actual wet weight of sludge applied to land. He noted that the panel had been calculating PFAS loads based on lab-reported dry weight concentrations without correcting for water content, potentially leading to overestimations of PFAS mass applied per volume of sludge. Linda confirmed the significance of this correction and offered to share an additional slide to further illustrate the point.

Linda elaborated that biosolids are typically applied based on their nitrogen content, and the amount applied can vary significantly depending on the nutrient density of the product. She cited the example of Milorganite, a commercially available biosolid product from Wisconsin, which has relatively high PFAS concentrations but, due to its high nitrogen content, is applied in smaller quantities—resulting in lower overall PFAS loads to soil compared to other biosolids with lower PFAS but also lower nutrient content. She also emphasised that when biosolids are mixed into soil, the PFAS concentrations are diluted significantly—often by a factor of 30 to 100—resulting in final soil concentrations of less than 1 part per billion (ppb), even when the biosolids themselves contain measurable PFAS.

Linda further explained that land application strategies, such as rotating fields and applying biosolids only every five years, can help manage PFAS accumulation. She advocated for such management approaches as alternatives to outright bans, especially if PFAS concentrations in biosolids can be reduced at the source.

Ian Cousins then commented on the situation in Jersey, stating that the PFAS levels in local biosolids appear to be relatively low and typical of general municipal waste, rather than being impacted by industrial or AFFF (aqueous film-forming foam) sources. Linda agreed, referring to such materials as “boring municipal biosolids,” and noted that even if precursor

compounds are present, they are likely to be at low levels compared to industrially impacted biosolids.

Ian added that although PFOS and PFOA are no longer in use in most parts of the world, including Jersey and the U.S., their persistence means they continue to be detected due to residual contamination in manufacturing equipment and infrastructure. Linda confirmed this, noting how difficult it is to fully remove PFAS from equipment such as fire trucks, where legacy contamination can persist despite cleaning efforts.

Tony Fletcher asked whether PFOS and similar compounds are still being released from precursors and intermediates in the environment. Linda responded that certain precursors, including those found in older AFFF formulations, continue to degrade slowly into PFOS over time. She emphasised that this degradation is influenced by environmental conditions such as temperature, soil type, and microbial activity. Even in healthy soils, the degradation process is slow, and in contaminated or nutrient-poor soils—such as those found at military sites—it is likely to be even slower.

Steve then asked whether it would be possible to model the future PFOS levels in contaminated areas based on the known half-life of these precursors. Linda confirmed that such data exists in the literature and that modelling is feasible, though outcomes would vary depending on local environmental conditions. She added that some precursors are more mobile than others and can leach through soil, as shown in her lysimeter studies, which capture leachate from biosolids-treated soils.

The discussion concluded with a shared understanding that while PFAS levels in biosolids are declining, legacy contamination and precursor transformation remain significant challenges. The panel acknowledged the importance of accurate measurement, source control, and thoughtful land management strategies in mitigating PFAS risks.

Final Plenary Discussion

The final plenary discussion was opened by Steve (Hajioff), who invited reflections and questions following the presentations by Linda, Jelena, and Steven (Chow). Jelena began by asking Linda about the role of side-chain fluorinated polymers—often used in paper products—as potential PFAS precursors. Ian clarified that the correct terminology was “side-chain fluorinated polymers” rather than “fluoropolymers,” which are chemically distinct. Linda confirmed that side-chain fluorinated polymers are indeed used in paper coatings and are difficult to quantify due to ionisation challenges in mass spectrometry. She shared that her own research projects had attempted to study their degradation but faced analytical limitations. However, early work showed that microbial degradation of these polymers is slow, and extraction processes can artificially break side chains, complicating analysis.

Linda also noted that recycled paper products, such as cereal boxes, are a significant source of PFAS in paper mill sludge. She observed that PFAS concentrations in such sludge have decreased over time, with a shift toward shorter-chain compounds like PFBS, which are more mobile but less bio accumulative than PFOS.

Steve (Hajioff) then asked about the spatial extent of PFAS contamination in rainwater near military sites. Linda responded that elevated PFAS levels had been detected in rainwater up

to five miles from an airport, though she clarified that the source was not definitively linked to the airport or military site. She emphasised that PFAS are now being detected in rainwater across many locations, likely due to diffuse sources such as atmospheric deposition from clothing, wastewater treatment plants, and sea spray. Ian agreed, noting that PFAS are ubiquitous in rain globally and that attributing contamination to a single aerial source is difficult due to atmospheric mixing and dilution.

The conversation then turned to the disposal of PFAS-laden materials such as granular activated carbon (GAC) and ion exchange resins. Ian asked what the best disposal options were for Jersey, given its limited infrastructure. Jelena explained that GAC is widely used in Europe, while ion exchange resins are more common in the U.S. Both technologies are expensive and generate waste streams that require further treatment. She noted that GAC is often incinerated, but the effectiveness depends on the incineration temperature and regulatory allowances. Ion exchange resins produce large volumes of regeneration brine and must be replaced periodically.

Steven (Chow) added that in the U.S., GAC used for potable water is typically virgin material, while GAC used for remediation can be thermally regenerated by manufacturers. However, regenerated GAC is generally not reused for drinking water. Ion exchange resins are often sent to hazardous waste incinerators, though some newer systems allow for in-situ regeneration. Jelena noted that in some cases, such as landfill leachate treatment, used GAC is simply disposed of in landfills due to cost considerations.

Steve (Hajioff) asked whether the temperatures required for PFAS destruction in GAC are similar to those for biosolids. Steven (Chow) confirmed that PFAS can begin to degrade at 600–800°C, but complete mineralisation is uncertain without comprehensive monitoring. Jelena added that cost often determines whether GAC is regenerated or discarded.

The discussion returned to Jersey's specific challenges. Ian noted that Jersey lacks hazardous waste incinerators, making it difficult to dispose of PFAS-laden GAC and powdered activated carbon (PAC). Steven (Chow) explained that whether a facility accepts such waste is often a regulatory decision, and some incinerators may refuse it to avoid future liability. Steve (Hajioff) suggested that a two-stage incineration process—initial volume reduction followed by high-temperature destruction—might be feasible, though Steven (Chow) cautioned that volatile PFAS could escape during the first stage if air pollution controls are inadequate.

Steve (Hajioff) then asked Jelena whether her electrochemical oxidation technology could be used to treat reverse osmosis (RO) concentrate, and whether carbon-based anodes risk fouling from organic matter. She confirmed that electrochemical oxidation is suitable for RO concentrate but warned that high chloride levels can lead to toxic byproducts like chlorate and perchlorate. Regarding fouling, she explained that graphene-based anodes differ from traditional carbon and appear resistant to biofilm formation, possibly due to their antimicrobial properties. However, long-term performance still needs to be validated in pilot-scale trials.

Tony raised a clarification about PFAS concentration units, asking whether measurements in solids were consistently reported on a dry weight basis. Jelena confirmed that her references to concentrations were for water, not solids. Steven (Chow) acknowledged a typo

in his presentation and confirmed that PFAS concentrations in biosolids are indeed reported per dry weight, consistent with European soil guidance values.

The session concluded with final reflections. Ian praised the quality of the presentations and discussions, and Steve (Hajioff) echoed his appreciation, especially thanking Linda for joining the meeting at an early hour from the U.S.

Any other business

Nothing to raise.

Date of next meeting

Wednesday 22nd October 2025. It will be held 10am - 1pm online.

The Chair thanked everyone for their contributions, those watching the meeting and those offering support throughout the whole process.

A reminder to the public that this meeting has been recorded, and the video will be available online on request by emailing the Regulation Enquiries mailbox on RegulationEnquiries@gov.je. This will take a couple of days to make sure the observers are anonymised.

There being no further business, the meeting was closed.

To note that the Panel can be emailed via PFASpanel@gov.je.

Details of meeting dates and times can be found at [PFAS in Jersey \(gov.je\)](https://www.gov.je/PFAS)

Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 4 September 2025

Panel Members present: Professor Ian Cousins – PFAS and Environment member (temporary chair)
Dr Tony Fletcher – PFAS and Health member

In attendance: Standing Observer (Regulation) - Kelly Whitehead - Group Director of Regulation, Infrastructure and Environment Department
Various Subject Matter Experts
Programme support team from I&E

Welcome:

Ian Cousins opened the session, noting the absence of the usual chair, Steve Hajioff, who was unwell and unable to attend. Despite Steve's illness, the decision was made to proceed with the meeting, given the presence of invited subject matter experts who had generously allocated their time to present. However, Ian informed attendees that the agenda would be slightly reduced to accommodate the circumstances. Specifically, reviewing the agenda, matters arising and other business would be deferred to the next panel meeting, when it is hoped that Steve will be well enough to resume his role as chair.

Introductions

Dr Tony Fletcher, PFAS and Health Panel Member: Environmental Epidemiologist at the London School of Hygiene and Tropical Medicine, working on PFAS since 2006 and member of the panel with experience of epidemiological studies on the health effects of PFAS in contaminated communities in West Virginia in the United States, in the Veneto region, in Italy, and in Ronneby, and is the health expert on the panel.

Professor Ian Cousins, PFAS and Environment Panel Member: A Professor in Environmental Chemistry at Stockholm University, an expert on PFAS, appointed as the environmental expert on this Panel and whose expertise on PFAS is on the sources, transport, fate, and exposure of PFAS.

Kelly Whitehead, Group Director for Regulation in the in the Infrastructure and Environment Department, leading on the Water Quality and Safety Programme, coordinating Government's response.

Declaration of Interests

- No new interests declared.

Presentation from Subject Matter Expert Thorhallur Halldórsson

Professor Thorhallur Halldórsson, from the Faculty of Food Science and Nutrition at the University of Iceland, opened his presentation by outlining the scope of his talk: the adverse health effects of PFAS (per- and polyfluoroalkyl substances), with a particular focus on the conclusions drawn in the European Food Safety Authority (EFSA) 2020 opinion. To provide context, he offered a historical overview of how public health authorities and regulatory agencies approached PFAS prior to 2020. He clarified that although he contributed to EFSA opinions in 2018 and 2020, the views expressed were his own and not representative of EFSA.

Halldórsson described PFAS as highly persistent environmental pollutants, characterised by their resistance to degradation. He focused on long-chain PFAS, defined by having more than eight carbon atoms (or six for sulfonates), which are particularly concerning due to their long elimination half-lives in humans. These compounds bind to proteins and mimic short-chain fatty acids, leading to reabsorption by the kidneys and slow excretion. Despite being phased out, long-chain PFAS remain detectable in the environment, especially near contaminated sites such as airports, due to their historical use in firefighting foams and industrial processes.

The presentation then shifted to the regulatory journey of PFAS, particularly PFOA and PFOS. Halldórsson highlighted EFSA's evolving stance, beginning with a 2008 tolerable daily intake (TDI) of 1500 ng/kg body weight for PFOA, based on increased liver weight in rats. Over time, other agencies such as the Dutch and Danish environmental authorities drastically reduced these values—sometimes by factors of 100—using the same studies. This discrepancy raised questions about the reliability of animal models, particularly rats, in predicting human toxicity. He suggested that differences in toxicokinetic, especially elimination half-lives, may explain why humans are more vulnerable to PFAS accumulation at lower doses.

Halldórsson detailed EFSA's 2018 opinion, which reviewed 35 PFAS compounds but found sufficient evidence to draw conclusions on only four: PFOS, PFOA, PFHxS, and PFNA. The review encompassed over 200 human studies and numerous animal studies. Key health outcomes identified included increased liver enzymes, reduced oxidative response, elevated cholesterol levels, and lower birth weight. While these associations were consistent across studies, the effect sizes were modest and often within normal biological variation. For example, the reduction in birth weight was comparable to changes seen with variations in maternal nutrition and did not result in clinically significant outcomes like low birth weight or small-for-gestational-age infants.

The most critical and sensitive endpoint identified was the impact of PFAS on the immune system, particularly reduced antibody response following vaccination. Halldórsson explained that PFAS, due to their structural similarity to fatty acids, may interfere with immune modulation. Multiple human observational studies showed a consistent association between PFAS blood concentrations and reduced antibody titres post-vaccination. Supporting evidence from animal studies, including a 2005 mouse study on PFOS, confirmed this effect at low doses. Although variability exists in experimental setups and species used, the overall

weight of evidence supported a causal relationship between PFAS exposure and immune suppression.

To establish the current TWI of 4.4 ng/kg body weight for the sum of PFOS, PFOA, PFHxS, and PFNA, EFSA used a modelling approach based on data from one-year-old German infants. These infants had both PFAS and antibody concentrations measured, allowing researchers to estimate the PFAS level associated with a 20% reduction in antibody response—a conservative threshold. The model back-calculated maternal PFAS concentrations that would result in this infant exposure level after one year of breastfeeding. This led to the derivation of the intake value that is now used as the health-based guidance level.

In closing, Halldórsson emphasised that the immune system endpoint is both sensitive and scientifically justified for regulatory purposes. He acknowledged that other endpoints—such as cholesterol, liver enzymes, mammary gland development, and birth weight—are also relevant but less critical. He cautioned against overinterpreting associations with severe disease outcomes, which typically occur at much higher PFAS concentrations. Halldórsson reflected on the challenges of PFAS risk assessment, noting that discrepancies between rodent and human data are not uncommon in toxicology. He expressed confidence in the robustness of human observational studies, which have been instrumental in shaping current regulatory standards.

Panel Discussion and Clarifications

Tony Fletcher opened the discussion by asking whether the tolerable weekly intake (TWI) set by EFSA for PFAS was also protective against other health endpoints such as cholesterol and birth weight. Professor Halldórsson confirmed that while the TWI was primarily based on immune system effects, it would likely be protective against other endpoints as well. However, if the TWI had been based on cholesterol or birth weight alone, the values would have been slightly higher, indicating those effects occur at higher exposure levels.

Tony then raised the issue of the relative potency factor (RPF) approach used by RIVM, which assigns different potencies to PFAS compounds like PFNA. Halldórsson explained that EFSA did not adopt this method because it was developed later and remains problematic. He noted that potency estimates vary significantly depending on whether they are based on intake or circulating concentrations, due to differences in elimination half-lives between rodents and humans. He emphasised that EFSA assumed equal potency among the four PFAS due to lack of robust comparative data and expressed scepticism about the scientific reliability of the RPF approach in its current form.

Ian Cousins asked about criticisms of EFSA's reliance on human epidemiological studies, referencing Australia's decision to disregard such data and set much higher PFAS limits. Halldórsson acknowledged that historically, epidemiological data were underutilised in setting health guidelines. However, he argued that the toxicological community in Europe has increasingly recognised the limitations of rodent models, especially due to differences in elimination half-lives. He defended EFSA's approach, stating that human data provide better predictions of relevant exposure levels, even if uncertainty factors are not strictly scientific. He criticised the dismissal of human studies without offering scientifically sound alternatives, especially when setting higher thresholds.

Ian asked why cancer was not considered a regulatory endpoint in EFSA's opinion. Halldórsson responded that while cancer was reviewed, the rodent studies were inconclusive, and human data—such as those from the C8 study—were not robust enough to support regulation. He acknowledged that PFAS may have immune-related mechanisms that could theoretically link to cancer, but the evidence was insufficient. He contrasted EFSA's cautious approach with the U.S. stance, which assumes no safe level and bases drinking water guidelines on what is technically achievable. Halldórsson disagreed with the “no safe level” concept, suggesting that some safe threshold likely exists, though he admitted this was a personal view.

Tony noted that EFSA's 2018 review concluded that only PFOS and PFOA had sufficient data to set health-based guidance values. He asked whether PFHxS, which is of particular concern due to its use in firefighting foams, showed any distinct effects in the 2020 assessment. Halldórsson replied that PFHxS appeared to have similar immune effects to PFOS, though possibly with slightly lower potency. However, he cautioned that the available human studies often involved co-exposure to multiple PFAS, making it difficult to isolate PFHxS effects. Rodent studies suggested that higher concentrations of PFHxS were needed to produce liver effects, but the data were not strong enough to draw firm conclusions.

Presentation from Subject Matter Expert Leo Yeung

Dr. Leo Yeung began by introducing his academic background and long-standing research on PFAS, which spans his master's, PhD, postdoctoral work, and current collaborations with Swedish government agencies. His focus is on analytical techniques for characterising PFAS in food and environmental samples. He aimed to provide an academic perspective on PFAS in food.

Yeung explained the chemical structure of PFAS, particularly PFOS, noting its similarity to fatty acids but with hydrogen atoms replaced by fluorine. This substitution results in a highly stable molecule due to the strength of the carbon-fluorine bond, making PFAS resistant to degradation. He distinguished between fully fluorinated and partially fluorinated compounds; the former being referred to as perfluoroalkyl substances. PFAS are widely used in consumer products for their ability to repel water and oil, and their persistence in harsh environments such as firefighting applications.

Unlike other persistent organic pollutants (POPs), PFAS do not accumulate in fatty tissues but bind to proteins, concentrating in blood and liver. Yeung cited studies from 2006 and beyond that confirmed this pattern in chickens and fish. He emphasised the importance of chain length: long-chain PFAS (e.g., more than seven fluorinated carbons for carboxylic acids or six for sulfonates) tend to bioaccumulate and persist in the body, while short-chain PFAS are more mobile and are excreted more rapidly. This also affects their environmental mobility, with long-chain PFAS remaining near the source and short-chain PFAS traveling further.

Yeung outlined the various pathways through which humans are exposed to PFAS, including industrial emissions, consumer product use, environmental contamination, and wastewater treatment. He emphasised that food and drinking water are the primary exposure routes, with breast milk and placental transfer contributing to early-life exposure. He referenced

studies showing that 40% of PFAS exposure research focuses on food and 30% on water, highlighting the significance of dietary intake.

He presented findings from studies that identified dietary ingestion as the predominant exposure pathway, followed by indoor dust and air. One study showed that detectable PFAS concentrations in drinking water were directly associated with serum levels of PFOA, PFHxS, and PFOS. Seafood consumption was linked to elevated levels of PFNA and other PFAS. These findings underscore the importance of monitoring food and water sources for PFAS contamination.

Using a case study from Japan, Yeung illustrated how PFAS from firefighting foams can disperse regionally and globally. He described how compounds released near Tokyo travelled over 60 kilometres to Tsukuba, where he conducted postdoctoral research. These compounds can undergo transformation through oxidation or rainwater transport, reaching distant ecosystems such as the Arctic. Long-chain PFAS tend to remain nearer the source, while short-chain PFAS can travel extensively depending on environmental conditions.

Yeung explained the shift from legacy PFAS like PFOS and PFHxS to newer compounds such as 6:2 fluorotelomer-based substances. These newer compounds share structural similarities but differ in functional groups and environmental behaviour. He noted that these compounds are increasingly detected in firefighting foams and other applications, raising concerns about their relevance to human exposure and environmental persistence.

He described how PFAS accumulate in various food sources, including fish, livestock, and crops. Long-chain PFAS bind to soil particles and are ingested by animals through grazing or feeding on contaminated soil and worms. These compounds are then transferred to meat, milk, and eggs. Short-chain PFAS, on the other hand, are more likely to be taken up by plants. Studies in Japan showed that rice and vegetables like lettuce, tomatoes, cucumbers, and potatoes absorb short-chain PFAS through root systems. Notably, PFAS contamination was found on potato skins even after washing, indicating persistent surface binding.

Yeung addressed the role of food packaging materials in PFAS exposure. He explained that PFAS can migrate from packaging into food, especially when heated in microwaves. While long-chain PFAS have been phased out due to regulatory bans, short-chain compounds and side-chain fluorinated polymers are still used. These materials can hydrolyse and release PFAS into food, contributing to overall exposure. He emphasised the importance of considering packaging materials in exposure assessments and noted that recycled packaging may retain residual PFAS.

Yeung reviewed the evolution of PFAS analytical methods over the past 25 years. Early studies faced challenges due to instrument contamination, lack of standards, and poor sensitivity. He showed examples of chromatographic interference and contamination from instrument components and sample vials. Over time, improvements in instrumentation, standardisation, and quality control have enabled detection limits to drop from nanograms to picograms per gram. He stressed the importance of rigorous contamination control during sample collection and preparation.

He cited a 2006 study that revealed significant variability in PFAS measurements across laboratories, with relative standard deviations reaching up to 250%. This was attributed to inconsistent methods and lack of standards. A 2008 publication was withdrawn due to

misidentification of PFAS compounds, highlighting the need for accurate transitions and separation techniques. Today, standardised methods and internal controls help mitigate ion suppression and signal enhancement, improving data reliability.

Yeung referenced technical guidance documents from the FDA and EFSA, which outline detection requirements for PFAS in food and feed. While current regulations focus on four main compounds, he advocated for broader monitoring of emerging short-chain PFAS. In Sweden, his team analyses up to 20 PFAS compounds, facing challenges with chromatographic interference and lack of standards for newer substances. He emphasised the need for methods to quantify total PFAS exposure, including unknown compounds.

Following the presentation, panel members raised questions about analytical methods, food packaging, and PFAS migration in plants. Yeung clarified that while long-chain PFAS are generally less mobile, they can still travel several kilometres in groundwater. He also explained that short-chain PFAS are more efficiently transported within plants, though long-chain compounds can occasionally be detected in above-ground parts. The panel discussed the importance of accurate data, the role of blanks in analysis, and the need for robust quality assurance to avoid contamination and misreporting.

Panel Discussion and Clarifications

Ian Cousins opened the discussion by commending Yeung for the depth of his analytical overview, particularly the historical evolution of PFAS detection methods. He emphasised the importance of blanks in analytical procedures to prevent contamination and noted that early PFAS studies often suffered from false positives due to inadequate detection limits and poor control measures. Yeung agreed and added that early data were often skewed due to the lack of mass-labelled standards, which led to both over- and underestimation of PFAS levels. He stressed that with the availability of better standards and techniques, current data are far more reliable.

Ian then shared an example from Germany, where a study had significantly overreported PFAS levels due to intermittent blank contamination. Upon reanalysis, the actual concentrations were found to be 50 to 100 times lower than initially reported. This highlighted the critical need for stringent quality control and the importance of interpreting literature data cautiously.

Tony Fletcher raised a question about food packaging, asking whether it still posed a risk for long-chain PFAS exposure given recent regulatory changes. Yeung responded that long-chain PFAS have largely been phased out due to international conventions like the Stockholm Convention. However, he cautioned that short-chain PFAS and side-chain fluorinated substances are still used in packaging materials and may migrate into food, especially when heated. He also noted that recycled packaging materials could retain residual PFAS, posing an additional exposure risk.

The panel discussed the broader industry trend toward eliminating PFAS from food contact materials, with Ian citing Denmark's complete ban on all PFAS in food packaging. However, he and Yeung agreed that while long-chain PFAS are mostly phased out, short-chain variants and precursors remain a concern due to their potential to degrade into harmful substances.

Tony then asked about the European Union’s delay in implementing a total fluorine standard for drinking water, questioning whether consensus had been reached on analytical methods. Yeung explained that the EU Drinking Water Directive sets a limit of 500 ng/L for total PFAS and offers three recommended methods for compliance. He noted that labs are also required to report trifluoroacetic acid (TFA) recovery, although how TFA data will be used remains under discussion.

Ian offered a clarification regarding PFAS mobility, noting that long-chain compounds can travel several kilometres in groundwater, contrary to the assumption that they remain localised. He cited the example of Jersey, where PFAS from a fire training ground migrated through groundwater, demonstrating that even long-chain PFAS can pose regional contamination risks. Yeung acknowledged the correction and agreed that environmental transport mechanisms must be considered carefully.

The discussion then turned to PFAS migration in plants. Tony asked whether long-chain PFAS could migrate beyond plant roots, referencing data on leafy vegetables. Yeung explained that short-chain PFAS are more efficiently transported within plants due to their mobility and potential for active transport mechanisms. While long-chain PFAS are generally retained in soil or root tissues, they can occasionally be detected in above-ground parts like stems and leaves. Ian confirmed this, noting that although long-chain PFAS are less mobile, they are not entirely immobile and can appear in plant tissues under certain conditions.

The panel concluded with consensus on the importance of continued research into PFAS transport, exposure pathways, and analytical improvements. There was strong agreement that high-quality data, robust standards, and careful interpretation are essential for effective regulation and public health protection.

Presentation from Subject Matter Expert Irina Gyllenhammar

Dr. Irina Gyllenhammar, a toxicologist at the Swedish Food Agency, presented an overview of PFAS exposure through food, with a focus on Sweden’s national monitoring and risk assessment efforts. She began by outlining the regulatory context, noting that both food and drinking water are the primary sources of PFAS exposure. Sweden has had action limits for PFAS in drinking water since 2014, and from 2026, these will become legally binding. She also referenced the 2020 EFSA risk assessment, which established a tolerable weekly intake (TWI) for four PFAS compounds, and the 2023 EU regulation that introduced maximum levels for PFAS in meat, fish, and eggs.

Gyllenhammar described the Swedish Market Basket Study (MB), a long-term surveillance programme designed to estimate the average dietary intake of nutrients and contaminants. The study involves purchasing food from supermarkets based on national consumption statistics, homogenising it into food groups, and analysing it for various substances. Since 1999, five MB studies have been conducted (1999, 2005, 2010, 2015, and 2022), allowing for temporal trend analysis.

In the 2022 study, with additional funding from the Swedish Environmental Protection Agency, the agency expanded PFAS testing to include more specific food samples. Analysis was conducted by Dr. Leo Yeung’s team at Örebro University, covering 14 PFAS

compounds. Among 17 food groups, only three—lean fish, fatty fish, and eggs—had detectable PFAS levels. Other food groups, including fruits, vegetables, beef, pork, lamb, and chicken, showed no detectable PFAS. Notably, PFAS was found in organic eggs but not in conventional eggs, a pattern also confirmed by the agency’s food control programme.

The highest PFAS concentrations were found in fish from the Baltic Sea and Swedish lakes, with lower levels in farmed salmon and oceanic fish like tuna. Swedish crayfish had higher PFAS levels than imported crayfish from Spain. PFAS was also detected in shellfish and wild boar meat, with low levels in reindeer and moose liver pâté. However, all levels were below EU maximum limits. The agency found no PFAS in fruits, vegetables, or common meats, and confirmed these findings through additional food control sampling.

Gyllenhammar presented data showing a clear downward trend in PFAS exposure from food over time. The per capita intake of PFAS has decreased steadily since 1999, with an estimated annual reduction of 8%. Concentrations in fish have also declined by approximately 5% per year, suggesting a broader environmental reduction in PFAS contamination. These trends were mirrored in human biomonitoring data from first-time mothers in Uppsala, where serum PFAS levels have also declined since 1996.

Using national dietary surveys and PFAS concentration data from the 2022 MB study, the agency calculated PFAS intake across different age groups. Most of the population had intake levels below the EFSA TWI, but some young children (1.5 and 4 years old) exceeded the threshold. When drinking water was included in the exposure model—assuming a concentration of 4 ng/L (the upcoming Swedish limit)—the contribution from water was roughly equal to that from food in adults. A separate model using a higher drinking water limit of 100 ng/L for 21 PFAS compounds showed that water could become the dominant exposure source under such conditions.

Panel Discussion and Clarifications

Ian Cousins praised the clarity of the presentation and confirmed that the most recent Market Basket report is available in English. Tony Fletcher raised two questions: first, whether the observed decline in PFAS levels in sea fish was surprising, given the persistence of PFAS in oceans. Gyllenhammar acknowledged the complexity of oceanic trends and noted that fish included in the MB study may not fully represent open ocean species. Ian added that trends in ocean PFAS levels are inconsistent, with clearer declines observed in coastal regions and human serum data.

Tony’s second question concerned the representativeness of the Swedish MB study for other countries. Gyllenhammar noted that while few countries conduct full MB studies, many monitor individual food items. She emphasised that sampling time is critical for comparisons, as PFAS levels have declined over time. Ian agreed and highlighted the importance of considering food origin and supply chains.

The panel also discussed the unexpected presence of PFAS in organic eggs. Gyllenhammar attributed this to the use of fish meal in organic poultry feed, a hypothesis supported by Danish studies. Tony suggested that free-range behaviour and worm and soil ingestion

might also contribute, as seen in Dutch data, but Gyllenhammar maintained that feed was the more likely source.

Tony then referenced the UK's 2012 Total Diet Study, which showed much higher PFAS levels in fish than current Swedish data. He questioned whether Sweden's observed 5% annual decline could be applied retrospectively to UK data. Ian and Gyllenhammar agreed that analytical comparability and methodological differences must be considered. Gyllenhammar confirmed that Sweden has archived samples from past MB studies and that PFAS analysis began in 2015, allowing for retrospective validation using modern methods.

Finally, Tony questioned whether this data fitted the assumption that food is the dominant PFAS exposure source, noting that in Sweden, drinking water at the 4 ng/L limit contributed about half of adult intake. Gyllenhammar explained that this varies by region and water source, and that Sweden uses a lower-bound approach (setting non-detects to zero), which may underestimate total intake. She acknowledged that using a middle-bound approach would yield higher estimates but could overstate risk.

Presentation from Subject Matter Expert Ida Hallberg

Dr. Ida Hallberg, a veterinarian and researcher, opened her presentation by introducing the scope of her work on PFAS contamination in animal-sourced food products near known contaminated sites in Sweden. The project was funded by the Swedish Environmental Protection Agency and involved collaboration with the Swedish Food Agency and Örebro University. The primary aim was to assess the risk of PFAS exposure through food produced in proximity to contaminated areas, focusing on beef, dairy cattle, and small-scale egg production. The study concentrated on the four PFAS compounds regulated by EU maximum levels, allowing for direct comparison with established thresholds.

Hallberg provided a schematic overview of PFAS circulation in the environment, emphasising that even in countries without PFAS manufacturing industries, contamination can occur through legacy uses—particularly firefighting foams. She explained that livestock exposure differs from human exposure, with feed, drinking water, and soil ingestion being the primary routes. Soil plays a dual role: animals may ingest it directly (especially hens), and PFAS can transfer from soil to crops consumed by livestock. She noted that while other exposure routes exist, they are less relevant due to controlled animal husbandry practices.

To contextualise the Swedish situation, Hallberg presented three international case studies:

4. **Maine, USA** – A dairy farm used biosolids from a nearby PFAS-producing industry as fertiliser for decades, resulting in milk contamination. The case led to severe consequences for the farmer and prompted the Maine government to develop PFAS monitoring strategies and food safety regulations.
5. **Belgium** – Eggs from backyard hens near PFAS industries showed elevated PFAS levels, with concentrations decreasing with distance from the source. Further sampling revealed additional hotspots and raised concerns about small-scale production near industrial zones.

6. **Denmark** – Beef cattle grazing downstream from a fire training site were exposed via contaminated grass and water. The meat was consumed by members of a cattle association, highlighting the risk of concentrated exposure in specific populations.

These cases underscored the importance of monitoring food production near contaminated sites and informed the design of the Swedish study.

Hallberg explained that in Sweden, PFAS hotspots are primarily linked to firefighting foam use rather than industrial production. She emphasised the difficulty of estimating safe PFAS levels in feed and water due to species-specific physiology, exposure routes, and compound properties. Milk and beef were identified as particularly sensitive due to high feed and water intake—lactating cows, for example, may consume over 100 litres of water daily. While PFOS transfer data are relatively robust, data for other PFAS remain uncertain, complicating risk assessments.

The team attempted to calculate theoretical maximum PFAS levels in feed and water that would not result in food exceeding EU thresholds. These calculations were based on published literature and transfer rates from feed to food products. For PFOS, estimates aligned with studies from Germany, but for other PFAS, data were sparse and uncertain. The team concluded that cattle grazing on contaminated land could produce food exceeding EU thresholds, especially when exposed to both contaminated feed and water. They also noted that real-world exposure is often a combination of sources, making single-pathway estimates insufficient.

The team conducted a screening study involving farms within close proximity of known PFAS hotspots, focusing on milk, beef, and eggs. Farms were selected regardless of water plume direction to maintain anonymity. Analysis was conducted by Dr. Leo Yeung's lab at Örebro University. Samples included blood and muscle tissue from cattle, milk from dairy cows, and eggs from backyard hens. The study aimed to identify PFAS levels in food products and assess whether they exceeded EU thresholds.

PFAS was detected in most milk samples but at low levels, below EU action limits. No clear evidence of contamination from local hotspots was found, and drinking water samples from dairy farms also showed no elevated PFAS levels. The team concluded that milk contamination was minimal and likely reflected background environmental levels rather than localised exposure.

Blood and muscle tissue were sampled from cattle within 5 km of hotspots. PFOS was the only compound detected in meat, with some samples exceeding EU thresholds. Blood PFAS levels varied widely, and no consistent reduction was observed after cattle were moved indoors. The team is planning further studies to better understand blood-to-muscle transfer dynamics. They noted that PFAS half-lives in cattle are relatively short (months or days), suggesting that switching to clean feed and water could reduce contamination over time, though practical implementation may be challenging.

Backyard flocks near contaminated and urban areas were sampled. Over half of the flocks had PFAS levels above EU thresholds. Eggs from rural areas without known contamination had lower PFAS levels, similar to those found in commercial organic eggs. The team concluded that backyard egg production near contaminated sites poses a significant exposure risk, especially for individuals who consume large quantities of their own eggs.

Using the same intake estimation model as Dr. Irina Gyllenhammar, the team assessed consumer risk based on PFAS levels found in beef and eggs. They concluded that individuals consuming large quantities of these products—such as backyard hen owners or farmers consuming their own meat—may exceed EFSA’s tolerable weekly intake. This highlights the need for targeted monitoring, public awareness, and risk communication in affected communities.

Panel Discussion and Clarifications

Ian Cousins praised the clarity and relevance of the presentation, especially for regions like Jersey, where firefighting foam use has raised similar concerns. He acknowledged the importance of understanding food contamination pathways and the implications for local populations.

Tony Fletcher asked whether contamination was confirmed through environmental sampling or inferred from proximity to hotspots. Hallberg clarified that while drinking water samples were available for dairy farms, full environmental data for other sites were still being processed. She noted that surface water access during grazing may be a significant exposure route for cattle.

Tony also queried the variation in detection limits for PFOS and PFOA in milk. Dr. Leo Yeung explained that contamination during sample handling can affect detection limits, and different compounds pose different analytical challenges. Ian added that academic labs often achieve lower detection limits than commercial labs, though commercial capabilities are improving.

Further discussion explored the role of biosolids, irrigation practices, and surface water in livestock exposure. Ian clarified that while PFOA is present in firefighting foam, it is typically at lower levels than PFOS and PFHxS. Tony emphasised the value of individual sample data for triangulating between background levels, contaminated sites, and historical datasets. He expressed interest in collaborating on future analyses and projections, particularly in comparing trends across regions and time periods.

Final Discussion with Subject Matter Experts

Ian Cousins invited general reflections on the day’s presentations and discussions. He explained that the team in Jersey is collecting samples from a range of locally significant food items, including potatoes, vegetables, milk, eggs, and milk products. These commodities are both consumed locally and exported, making them important for public health and economic reasons. Halldórsson asked whether seafood had been sampled, given the proximity of contaminated sites to coastal areas. Ian confirmed that seafood sampling is planned, likely to occur in autumn when wave action may stir up PFAS-containing sea foam, which is known to be a problematic matrix for analysis.

Halldórsson referenced a case from Denmark where cattle grazing near the coast were exposed to PFAS coming from sea foam, which had settled inland from the shoreline. Ian acknowledged the relevance of this example and noted that while Jersey's cattle may not graze directly on the coast, sea foam contamination is a concern. He explained that sampling sea foam is technically challenging due to its unstable nature and lack of standardised protocols, but efforts are underway to develop suitable methods.

Ian raised the issue of backyard egg production, noting that while eggs are being sampled in Jersey, it is unclear how much attention is being given to non-commercial sources. He emphasised that individuals who use borehole water for irrigation or poultry drinking water, and who also keep hens, could be at risk of elevated PFAS exposure. Hallberg agreed, adding that in her research, soil and feed appeared to be more significant exposure pathways for hens than water. She noted that even in urban areas with clean municipal water, eggs from backyard hens had elevated PFAS levels, despite owners reporting no use of fish-based feed.

Hallberg elaborated on the differences between commercial and backyard egg production. Commercial operations are highly standardised, with controlled feed and water sources. In contrast, beef cattle farms—particularly in Sweden—tend to use locally grown feed, which may be more susceptible to environmental contamination. This distinction is important when assessing PFAS exposure risks across different types of food production.

Ian noted that Jersey's approach differs from Sweden's Market Basket Study, as Jersey is sampling individual food items rather than compiling a representative dietary profile. He asked whether this assumption—that supermarket food in Jersey is comparable to that in Sweden or the UK—is valid. Tony responded by pointing out that the Swedish Market Basket identified only three food groups with detectable PFAS: lean fish, fatty fish, and eggs. Jersey is sampling all three, but Tony cautioned against assuming zero PFAS in all other food groups without further data.

Tony emphasised the importance of accessing recent food basket data from other countries to validate assumptions and ensure comprehensive exposure assessments. He mentioned that EFSA has a programme for collecting food sampling data from member states and that he is in the process of requesting access to these datasets. He noted that many of the studies cited in EFSA's 2020 report are outdated, and newer data would be essential for accurate comparisons.

Halldórsson added that Germany contributes a significant proportion of food sampling data to EFSA—up to 70–80%—due to regulatory requirements mandating annual testing. He suggested contacting the German Federal Institute for Risk Assessment (BfR), which may have recent data. He also noted that chicken and pork production is relatively standardised across Europe due to the widespread use of soy-based feed, whereas cattle feed tends to be more locally sourced and variable.

Ian concluded the discussion by thanking all participants for their contributions and presentations. He expressed interest in maintaining contact with the panel members for future advice and collaboration as the Jersey PFAS investigation progresses. Tony reiterated the importance of triangulating data from background levels, contaminated sites, and historical datasets to ensure robust conclusions. The discussion ended with a shared

understanding of the complexity of PFAS exposure and the need for continued research and data sharing.

Any other business

No other business was raised by the panel.

Date of next meeting

Thursday 25th September 2025. It will be held 10am - 1pm online.

The Chair thanked everyone for their contributions, those watching the meeting and those offering support throughout the whole process.

A reminder to the public that this meeting has been recorded, and the video will be available online on request by emailing the Regulation Enquiries mailbox on RegulationEnquiries@gov.je. This will take a couple of days to make sure the observers are anonymised.

There being no further business, the meeting was closed.

To note that the Panel can be emailed via PFASpanel@gov.je.

Details of meeting dates and times can be found at [PFAS in Jersey \(gov.je\)](https://www.gov.je/PFAS)

Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 25 September 2025

Panel Members present: Dr Steve Hajjoff – Independent Chair
Dr Tony Fletcher – PFAS and Health member
Professor Ian Cousins – PFAS and Environment member

In attendance: Standing Observer (Regulation) - Kelly Whitehead - Group Director of Regulation, Infrastructure and Environment Department
Various Subject Matter Experts
Programme support team from I&E

Welcome:

The Chair welcomed everyone to the Panel meeting and reminded people the meeting was being recorded.

Introductions

The Chair and Panel members introduced themselves.

Dr Steve Hajjoff, Independent Panel Chair: A retired Director of Public Health from an area of London with two major international airports and a variety of other environmental hazards and challenges, with 35 years in clinical medicine. An expert on translating science into policy, he has worked with Nice, the Greater London Authority, the EU, WHO and World Bank, several UK government departments and several international governments. Dr Hajjoff has also worked extensively in the pharmaceutical industry.

Dr Tony Fletcher, PFAS and Health Panel Member: Environmental Epidemiologist at the London School of Hygiene and Tropical Medicine, working on PFAS since 2006 and member of the panel with experience of epidemiological studies on the health effects of PFAS in contaminated communities in West Virginia in the United States, in the Veneto region, in Italy, and in Ronneby, and is the health expert on the panel.

Professor Ian Cousins, PFAS and Environment Panel Member: A Professor in Environmental Chemistry at Stockholm University, an expert on PFAS, appointed as the environmental expert on this Panel and whose expertise on PFAS is on the sources, transport, fate, and exposure of PFAS.

Kelly Whitehead, Group Director for Regulation in the in the Infrastructure and Environment Department, leading on the Water Quality and Safety Programme, coordinating Government's response.

Declaration of Interests

- No new interests declared.

Minutes

- Minutes from 24 July 2025 meeting approved as a true and accurate record by the panel.

Matters Arising

- Nothing to report

Additional Findings Since the Last Meeting

Steve Hajioff began by referencing a recent public meeting held a few weeks prior, which was not a formal panel session but rather a presentation of the panel's third report. This report focused on PFAS testing in the human population, the consequences of PFAS exposure, and potential interventions to reduce PFAS levels in the body. The meeting also included the government's response to the report. Steve noted that the discussions during this public meeting were in-depth and, at times, heated, prompting the need for clarification on certain points.

One major concern raised was the panel's recommendation of the drug Colesevelam for certain population groups, despite the published research at the time focusing on Cholestyramine. Although both drugs belong to the same pharmacological class, they are not identical, and this discrepancy caused discomfort among some community members. Steve outlined three key reasons for the panel's recommendation of Colesevelam over Cholestyramine:

4. **Forthcoming Research:** At the time of the recommendation, the panel was aware of ongoing research involving Colesevelam that had not yet been published. This research has since been released, and the panel intends to update Report 3 to reflect this and provide traceability to the relevant study.
5. **Tolerability and Side Effects:** Colesevelam is significantly better tolerated than Cholestyramine, which often causes patients to discontinue use after only a few doses due to adverse effects. The panel believed that recommending a drug with fewer side effects would result in better outcomes for affected individuals.
6. **Pharmacological Class Considerations:** In clinical practice, it is common to prescribe drugs within the same class based on shared mechanisms of action. Steve explained that this is standard behaviour in medicine, citing examples such as the substitution of ampicillin with amoxicillin due to convenience, despite differences in trial data. Since Colesevelam and Cholestyramine belong to the same class, the panel deemed it appropriate to recommend Colesevelam.

Steve confirmed that these justifications would be incorporated into the updated version of Report 3, which he hoped to complete in the coming days. He invited Ian Cousins and Tony

Fletcher to add any further points. Tony contributed an important clarification regarding ethical concerns. He confirmed that the Colesevelam trial conducted in Sweden had received full ethical approval and had been properly scrutinised. He emphasised that Colesevelam is not a novel drug—it has been used and trialled extensively for other purposes, such as lowering cholesterol, and is considered safe.

Steve reiterated that the recent study focused specifically on Colesevelam’s application in reducing PFAS levels, but the drug itself is well-established. He then asked if there were any other developments in the PFAS field since the last meeting.

Tony shared that he had recently attended the International Society of Biological Monitoring meeting in Milan, which focused on biomonitoring in environmental and occupational settings. At this event, Axel—the lead author of the Colesevelam trial—presented the study, and Tony summarised the conclusions of Report 3. The audience was receptive, and no challenging questions were raised. However, one occupational specialist cautioned against using the drug as a substitute for controlling PFAS exposure at the source. Tony reassured the individual that the panel prioritises reducing exposure and that the drug is intended only for those already exposed, to help manage body burden.

Subject Matter Experts Introductions

Jelena Rejanovic is an ICREA research professor at the Catalan Institute for Water Research in Girona, Spain. She leads a group focused on developing nanostructured materials for electrochemical water treatment and recovery systems. She included a brief introduction about herself for the livestream audience and expressed hope that the evidence she prepared for the session would be useful.

Steven Chow is a scientist at the Swiss Federal Institute of Aquatic Science and Technology in Zurich, Switzerland. He specialises in the fate, transport, and treatment of PFAS in water systems, and currently leads a study focused on PFAS behaviour in wastewater treatment. Originally from the United States, he has a background in applied PFAS treatment in drinking water.

Linda Lee is a professor at Purdue University with a joint appointment in agriculture and engineering. She has been researching PFAS for about 20 years, focusing on its fate, transport, and remediation. Her work includes collaborations with farmers and sanitation districts to address PFAS-related challenges.

Presentation from Subject Matter Expert Jelena Rejanovic

Jelena Rejanovic, delivered a comprehensive presentation on PFAS treatment technologies, particularly focusing on electrochemical water treatment and resource recovery systems. She began with a brief personal and institutional introduction, outlining her academic journey from Serbia to Spain and Australia, and her current leadership of a research group at ICRA. The institute, though relatively small with around 120 staff, conducts research across the entire continental water cycle, including conventional and next-generation water and wastewater treatment technologies.

Jelena provided an overview of PFAS (per- and polyfluoroalkyl substances), referencing the broad OECD definition and highlighting the structural diversity of PFAS compounds. She noted the increasing regulatory attention and public concern surrounding PFAS contamination, particularly in Europe, where directives such as the Drinking Water Directive, Urban Wastewater Directive, and Water Framework Directive set stringent limits and monitoring requirements. She emphasised the challenge posed by ultra-short chain PFAS like trifluoroacetic acid (TFA), recently added to the European Council’s priority list due to its extreme persistence and difficulty of removal.

The presentation then shifted to available PFAS removal technologies, which she categorised into separation and destruction methods. Mature separation technologies include granular activated carbon (GAC), ion exchange resins, reverse osmosis, and foam fractionation. While effective, these methods generate PFAS-laden residuals requiring further treatment and are associated with high operational costs. Jelena detailed the limitations of each, such as frequent replacement needs, brine generation, and energy-intensive processes.

She then explored destruction technologies, including electrochemical oxidation, supercritical water oxidation (SCWO), hydrothermal alkaline treatment, and plasma oxidation. These methods aim to break down PFAS molecules but face significant challenges, particularly high energy consumption and the formation of toxic byproducts. Using electrochemical oxidation as a case study, she explained the technical bottlenecks, such as non-selective oxidation leading to chlorinated byproducts and mass transfer limitations due to the need for PFAS molecules to interact directly with electrode surfaces.

To address these issues, Jelena’s group developed a novel graphene sponge electrode under the European Research Council’s “Electrochem4Water” project. This material showed promise in avoiding toxic byproduct formation while effectively degrading contaminants. The team secured patents in the US and Europe and progressed to developing scalable reactors and system-integrated units under the “Forever Water” project, funded by the European Innovation Council. Collaborating with partners in Germany, France, and Spain, they aim to validate their technology through pilot trials treating PFAS-contaminated wastewater from semiconductor manufacturing, groundwater affected by firefighting activities, and landfill leachate.

Jelena emphasised the difficulty of scaling up PFAS destruction technologies from lab to market, citing the long timelines, regulatory hurdles, and lack of industry partnerships typical in the conservative water sector. She illustrated the concept of Technology Readiness Levels (TRLs), noting that her team’s technology is currently at TRL 4–5, with the goal of reaching TRL 7 for commercial deployment. She also discussed the formation of a spin-off company to support commercialisation and compared her group’s approach to other PFAS destruction technologies, many of which rely on commercial anodes and are still in early development stages.

In closing, Jelena reflected on the broader challenges facing PFAS remediation: the extreme persistence of PFAS compounds, the need to meet ultra-low concentration limits, and the difficulty of bridging the gap between innovative lab research and real-world application. She highlighted the importance of pilot-scale trials and industry collaboration to demonstrate the value of new technologies and cautioned against overpromising results without validated

destruction data. Her presentation concluded with acknowledgements to her research team and an invitation for further discussion, noting that she had intentionally kept the technical depth moderate for the panel audience.

Discussion

Following Jelena's presentation, the panel engaged in a technical and exploratory discussion on the implications and challenges of PFAS destruction technologies, particularly electrochemical oxidation. Steve initiated the conversation by asking whether the presence of chloride ions in electrochemical oxidation systems could lead to the formation of new, potentially harmful compounds when interacting with fluorinated organics. Jelena responded that such reactions could occur, especially if the PFAS molecules have aromatic structures, which are highly reactive with chlorine. She noted that while this is theoretically plausible, it has not yet been thoroughly investigated in the literature.

Tony then raised a related concern about the fate of fluoride released during PFAS breakdown. Jelena explained that fluoride is typically present in trace concentrations and, in some cases, may be incorporated into the electrode material without affecting performance. However, most fluoride is released into the treated water stream. She emphasised that electrochemical processes are inherently non-selective, with multiple reactions occurring simultaneously, making it difficult to control byproduct formation.

Steve followed up with a question about hydrothermal alkaline treatment (HALT), asking whether sodium hydroxide used in the process effectively neutralises hydrofluoric acid, a toxic byproduct. Jelena confirmed that this is indeed one of HALT's advantages over supercritical water oxidation (SCWO), which requires extreme conditions and can generate corrosive HF. However, she cautioned that both technologies are complex and energy-intensive, and may not be suitable for continuous, scalable operation.

Ian then shifted the discussion to the broader application of destruction technologies. He asked whether the ultimate goal was to integrate electrochemical oxidation into drinking water treatment plants as a replacement for conventional methods like granular activated carbon (GAC). Jelena clarified that her team is not currently testing their technology on drinking water due to safety concerns and regulatory constraints. Instead, they are focusing on contaminated groundwater and industrial wastewater. She explained that their system integration approach involves pre-concentration of PFAS to improve energy efficiency, with the potential to add GAC as a polishing step if needed.

Ian further noted that, to his knowledge, no PFAS destruction technologies are currently deployed in drinking water treatment globally. Jelena agreed, stating that despite significant investment and commercial interest, she is unaware of any full-scale implementation for drinking water. She speculated that some companies may be piloting systems for industrial wastewater, which poses lower risks, but expressed scepticism about the effectiveness of commercial anodes in avoiding toxic byproducts like chlorate and perchlorate.

The conversation concluded with a reflection on the maturity of available technologies. Jelena reiterated that absorption methods, such as GAC and ion exchange resins, remain the only widely adopted and reliable solutions. Ian agreed and raised a final question about the best methods for destroying PFAS-contaminated absorption materials. Jelena

acknowledged the importance of this issue but suggested it be addressed later in the plenary session, as others on the panel may have insights to contribute.

Presentation from Subject Matter Expert Steven Chow

Steven Chow, presented on the fate and transport of PFAS in wastewater systems, with a particular focus on sludge management and incineration practices in Switzerland. He began by contextualising PFAS contamination within wastewater treatment plants, which act as aggregate sources due to inputs from households, industry, and commerce. These contaminants settle into sewage sludge—a byproduct of wastewater treatment—which is often land-applied in many countries to recycle nutrients like nitrogen and phosphorus. However, PFAS contamination poses risks of accumulation in soil, crops, livestock, and water sources, especially in inland regions where treated wastewater may enter potable water systems.

Steven explained that PFAS partitioning occurs during wastewater treatment: short-chain PFAS (typically fewer than eight carbon atoms) tend to remain in the liquid phase, while long-chain PFAS (eight or more carbon atoms) accumulate in sludge. In a Swiss national study of 21 wastewater treatment plants, approximately 90% of measurable PFAS mass was found in the wastewater, and 10% in the sludge—though the sludge contained more bio accumulative long-chain compounds like PFOS, which was found to partition 75% into wastewater and 25% into sludge.

He then discussed the widespread practice of land application of sludge, particularly in the United States, where 60% of sludge is land-applied, 14% incinerated, and 24% landfilled. While this method is cost-effective and supports nutrient recycling, it raises concerns about contaminants such as heavy metals, pathogens, pharmaceuticals, microplastics, and PFAS. Several countries have begun restricting land application due to PFAS risks. For example, Germany plans to phase out land application for large treatment plants by 2032, and U.S. states like Maine have banned PFAS-contaminated sludge from being land-applied. Denmark has introduced action levels for PFAS in sludge ranging from 10 to 50 ppb.

Switzerland presents a unique case, having banned land application of sludge since 2006 due to concerns over pathogens and heavy metals. The economic impact was minimal, as only a small fraction of nitrogen and phosphorus from sludge was used in agriculture. Today, nearly all Swiss sludge undergoes thermal treatment, primarily incineration, although there are no specific PFAS limits in sludge.

Steven provided a detailed overview of sludge incineration, describing it as a high-temperature combustion process that produces flue gas, bottom ash, and heat. The ash, containing inorganic materials, is typically landfilled, while the heat is recovered for energy. Incineration reduces sludge volume by over 95% but also results in nutrient loss and requires significant capital and operating costs. Effective pollution control—particularly for flue gas—is essential, often involving particle removal, acid gas scrubbers, and activated carbon filters.

He described the operational flow of a sludge incineration facility, emphasising the need for pre-drying sludge to increase solids content for efficient combustion. Incinerators operate at

temperatures above 650°C, with air pollution controls and energy recovery systems in place. In Switzerland, sludge is treated in dedicated incinerators, municipal waste-to-energy plants, or cement kilns. Zurich, for example, has a centralised sludge facility co-located with its wastewater plant. Starting in 2026, Switzerland will mandate phosphorus recovery from incineration ash.

Regarding PFAS destruction, Steven explained that successful incineration breaks PFAS into HF gas and CO₂. HF is corrosive and must be scrubbed using alkaline bases. Incomplete combustion can result in short-chain PFAS and volatile fluorinated compounds escaping into the air. Effective PFAS destruction requires high temperatures (above 1000°C), sufficient residence time (over 2 seconds), and homogeneous heating. Cement kilns and hazardous waste incinerators meet these criteria better than older sludge or municipal waste incinerators.

He reviewed literature from Sweden and the U.S. showing that while incineration can reduce PFAS, residual short-chain PFAS often remain in ash and rinse water. A recent USEPA study using advanced monitoring confirmed high PFAS destruction in hazardous waste incinerators but cautioned that performance varies by facility type.

Steven concluded by discussing the broader implications of sludge management. He emphasised that incineration may offer high destruction of long-chain PFAS but could increase short-chain PFAS, requiring careful risk assessment. The USEPA recommends high-temperature treatment but acknowledges no current method is ideal. He stressed the importance of considering PFAS precursors, other pollutants, and the need for upstream source reduction.

Finally, he highlighted emerging sludge treatment technologies, including supercritical water oxidation and gasification/pyrolysis. These offer potential advantages such as carbon sequestration and energy recovery but remain costly and underdeveloped at scale. Steven ended his presentation by inviting questions from the panel.

Discussion

Following Steven's presentation on PFAS fate and sludge incineration, the panel engaged in a technical discussion focused on the feasibility and implications of thermal treatment options, particularly in the context of Jersey's infrastructure. Steve (Hajioff) opened the floor for questions, prompting Ian Cousins to note that Jersey has a waste-to-energy incinerator but lacks other thermal treatment facilities such as cement kilns or hazardous waste incinerators. Kelly Whitehead confirmed this, explaining that Jersey operates two incineration facilities: a waste-to-energy plant burning at 850°C and a small clinical waste incinerator operating at 1100°C. However, there are no dedicated hazardous waste incinerators, and the island's hazardous waste containment cells have limited capacity—estimated at only 20 to 30 years under current usage.

Steve (Hajioff) posed a follow-up question to Steven (Chow), asking whether it would be technically feasible to use a two-stage incineration process: first reducing sludge volume at a lower temperature (e.g., 850°C), followed by complete PFAS destruction in a higher-temperature facility (e.g., 1100°C). Steven (Chow) found the idea intriguing and plausible,

noting that while the ash produced has no energy value, the concept of staged treatment could be viable depending on how the waste is mixed and managed.

Ian added that one of the Swedish researchers involved in PFAS incineration studies had been invited to the meeting. He referenced a study that performed a mass balance on PFAS at a waste-to-energy facility, noting that while volatile PFAS compounds were not measured, the detected levels of PFAS in emissions were low. Interestingly, the study found that the largest environmental emission source was not the incinerator itself but the leachate from stored solid waste piles prior to combustion, which contaminated nearby streams.

Steven (Chow) agreed, stating that most PFAS emissions from incineration appear to be minimal and that the majority of PFAS mass is either retained in ash or released via wastewater effluent. He emphasised that while PFAS are not completely destroyed, the residual levels in ash are relatively low and comparable to those found in untreated municipal sludge. Importantly, incineration achieves a 95% reduction in sludge volume, making the remaining waste more manageable for disposal or export.

Tony raised concerns about incineration temperature, noting that previous discussions had suggested 850°C might be sufficient, but recent comments implied that temperatures above 1000°C may be necessary for complete PFAS destruction. He questioned whether sludge could be cost-effectively added to waste-to-energy streams, given its organic content and potential calorific value. Steven (Chow) responded that the most significant cost in sludge incineration is the drying process. Sludge must be actively dried to increase its solids content before incineration, which adds to operational costs. However, once dried, sludge does contribute to the heating value of the process.

Steven (Chow) cautioned against overinterpreting trace PFAS findings in research studies, noting that comprehensive mass balance data for PFAS in municipal incinerators is still lacking. He added that the Swiss government has no plans to change its policy of incinerating sludge, viewing it as a less problematic exposure pathway compared to land application.

Tony then returned to the topic of land application, asking whether Switzerland had concerns about the loss of organic matter in agricultural soils due to the removal of sewage sludge from the fertiliser stream. Steven (Chow) acknowledged that maintaining soil organic matter is a general agricultural concern but explained that the contribution of sewage sludge to soil nutrients in Switzerland was minimal. Farmers often rely on manure and composting for soil amendment, which more than compensates for the absence of sewage sludge.

Presentation from Subject Matter Expert Linda Lee

Linda Lee, delivered a comprehensive presentation on PFAS in biosolids, drawing from over two decades of research and numerous field sites across the United States. Linda focused specifically on the fate of PFAS during biosolids processing and after land application. She began by emphasising that wastewater treatment plants—now often referred to in the U.S. as “water resource recovery facilities”—receive PFAS from a wide range of sources, including domestic, industrial, and commercial inputs. These compounds either remain in

the effluent or adsorb to solids, which are then processed into biosolids and often land-applied.

Linda explained that biosolids vary widely in moisture content and physical form, ranging from liquid-like materials to dry, pelletised solids. The treatment processes used—such as anaerobic or aerobic digestion, thermal hydrolysis, centrifugation, filtration, composting, and drying—affect the final form and handling of biosolids but do little to degrade PFAS. In fact, water removed during processing (centrate) often contains high PFAS concentrations and is recycled back into the treatment plant, perpetuating contamination. Some emerging technologies are being tested on this centrate to break the cycle.

In the U.S., biosolids are classified as Class A, Class B, or Exceptional Quality (EQ), based on pathogen and metal content—not PFAS. Linda noted that regulatory success in reducing metals in biosolids came from enforcing pretreatment requirements (prior to discharge into wastewater treatment plants), a model that could inform PFAS management. She also highlighted that PFAS concentrations in biosolids are reported on a dry weight basis, which can make levels appear deceptively high given the low solids content.

Linda reviewed the limitations of current disposal options. Landfilling is increasingly costly and perpetuates PFAS cycling via leachate. Incineration is not widely accepted in the U.S. due to concerns about incomplete destruction and emissions. Alternative thermal treatments like pyrolysis and gasification are being piloted but face technical and economic challenges. She emphasised that no treatment method is problem-free, and even promising technologies like alkaline hydrolysis and supercritical water oxidation face issues such as equipment corrosion and scalability.

A key theme in Linda's presentation was the growing contribution of domestic wastewater to PFAS loads, especially as industrial and AFFF (aqueous film-forming foam) discharges are more tightly regulated. She noted that most PFAS from domestic sources exit both in the effluent and the sludge. Her research coupled to others research in the past few years has shown that biosolids processing can reduce PFAS concentrations by up to 80%, likely due to volatilisation rather than degradation. This opens the possibility of capturing and treating PFAS in off-gas streams.

Linda warned against assuming that biosolids are the only source of PFAS in composted materials, noting that paper waste—a common compost input—contains high PFAS levels. She stressed the value of biosolids as a resource, citing their nutrient content, slow-release fertilisation properties, and ability to improve soil health and productivity. However, she acknowledged that legacy PFAS contamination from historic biosolids and compost applications remains a major challenge.

She presented data from her research showing wide variability in PFAS concentrations across biosolids samples, driven by input sources and analytical scope. Many studies only measure a few compounds like PFOS and PFOA, missing the majority of PFAS mass, which often consists of unmonitored precursors. These precursors can transform into the more commonly regulated PFAS during treatment or after land application, creating the illusion that PFAS are being “created” in the process.

Linda reviewed state-level regulatory responses in the U.S., ranging from interim strategies to outright bans on biosolids use. She criticised the narrow focus on PFOS and PFOA in

some regulations, arguing that many precursors are being overlooked. She also highlighted the problem of industrially impacted biosolids, which include several types of industries, but she noted in particular paper mills which have been overlooked. Paper mill wastes can contain extremely high PFAS levels and have been linked to contamination of farmland and water supplies.

She presented several case studies illustrating PFAS behaviour after land application. In one long-term disposal site, biosolids increased soil organic carbon significantly, but PFAS—especially long-chain compounds—remained in the upper soil layers, while short-chain PFAS leached into groundwater. Another site showed how soil type affects PFAS mobility, with sandy soils allowing deeper leaching. She also discussed atmospheric deposition of PFAS, noting that rainwater near military and airport sites in the U.S. has exceeded drinking water limits for PFOS.

Linda emphasised the importance of considering runoff and tile drainage as major PFAS transport pathways. She shared data showing high PFAS loads in runoff following heavy rainfall and noted that closed water bodies like ponds can accumulate PFAS, posing risks to wildlife and livestock. In one case, fish in a pond near a former biosolids application site had PFOS levels exceeding 1,200 ppb, more than 2 decades after application had ceased.

Despite these concerns, Linda concluded on a cautiously optimistic note. In her own county in Indiana, extensive well testing near biosolids application sites showed low PFAS levels, suggesting that with proper management, risks can be minimised. She reiterated that PFAS concentrations in biosolids are generally decreasing and that innovation in treatment technologies is ongoing. However, she stressed the need for better monitoring of precursors, more comprehensive analytical methods, and a shift toward source reduction and treatment trains rather than reliance on any single solution.

Discussion

Steve Hajioff opened the discussion by highlighting a key insight from her talk: the importance of distinguishing between PFAS concentrations reported on a dry weight basis versus the actual wet weight of sludge applied to land. He noted that the panel had been calculating PFAS loads based on lab-reported dry weight concentrations without correcting for water content, potentially leading to overestimations of PFAS mass applied per volume of sludge. Linda confirmed the significance of this correction and offered to share an additional slide to further illustrate the point.

Linda elaborated that biosolids are typically applied based on their nitrogen content, and the amount applied can vary significantly depending on the nutrient density of the product. She cited the example of Milorganite, a commercially available biosolid product from Wisconsin, which has relatively high PFAS concentrations but, due to its high nitrogen content, is applied in smaller quantities—resulting in lower overall PFAS loads to soil compared to other biosolids with lower PFAS but also lower nutrient content. She also emphasised that when biosolids are mixed into soil, the PFAS concentrations are diluted significantly—often by a factor of 30 to 100—resulting in final soil concentrations of less than 1 part per billion (ppb), even when the biosolids themselves contain measurable PFAS.

Linda further explained that land application strategies, such as rotating fields and applying biosolids only every five years, can help manage PFAS accumulation. She advocated for

such management approaches as alternatives to outright bans, especially if PFAS concentrations in biosolids can be reduced at the source.

Ian Cousins then commented on the situation in Jersey, stating that the PFAS levels in local biosolids appear to be relatively low and typical of general municipal waste, rather than being impacted by industrial or AFFF (aqueous film-forming foam) sources. Linda agreed, referring to such materials as “boring municipal biosolids,” and noted that even if precursor compounds are present, they are likely to be at low levels compared to industrially impacted biosolids.

Ian added that although PFOS and PFOA are no longer in use in most parts of the world, including Jersey and the U.S., their persistence means they continue to be detected due to residual contamination in manufacturing equipment and infrastructure. Linda confirmed this, noting how difficult it is to fully remove PFAS from equipment such as fire trucks, where legacy contamination can persist despite cleaning efforts.

Tony Fletcher asked whether PFOS and similar compounds are still being released from precursors and intermediates in the environment. Linda responded that certain precursors, including those found in older AFFF formulations, continue to degrade slowly into PFOS over time. She emphasised that this degradation is influenced by environmental conditions such as temperature, soil type, and microbial activity. Even in healthy soils, the degradation process is slow, and in contaminated or nutrient-poor soils—such as those found at military sites—it is likely to be even slower.

Steve then asked whether it would be possible to model the future PFOS levels in contaminated areas based on the known half-life of these precursors. Linda confirmed that such data exists in the literature and that modelling is feasible, though outcomes would vary depending on local environmental conditions. She added that some precursors are more mobile than others and can leach through soil, as shown in her lysimeter studies, which capture leachate from biosolids-treated soils.

The discussion concluded with a shared understanding that while PFAS levels in biosolids are declining, legacy contamination and precursor transformation remain significant challenges. The panel acknowledged the importance of accurate measurement, source control, and thoughtful land management strategies in mitigating PFAS risks.

Final Plenary Discussion

The final plenary discussion was opened by Steve (Hajioff), who invited reflections and questions following the presentations by Linda, Jelena, and Steven (Chow). Jelena began by asking Linda about the role of side-chain fluorinated polymers—often used in paper products—as potential PFAS precursors. Ian clarified that the correct terminology was “side-chain fluorinated polymers” rather than “fluoropolymers,” which are chemically distinct. Linda confirmed that side-chain fluorinated polymers are indeed used in paper coatings and are difficult to quantify due to ionisation challenges in mass spectrometry. She shared that her own research projects had attempted to study their degradation but faced analytical limitations. However, early work showed that microbial degradation of these polymers is slow, and extraction processes can artificially break side chains, complicating analysis.

Linda also noted that recycled paper products, such as cereal boxes, are a significant source of PFAS in paper mill sludge. She observed that PFAS concentrations in such sludge have decreased over time, with a shift toward shorter-chain compounds like PFBS, which are more mobile but less bio accumulative than PFOS.

Steve (Hajioff) then asked about the spatial extent of PFAS contamination in rainwater near military sites. Linda responded that elevated PFAS levels had been detected in rainwater up to five miles from an airport, though she clarified that the source was not definitively linked to the airport or military site. She emphasised that PFAS are now being detected in rainwater across many locations, likely due to diffuse sources such as atmospheric deposition from clothing, wastewater treatment plants, and sea spray. Ian agreed, noting that PFAS are ubiquitous in rain globally and that attributing contamination to a single aerial source is difficult due to atmospheric mixing and dilution.

The conversation then turned to the disposal of PFAS-laden materials such as granular activated carbon (GAC) and ion exchange resins. Ian asked what the best disposal options were for Jersey, given its limited infrastructure. Jelena explained that GAC is widely used in Europe, while ion exchange resins are more common in the U.S. Both technologies are expensive and generate waste streams that require further treatment. She noted that GAC is often incinerated, but the effectiveness depends on the incineration temperature and regulatory allowances. Ion exchange resins produce large volumes of regeneration brine and must be replaced periodically.

Steven (Chow) added that in the U.S., GAC used for potable water is typically virgin material, while GAC used for remediation can be thermally regenerated by manufacturers. However, regenerated GAC is generally not reused for drinking water. Ion exchange resins are often sent to hazardous waste incinerators, though some newer systems allow for in-situ regeneration. Jelena noted that in some cases, such as landfill leachate treatment, used GAC is simply disposed of in landfills due to cost considerations.

Steve (Hajioff) asked whether the temperatures required for PFAS destruction in GAC are similar to those for biosolids. Steven (Chow) confirmed that PFAS can begin to degrade at 600–800°C, but complete mineralisation is uncertain without comprehensive monitoring. Jelena added that cost often determines whether GAC is regenerated or discarded.

The discussion returned to Jersey's specific challenges. Ian noted that Jersey lacks hazardous waste incinerators, making it difficult to dispose of PFAS-laden GAC and powdered activated carbon (PAC). Steven (Chow) explained that whether a facility accepts such waste is often a regulatory decision, and some incinerators may refuse it to avoid future liability. Steve (Hajioff) suggested that a two-stage incineration process—initial volume reduction followed by high-temperature destruction—might be feasible, though Steven (Chow) cautioned that volatile PFAS could escape during the first stage if air pollution controls are inadequate.

Steve (Hajioff) then asked Jelena whether her electrochemical oxidation technology could be used to treat reverse osmosis (RO) concentrate, and whether carbon-based anodes risk fouling from organic matter. She confirmed that electrochemical oxidation is suitable for RO concentrate but warned that high chloride levels can lead to toxic byproducts like chlorate and perchlorate. Regarding fouling, she explained that graphene-based anodes differ from traditional carbon and appear resistant to biofilm formation, possibly due to their

antimicrobial properties. However, long-term performance still needs to be validated in pilot-scale trials.

Tony raised a clarification about PFAS concentration units, asking whether measurements in solids were consistently reported on a dry weight basis. Jelena confirmed that her references to concentrations were for water, not solids. Steven (Chow) acknowledged a typo in his presentation and confirmed that PFAS concentrations in biosolids are indeed reported per dry weight, consistent with European soil guidance values.

The session concluded with final reflections. Ian praised the quality of the presentations and discussions, and Steve (Hajioff) echoed his appreciation, especially thanking Linda for joining the meeting at an early hour from the U.S.

Any other business

Nothing to raise.

Date of next meeting

Wednesday 22nd October 2025. It will be held 10am - 1pm online.

The Chair thanked everyone for their contributions, those watching the meeting and those offering support throughout the whole process.

A reminder to the public that this meeting has been recorded, and the video will be available online on request by emailing the Regulation Enquiries mailbox on RegulationEnquiries@gov.ie. This will take a couple of days to make sure the observers are anonymised.

There being no further business, the meeting was closed.

To note that the Panel can be emailed via PFASpanel@gov.ie.

Details of meeting dates and times can be found at [PFAS in Jersey \(gov.ie\)](https://www.gov.ie/en/topics/pfas-in-jersey/)

Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 15:00 on 16 October 2025

Panel Members present: Dr Steve Hajjoff – Independent Chair
Dr Tony Fletcher – PFAS and Health member
Professor Ian Cousins – PFAS and Environment member

In attendance: Standing Observer (Regulation) - Kelly Whitehead - Group Director of Regulation, Infrastructure and Environment Department
David Andrews - Subject Matter Expert
Programme support team from I&E

Welcome:

The Chair welcomed everyone to the Panel meeting and reminded people the meeting was being recorded.

Introductions

The Chair and Panel members introduced themselves.

Dr Steve Hajjoff, Independent Panel Chair: A retired Director of Public Health from an area of London with two major international airports and a variety of other environmental hazards and challenges, with 35 years in clinical medicine. An expert on translating science into policy, he has worked with Nice, the Greater London Authority, the EU, WHO and World Bank, several UK government departments and several international governments. Dr Hajjoff has also worked extensively in the pharmaceutical industry.

Dr Tony Fletcher, PFAS and Health Panel Member: Environmental Epidemiologist at the London School of Hygiene and Tropical Medicine, working on PFAS since 2006 and member of the panel with experience of epidemiological studies on the health effects of PFAS in contaminated communities in West Virginia in the United States, in the Veneto region, in Italy, and in Ronneby, and is the health expert on the panel.

Professor Ian Cousins, PFAS and Environment Panel Member: A Professor in Environmental Chemistry at Stockholm University, an expert on PFAS, appointed as the environmental expert on this Panel and whose expertise on PFAS is on the sources, transport, fate, and exposure of PFAS.

Kelly Whitehead, Group Director for Regulation in the in the Infrastructure and Environment Department, leading on the Water Quality and Safety Programme, coordinating Government's response.

Subject Matter Expert Introduction

David Andrews, Acting Chief Science Officer at the Environmental Working Group (EWG), a nonprofit organisation based in Washington, D.C. David has been with EWG for approximately 15 to 17 years, with over a decade of his work focused on PFAS (per- and polyfluoroalkyl substances) contamination, particularly in water. His expertise includes examining exposure pathways and the implications of PFAS for human health. He also noted that EWG is actively involved in identifying policy solutions and advocating for regulatory changes aimed at reducing overall PFAS exposure.

Presentation from Subject Matter Expert David Andrews

David Andrews began his presentation by introducing the Environmental Working Group, a U.S.-based nonprofit and nonpartisan organisation dedicated to protecting human health and the environment. He explained that EWG's mission involves translating complex scientific topics into accessible information for the public, advocating for healthier living through improved environmental policies, and increasing transparency around chemical exposures. Their work spans various domains including drinking water, food systems, consumer products, and agricultural practices, with a particular emphasis on PFAS (per- and polyfluoroalkyl substances) contamination. Andrews highlighted EWG's long-standing involvement in PFAS research, dating back to the early 2000s, when they began analysing documents from legal trials in Parkersburg, West Virginia. These documents revealed significant health risks associated with PFAS and led to public databases and reports that informed both media and regulatory bodies.

He then shifted focus to EWG's research on drinking water contamination, particularly the organisation's efforts to compile and analyse water quality data from public utilities across the United States. This data is made publicly accessible and compared against health-based standards, which often differ from legal limits. Andrews emphasised the importance of understanding local water contamination levels and the need for effective household filtration methods. He discussed various types of water filters, including point-of-entry and point-of-use systems, and shared findings from EWG's testing of ten commonly available filters. Results showed significant variability in PFAS removal efficiency, with some filters achieving complete removal and others only reducing levels by about 20%.

Reverse osmosis systems and multi-stage carbon filters were identified as the most effective, achieving 95–100% PFAS removal, though they come with higher installation costs. Andrews also referenced peer-reviewed studies, including one conducted in North Carolina, which confirmed similar findings and highlighted the importance of evaluating filter performance under real-world conditions. He noted that longer-chain PFAS compounds are more effectively removed and stressed the critical role of regular filter maintenance to prevent desorption and recontamination.

Additionally, he discussed the broader benefits of advanced filtration systems, including the removal of co-contaminants such as disinfection byproducts and heavy metals. He cited recent research indicating that these systems could offer substantial health benefits beyond

PFAS removal, potentially influencing cost-benefit analyses for regulatory standards. He concluded by recommending certified water filters, acknowledging limitations in current certification standards that do not reflect the low concentration thresholds now considered safe. He reiterated the importance of following manufacturer guidelines for filter maintenance and highlighted key studies and resources that support EWG's recommendations.

Discussion

The discussion began with clarification around EWG's recommendation to avoid bottled water, which David Andrews explained was a general public health recommendation across the U.S., not specific to PFAS contamination, but rather due to broader concerns such as microplastics. Questions then turned to reverse osmosis (RO) systems, with Steve Hajioff asking whether users need to remineralise water filtered through RO systems. David responded that while many RO systems include remineralisation cartridges, the literature suggests that the impact on daily mineral intake is negligible, and supplementation is generally unnecessary.

Ian Cousins raised concerns about the disposal of reject water from RO systems, to which David explained that PFAS-contaminated water typically enters the wastewater stream, with waste-to-drinking water ratios varying by system. He noted that while individual household contributions are small, the cumulative impact at community scale could be significant. Additionally, PFAS captured in carbon filters often ends up in landfill waste, highlighting the lack of effective disposal or destruction mechanisms for PFAS in home filtration systems.

The panel also discussed ion exchange technologies, which David noted are more common at municipal treatment scales but less available for household use. Questions about filtration efficacy followed, particularly regarding whether filters can reduce PFAS levels to parts per trillion. David confirmed that while certification standards (e.g., NSF) do not currently guarantee reductions to such low levels, independent testing—including EWG's and academic studies—has shown that some filters can achieve reductions below detection limits, potentially meeting health-based thresholds.

Concerns were raised about filter maintenance, with panellists asking whether service contracts are available and how consumers can ensure timely replacement. David noted that the EPA includes professional maintenance in its cost estimates for small systems and that some companies offer installation and servicing. However, guidance on replacement frequency based on contamination levels is limited, and variability in water quality complicates standard recommendations.

The conversation then shifted to the reliability of certified products. David clarified that while certification indicates some level of testing, it does not necessarily correlate with superior performance, especially given the lack of low-level certification standards. Tony Fletcher and others highlighted the variability in filter performance, referencing real-world studies showing lower efficacy in under-maintained systems. David confirmed that single-stage carbon filters showed modest reductions, while multi-stage and RO systems performed significantly better.

Further discussion explored factors influencing filter performance, including ambient temperature, maintenance frequency, and water composition. While temperature effects were not studied, David acknowledged that variability in household conditions likely contributes to inconsistent results. The panel praised EWG's consumer resources, noting their uniqueness and value in guiding product selection, despite limitations in scale and variability.

Finally, David recommended under-sink RO or multi-stage carbon systems for those concerned about PFAS in drinking water, citing their effectiveness and manageable maintenance. He shared his personal experience with installing and maintaining such a system, aligning with manufacturer guidelines. The panel concluded with reflections on the importance of understanding co-contaminants and water quality when selecting filtration technologies, and the broader resilience of RO systems in handling diverse contaminants.

Date of next meeting

Wednesday 22nd October 2025. It will be held 10am - 1pm online.

The Chair thanked everyone for their contributions, those watching the meeting and those offering support throughout the whole process.

A reminder to the public that this meeting has been recorded, and the video will be available online on request by emailing the Regulation Enquiries mailbox on RegulationEnquiries@gov.je. This will take a couple of days to make sure the observers are anonymised.

There being no further business, the meeting was closed.

To note that the Panel can be emailed via PFASpanel@gov.je.

Details of meeting dates and times can be found at [PFAS in Jersey \(gov.je\)](https://www.gov.je/PFAS)

Minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 22 October 2025

Panel Members present: Dr Steve Hajjoff – Independent Chair
Dr Tony Fletcher – PFAS and Health member
Professor Ian Cousins – PFAS and Environment member

In attendance: Standing Observer (Regulation) - Kelly Whitehead - Group Director of Regulation, Infrastructure and Environment Department
Subject Matter Expert – Michel Hubert (Ph.D.)
Programme support team from I&E

Welcome:

The Chair welcomed everyone to the Panel meeting and reminded people the meeting was being recorded.

Introductions

The Chair and Panel members introduced themselves.

Dr Steve Hajjoff, Independent Panel Chair: A retired Director of Public Health from an area of London with two major international airports and a variety of other environmental hazards and challenges, with 35 years in clinical medicine. An expert on translating science into policy, he has worked with Nice, the Greater London Authority, the EU, WHO and World Bank, several UK government departments and several international governments. Dr Hajjoff has also worked extensively in the pharmaceutical industry.

Dr Tony Fletcher, PFAS and Health Panel Member: Environmental Epidemiologist at the London School of Hygiene and Tropical Medicine, working on PFAS since 2006 and member of the panel with experience of epidemiological studies on the health effects of PFAS in contaminated communities in West Virginia in the United States, in the Veneto region, in Italy, and in Ronneby, and is the health expert on the panel.

Professor Ian Cousins, PFAS and Environment Panel Member: A Professor in Environmental Chemistry at Stockholm University, an expert on PFAS, appointed as the environmental expert on this Panel and whose expertise on PFAS is on the sources, transport, fate, and exposure of PFAS.

Kelly Whitehead, Group Director for Regulation in the in the Infrastructure and Environment Department, leading on the Water Quality and Safety Programme, coordinating Government's response.

Declaration of Interests

- No new interests declared.

Minutes

- Minutes from 4 September 2025 meeting approved as a true and accurate record by the panel.

Matters Arising

- Nothing to report

Additional Findings Since the Last Meeting

The panel addressed a concern raised by a member of the public following a recent public meeting on in-home water treatment. The concern related to a perceived discrepancy between published documents and statements made by an expert during that meeting. Tony responded to this issue, referencing the Environmental Working Group's (EWG) testing of home water filters and comparing it to findings in a published paper from North Carolina. He noted that while the general consensus—echoed by David Andrews—was that tabletop and jug filters were not highly effective, further investigation into the supplementary data of the North Carolina paper revealed more nuanced results.

Tony highlighted that although the average effectiveness of tabletop filters was modest (around 75–80%), one specific product—the Berkey filter, which is a large, drum-like tabletop unit—showed 100% effectiveness in reducing PFAS compounds (PFOA, PFOS, and PFHxS) to below detectable levels in one household. This finding aligned with EWG's recommendation of the Berkey as a highly effective filter. However, Tony emphasised that this conclusion was based on very limited data—only one result in one study—and that other top-rated filters listed by EWG were not represented in the supplementary data of the North Carolina paper. He also noted that the Berkey filter may not be available in the UK, making it unsuitable for formal recommendation by the panel. Ultimately, Tony concluded that while the apparent contradiction between sources was resolved upon closer examination, the evidence base remains too limited to support specific product endorsements.

Michel Hubert Introduction

Michel Hubert introduced himself to the panel, stating that he is a senior engineer at the Norwegian Geotechnical Institute (NGI). He holds both bachelor's and master's degrees in environmental engineering. Following his academic training, he spent several years working in consultancy, where his focus was primarily on groundwater modelling and pollutant transport. Michel then moved to Norway to pursue a PhD, which he completed over the past five years. His doctoral research concentrated on the remediation of PFAS-contaminated soils. He is currently continuing his work at NGI, where he remains actively involved in

projects addressing PFAS contamination, particularly at sites affected by aqueous film-forming foam (AFFF).

Presentation from Subject Matter Expert Michel Hubert

Michel began with a brief overview of the PFAS contamination problem, particularly in the soil-groundwater system, highlighting the persistence of PFAS due to their fluorinated molecular structure and their tendency to accumulate at the air-water interface in the vadose zone (unsaturated zone). He explained how PFAS contamination typically originates from hotspot areas—often above the groundwater level—especially at sites where aqueous film-forming foam (AFFF) has been applied to the surface, such as airports and firefighting training grounds.

Michel described how PFAS compounds, including precursors, migrate through soil via percolation and eventually contaminate groundwater, forming plumes that can reach drinking water sources or natural recipients like surface waters. He emphasised the complexity of remediation due to the presence of various PFAS compounds with differing chemical properties, including shorter-chain PFAS that are more mobile and harder to contain.

He then presented a detailed overview of current and emerging soil remediation technologies, referencing a 2025 Concawe report (https://www.concawe.eu/wp-content/uploads/Rpt_24-8.pdf). These technologies were categorised by their development stage and effectiveness. Commercially used methods include excavation and landfilling, engineered containment, soil washing, and stabilisation techniques. Emerging methods still under research include phytoremediation, soil leaching, and thermal desorption.

Michel elaborated on excavation and landfilling, noting that while these methods remove contamination from the site, they do not destroy PFAS and pose challenges related to leachate treatment and landfill acceptance criteria. He discussed soil washing and flushing as separation techniques that transfer PFAS from soil to water, which then requires treatment. He cited pilot studies, including one in Australia (doi: 10.1016/j.jhazmat.2022.130441), showing high removal efficiencies for shorter-chain PFAS but lower effectiveness for longer-chain compounds like PFOS.

Stabilisation and solidification techniques were also covered. These methods aim to reduce PFAS leaching from contaminated soil rather than remove the contamination. Michel shared results from field trials and NCI's collaborative research with SLU in Sweden, demonstrating that amendments like biochar can significantly reduce PFAS leaching over long timeframes.

Thermal treatment options were discussed next, including desorption and high-temperature incineration. Michel explained that while desorption removes PFAS from soil it does not destroy them, necessitating careful gas capture and treatment. Incineration at temperatures above approximately 1000 °C can mineralize PFAS into inert compounds, such as calcium fluoride, when PFAS wastes are co-processed in cement kilns. However, thermal approaches require robust infrastructure and continuous monitoring of gas emissions

He then introduced phytoremediation as a novel, nature-based approach using plants like hemp and sunflower to absorb PFAS from soil (doi:10.1016/j.envpol.2023.122038). While

promising for short-chain PFAS, this method requires long remediation periods—up to 50 years in some cases—and is not yet viable for large-scale application.

For groundwater remediation, Michel focused on two main techniques: pump-and-treat systems and permeable reactive barriers. Pump-and-treat involves extracting contaminated groundwater, treating it (often with activated carbon, ion-exchange resins or membrane filtration), and reinjecting it to contain and reduce PFAS concentrations. He noted that while effective initially, this method requires long-term operation due to slow PFAS release over time. He cited examples from the Oslo airport and U.S. Superfund sites to illustrate its application and limitations.

Permeable reactive barriers, often using sorbents like activated carbon, were presented as a passive containment strategy for groundwater plumes. Michel shared a successful case study from northern Norway, where natural geological conditions facilitated effective PFAS capture and reduction.

In conclusion, Michel emphasised that no single remediation method can address all PFAS contamination scenarios. Site-specific conditions, PFAS profiles, and regulatory considerations necessitate tailored, multi-step treatment trains combining various technologies. He highlighted ongoing research and the need for innovation in remediation approaches, particularly for persistent and mobile PFAS compounds.

Discussion

Following his presentation, Michel opened the floor for discussion and questions. He reiterated key points from his talk, emphasising the complexity of PFAS contamination in both soil and groundwater systems. He explained that PFAS compounds, particularly those found at AFFF-impacted sites, are highly persistent due to their fluorinated molecular structure and hydrophilic head groups, which cause them to accumulate at the air-water interface in the vadose zone. This unique behaviour complicates remediation efforts, especially as PFAS precursors can transform into other PFAS compounds over time, including shorter-chain variants that are more mobile and harder to contain.

Michel provided a detailed overview of available remediation technologies, categorising them by their development stage and effectiveness. He discussed commercially used methods such as excavation and landfilling, engineered containment, soil washing, and stabilisation techniques, as well as emerging approaches like phytoremediation and thermal desorption. He highlighted the limitations of landfilling, including the challenge of finding suitable disposal sites and the long-term risks of leachate contamination. Soil washing and flushing were presented as effective for certain soil types and PFAS compounds, but their efficiency diminishes in soils with high clay or organic content.

The discussion also covered stabilisation and solidification techniques, which aim to reduce PFAS leaching rather than remove the contamination. Michel shared results from field trials and collaborative research with SLU in Sweden, demonstrating that amendments like biochar can significantly reduce PFAS leaching over extended periods. He noted, however, that long-term performance data is still limited, and regulatory acceptance of these methods may vary.

Thermal treatment options were explored, including desorption and high-temperature incineration. Michel explained that while desorption removes PFAS from soil, it does not destroy them, necessitating careful gas capture and treatment. Incineration at temperatures above approximately 1000 °C can mineralize PFAS into inert compounds, such as calcium fluoride, when PFAS wastes are co-processed in cement kilns. However, thermal approaches require robust infrastructure and continuous monitoring of gas emissions. Michel mentioned that closing the fluorine mass balance for methods aimed at destroying PFAS — to confirm complete mineralization — has not been performed in many scientific studies due to its difficulty.

Phytoremediation was discussed as a novel, nature-based solution using plants like hemp and sunflower to absorb PFAS from soil. While promising for short-chain PFAS, this method requires long remediation periods—up to 50 years in some cases—and is not yet viable for large-scale application.

Groundwater remediation techniques were also addressed, with a focus on pump-and-treat systems and permeable reactive barriers. Michel explained that pump-and-treat systems help contain and reduce PFAS concentrations but require long-term operation due to slow contaminant release. He cited examples from Oslo airport and U.S. Superfund sites to illustrate the method's application and limitations. Permeable reactive barriers, often using activated carbon, were presented as passive containment strategies for groundwater plumes, with successful case studies from Norway demonstrating significant PFAS reduction. Michel mentioned that pump-and-treat systems and permeable reactive barriers need to be tailored to each site, taking into account not only the PFAS contamination but also the geological and hydrogeological conditions present on site.

In conclusion, Michel emphasised that no single remediation method can address all PFAS contamination scenarios. Site-specific conditions, PFAS profiles, and regulatory considerations necessitate tailored, multi-step treatment trains combining various technologies. He highlighted ongoing research and the need for innovation in remediation approaches, particularly for persistent and mobile PFAS compounds. The discussion closed with appreciation from Steve Hajioff, who described Michel's presentation and insights as brilliant and fascinating.

Treatment technologies for PFAS in environmental waters and soils

The panel proceeded to item on the agenda, focusing on treatment technologies for PFAS in environmental waters and soils. Ian presented findings from a literature review, expanding the scope beyond drinking water to include groundwater and soil treatment technologies. He emphasised that while the review was not exhaustive, it captured the key developments and aligned with insights from subject matter experts.

Ian began by stressing the importance of understanding the specific site conditions before selecting treatment technologies. This includes identifying the types of PFAS present, their sources (such as AFFF use in Jersey), and the site's hydrogeology. He introduced the concept of Technology Readiness Levels (TRLs), which range from 1 (basic principles) to 9 (fully tested and commercially available). Most technologies reviewed were not yet at TRL 9,

and some commercially available methods lacked rigorous testing, making them potentially misleading.

For environmental waters, Ian reviewed absorption technologies such as activated carbon, ion exchange resins, and foam fractionation. These are effective but face challenges in complex water matrices due to fouling and reduced efficiency. Destruction technologies, including advanced oxidation and UV treatments, were also discussed. Despite claims of high PFAS destruction rates, Ian cautioned that many lack comprehensive validation, such as fluorine mass balance studies or testing in real-world conditions. He noted that most destruction technologies remain in development and are not yet deployable.

Regarding soil treatment, Ian echoed Michel Hubert's earlier presentation, listing methods such as excavation and disposal, soil washing, stabilisation, solidification, phytoremediation, and thermal treatment. He clarified distinctions between electrokinetic remediation (for soil) and electrochemical oxidation (for water), noting that neither is currently ready for practical use. His summary highlighted that absorption and membrane filtration technologies are the most mature for water treatment, while excavation and thermal treatment are effective but costly for soil.

Steve praised the clarity of Ian's paper and referenced Michel's graph showing TRLs versus effectiveness, suggesting it could be useful to include a similar figure. Ian agreed, noting his tables conveyed the same message, albeit less visually. Both emphasised the need to focus on technologies in the top-right quadrant of that graph—those with high TRLs and proven effectiveness—even though they are few and expensive.

The discussion turned to commercial claims, with Steve warning against overreliance on manufacturer assertions, drawing parallels to the pharmaceutical industry where many promising treatments fail. Ian agreed, stressing the need for rigorous testing and transparency in claims, including real-world validation and monitoring of degradation products.

Tony raised questions about the intended audience for the report, suggesting it should consider different stakeholder levels—from large entities like Ports of Jersey to individual landowners. Ian responded that tailoring solutions requires detailed site-specific data, which was beyond the scope of his review. Steve added that future recommendations would need to be based on local assessments, and Kelly Whitehead noted that site-specific redevelopment projects would likely be the most relevant use case for the report.

Ian concluded by referencing international experiences, such as the Netherlands, where stringent soil guidelines for PFAS halted redevelopment until thresholds were adjusted. Steve suggested that comparative data from European countries could be useful when evaluating Jersey's situation. Ian indicated that future work would include soil and biosolids, potentially in a separate report.

Borehole level treatment approaches

The panel moved on to the next agenda item, a review paper on borehole treatment technologies presented by Steve. He began by noting that many of the technologies discussed in the context of mains water, surface water, and soil treatment were also

applicable to borehole treatment. These included granular activated carbon (GAC), ion exchange resins, and membrane filtration methods such as reverse osmosis and nanofiltration. Steve briefly outlined how each technology works and their respective limitations, particularly in borehole settings where water quality and scale can vary significantly.

He emphasised that while GAC and ion exchange are effective, their performance can be compromised by the presence of certain ions and organic compounds. Reverse osmosis and nanofiltration, though highly effective, produce significant volumes of reject water, which may be problematic in resource-limited settings. Foam fractionation was mentioned as a potentially useful add-on technology, but destruction technologies were deemed not yet proven for field use at this scale.

Steve then discussed the physical design options for borehole treatment systems, which typically involve installation either at the borehole itself (well house) or at the point of entry into a household. He explained that the choice of technology—whether GAC, ion exchange, or reverse osmosis—should be guided by the specific PFAS profile and co-contaminants present. For single-household boreholes, he suggested that household-level treatment (e.g., under-sink or countertop filters) might be more cost-effective than installing a full-scale borehole treatment system.

Monitoring was highlighted as essential, both for PFAS and co-contaminants, and for managing residuals such as concentrate from reverse osmosis or spent media from GAC and ion exchange. Steve reiterated that most technologies are separation-based and that treatment trains—combinations of technologies—often yield better results and reduce risk. He stressed the importance of piloting technologies on-site or in similar conditions due to the variability of borehole water characteristics.

Ian raised a question about the availability of commercial borehole treatment solutions that address PFAS, sharing his own experience with a wastewater treatment system installed on his property. He noted that the system focused on nitrate removal and did not consider PFAS. Steve responded that while he had reviewed commercial domestic treatment options, he had not explored borehole-specific offerings due to the need for site-specific solutions. He offered to investigate further if the panel deemed it helpful.

Tony contributed by emphasising the importance of tailoring treatment approaches based on the intended use of borehole water. For example, if the water is only used for irrigation or non-potable purposes, treatment may be unnecessary. He suggested that for single-household boreholes, focusing treatment on kitchen taps used for drinking and cooking might be sufficient. For boreholes serving multiple dwellings, more robust treatment systems would be required.

Kelly informed the panel that her team was preparing a paper on borehole registrations and private water supply legislation, which would provide contextual data for future discussions. Tony noted that even without precise numbers, the panel could outline principles for different borehole use cases—single household, garden use, and multi-dwelling supply.

The discussion concluded with agreement that the paper should be expanded to include practical considerations for different borehole contexts and that future recommendations would benefit from this tailored approach.

Domestic appliances for reducing PFAS in drinking water

The panel turned to the topic of domestic appliances for treating PFAS in drinking water. Steve introduced the discussion by noting that there are currently no formal regulations in Europe, the UK, or Australia governing devices that claim to reduce PFAS levels in water. The only existing standards are in North America, particularly the U.S. and Canada, but even the most stringent of these fall short of the drinking water thresholds recommended for Jersey. Nonetheless, devices that meet these standards often outperform them in practice, as noted in previous expert presentations.

Steve outlined the three main technologies used in domestic filtration: activated carbon, ion exchange, and reverse osmosis. He referenced studies from the Environmental Working Group (EWG), North Carolina, and the Pacific Northwest that evaluated the effectiveness of these technologies in household settings. The findings showed variable performance, with activated carbon being the most commonly used but not always the most effective.

He described four levels of deployment for domestic filtration systems:

1. **Point-of-entry systems**, which treat all water entering a household and are typically carbon-based. These are suitable for boreholes supplying a single home but may be less effective with high water demand due to reduced contact time.
2. **Under-sink systems**, which treat water at a specific tap (usually the kitchen). These often use composite cartridges combining ion exchange and carbon, or reverse osmosis with carbon polishing.
3. **Worktop filters**, which are larger countertop units that perform similarly to under-sink systems.
4. **Gravity-fed filter jugs**, which are the least effective due to their single-stage carbon filtration and shorter contact time.

Steve emphasised that the effectiveness of these devices depends on the PFAS chain length of concern. For long-chain PFAS, carbon filtration may suffice, but for short-chain PFAS, ion exchange or reverse osmosis is necessary. He also noted that performance can degrade quickly if cartridges are not replaced regularly, and raised concerns about the disposal of spent cartridges, which often end up in municipal waste.

Kelly clarified that in Jersey, domestic waste—including used cartridges—is incinerated rather than landfilled. However, since the energy-from-waste facility does not operate at temperatures above 1000–1200°C, there is a risk that PFAS may escape into the environment during incineration.

The panel discussed the limitations of laboratory certification versus real-world performance, especially in the presence of co-contaminants. Steve reiterated that no device is currently certified to reduce PFAS levels to the thresholds recommended in Jersey’s interim report. Ian added that the state of Massachusetts does not recommend reverse osmosis for household use due to concerns about PFAS-laden reject water entering septic systems and groundwater. He also noted the lack of borehole-specific PFAS treatment options, with most commercial solutions focused on point-of-entry systems.

Tony questioned the logic behind Massachusetts' stance, arguing that separating and concentrating PFAS does not increase the total amount released into the environment. He expressed greater concern about solid waste from filter cartridges, which concentrate PFAS and may pose a disposal risk. The panel agreed that incineration could reintroduce PFAS into the environment if not properly managed.

Steve concluded by noting that while some devices tested in studies did achieve PFAS reductions below the recommended levels, these results were based on limited data and not representative of broader performance. He emphasised the challenge of relying on percentage reduction claims, which vary depending on initial PFAS concentrations. Without a standard that aligns with Jersey's thresholds, the panel cannot confidently recommend specific products, though they may signpost promising studies.

The discussion ended with consensus on the need for cautious interpretation of commercial claims and certification standards, and the importance of considering site-specific factors when evaluating domestic filtration options.

Any other business

Tony raised a noteworthy point that he had intended to mention earlier in the meeting. He shared details of a recent initiative by the European Environmental Bureau, which involved voluntary PFAS blood testing among 24 individuals—including commissioners, politicians, and bureaucrats—from 16 different EU countries. The purpose of the study was to assess PFAS exposure levels across a geographically diverse group of non-industrial participants.

Tony noted that while the press release accompanying the study presented a range of exposure levels, it lacked an average value suitable for comparative analysis. Upon contacting the organisation, he received confirmation that the median PFAS concentration (sum of four PFAS compounds) among the participants was 7.1 nanograms per millilitre. He found this figure particularly interesting, as it aligned closely with the target level discussed in the panel's third report. He speculated that the average age of participants was likely around 55 and emphasised that these individuals were not exposed to PFAS through industrial or hotspot sources, making the data a useful reference point for general European background exposure.

Steve responded by acknowledging the value of this data, noting that although the sample was small and not fully representative, it provided a useful triangulation point. He suggested that the findings imply Jersey may not have a significantly greater PFAS exposure problem than the broader European population, at least outside of known contamination plumes. Both agreed that expanding such studies would be beneficial for future comparative assessments.

Date of next meeting

Thursday 6 November 2025. It will be held 10am - 1pm online.

The Chair thanked everyone for their contributions, those watching the meeting and those offering support throughout the whole process.

A reminder to the public that this meeting has been recorded, and the video will be available online on request by emailing the Regulation Enquiries mailbox on RegulationEnquiries@gov.je. This will take a couple of days to make sure the observers are anonymised.

There being no further business, the meeting was closed.

To note that the Panel can be emailed via PFASpanel@gov.je.

Details of meeting dates and times can be found at [PFAS in Jersey \(gov.je\)](http://PFASinJersey.gov.je)

DRAFT

Draft minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 11 November 2025

Panel Members present: Dr Steve Hajioff – Independent Chair
 Dr Tony Fletcher – PFAS and Health member
 Professor Ian Cousins – PFAS and Environment
 member

In attendance: Standing Observer (Regulation) - Kelly Whitehead -
 Group Director of Regulation, Infrastructure and
 Environment Department
 Programme support team from I&E

Welcome:

The Chair welcomed everyone to the Panel meeting and reminded people the meeting was being recorded.

Introductions

The Chair and Panel members introduced themselves.

Dr Steve Hajioff, Independent Panel Chair: A retired Director of Public Health from an area of London with two major international airports and a variety of other environmental hazards and challenges, with 35 years in clinical medicine. An expert on translating science into policy, he has worked with Nice, the Greater London Authority, the EU, WHO and World Bank, several UK government departments and several international governments. Dr Hajioff has also worked extensively in the pharmaceutical industry.

Dr Tony Fletcher, PFAS and Health Panel Member: Environmental Epidemiologist at the London School of Hygiene and Tropical Medicine, working on PFAS since 2006 and member of the panel with experience of epidemiological studies on the health effects of PFAS in contaminated communities in West Virginia in the United States, in the Veneto region, in Italy, and in Ronneby, and is the health expert on the panel.

Professor Ian Cousins, PFAS and Environment Panel Member: A Professor in Environmental Chemistry at Stockholm University, an expert on PFAS, appointed as the environmental expert on this Panel and whose expertise on PFAS is on the sources, transport, fate, and exposure of PFAS.

Kelly Whitehead, Group Director for Regulation in the in the Infrastructure and Environment Department, leading on the Water Quality and Safety Programme, coordinating Government's response.

Declaration of Interests

- No new interests declared.

Minutes

Following sets of minutes were approved as a true and accurate record by the panel:

- 25 September 2025
- 16 October 2025
- 22 October 2025

Matters Arising

- Nothing to report

Additional Findings Since the Last Meeting

Tony shared an update regarding UK regulations on PFAS, noting a recent news report indicating that the Drinking Water Inspectorate has begun issuing notices to Tier 2 water suppliers where PFAS levels exceed 10 nanograms per litre. Previously, guidance required suppliers to have a plan to reduce PFAS levels, but enforcement now appears to be stricter, aiming to bring all supplies below the 10 nanogram threshold. It remains unclear whether this limit applies to the sum of PFAS compounds or individual substances, as earlier reports identified exceedances for specific PFAS chemicals.

Tony highlighted that this shift suggests a move toward more rigorous compliance. He also mentioned attending a Royal Society of Chemistry meeting on PFAS later in the week, where he hopes to gather informal insights on the matter.

Steve Hajioff expressed interest in the update and reminded attendees that the group has already made recommendations aligned with the UK drinking water threshold. Steve also noted that BBC Radio 4 is planning a documentary on PFAS, which will include coverage in Jersey, and he has an informal meeting scheduled with the journalist to learn more. He committed to providing feedback after the discussion.

Estimated PFAS contributions from food – discussion paper

The discussion focused on estimating baseline PFAS intake from food sources. Tony explained that this requires either measuring a representative sample of purchased foods or analysing individual items such as fish, potatoes, and rice, combined with dietary questionnaires. He noted that no such survey has been conducted in Jersey and that UK data is outdated, with the last total diet survey from 2012. EFSA's 2020 report, based on European data from the previous decade, provides a useful but dated baseline. Fish and seafood were identified as the dominant contributors to PFAS intake, accounting for approximately 49% of exposure. Using European averages applied to UK dietary patterns, the estimated intake was 0.62 ng/kg/day, but UK-specific measurements suggest this figure should be scaled up by two to five times, giving a likely historical range of 1–3 ng/kg/day.

This exceeds EFSA's tolerable weekly intake (TWI) of 4.4 ng/kg/week, though these figures reflect conditions over a decade ago.

Tony highlighted significant uncertainties in these estimates, particularly regarding how to treat measurements below detection limits, which can dramatically alter results. He also presented trend data from Sweden and other countries showing an 8- to 10-fold decline in PFAS levels since 2010, suggesting current intake from food is likely between 0.1 and 0.7 ng/kg/day. Drinking water contributes an additional 0.1–0.2 ng/kg/day, making food and water sources now comparable, whereas food was historically dominant. Tony emphasised that recent Swedish data show most foods, except fish and eggs, now fall below detection limits, reinforcing the downward trend. He also noted that PFOS and PFOA are now minor contributors compared to other PFAS compounds.

Steve stressed the need to combine Jersey-specific data with UK or European benchmarks to estimate total weekly intake before the next meeting. This calculation will inform whether current water recommendations keep overall exposure below EFSA's TWI, or if stricter controls are needed. He reminded the panel of the urgency to finalise recommendations before the upcoming election to avoid legislative delays.

Discussion then turned to local dietary patterns. Kelly confirmed that Jersey lacks comprehensive diet surveys but can provide market share data for local versus imported foods, particularly fish, dairy, and eggs. Ian noted that fish consumption varies culturally, with Sweden having higher intake, and freshwater fish posing greater PFAS risks than marine species. Tony added that lean fish tends to have higher PFAS concentrations than fatty fish, contrary to patterns seen with other contaminants. The panel agreed to make preliminary assumptions about food sources and consumption patterns to support exposure estimates.

The discussion concluded with consensus on next steps: calculate total weekly PFAS intake from food using available data and assumptions, integrate this with water exposure estimates, and ensure recommendations remain precautionary.

PFAS soil guidelines and sludge management options

Ian presented a comprehensive review of global soil guidelines, noting significant variability and lack of consensus across jurisdictions. He referenced the Interstate Technology and Regulatory Council as a key resource for international standards and highlighted that only four European countries—Belgium, Denmark, Netherlands, and Norway—have established soil guidelines. Ian emphasised the importance of understanding local background soil levels before setting enforceable limits, citing the Netherlands' experience where overly stringent initial guidelines disrupted the construction industry and had to be relaxed. He explained that PFAS contamination is ubiquitous, with typical background levels around 1 µg/kg, making some U.S. state guidelines unrealistically low. The Flemish region of Belgium was identified as having the most detailed and scientifically robust approach, aligning with EFSA health-based guidance and setting remediation values close to background levels. Ian noted that ecotoxicological thresholds are generally higher than human health-based limits and warned that setting strict soil guidelines could have major consequences for agriculture and construction.

The discussion then turned to biosolids management. Ian explained that wastewater treatment plants are not sources of PFAS but receive contamination from upstream uses, including consumer products and human excretion. PFAS partitions into sludge during treatment, and anaerobic digestion does not destroy these chemicals. Land application of biosolids, historically practiced in Jersey, introduces PFAS into agricultural soils. While single applications may not exceed background levels, repeated use could lead to accumulation above low guideline thresholds. Alternative disposal options were reviewed, including landfilling (not feasible in Jersey), hazardous waste incineration (effective but costly), and emerging thermal treatments such as pyrolysis and gasification, which require significant capital investment. Incineration studies show most PFAS is destroyed, though trace amounts remain in waste streams. Ian stressed that none of the options are ideal, and decisions will involve trade-offs between environmental protection, agricultural needs, and economic feasibility.

Steve acknowledged the complexity and suggested that recommendations might need to differentiate between land types—agricultural, residential, and other uses—and potentially set tolerable PFAS levels for each. He proposed considering conditional biosolid application based on soil PFAS concentrations, though Ian cautioned that cumulative applications would eventually exceed limits, necessitating alternative disposal strategies. The panel discussed the implications of stricter guidelines, including increased reliance on imported fertilisers and potential carbon impacts. Kelly highlighted the need for at least indicative soil targets to avoid a regulatory vacuum and confirmed efforts to fast-track soil monitoring data, which may inform decisions before the next meeting. Ian recommended leaning on the Flemish model as the most developed European approach, while noting the need for translation and further review. Tony raised questions about European-level proposals and PFAS leaching dynamics, which Ian explained are complex and uncertain, with soil retention generally strong.

The panel agreed that final recommendations will depend on forthcoming soil data and acknowledged the time pressure to provide interim guidance before legislative deadlines. They recognised that some decisions may ultimately require political judgment beyond scientific evidence, given competing priorities and resource constraints. The meeting concluded with a commitment to revisit these issues at the next session, incorporating any available soil data and further analysis of the Flemish framework. Kelly also provided an update on locally consumed fish species—mackerel (recreational), bass, and bream (commercial)—with market share data to follow, supporting parallel work on dietary PFAS exposure.

Government of Jersey discussion papers

1. Private Water Supplies in Jersey

The meeting focused on private water supplies in Jersey, comparing local regulations with those in England. Steve Hajioff introduced the paper outlining key differences in monitoring parameters, testing arrangements, and the legislative framework. He noted that Jersey has 51 private water supplies serving more than one property, which could be significant for future policy considerations. Kelly Whitehead emphasised that, unlike England, Jersey has minimal regulation for private water supplies, making it challenging to impose conditions or

requirements without major legislative changes. The current Water Law applies only to the public water supplier, Jersey Water, and does not extend to private suppliers, even those serving multiple households. This contrasts with England, where supplying water to others imposes additional obligations to ensure wholesomeness.

The panel discussed the implications of this gap, noting that any recommendation to regulate private supplies would require primary legislation and a substantial lead time. Steve highlighted the societal principle that activities harmful to others are more likely to be regulated than those affecting only oneself, suggesting a distinction between single-household and multi-household supplies. Kelly provided data indicating that approximately 1,700 properties use borehole water and 400 use well water, with at least 51 supplies serving multiple properties. However, due to the absence of a legislative framework, these figures are based on voluntary disclosures and property reference data, making accurate estimates difficult.

Questions arose about the nature of boreholes and wells. Kelly clarified that both can be pumped, with wells typically older and used for garden watering, while boreholes are deeper and generally supply households. The panel also discussed PFAS testing, noting that while some data exists from government and private testing, sharing results requires agreements with landowners, and the proportion of tested supplies remains unclear. Historic data is available, and Kelly committed to providing further details on testing coverage.

The discussion concluded that the lack of regulation severely limits the ability to estimate PFAS levels or enforce standards for private supplies. Any recommendations would need to account for significant implementation delays. The panel agreed to acknowledge these constraints in future planning.

2. La Collette Energy Recovery Facility

The La Collette Energy Recovery Facility paper outlines the plant's operation, input load, and electricity output. Steve highlighted that the facility operates at 850°C, a temperature that significantly degrades PFAS but does not completely eliminate it, leaving crystalline residues. This has implications for recommendations on diverting PFAS-containing waste streams to the facility. Steve noted that while the plant currently processes 70,000 tonnes of waste annually, its maximum capacity is unclear, and understanding this figure is critical for planning. If capacity is significantly higher, such as 150,000 tonnes, the facility could accommodate biosolids and future increases in domestic waste. However, if capacity is close to current levels, additional infrastructure would be required for any diversion.

Ian raised concerns about the practicality of handling biosolids given population growth and waste increases. Tony observed that the waste categories include “putrescibles,” likely food and organic waste, which may be comparable to biosolids in terms of calorific value. Kelly confirmed that biosolids from sewage treatment contain about 70% water, meaning pre-drying may be necessary depending on the volume processed. The panel agreed that determining the maximum allowable proportion of biosolids without disrupting plant operations is essential.

Discussion then turned to storage and leachate management. Ian questioned how waste is stored before incineration and whether leachate from the waste bunker is tested for PFAS, referencing studies showing PFAS presence in leachate elsewhere. Kelly confirmed that

municipal waste is stored in a bunker and mixed before incineration, while liquid waste and sludge have separate storage arrangements. The panel requested clarity on storage duration, leachate handling, and whether it is treated or incinerated. Steve noted that activated carbon and ion exchange residues from water treatment will likely require incineration at this or another facility, making capacity estimates even more critical.

The discussion concluded that further information is needed on the facility's maximum capacity, tolerance for biosolids, leachate management practices, and integration of PFAS-contaminated residues. These details will inform recommendations on waste diversion and PFAS destruction strategies. Kelly committed to seeking answers from the waste management team.

3. La Collette Clinical Waste Incinerator

The discussion focused on the clinical waste incinerator at La Collette, which is the only hazardous waste incineration facility in Jersey. Steve outlined key points, noting that the facility processes approximately 150 tonnes of waste annually and has a maximum additional capacity of 80 tonnes, meaning it cannot be significantly scaled up. The incinerator operates at 1,100°C in a two-step process, a temperature sufficient to completely degrade PFAS. However, Steve emphasised that the volume of PFAS-contaminated material that might require disposal would far exceed the facility's capacity, making it unsuitable for large-scale PFAS waste treatment. While the process details are important for general understanding, they are not directly relevant to PFAS because clinical waste currently does not contain PFAS leachates.

Steve added that any PFAS-contaminated waste recommended for incineration cannot initially be processed at La Collette due to volume constraints. However, very small, highly concentrated PFAS waste streams might be considered, subject to logistical and regulatory hurdles. He suggested that if municipal waste incineration were to divert PFAS-containing streams, the resulting ash could potentially be processed at La Collette, given its low volume, though this remains speculative.

Ian proposed measuring PFAS levels in ash from the domestic waste-to-energy plant, noting that this is relatively straightforward compared to sampling flue gases or other waste streams. He highlighted that similar studies have been conducted internationally, and protocols could be easily adapted. Steve agreed that this would be a useful next step and committed to exploring the feasibility of such testing.

4. Waste Disposal Cells at La Collette Reclamation Site

The discussion focused on hazardous waste disposal cells at the La Collette Reclamation site. Steve Hajioff summarised key points, noting that the facility has very limited capacity, currently holding just over 17,000 cubic metres of material, and is nearing its limit. The site uses artificial membrane barriers due to Jersey's soil characteristics, but these barriers have a finite lifespan, adding to long-term concerns. Hazardous waste cannot be exported, and the site currently receives ash from both incinerators as well as contaminated soils, although the specific contaminants in these soils were not detailed in the paper. Steve highlighted that leachate from the cells is monitored and pumped to the sewage treatment works (STW), but monitoring appears focused on heavy metals rather than PFAS, which may need to change going forward.

Ian confirmed that landfill leachate typically contains PFAS and suggested that testing should occur before treatment at the STW. Kelly clarified that the STW conducts extensive testing at its inputs and outputs, but it is unclear whether leachate from the disposal cells is tested for PFAS prior to entering the STW. She agreed to investigate and provide results.

Tony raised questions about the composition of contaminated soils, noting that over 90% of the material in the cells consists of soils from property development. Kelly explained that these soils originate from heavily contaminated brownfield sites, often linked to historical industrial activities such as petrol storage, gas works, and pumping stations. These sites can contain hazardous substances requiring strict handling protocols, including controlled truck routes and contingency plans for spills. Ian added that some soils are so contaminated that protective equipment is necessary during remediation. Kelly confirmed that contaminants include substances associated with gas storage and other industrial uses, such as arsenic.

The panel agreed that the site's limited capacity—estimated to last less than a decade under current usage—combined with the complexity of managing highly contaminated soils and potential PFAS in leachate, poses significant challenges for future waste management strategies. Further clarity on PFAS monitoring and a detailed breakdown of soil contaminants will be provided by Kelly for the next meeting.

5. Bellozanne Valley Wastewater Treatment Plant Summary

The discussion focused on the Bellozanne Valley Wastewater Treatment Plant. Steve noted that the panel is already familiar with the plant's operations following a site visit and previous briefings. He summarised the key process steps: post-settlement and separation, followed by anaerobic digestion of biosolids for biogas generation. These biosolids, after digestion, are the material potentially applied to land, which is a critical consideration for PFAS management. Additionally, wastewater from the digestion process is recirculated within the system.

Ian highlighted the importance of PFAS-specific data, noting that effluent measurements from the plant show PFAS levels in the nanograms-per-litre range, which he found surprisingly low but consistent with expectations that longer-chain PFAS compounds partition primarily into biosolids. He confirmed that the plant does not currently employ PFAS-specific treatment technologies, relying instead on conventional wastewater treatment methods. Options such as activated carbon and ion exchange resins, commonly recommended for PFAS removal in drinking water, could theoretically be applied to wastewater, but these are not currently in use. Ian suggested that these considerations should be addressed in future planning.

Steve agreed, stating that recommendations on wastewater treatment will not be made before Christmas, allowing time to gather additional monitoring data and review treatment options in the new year. The panel acknowledged that PFAS management in wastewater will require further analysis and is included in the work plan for future discussions.

Before closing, Kelly Whitehead provided an update on the Energy-from-Waste (EFW) facility's capacity, clarifying that its maximum potential is 100,000 tonnes per year, compared to the current 70,000 tonnes. While this indicates some spare capacity, Kelly cautioned that operating at maximum load would reduce the ability to perform planned maintenance and

cleaning, creating operational challenges. Steve noted that population growth will likely absorb much of this capacity, making diversion of additional waste streams problematic in the longer term. Kelly agreed to seek further factual details from the solid waste team for the next meeting.

The discussion concluded with agreement that PFAS-specific monitoring and treatment options for wastewater will be revisited in early 2026, and that capacity constraints at the EFW facility will need to be factored into any future waste management recommendations.

6. PFAS Testing Protocol & Food And Soil Testing Methodology

The discussion addressed the testing rationale and methodologies for PFAS sampling in Jersey. Steve acknowledged the inclusion of testing protocols in the documentation and noted their relevance as background information for stakeholders. Kelly explained that two papers were prepared: the first outlines the published testing protocols established prior to the testing programme, which were made publicly available on Gov.je to ensure transparency. The second paper details the step-by-step methodology for sample collection across various categories, including soil, plant and animal origins, and potatoes.

This methodology covers procedures for labelling, transport, and general descriptions of sampling locations, while site-specific details remain confidential for data protection reasons. Kelly also noted that testing was conducted through multiple accredited laboratories, including FERA, Eurofins, and Veritas, depending on sample type.

Steve emphasised that these documents provide valuable context for Islanders and other stakeholders but do not require detailed commentary within the main report. Instead, they will be included as appendices in the final report to ensure accessibility and transparency. The panel agreed that while the methodologies are important for public confidence, they are not central to the report's conclusions and recommendations.

Any other business

No other business was raised.

Date of next meeting

Tuesday 18 November 2025. It will be held 10am - 1pm online.

The Chair thanked everyone for their contributions, those watching the meeting and those offering support throughout the whole process.

A reminder to the public that this meeting has been recorded, and the video will be available online on request by emailing the Regulation Enquiries mailbox on RegulationEnquiries@gov.je. This will take a couple of days to make sure the observers are anonymised.

There being no further business, the meeting was closed.

To note that the Panel can be emailed via PFASpanel@gov.je.

Details of meeting dates and times can be found at [PFAS in Jersey \(gov.ie\)](https://www.pfasinjersey.gov.ie)

DRAFT

Draft minutes of public meeting of the PFAS Scientific Advisory Panel on Teams 10:00 on 18 November 2025

Panel Members present: Dr Steve Hajioff – Independent Chair
 Dr Tony Fletcher – PFAS and Health member
 Professor Ian Cousins – PFAS and Environment
 member

In attendance: Standing Observer (Regulation) - Kelly Whitehead -
 Group Director of Regulation, Infrastructure and
 Environment Department
 Programme support team from I&E

Welcome:

The Chair welcomed everyone to the Panel meeting and reminded people the meeting was being recorded.

Introductions

The Chair and Panel members introduced themselves.

Dr Steve Hajioff, Independent Panel Chair: A retired Director of Public Health from an area of London with two major international airports and a variety of other environmental hazards and challenges, with 35 years in clinical medicine. An expert on translating science into policy, he has worked with Nice, the Greater London Authority, the EU, WHO and World Bank, several UK government departments and several international governments. Dr Hajioff has also worked extensively in the pharmaceutical industry.

Dr Tony Fletcher, PFAS and Health Panel Member: Environmental Epidemiologist at the London School of Hygiene and Tropical Medicine, working on PFAS since 2006 and member of the panel with experience of epidemiological studies on the health effects of PFAS in contaminated communities in West Virginia in the United States, in the Veneto region, in Italy, and in Ronneby, and is the health expert on the panel.

Professor Ian Cousins, PFAS and Environment Panel Member: A Professor in Environmental Chemistry at Stockholm University, an expert on PFAS, appointed as the environmental expert on this Panel and whose expertise on PFAS is on the sources, transport, fate, and exposure of PFAS.

Kelly Whitehead, Group Director for Regulation in the in the Infrastructure and Environment Department, leading on the Water Quality and Safety Programme, coordinating Government's response.

Declaration of Interests

- No new interests declared.

Minutes

Minutes from 11 November were not ready for approval and will be taken in December meeting.

Matters Arising

- Nothing to report

Additional Findings Since the Last Meeting

Tony reported attending a recent webinar organised by the European Food Safety Authority (EFSA) on PFAS, which included contributions from the European Chemicals Agency, the EU, EFSA, and the European Environment Agency. He noted that the session was highly intensive, covering a wide range of activities across the EU. Tony mentioned that the presentations and summaries from the webinar would be made available in due course and promised to share the link when it becomes publicly accessible. He emphasised that while he could not summarise the extensive information presented, some aspects were relevant to their work, and he would follow up on specific reports and references.

Following this, Ian shared that he had been in Brussels on Friday engaging with the European Commission, specifically DG Environment and DG Grow, regarding PFAS-related issues. His discussions focused on ensuring that the restriction proposal for PFAS remains on track despite resistance, particularly concerning the phasing out of fluoropolymers and fluorinated gases, which degrade into trifluoroacetic acid. Ian explained his efforts to collaborate with other scientists to advocate for science-based decisions and clarify the scientific concerns surrounding these substances.

Steve concluded by informing the group about two upcoming documentaries on PFAS—one for television and one for radio. While details remain unclear, and it is not yet known whether Jersey will be featured, Steve assured the team that updates would be provided as more information becomes available.

Discussions and Recommendations

The meeting transitioned to item five, which Steve noted would form the main focus of the session. He reminded attendees that draft summaries of discussions since the last interim report had been circulated. Steve explained that a few additional points raised by Ian would be incorporated into the final report, specifically relating to the energy footprint of various technologies. Ian emphasised that energy consumption is a significant drawback for some technologies, as it impacts both feasibility and cost considerations. Steve acknowledged this and apologised for not including these points in the initial summary, assuring that they would be added.

Steve then outlined the purpose of the summary document, stating that it consolidates key insights from expert consultations, literature reviews, and internal discussions, organised by section. He proposed a revised running order for the meeting to allow for natural breaks: starting with soil, non-drinking water, and biosolids, followed by food, borehole water treatment, home water treatment, and finally destruction and disposal. Ian agreed with the approach, and the group prepared to proceed accordingly.

The session opened with Steve introducing the agenda on soil, non-drinking water, and biosolids, noting he had prepared guiding questions. He began by asking about the group's appetite for technology readiness levels (TRLs) in separation and containment interventions—whether mature, proven technologies should be prioritised or if emerging solutions could be considered. Ian responded that the preference should be for high-TRL technologies (levels 8–9) that are operational and effective now, emphasising that cost is the main drawback and a political decision. He outlined options such as soil washing, which requires building a dedicated plant and is expensive, and immobilisation using sorbents, which is cheaper and widely used internationally. Ian noted that immobilisation reduces PFAS availability in soil and groundwater but requires ongoing monitoring and periodic sorbent replacement. He referenced trials in Sweden, Norway, and Australia, highlighting that pump-and-treat systems for groundwater are effective but costly due to prolonged pumping and subsequent treatment with activated carbon or ion exchange resins. He stressed that in-situ destruction technologies are not yet viable, meaning contaminated soil or water must be removed for treatment.

Steve summarised that the group appears risk-averse, favouring proven solutions. Tony added that treatment decisions depend on land use, distinguishing between agricultural land and areas like airport runways. This led to a structured review of land categories and acceptable PFAS thresholds. Ian referenced Flemish guidelines as the most comprehensive in Europe, proposing 4 µg/kg for agricultural land to protect the food chain, noting background levels typically range from 0.1 to 1 µg/kg due to atmospheric deposition. Tony agreed these values seem strict but reasonable, though he stressed the need for clarity on whether thresholds apply to individual PFAS or sums of multiple compounds. The group tentatively agreed to adopt Flemish values, focusing on the sum of four major PFAS for simplicity and consistency with water guidelines.

For sensitive land, such as water protection zones, the group wanted to follow the Flemish guidelines and believed that that threshold was lower, at threshold 1 µg/kg, reflecting minimal human exposure risk [the actual Flemish recommendation is the same as that for agricultural land] The panel resolved to apply the threshold from the Flemish guidance. Land for human habitation was discussed next, with Flemish guidance suggesting 8 µg/kg due to fewer exposure pathways compared to agricultural land. Steve and Ian explored the rationale, noting that livestock-driven biomagnification likely explains the lower agricultural threshold. Tony highlighted the importance of specifying which PFAS are included in calculations, and the group agreed to clarify this in the final report. Industrial land has the same threshold in the Flemish guideline, For other land types, a threshold of 20 µg/kg was considered, given reduced exposure pathways. The group agreed that the thresholds be those from the Flemish recommendations and should apply to the sum of four key PFAS associated with AFFF contamination, aligning with the remit of the commission.

The conversation then shifted to water. Ian explained that European surface water guidelines (.65 ng/L) are unrealistically low and unenforceable, as rainwater alone exceeds these levels. Steve proposed not setting a strict contamination threshold for surface water but instead recommending a trigger level for source investigation, tentatively set at 10 ng/L for the sum of four PFAS. The same approach was agreed for groundwater, except where water is used for human consumption, which will be addressed separately. The group acknowledged that these recommendations aim to identify contamination sources rather than mandate treatment. Tony noted that recent European Environment Agency data show average PFAS levels in surface waters have declined from 10 ng/L to 5 ng/L over five years, but still exceed the EQS, reinforcing the impracticality of current European standards.

On treatment technologies for contaminated environmental waters, Ian confirmed there is no universal solution, but mature options such as granular activated carbon (GAC), ion exchange resins, and foam fractionation should be prioritised. Site-specific conditions will dictate the choice, and recommendations will emphasise high-TRL interventions. Membrane technologies like nanofiltration and reverse osmosis were noted as alternatives, primarily for drinking water, but their energy intensity limits broader application. Ian highlighted that bespoke treatment trains combining these technologies are common internationally, citing examples from Australia where ion exchange and soil washing plants operate continuously to remediate hotspots.

Finally, the group addressed biosolids management. Steve outlined three scenarios: restricting application to certain land types, applying based on soil thresholds, or destroying biosolids. Landfilling was ruled out due to local constraints. Ian favoured the second option as an interim measure, combined with ongoing monitoring to track PFAS accumulation and inform future decisions. He cautioned that limited land availability in Jersey and enforcement challenges could complicate implementation. Tony confirmed that biosolids are currently applied to both agricultural and other land. The group agreed on two recommendations: (1) biosolids should only be applied where resulting soil concentrations remain below the threshold for that land type, and (2) a monitoring program should assess long-term trends and guide planning for potential destruction technologies. Ian noted that international practices vary widely, from unrestricted land application to complete prohibition, underscoring the need for a pragmatic, precautionary approach. The discussion acknowledged that destruction options such as pyrolysis or gasification require significant capital investment and carry uncertainties around emissions and occupational exposure, particularly given the proximity of Jersey's wastewater treatment plant to populated areas. The meeting concluded with consensus to adopt Flemish thresholds provisionally, subject to further data review and feasibility considerations, and to recommend a phased approach balancing environmental protection with practical constraints.

Food

The discussion on food began with Steve introducing three key questions, including one raised earlier by Ian. Steve referenced Tony's analysis on PFAS intake from water as a proportion of the EFSA tolerable weekly intake (TWI). Using Tony's calculations, Steve noted that at 10 ng/L in drinking water, weekly PFAS intake would be approximately 1.4 ng/kg body weight, leaving about 3 ng/kg/week for food while remaining under EFSA's threshold. At the future target of 4 ng/L, water contribution would drop to 0.6 ng/kg/week, increasing the

margin for food intake. Steve asked at what PFAS level in food the group might need to reconsider the recommended water limit of 4 ng/L.

Tony confirmed that earlier assumptions about water contributing only 20% of total PFAS intake relative to food are outdated, as food contributions have declined over time. He emphasised that current water and food levels are well below EFSA's TWI, meaning the safety factors previously applied to water guidelines are no longer critical. Steve reassured listeners that the panel will not raise the water guideline above 4 ng/L. He concluded that with food levels trending lower, the water limit is not at risk of breaching EFSA thresholds. Tony added that while average intake estimates for the UK population are informative, they carry uncertainty due to variability in food measurements and limited sample sizes. He suggested comparing local Jersey data with UK averages for similar food categories, including locally produced eggs, fish, meat, and milk, to validate assumptions.

The panel agreed that as long as the composite food basket does not exceed approximately 3 ng/kg/week at current water levels and 3.8 ng/kg/week at future water targets, there is no need to revise drinking water recommendations. Tony noted that specific food items might warrant closer scrutiny if they disproportionately contribute to PFAS intake, though current data do not identify any clear outliers. This led to Steve's second question: whether residents in contaminated areas should keep backyard chickens. Ian advised against it, citing evidence from Flanders where eggs from free-ranging chickens near contamination hotspots showed very high PFAS levels. Tony concurred, explaining that chickens confined indoors and fed commercial feed pose less risk, whereas those foraging in contaminated soil are likely to ingest PFAS via earthworms. Steve highlighted biomagnification through worms as a plausible mechanism. Ian added that organic eggs often contain higher PFAS levels due to fish meal in organic feed, a counterintuitive finding that underscores complexity in exposure pathways.

The third question concerned freshwater fish consumption. Ian explained that freshwater fish can be a significant PFAS exposure source, with advisories in Sweden warning that a single fish could equal months of exposure from drinking water at 40 ng/L. However, Kelly Whitehead clarified that Jersey does not produce freshwater fish for consumption; local ponds support recreational angling only, and most clubs enforce no-kill policies. Imported freshwater fish, primarily from the UK, is the main source for consumers. The group agreed that formal recommendations are unnecessary but suggested providing informational guidance on PFAS risks in freshwater fish, particularly noting biomagnification in predatory species like pike. Steve observed that UK food basket data did not show high PFAS levels in freshwater fish, likely because most are farmed, which generally results in lower contamination than wild-caught fish. The panel concluded that further analysis of UK data will determine whether advisories on consumption frequency are warranted.

The discussion closed with consensus on key points: (1) current and projected water limits remain appropriate provided food intake stays within EFSA-derived thresholds; (2) backyard chickens in contaminated areas should be discouraged unless kept indoors and fed uncontaminated commercial feed; and (3) freshwater fish consumption is not a major concern locally but should be addressed through public information, emphasising biomagnification risks and confirming angling policies. No additional food-related issues were raised.

Boreholes and other private water supplies

The discussion on borehole water and private supplies began with Steve outlining three key questions: whether to recommend target PFAS concentrations for borehole water used by multiple households, for single-household supplies, and whether to advise specific treatment technologies. Steve noted that borehole supplies are currently outside Jersey's statutory water regulations, which raises questions about liability and enforcement. He suggested that any recommendation would likely be advisory rather than mandatory, given the absence of a legal framework.

For boreholes serving multiple households, Steve asked if the panel should recommend maintaining PFAS levels at the same threshold as public drinking water (currently 4 ng/L for the sum of four PFAS). Tony supported setting an aspirational target aligned with mains water standards but emphasised that it should remain advisory due to cost and proportionality concerns. He highlighted that reducing PFAS from 5 ng/L to 4 ng/L in a shared borehole could impose disproportionate financial burdens on landowners and users. The group agreed that recommendations should be framed as guidance rather than enforceable limits, recognising that any disputes would likely be civil matters between households and borehole owners.

The conversation then turned to single-household boreholes and wells. Steve asked whether similar thresholds should apply. Tony queried whether borehole owners supplying multiple households have any legal obligation to provide wholesome water, as in UK law. Steve confirmed that Jersey law does not impose such obligations, reinforcing the advisory nature of any recommendations. Ian raised a hypothetical concern about households discharging contaminated borehole water into the wastewater system, potentially introducing PFAS into municipal treatment processes. Kelly Whitehead explained that there is no licensing system for private supplies and no comprehensive data on borehole use or sewerage connections. She noted that while some borehole users may also discharge to foul mains, this is not systematically tracked. The panel agreed that any contribution to wastewater PFAS levels from private boreholes would likely be minimal and not a regulatory priority. Ian concluded that treatment decisions for single-household boreholes should remain a matter of personal choice, supported by clear public information rather than prescriptive rules.

The third question addressed treatment technologies for contaminated private water supplies. Steve asked whether the panel should recommend specific technologies or adopt a case-by-case approach. Ian advised against prescribing fixed solutions, noting that technology evolves rapidly and recommendations could become outdated. The group agreed that treatment should be tailored to site-specific conditions, including water chemistry, contamination levels, and supply capacity. However, they endorsed high-TRL (Technology Readiness Level) interventions currently available on the market, including granular activated carbon (GAC), ion exchange resins, reverse osmosis (RO), and nanofiltration. Ian observed that RO is generally the most effective for PFAS removal, offering high efficiency and a compact footprint, though it carries drawbacks such as energy demand and wastewater generation. Steve added that RO's suitability depends on water availability; if a borehole comfortably meets household needs, RO is viable, but if water

scarcity would result from 20% or more wastage, alternative technologies should be considered. The panel agreed to include these considerations in guidance, emphasising flexibility and proportionality.

The panel reached a clear consensus on three key points regarding borehole water and private supplies:

First, for boreholes serving multiple households, the group agreed to recommend maintaining PFAS concentrations at the same threshold as public drinking water—currently 4 ng/L for the sum of four PFAS—while emphasising that this should remain advisory rather than mandatory due to cost, proportionality, and the absence of a legal framework.

Second, for single-household boreholes and wells, the panel decided not to set formal thresholds, instead advocating for an information-based approach that enables individuals to make informed choices without imposing regulatory burdens.

Finally, on treatment technologies, the panel concluded that solutions should be determined on a case-by-case basis, reflecting site-specific conditions and water characteristics. However, they endorsed the use of mature, high-TRL interventions currently available, such as granular activated carbon (GAC), ion exchange resins, reverse osmosis (RO), and nanofiltration, noting that RO offers superior PFAS removal but may be constrained by water availability and wastewater management considerations. These recommendations aim to balance precautionary principles with practicality and flexibility.

Home water treatment

The discussion on in-home water treatment began with Steve introducing the topic, which included under-sink systems, countertop units, and filter jugs. He posed two key questions: whether the panel should recommend specific products or technologies, and whether they should signpost resources to help households make informed decisions. Ian responded that the same principles applied as for borehole treatment: recommendations should remain general rather than prescriptive. He noted that reverse osmosis (RO) systems tend to perform better than single-stage carbon filters, but highlighted trade-offs such as water wastage—up to 20%—which could be problematic in Jersey given occasional water shortages. Steve confirmed that expert reviews and previous discussions indicated multi-stage systems, including RO, are highly effective at PFAS removal, whereas single-stage carbon filters, commonly found in filter jugs, are not efficient.

Tony added insights from two key studies: the Environmental Working Group (EWG) laboratory tests and a North Carolina field survey. He explained that while EWG tests under controlled conditions showed strong performance for certain countertop devices, real-world testing in North Carolina revealed that many jug filters underperformed compared to lab results. This discrepancy was attributed to factors such as inconsistent filter replacement and variable usage practices. Tony emphasised that filter jugs are less reliable than fixed installations under sinks, which generally provide more consistent performance when properly maintained.

Tony thanked an islander who noted an error in how we discussed the evidence for countertop PFAS filters. The minutes of the October 22 meeting summarised how we compared the

PFAS test results for home water filters, of the Environmental Working Group, with the detailed results in a paper measuring home filters in North Carolina. We stated that the Berkey filter was the only one that seemed 100% effective in the EWG reported and was also in the second report. (There was 1 Berkey device tested in the EWG survey, and 4 Berkey devices tested in the NC paper – 3 pitcher and one larger counter-top model). However, we missed that a pitcher filter “Zero Water” also deemed 100% by EWG was also tested in the NC paper, in one household where PFAS levels (for the sum of PFOS, PFOA, PFHxS and PFNA) were reduced from 7.5 to 1.0 ng/ml.

The panel agreed that while RO and multi-stage systems are more effective, they cannot recommend specific products. Instead, they proposed referencing the EWG report and North Carolina study in public guidance, enabling consumers to make informed choices. Tony underscored the importance of regular filter replacement and proper storage to maintain effectiveness. Steve reiterated that recommendations should focus on directing households to credible resources rather than endorsing individual technologies or brands. The group also briefly discussed whether to advise connecting to mains water; Steve confirmed no such recommendation would be made at this stage, noting that approximately 2,500 households remain on borehole supplies, with PFAS levels in non-airport areas to be reviewed in December.

The discussion concluded with agreement on three main points:

First, multi-stage treatment systems, particularly reverse osmosis (RO), were recognised as generally more effective than single-stage carbon filters for removing PFAS, although considerations such as water wastage and ongoing maintenance requirements must be factored in.

Second, the panel noted that filter jugs tend to perform less reliably in real-world conditions compared to laboratory tests, largely due to inconsistent filter replacement and variations in usage practices.

Finally, rather than endorsing specific products, the group agreed that public guidance should focus on directing consumers to authoritative resources—such as the Environmental Working Group (EWG) report and the North Carolina field study—while emphasising the importance of proper maintenance and informed decision-making.

No additional recommendations were made regarding mandatory connections to mains water or prescribing specific technologies beyond this general guidance.

PFAS Destruction Technologies

The discussion on PFAS destruction and disposal began with Steve introducing the topic and posing a key question about the group’s appetite for technology readiness levels (TRLs) in destruction technologies. He asked whether the panel should maintain the same standard as for other interventions—TRL 8 or 9—or consider lower levels. Ian clarified that only technologies at TRL 8 or 9 are practically usable, as anything below that remains experimental and unproven at scale. He noted that while many technologies are marketed as solutions, some lack real-world validation, making it essential to focus on those demonstrated to work consistently in operational settings. The panel agreed that their risk

appetite should prioritise proven technologies, analogous to requiring clinical trials for medicines before adoption.

Ian explained that effective PFAS destruction requires breaking the strong carbon-fluorine bond, which typically demands very high temperatures—around 1,100°C for complete destruction, though incineration at 850°C in waste-to-energy plants has shown reasonable effectiveness. Data from limited studies indicate that such incineration does not fully eliminate PFAS but reduces residual levels to very low concentrations in ash and wastewater streams. These findings underscore that while thermal treatment is not perfect, it achieves approximately 99.9% destruction, leaving trace amounts in solid residues and leachate.

The conversation then turned to landfill as a disposal option for PFAS-contaminated materials. Ian highlighted significant concerns: PFAS in landfill remains indefinitely, posing long-term containment challenges. Modern landfills capture leachate, which must undergo specialised treatment, but volatile PFAS can still diffuse into the atmosphere. Steve clarified that in Jersey, hazardous waste storage facilities—not general landfill—would be considered. Ian stressed that landfill is not a destruction technology but merely containment, making it a last resort for small-volume residues rather than bulk contaminated materials. The panel agreed that using hazardous waste facilities for large volumes of soil or biosolids would be impractical due to capacity constraints, reinforcing the need for alternative strategies such as soil washing or thermal treatment for highly contaminated hotspots.

Steve raised the issue of residual PFAS in ash from incineration and whether secondary treatment—such as re-incineration at higher temperatures—could be viable. Ian noted that while theoretically possible, this approach is untested (TRL 1–2) and constrained by limited capacity in Jersey’s clinical waste incinerator, making it impractical. The panel concluded that such methods fall outside their TRL appetite and should not be recommended. Discussion also covered the potential for incinerating PFAS-containing materials like spent granular activated carbon (GAC) in municipal waste-to-energy plants. Steve observed that GAC is combustible, relatively low in PFAS contamination, and produced in small volumes, making it a feasible option compared to non-combustible rejectate from reverse osmosis or nanofiltration. Ian agreed, noting that disposal considerations should inform technology choices in water treatment planning.

The group acknowledged that large-scale destruction of biosolids or contaminated soil would require significant infrastructure investment, such as dedicated soil washing plants, which are currently absent in Jersey. For less contaminated land, containment remains an option, though it is not ideal due to long-term persistence of PFAS. Emerging technologies like supercritical water oxidation and other high-energy processes were briefly discussed but deemed too early-stage to meet TRL requirements. Ian emphasised that breaking the carbon-fluorine bond invariably demands high energy input, reinforcing thermal destruction as the only mature option currently available.

The panel agreed on several key points regarding PFAS destruction and disposal:

Only technologies with a Technology Readiness Level (TRL) of 8 or 9—those proven effective under real-world conditions—should be considered for implementation.

Among available options, thermal destruction through high-temperature incineration emerged as the only mature and viable method, capable of achieving near-complete PFAS breakdown, although not absolute elimination.

Landfill was recognised as a containment measure rather than a destruction technology and should therefore be reserved for small-volume residues such as ash from incineration, not for bulk contaminated materials like soil or biosolids.

The panel acknowledged significant practical constraints, noting that large-scale destruction of soil or biosolids is currently impractical in Jersey without substantial investment in new infrastructure; interim strategies may include soil washing for highly contaminated hotspots and containment for lower-risk areas.

Finally, while advanced technologies such as supercritical water oxidation show promise, they remain at early development stages and are not yet ready for deployment.

These conclusions reflect a pragmatic approach that balances scientific rigor, operational feasibility, and the limitations of Jersey’s existing infrastructure.

Any other business

No other business was raised.

Date of next meeting

Wednesday 17 December 2025. It will be held 10am - 1pm online.

The Chair thanked everyone for their contributions, those watching the meeting and those offering support throughout the whole process.

A reminder to the public that this meeting has been recorded, and the video will be available online on request by emailing the Regulation Enquiries mailbox on RegulationEnquiries@gov.je. This will take a couple of days to make sure the observers are anonymised.

There being no further business, the meeting was closed.

To note that the Panel can be emailed via PFASpanel@gov.je.

Details of meeting dates and times can be found at [PFAS in Jersey \(gov.je\)](https://www.gov.je/PFAS)

DRAFT

Appendix 2 – Government documents received on waste management in Jersey

La Collette energy recovery facility



La Collette Energy Recovery Facility

Overview

Infrastructure & Environment operates the Energy Recovery Facility (ERF) at La Collette to incinerate Jersey's municipal and commercial waste. Typically, 70,000 tonnes of waste is received and processed every year. The process also normally generates around 7.5MW of electricity some of which is transmitted directly onto the Jersey electrical grid network. The ERF is regulated under Waste Management (Jersey) Law and holds licence WML019 which describes the types of waste that can be accepted and defines limits on emissions to land, sea and air.

Plant and Operational Description

The ERF receives commercial and municipal waste from the Jersey Parishes and Jersey's commercial companies. The waste is mixed in the bunker by two grab cranes and fed to two identical boilers where it is burnt as it travels down the boiler grates. The internal combustion temperature is maintained above the minimum requirement of 850°C. There is around three hours retention time for waste to travel across the grates before dropping into the ash extraction system. The ash is exported to the UK where it is processed in a facility that removes any metal for recycling and prepares the ash to be used as aggregate, for example in road foundations etc.

The hot gasses from the combustion process flow through the boilers turning water into superheated steam with conditions of up to 43 Bara and 397°C. This steam is then expanded through a steam turbine before being condensed back to water in the condensers and pumped back around the system and reused.

The superheated expanding steam from the boilers spins the single steam turbine shaft that is mechanically coupled to a 4-pole generator. The generator spins at 1500rpm to produce up to

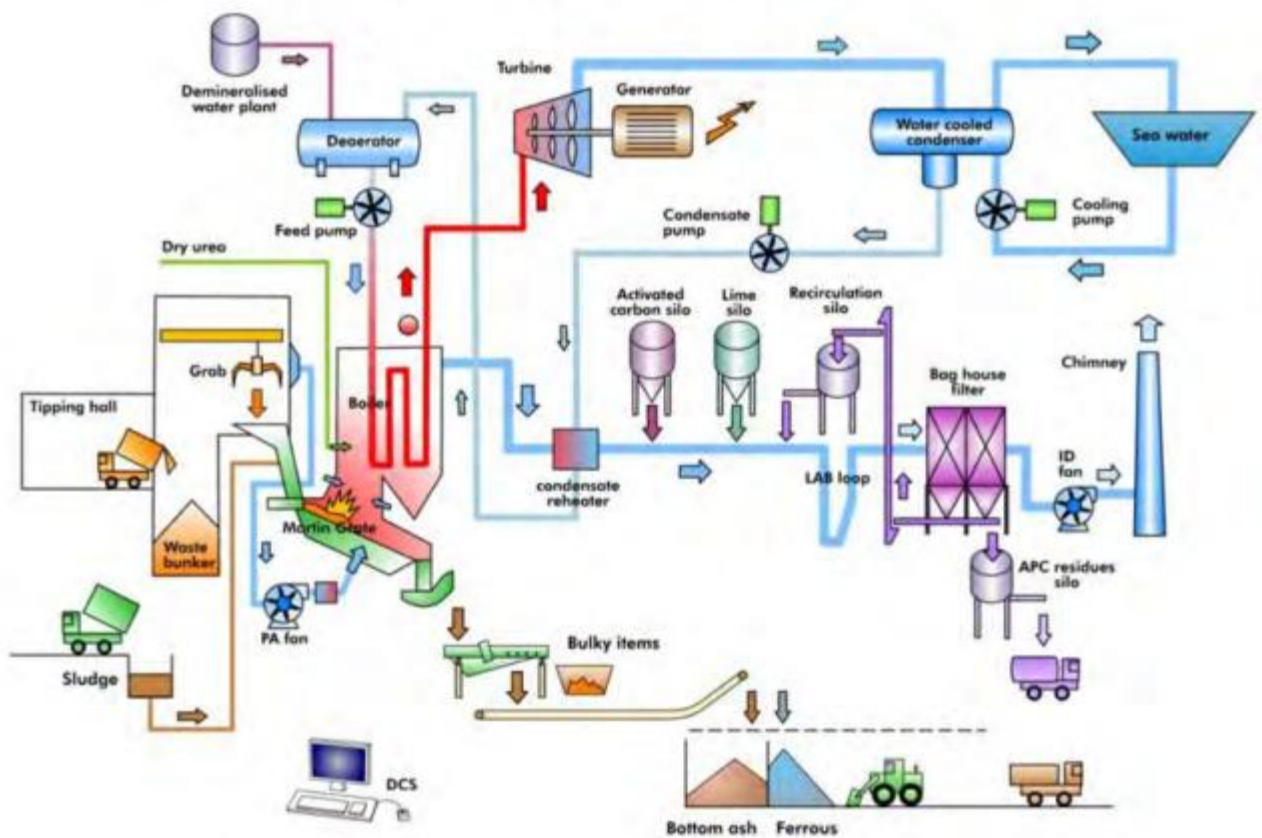
10.24MW of electrical power for distribution to the La Collette Peninsula and the Jersey electricity grid.

The condensers are cooled by seawater passing through titanium tubes. The differential between inlet and outlet temperature is limited to 8°C so there is negligible impact on sea life.

The hot combustion gasses are cleaned and conditioned by the flue gas treatment system so that they can be released into the atmosphere via the chimney within licence limits without causing pollution. Urea is added to remove nitrogen oxides (NOx), lime is added to correct the pH and activated carbon is added to remove any dioxins & furans, trace amounts of any heavy metals and volatile organic compounds (VOCs). Bag filters then filter the gasses to prevent small particles being discharged. The small particle residue or air pollution control residue (APCR) is bagged and exported to the UK to be used in concrete production etc following stringent testing.

The diagram below shows the process for the ERF as per the above description.

PROCESS OVERVIEW - DIAGRAM



Waste Inputs

Municipal and commercial rubbish that has not been separated for recycling is accepted at the ERF. In 2023 a waste composition analysis was carried out which shows the unseparated waste is made up of:

Categories	Average
1. Paper and Card	24.5%
2. Plastic Film	7.8%
3. Dense Plastic	9.7%
4. Textiles	3.4%
5. Other Combustible	22.2%
6. Other Non-Combustible	1.3%
7. Glass	2.4%
8. Putrescibles	21.4%
9. Metal	3.4%
10. Waste Electrical and Electronic Equipment	0.7%
11. Potentially Hazardous Waste Items	0.6%
12. Fine Material	2.6%

Operational Parameters

Although the ERF typically receives 70,000 tonnes of waste per annum the design can handle more than this. The ERF design parameters are shown below:

Parameter	Design Quantity
Waste	16.1 t/h @ CV between 7.5 and 8.5 MJ/kg
Steam production	47.1 t/h at 43 bara and 397°C (8,000 hours)
Gross electrical output	10.24 MWe
Hydrated lime consumption	185 kg/h (with recirc.)
Activated carbon consumption	10.7 kg/h
Urea consumption	35 kg/h
Process water consumption	4.5 m ³ /h
APCR production	550 kg/h

Monitoring, Testing and Reporting

All monitoring, testing and reporting requirements are set out in the Waste Management Licence WML019 sections 4 & 5 and the tables in Schedules 4 & 5. All reports are sent to the Regulator as required under the licence.

La Collette clinical waste incinerator



La Collette Clinical Waste Incinerator

Overview

Infrastructure & Environment operates the Clinical Waste Incinerator at La Collette to dispose of wastes generated by healthcare industries. Such wastes require incineration at higher temperatures than the Energy Recovery Facility runs at. Typically, 150 tonnes of waste is received every year; the maximum it could process in a year is 230 tonnes. The incinerator is regulated under Waste Management (Jersey) Law and holds license WML038 which describes the types of waste that can be accepted and defines limits on airborne emissions.

Plant Description

The Clinical Waste Incinerator is an auto-load, stepped hearth plant with two-staged pyrolytic gasification and combustion. The maximum throughput is 200 kg per hour, and the internal combustion temperature is maintained at above 1,100°C.

Waste Inputs

Only clinical wastes are accepted for disposal. Clinical wastes include infectious wastes, needles and other sharps, and some types of medicines. These wastes may come from the General Hospital, private medical practices, pharmacies, dentists, tattoo and piercing studios, or nursing homes.

Operational Throughput

The plant typically receives 150 tonnes of healthcare waste per annum. Although the maximum design throughput is 200 kg per hour, the plant is run at 180 kg per hour as higher throughputs can cause exceedances of the emissions limits.

Due to the large amount of metal and glass within the waste, the plant can run for up to three consecutive days before it needs to be shut down to manually clear large solid parts of bottom ash. It takes four days for the plant to cool and one day to clean the primary chamber, so the plant runs on an eight-day cycle. This reduces the possible annual throughput through the plant and means that the maximum volume of waste the plant could burn is 230 tonnes per year.

Operational Process

Clinical Waste is delivered to the facility in lockable wheeled bins. The bins are weighed before they are stored in refrigerated cold rooms until incineration. When the incinerator is online, bins are placed into an elevator which empties the contents into the ram loader. A series of hydraulic functions delivers the waste into the incinerator's primary combustion chamber through the charge door.

The primary combustion chamber incorporates a stepped hearth which cascades the waste down a series of steps to the conditioning vestibule where combustion is completed and the solids are rendered to ash. Dehydration and ignition of the waste is provided by a diesel-fired ignition burner. Bottom ash is discharged into a water bath with a conveyor which deposits the ash into an external skip.

Gaseous products of combustion flow into the floor-mounted secondary combustion chamber where they are further heated, oxidised, and subjected to turbulence to ensure complete destruction of the combustion emissions. The temperature within the secondary chamber is maintained in excess of 1,100°C.

The gases exit the secondary chamber along a refractory lined hot gas ductwork. Gas within the transfer duct is treated with a urea solution to reduce the levels of nitrogen oxide and nitrogen dioxide. The duct incorporates a dilution fan to ensure the optimum reaction temperature.

Treated gases then pass into the heat exchanger which is a low-pressure boiler containing water and glycol. The resulting exchange of energy cools the gases to approximately 180°C. Gases exiting the boiler are injected with sodium bicarbonate and activated carbon to neutralise the acid content and to capture vapour phase heavy metals before entering the abatement plant.

The abatement plant consists of a filter house which captures both the combustion particulates and the chemicals injected to control the acid gases and heavy metals. The resulting gases are continuously monitored by an emission monitoring system to ensure they are clean before being finally released to atmosphere. The particulate air pollution control residues are disposed off-island as solid waste.

DRAFT

Waste Inputs

The types of waste that are accepted for disposal are: contaminated soils from property development, ash and residues from the clinical waste and animal carcass incinerators, gas scrubbers from the sewage treatment works and spent sandblasting material. Asbestos wastes are deposited into a separate cell which does not receive any other type of waste. Annual input volumes are:

ERF Ash	ACI Ash	CWI Ash	Soils	Asbestos	Other	Total
0 m ³	250 m ³	50 m ³	16,000 m ³	1,000 m ³	10 m ³	17,310 m ³

All waste accepted into the cells is classified by the waste producer following WM3 Guidance and checked against the site's waste acceptance criteria prior to disposal. The department insists on waste treatment prior to disposal where this is feasible to remove or reduce the hazard or to reduce the volume of material for disposal.

Waste Acceptance Criteria

The acceptance criteria for landfilling of waste are published on www.gov.je to allow waste producers to easily reference them and plan treatments or disposal. The criteria have been designed to ensure the liners are protected from chemical or physical damage. No waste will be accepted if it does not meet all the criteria.

Leachate Monitoring & Management

Leachate is the liquid that forms when rainwater filters through waste. As it passes through, it can pick up the chemicals in the waste stored in the cells and become contaminated. This liquid is carefully managed to protect the sea and the environment. Leachate is collected and pumped into the sewage treatment system so it can be safely processed. This prevents it from leaking into the sea or surrounding land. Once a disposal cell is full, it is sealed with a permanent cap which stops rainwater from getting and forming more leachate.

A water quality monitoring regime that tests for heavy metals, nitrates and organic compounds in the leachate, groundwater and seawater has been in place since 2011.

Exporting Waste

Jersey is a member of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal. The convention requires that adequate disposal facilities are made available, and the export of waste is reduced to the minimum amount possible.

It is estimated that the cells will be operational for another 8 to 10 years at the current rate of disposal. When filled, there will be no more space to dispose of contaminated or hazardous wastes unless an alternative solution can be found.

Bellozanne Valley Wastewater Treatment Plant Summary

Overview

The works is a conventional activated sludge facility utilising biological processes to break down waste to ensure a compliant final effluent. It incorporates a complete sludge treatment line utilising pasteurisation and anaerobic digestion to produce biogas for energy recovery, as well as dewatering to allow for biosolids utilisation.

Inlet

All flow that enters the plant, regardless of whether it enters the main plant or is sent to the storm tanks, goes through a set of metal mesh screens to remove large solids and rags from the flow. The screened flow then enters a vortex grit chamber, which removes grit, sand, and any other heavy solids that typically have no calorific value.

From this point, the flow enters the primary settlement tanks. This is where the plant separates between the liquid and solids portion of the sewage. Heavy organic particles sink to the bottom of the tank and are pumped out from the bottom – this solid matter is known as sludge. Any fats, oils, and grease (FOG) floating on the surface are removed by a rotating bridge, which scrapes the FOG into a hopper and sends it along with the sludge to the digester site.

The plant from this point onward is split into two processes: one for processing the remaining liquid waste and the other for processing sludge at the digester site.

Liquid Processing

The liquid portion that weirs over the weir wall from the primary settlement tank then enters the activated sludge process, which comprises firstly an anoxic zone. Due to its very nature of being devoid of oxygen, the purpose of the anoxic zone is to break down nitrates and nitrites into nitrogen gas via denitrification. The anoxic zone is a plug flow configuration.

This is then fed into the aeration zone, whereby air is blown into the tanks to provide oxygen for the biological organisms known as “bugs” to break down any carbonaceous matter. The input of air also causes nitrification, whereby ammonia is turned into nitrates and nitrites. The retention time for these tanks is approximately an hour depending on the rate of flow to the works.

At the outfall of this tank, a portion of the outfall is returned via the mixed liquor return pumps to the start of the anoxic zone to break down the nitrates and nitrites produced in the anoxic zone. The remaining outfall is distributed between six final settlement tanks (FSTs).

Once again, any remaining sludge that settles to the bottom is pumped out. The sludge in the final settlement tank is known as activated sludge due to the presence of bugs.

To keep a healthy culture alive in the activated sludge tank, this sludge is pumped back to the start of the anoxic zone so that bugs are retained in the system (known as return activated sludge (RAS)). To ensure the bugs don't grow too large and die off from over competition, a portion of the activated sludge is diverted and sent to the digester site for solids processing (known as surplus activated sludge (SAS)). The SAS can also be co-settled with raw sludge in the primary settlement tanks.

The water that weirs over the FST weir wall is then sent through one final screen (known as the "leaf screen") to remove any remaining large objects. It is then passed through a series of UV banks to kill off any bacteria and bugs still present in the final effluent. This is then sent through the culvert to the outfall at sea at First Tower.

The final effluent is tested two to three times a week to understand the composition of the raw sewage, settled sewage, and final effluent.

Digester Plant

The SAS from the activated sludge process is put into the un-thickened sludge tank, whereby a drum thickener is used to thicken the sludge to around 5–6% dry solids.

This thickened SAS is then sent along with the raw sludge and FOGs to the thickened sludge tank. The sludge then proceeds through one final screen to remove any remaining rags or solids before entering the heat exchanger. It is heated up to 55°C and sent to the pasteurisation tanks, where it remains at 55°C for four hours. This kills off any diseases and harmful pathogens in the sludge. It also helps break down the sludge in preparation for digestion.

The sludge is then fed through another heat exchanger to cool the sludge down to 35°C. This is then sent to the anaerobic digesters, which have a retention time of approximately 12 days to ensure the sludge is broken down. This is achieved by microbes in the tanks, which generate biogas. This biogas is then cleaned and utilised by the combined heat and power unit (CHP) to provide electricity for the plant, as well as heating for the heat exchanger used in the pasteurisation process. A supplementary boiler is also present on site to provide heating for the pasteurisation process should the CHP undergo servicing or maintenance.

The digested sludge is then sent to the digested sludge tank, where it is dewatered into biocake via the use of centrifuges, which dry the cake to approximately 25% dry solids.

The sludge composition is tested daily during the working week. Pathogens in the biocake are tested quarterly.

Biosolid Disposal

The solid material resulting from the wastewater treatment plant is known as "enhanced treated biosolids." The annual production of biosolids is approximately 6,800 m³. The

biosolids are routinely sampled and analysed for pH, bacteria, nutrient values, and potentially toxic elements as a suite of heavy metals.

The application of biosolids to agricultural land has a fertilising effect due to the concentration of nitrogen, phosphorus, and potassium. These values are used to calculate the maximum beneficial application of the biosolids within the specifications of the Water Pollution (Code of Good Agricultural Practice) (Jersey) Order 2009, Code of Practice for Agricultural Use of Sewage Sludge (Defra, 1996), and other guidance notes. The typical rate of application is 2.3 m³ per vergée for arable land and 3.4 m³ per vergée for grass (NOTE: 1 Jersey vergée = 1,798.6 m²). Farmers or land managers are consulted prior to application to ensure that allowances for soil pH, crop-available nitrogen, and loadings of phosphate, potash, and magnesium are made and the spread rate is adjusted accordingly.

Biosolids are collected from the STW production site and delivered to the field in an agricultural spreader. Grass applications are distributed to the surface only. Arable applications are ploughed into a depth of 30 cm. Watercourses and boreholes are avoided. The receiving land is recorded and will only have biosolids applied once in any rolling 12-month period.

Intensive farming practices in Jersey mean that there is not enough landbank to handle all of the biosolids produced. Currently, around 50% of the production is used in this way. The remainder is delivered to the Energy Recovery Facility at La Collette. Biosolids are approximately 70% water, so incineration is currently seen as a last resort.

Appendix 3 – Government of Jersey sampling methodology and PFAS testing protocol



Infrastructure
and Environment

FOOD AND SOIL

TESTING METHODOLOGY

WATER QUALITY AND SAFETY PROGRAMME

1. INTRODUCTION

The PFAS testing programme in Jersey is designed to support the Independent Scientific Advisory Panel in understanding the average PFAS exposure through food, water, and environmental sources.

This data will be critical in determining whether current PFAS levels in drinking water are compatible with maintaining exposure below the EFSA TWI threshold. If food contributes significantly to the total PFAS intake, the regulatory standard for PFAS in water may need to be adjusted downward to ensure that total exposure remains within safe limits.

This approach mirrors international best practices, such as those used in Denmark, where water quality standards were derived by working backwards from the TWI, factoring in dietary intake and vulnerable population groups.

The WQS Programme will also focus on understanding PFAS in food, water, the marine environment, and waste, to gain a better understanding of PFAS levels and their impacts on public health and the environment.

2. METHODOLOGY

2.1 SAMPLING

In order to minimise the risk that the samples of food and soil were not contaminated during collection a number of precautions were taken. These included the use of:

- **Powder-free nitrile gloves** (no PTFE/fluoropolymer coatings)
- **Nitrile shoe covers**
- **Stainless steel or HDPE tools** (e.g., trowels, spatulas, scissors)
- **Polypropylene (PP) or high-density polyethylene (HDPE) containers** (no Teflon® or PTFE linings) (as recommended by the accredited laboratories used to test the samples)
- **Aluminium foil** (PFAS-free) for wrapping samples when needed
- **Cool boxes with PFAS-free ice packs**
- **PFAS-free water** for cleaning tools between samples if needed

2.2 SAMPLE COLLECTION PROCEDURES

General Precautions

- Avoid clothing or PPE treated with water-repellent coatings (may contain PFAS) and use natural fibres where possible. Ensure this is not washed with fabric softener.
- Do not apply sunscreen, insect repellent, or cosmetics prior to sampling.
- Clean sampling tools with blue paper towel and rinse with PFAS-free water before and between sample points if required.

2.3 SOIL SAMPLING

Procedure:

1. Identify and mark the sampling location using the 'PFOS Sampling Points' form on Survey123 app. This will record the field number and location of your points giving a 5m radius within which to take the sample.
2. Clear the surface of organic debris without disturbing the soil.
4. Use a **stainless-steel auger** to collect cores of soil.
5. Place soil in **PFAS-free polypropylene sample pots** (lab supplied).
6. For composite samples, mix soil in a stainless-steel bowl before subsampling.
7. Label and seal container; record date/time, depth, and sample ID.
8. Repeat for 4 more points in a w-shaped path across the field.

Storage:

- Freeze samples at -20°C as soon as possible or store at 4°C for short-term holding (<48 h).

2.4 PLANT MATERIAL SAMPLING

Procedure:

1. Identify and mark the sampling location using the 'PFOS Sampling Points' form on Survey123 app. This will record the field number and location of your points giving a 5m radius within which to take the sample.
2. Use **clean stainless-steel scissors or shears** if needed.
3. Wear fresh nitrile gloves, changing them between samples.
4. Collect aboveground tissue (e.g., leaves, stems) or root material depending on study aim using gloved hands.
5. Place samples in **aluminium foil (PFAS-free)** or polypropylene containers.
6. Record species, part collected, location, and sampling time.
7. Use different gloves and tools between sampling points or decontaminate thoroughly.

Storage:

- Store in fridge and place filled sample pots in cool box containing PFAS-free ice packs and a data logger

2.5 POTATO SAMPLING

Procedure:

1. Identify and mark the sampling location using the 'PFOS Sampling Points' form on Survey123 app. This will record the field number and location of your points giving a 5m radius within which to take the sample.
2. Clear the surface of organic debris without disturbing the soil.
3. Put on fresh nitrile gloves. Using nitrile-gloved hands, pull up potato plant and grub up and select 2-3 potatoes from 5m radius of recorded survey point.

4. Rub off as much soil as possible if its relatively dry. If soil adheres to the potato, scrub it off with blue paper towel and gloved hands (we did this later at the lab, collecting potatoes in PFAS-free sandwich bags and wrapping filled bags in PFAS-free aluminium foil until preparing the samples at the lab).
5. Repeat for 4 more points in a w-shaped path across the field.
6. Place potatoes in **PFAS-free polypropylene sample pot** labelled with sample number in ballpoint pen.
7. Add all potatoes from field to the same pot, using a second one if required.
8. Place filled sample pot in cool box with PFAS-free ice packs and a data logger.

2.6 PRODUCT OF ANIMAL ORIGIN SAMPLING

1. Select the Jersey produce from the fishmonger or shellfish supplier. The UK produce was purchased from Jersey supermarkets that stock UK products.
2. Place samples in aluminium foil (PFAS-free) or polypropylene containers when purchased if not packaged, otherwise keep sample in original packaging.
3. Samples kept chilled with the use of PFAS-free frozen gel packs and aluminium foil (PFAS-free) lined insulated cool box.
4. Samples taken directly to central facility, wrapped in aluminium foil (PFAS-free) where necessary and placed into designated freezer.
5. Frozen samples then wrapped in aluminium foil (PFAS-free) where necessary for transport

2.7 LABELLING AND DOCUMENTATION

- Each sample must be labelled with the below information. This can be written on the evidence bag with sample sealed in it.
- Sample ID (generated by Bigbit before sampling)
- Matrix type (soil or plant)
- Date and time
- Collector initials
- Complete a **chain-of-custody form** for each sample batch.
- Log all actions in the field notebook/ on mobile phone, taking photos where possible.

2.8. TRANSPORT AND STORAGE

- Use **coolers with non-fluorinated ice packs** for transport.
- Prevent samples from warming above 4°C.
- Send chilled samples with a datalogger so maintenance of cold chain can be demonstrated.
- In the lab, store at -20°C or colder until analysis.

2.9. QUALITY ASSURANCE AND CONTROL

- Ensure equipment and methodology is consistent across the sampling team.
- Include **equipment blanks** and **trip blanks** where appropriate.
- Use UK origin **control samples** for reproducibility checks and comparisons.

3.0 LOCATIONS

Fresh produce sampled was selected based on area where it was grown, and to include most of the crops grown on a commercial scale by local producers for human consumption.

Soil areas were selected to cover the following criteria:

- Fields where potatoes and other vegetables are grown.
- Fields where bio-solids from sewerage works have been spread.
- Fields where water filter cake from water treatment works has been spread
- ‘Wild’ areas for baseline comparison.
- Creepy Valley area.
- Re-sampling fields previously analysed for PFAS contamination.
- Fields within the known plume area.

Consideration was also given to distributing areas sampled across the Island where possible and appropriate.

4.0 LABORATORIES USED

Fera Science Ltd (FERA) is a UK-based scientific organization specialising in agri-food research, environmental safety, and diagnostics. They are assessed externally by both the United Kingdom Accreditation Service (UKAS) and the Good Laboratory Practice (GLP) Monitoring Authority.

Eurofins Scientific is a global leader in laboratory testing services across food, environment, pharmaceuticals, cosmetics, and clinical diagnostics. Eurofins hold a wide range of internationally recognized accreditations, including ISO/IEC 17025 and UKAS, depending on the country and specific lab.

Veritas Laboratory Services Ltd is a leading analytical laboratory in the UK, based in Southampton, Hampshire. Established in 2022, we are a family-owned and independent laboratory specialising in the testing of Persistent Organic Pollutants (POPs). Veritas Laboratory Services Ltd achieved UKAS accreditation to ISO/IEC 17025:2017.

PFAS Testing Protocol – Informing Report Four by the Independent PFAS Scientific Panel

1. Rationale for Testing

The rationale for PFAS testing in Jersey is grounded in the need to protect public health and the environment, supporting Jersey to understand the levels of PFAS on the broader environment and food chain. The Water Quality and Safety (WQS) Programme is a comprehensive initiative that addresses public concerns about PFAS contamination in the environment and its impact on water quality.

The programme will review and monitor PFAS in the broader environment and food, ensuring that actions are grounded in research and backed by scientific evidence.

The Independent Scientific Advisory Panel, commissioned by the Government, is undertaking Report 4 - PFAS in the Environment in 2025. This report will review global water standards to recommend a regulatory standard for Jersey. The Minister for the Environment plans to introduce this standard within the current government term, with a phased implementation period.

The European Food Safety Authority (EFSA) has established a Tolerable Weekly Intake (TWI) of 4.4 nanograms per kilogram of body weight per week for the sum of four PFAS compounds: PFOS, PFOA, PFNA, and PFHxS.

The PFAS testing programme in Jersey is designed to support the Independent Scientific Advisory Panel in understanding the average PFAS exposure of residents through food, water, and environmental sources

This data will be critical in determining whether current PFAS levels in drinking water are compatible with maintaining exposure below the EFSA TWI threshold. If food contributes significantly to the total PFAS intake, the regulatory standard for PFAS in water may need to be adjusted downward to ensure that total exposure remains within safe limits.

This approach mirrors international best practices, such as those used in Denmark, where water quality standards were derived by working backwards from the TWI, factoring in dietary intake and vulnerable population groups like children.

The WQS Programme will also focus on understanding PFAS in food, water, the marine environment, and waste, to gain a better understanding of PFAS levels and their impacts on public health and the environment.

The panel will ensure comparison with international data to understand how PFAS levels in Jersey compare generally. The testing information will also help to shape Jersey PFAS remediation strategy relating to the historic hotspot contamination at Jersey Airport.

2. Scope of Testing

2.1. Selection of Vegetables for PFAS Testing

Given the known behaviour of long-chain PFAS compounds, such as PFOS and PFOA, which tend to bind strongly to soil and accumulate in the roots and lower parts of plants, the vegetable testing strategy recommended by the panel will prioritise crops that are either root vegetables or grow close to the ground.

Vegetables and fruit grown as crops in Jersey will be tested to ascertain the level of PFAS compound contamination. Additionally, where possible, produce grown in areas of proven increased exposure will be compared to produce grown outside of these areas to determine the effect of the contaminated area on fruit and vegetables grown for consumption.

A range of fresh produce grown as commercial crops will be sampled for PFAS testing. These will include root vegetables such as potatoes and carrots and low growing vegetables such as cauliflower and courgettes. These are more likely to absorb PFAS from contaminated soil or irrigation water due to their proximity to the ground and the nature of their edible parts. A range of commercially grown fruit will also be tested, such as grapes and strawberries.

This targeted approach ensures that testing focuses on the most likely exposure pathways for consumers, supporting accurate dietary exposure assessments.

2.1. Selection of Meat Products for PFAS Testing

Although the production of beef, pork, and offal in Jersey is limited and most meat products are imported, it remains important to test locally produced meat to assess potential PFAS exposure from the environment.

The following meat products are recommended for PFAS testing as the main meat products produced and sold in Jersey.

- Beef
- **Pork**
- **Offal** (e.g. liver, kidney)

These products are prioritised because PFAS compounds, especially long-chain variants, are known to bioaccumulate in animal tissues, particularly in liver and kidneys, which are key organs for PFAS retention. Testing offal provides a sensitive indicator of environmental exposure in livestock.

While Jersey's domestic meat production is small, testing local samples will provide reassurance to consumers and help validate whether international data on PFAS levels in meat products applies to Jersey's context. The Independent Scientific Advisory Panel can also draw on comparative data from global studies to contextualise findings.

2.1. Selection of Dairy and Egg Products for PFAS Testing

Milk and eggs are important components of the local diet and can serve as indicators of PFAS transfer through the food chain, particularly where livestock are exposed to contaminated water, feed, or pasture. Jersey Milk is the only milk available in Jersey and is therefore of particular importance.

The following products are recommended for PFAS testing:

- Milk
- **Jersey Eggs**

Milk is a key focus because PFAS compounds can be excreted through lactation, and levels in milk may reflect environmental exposure from soil, water, and feed. Testing milk from farms with differing land management practices, particularly those that have or have not applied sewage or water treatment sludge, will help assess the influence of biosolids on PFAS uptake.

Eggs are also relevant, as PFAS can accumulate in poultry exposed through feed or water, and eggs provide a concentrated biological sample for detecting contamination.

Although Jersey's production of these items is relatively small, testing local samples will provide reassurance to consumers and help determine support the Independent Scientific Advisory Panel in building a comprehensive exposure profile for the Island.

2.1. Selection of Marine Environment and Seafood for PFAS Testing

The marine environment is a critical component of Jersey's ecosystem and food chain. PFAS contamination in coastal waters can affect both marine biota and seafood consumed by the public, particularly in areas near known discharge points such as St Ouen's Bay and St Aubin's Bay. Where historic/third party local data is available this will be used in conjunction with any new sampling undertaken by government officers.

The following marine elements are recommended for PFAS testing:

- Marine:
 - Sea lettuce and seaweed which may be applied to land
 - Sea foam

- **Seafood:**
 - Crustaceans (e.g. crabs, lobsters)
 - Bivalve molluscs (e.g. oysters, mussels)
 - Fish (including freshwater and low-water)
- **Seawater:**
 - Seawater sampling, with a focus in St Ouen and St Aubin's Bay. Control sites in the North and East of the Island

Marine matter, such as seaweed and sea lettuce, is stationary and absorbent, making them useful indicators of PFAS presence in the marine environment. These samples will help assess ecological exposure.

Seafood testing will prioritise species that are locally harvested, especially those likely to be caught or gathered by amateur fishers. This includes low-water fish and shellfish, which may be consumed. Crustaceans and molluscs are particularly important due to their sediment-dwelling and filter-feeding behaviours, which increase their risk of PFAS accumulation.

Seawater samples will be collected from across the Island, with targeted sampling to support both environmental and food safety assessments.

This integrated approach ensures that marine testing is ecologically representative, dietarily relevant, and aligned with international best practice. It also supports public reassurance and provides essential data for the Independent Scientific Advisory Panel to assess total exposure and inform regulatory decisions.

2.1. Selection of Water Sources for PFAS Testing

Water is a primary exposure pathway for PFAS, and understanding its contribution to overall intake is essential for public health protection and regulatory planning.

Jersey's approach to water testing will combine existing data with targeted sampling to build a comprehensive picture of PFAS presence across the Island.

The following water sources testing for PFAS will be undertaken:

- **Drinking Water:**
 - Post-treatment water supplies (existing data)
- **Surface and Rainwater:**
 - Streams entering reservoirs
 - Raw water pre-treatment at treatment plants

- Rainwater (existing data)
- Groundwater:
 - Island-wide boreholes (a representative number of boreholes in each of the Island's water catchment areas)

Jersey Water already publishes extensive annual testing data for the public water supply, including PFAS results. This data will be used by the Independent Scientific Advisory Panel to assess compliance with international standards and to understand the contribution of mains water to overall PFAS exposure.

In addition, private borehole testing, particularly in areas affected by the plume, will be used to assess localised exposure risks. Where data gaps exist, new borehole samples will be collected to ensure island-wide coverage and to establish background PFAS levels in groundwater.

Surface water testing will focus on streams feeding reservoirs and raw water entering treatment plants, helping to identify upstream sources of contamination. Seawater sampling in known discharge areas will support the marine and seafood testing programme.

This integrated approach ensures that water testing is scientifically robust, geographically representative, and aligned to protect public health and inform future regulatory standards for drinking water.

2.1. Selection of Waste Processes and Soil for PFAS Testing

Waste and soil are key environmental reservoirs for PFAS, particularly where biosolids from water and sewage treatment processes have been applied to land. Testing in these areas is essential to understand the potential for PFAS to enter the food chain and water courses and to assess the long-term environmental impact.

The following waste and soil sources will be tested for PFAS:

- Sewage Sludge:
 - From sewage treatment works
 - Effluent discharge from sewage works
- Water Treatment Process
 - Sludge from water treatment process
 - Effluent from the water treatment process
- Soil:
 - Before and after biosolid application to assess PFAS uptake and persistence
 - On control fields with no history of biosolid use, to establish background

levels

- At inert waste sites, to monitor for any leaching or contamination from stored materials
 - From the fields where potato samples have been taken
 - Environmental background soil sample from wild/unfarmed or developed land.
- **Leachate and Surface Water:**
 - Landfill leachate
 - Surface water near landfill sites

3. Methodology

3.1 Analytical Methods

- **PFAS Suite:** Where possible full panel of UK Drinking Water Inspectorate 48 PFAS compounds will be tested for.
- Please note for food sampling it may only be possible to test for the 4 EFSA TWI compounds.
- **Testing Requirements:**
 - Individual PFAS compound concentrations
 - Sum of PFAS compounds
 - Specific quantification of the 4 EFSA TWI compounds
 - Use of existing Jersey Water data, where available
 - New borehole sampling to fill data gaps and establish background levels

3.2 Laboratory and Quality Assurance

- **Accreditation:** Where possible, new testing must be conducted by ISO/IEC 17025-accredited laboratories with demonstrated PFAS testing capability relevant to the sample being taken.
- **Detection Limits:** Laboratories must achieve ultra-trace detection limits:
 - Water: Low ng/L (parts per trillion)
 - Solids/Food: Low ng/kg

- Lowest detection rate achievable
- Chain of Custody for New Samples:
 - Use of PFAS-free sampling equipment (e.g. HDPE or polypropylene containers)
 - Avoidance of fluoropolymer materials (e.g. PTFE, Gore-Tex)
 - Use of appropriate methods and procedures to minimise the possibility of cross-contamination.
 - Use of field and procedural blanks
 - Full documentation of sample handling, transport, receipt and through to results.
- Cost and Capability Review:
 - Evaluation of lab turnaround times, capacity, and cost-effectiveness

4 Data Management and Reporting

4.1 Data Aggregation

- Test results will be interpreted alongside existing international studies to provide context and comparability.
- Where appropriate, data from other jurisdictions will be used to benchmark Jersey's results and support evidence-based conclusions.

4.2 Exposure Assessment

- A comprehensive exposure model will be developed by combining PFAS concentrations from:
 - Food (local and imported)
 - Drinking water and private supplies
 - Environmental sources (soil, sludge, marine and freshwater)
- This model will estimate total PFAS intake for Jersey residents and help assess compliance with the European Tolerable Weekly Intake (TWI).

4.3 Interpretation and Reporting

- All test results will be reviewed and interpreted by the Independent PFAS Scientific Advisory Panel as part of Report Four.

- The Government of Jersey (GOJ) will not release individual test results separately.
- Instead, all findings will be published collectively within Report Four to ensure:
 - Scientific interpretation is provided
 - Results are placed in appropriate context
 - Public understanding is supported by expert commentary
 - Public consultation will take place on Report Four late in 2025

12.1 Transparency and Scientific Integrity

- This approach ensures that data is not misinterpreted or taken out of context.
- It also aligns with the Government's commitment to evidence-led policy, public transparency, and international best practice in environmental health reporting.

Appendix 5 – Islander input and panel responses

DRAFT