GHD

Airservices Australia

Managing PFC Contamination at Airports

Interim Contamination Management Strategy and Decision Framework

June 2015

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Glossary

Acronym	Definition
AFFF	Aqueous film forming foam – product used for fire-fighting. Main source of PFC contamination.
Airservices	Airservices Australia
ASLP	Australian Standard Leaching Procedure
ANZECC	Australian and New Zealand Environment and Conservation Council
Aquifer	A body of permeable or relatively permeable materials that functions regionally as a water yielding unit.
Beneficial use	A use of the environment or any element of the environment which is conducive to public benefit, welfare, safety, health or aesthetic enjoyment and which requires protection from the effects of waste discharges, emissions or deposits.
CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
CSM	Conceptual site model – a model that describes the fate and transport of contaminants within a particular setting including potential receptors of contamination, exposure pathways and risks.
DoIRD	Department of Infrastructure and Regional Development
Ecological receptor	Non-human living organisms, the habitat which supports such organisms, or natural resources, which could be adversely affected by environmental contamination.
EIL	Ecological investigation level developed by the NEPM.
EISL	Ecological interim screening level
EPA	Environment Protection Authority – State-based environmental regulatory authority.
HIL	Health investigation level developed by the NEPM.
HISL	Health interim screening level
Hydraulic conductivity	The rate of flow under a unit hydraulic gradient through a unit cross-sectional area of aquifer.
Interim screening levels	Criteria for PFCs developed for making decisions on management options. The levels are interim as they have not gained regulatory acceptance.
IWRG	Industrial Waste Resource Guidelines. Developed by the Victorian EPA to define prescribed waste and their management. Waste is divided into Category A, B and C and Fill material.
LOR	Laboratory limit of reporting
NEPM	National Environment Protection (Assessment of Site Contamination) Measure (NEPM) 1999 as amended 2013.

Acronym	Definition
NICNAS	National Industrial Chemicals Notification and Assessment Scheme
PFCs	Perfluorinated or polyfluorinated compounds, or fluorosurfactants
PFOA	Perfluorooctanoic acid – a PFC
PFOS	Perfluorooctane sulphonate – a PFC
PNEC	Predicted no-effect concentration
POP	Persistent organic pollutant
SWL	Standing Water Level
TDS	Total dissolved solid – the total amount of mobile charged ions, including minerals, salts or metals dissolved in a given volume of water.
Toxicity	The degree to which a substance can damage an organism.
Water table	The level at which the groundwater pressure is equal to atmospheric pressure. It may be conveniently visualised as the 'surface' of the subsurface materials that are saturated with groundwater.
6:2FtS	6:2 Fluorotelomer Sulphonate
8:2FtS	8:2 Fluorotelomer Sulphonate

1. Introduction

1.1 Background

Aqueous film-forming foams (AFFF) have been used for fire-fighting purposes around Australia for decades. On airports, AFFF has been used at fuel depots, hangars, and for aviation rescue fire-fighting (for both operational and training purposes). AFFF has not been used for aviation rescue and fire-fighting by Airservices since 2010 but continues to be used around fuel depots, hangars etc. at many airports. AFFF products currently or historically used on airport sites contain perfluorinated or polyfluorinated compounds, or fluorosurfactants (PFCs). Depending on the type of AFFF used, the principal PFC constituents (as active or by-product ingredients) could have included, perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA) and fluorotelomers such as 6:2 fluorotelomer sulfonate (6:2FtS) and 8:2 fluorotelomer sulfonate (8:2FtS).

PFCs are non-biodegradable chemicals that have not only contaminated the sites at which AFFF was employed but also the assets used to apply it. These PFCs are highly persistent in the environment, can bioaccumulate, and can be harmful to animal and human health (US EPA 2014).

There is currently a lack of regulatory guidance on management of PFCs in Australia, which has resulted in a generally conservative approach being adopted when PFC contamination is identified during airport operational and construction activities. This is increasingly placing a burden on aviation operations and other commercial undertakings at airport sites, particularly in circumstances where any disruption or closure to areas of an airport site could substantially impact its ongoing operations.

In the absence of recognised Australian guidance, airports and their tenants require practicable contamination management solutions that take a broader set of risk dimensions into consideration. This Interim Contamination Management Strategy and Decision Framework (referred to here as the Interim Framework) has been developed to be relevant to a range of aviation and other activities that occur on Federally leased airports. It is intended to become a decision making platform upon which to seek regulatory approvals.

While there are numerous PFCs and fluorotelomers, PFOS, PFOA, 6:2FtS and 8:2FtS are generally the compounds that are of concern at aviation sites. These compounds can be expected to be limiting in terms of risk and would determine the remediation and management requirements. The Interim Framework therefore focuses specifically on the management of PFOS, PFOA, 6:2FtS and 8:2FtS.

1.2 Scope and methodology

Six scenarios have been identified whereby the management of PFC contamination may be required.

1.2.1 Scenarios 1 to 4 – managing PFC contaminated media

The Interim Framework provides strategies for dealing with contaminated soil and sediment, rainfall runoff, as well as contaminated groundwater generated from dewatering. Four scenarios have been considered in relation to construction and operational activities encountering PFC contaminated soil, sediment, groundwater and rainwater runoff:

Scenario 1: Construction activities requiring the excavation of PFC contaminated soil and generation of PFC impacted spoil.

Scenario 2: Construction activities where interception of groundwater will occur potentially resulting in the generation of a waste stream of PFC impacted water.

Scenario 3: Generation of PFC impacted water as a result of rainwater coming into contact with PFC contaminated infrastructure.

Scenario 4: Maintenance activities such as dredging of waterways, de-silting of drains or installation of monitoring wells resulting in the generation of PFC contaminated sediments.

In developing the Interim Framework, relevant management options have been developed through an options assessment which focuses on PFC contamination levels, the risk that these pose given the site setting and therefore what options can be available for each scenario, and then the technical feasibility and practicability of the available options.

The assessment of options for each scenario has been based on a risk-based decision framework, utilising a set of interim criteria that can be used to determine the risk, requirements that need to be met and the acceptability of each option. Recommendations have been provided in relation to implementing each of the contamination management options proposed.

1.2.2 Scenario 5 – groundwater management regimes

Scenario 5 relates to the nature and extent of groundwater management required at sites where groundwater has been found to be impacted by PFCs. Similar to the preceding scenarios, a risk-based decision framework has been developed for establishing a management response commensurate with the level of contamination risk, as defined by site characteristics and nature and extent of contamination.

In formulating a decision framework for this scenario, a generic conceptual site model (CSM) was developed that describes the key source, pathway and receptor parameters for PFC contamination issues, and defines the parameters to be used in the decision process for determining the nature and extent of monitoring.

A groundwater management regime decision framework was then developed, based on site-specific hydrogeological and beneficial use factors and the potential or actual extent and magnitude of groundwater contamination, and whether off-site contamination has, or may have occurred. This approach is consistent with the risk-based approach recommended by EPA Victoria for developing groundwater monitoring plans for sites where groundwater contamination is likely. Three management regimes were identified that may be applied on a site by site basis.

In developing the framework, consideration was given to the mass flux and mass discharge of contamination from source areas and to receiving environments. This was to allow consideration of dilution in the receiving environment and to focus attention on significant source areas where action might be more usefully initiated. It also provides a basis for assigning a low priority for action to areas where the mass is not significant or is dispersed and diffuse.

The management response recognises the lack of current regulatory requirements for monitoring PFCs in groundwater. Therefore, groundwater monitoring frequency has not been included in the management response. The emphasis rather is on providing sufficient evidence to indicate the potential extent of the contamination, in particular whether it has migrated off-site.

1.2.3 Scenario 6 - management of PFC impacted areas

Scenario 6 considers management of PFC impacted sites that are not operational and are publicly accessible (e.g. decommissioned fire training grounds). The framework developed for this scenario is based on the requirements outlined in the National Environment Protection Council *National Environment Protection (Assessment of Site Contamination) Amendment*

Measure 2013 (No. 1), amendment of the National Environment Protection (Assessment of Site Contamination) Measure 1999 (herein referred to as the NEPM).

1.3 Use of this guideline

There are varying levels of information regarding the presence, extent and concentrations of PFC contaminants, with considerable uncertainty in some situations. In view of this, decisions have been framed in terms of risk and priority, with high risk being assigned a higher priority and vice versa. Judgement will need to be applied in each instance in reaching decisions on specific matters and, because of this, it is essential that the application of this Interim Framework involve persons with an appropriate level of knowledge regarding PFC contamination.

1.4 Limitations

This report

1. has been prepared by GHD for Airservices Australia (Airservices) and Department of Infrastructure and Regional Development (DoIRD) and may only be used and relied on by Airservices and DoIRD for the purpose agreed between GHD and Airservices as set out in Sections 1.1, 1.2 and 1.3 of this report, and
2. may be provided to Department of the Environment (Cth) (DoE) for the purposes of seeking its agreement to the proposed methodology outlined in this report regarding the management of PFC contamination on the sites identified in this report.

GHD otherwise disclaims responsibility to any person other than Airservices, DoIRD and DoE arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

It is cautioned that the criteria that should be used to assess the risk associated with PFC contamination have not been established by any regulatory agency in Australia, and the current state of knowledge and understanding regarding the acceptability and feasibility of particular management and treatment strategies for PFC is still evolving. While GHD has considered this matter and has suggested criteria and strategies that GHD expects to be appropriate at the time of writing this report, it should be highlighted that knowledge in this area is evolving. Therefore, it will be important to review and revise the Interim Framework as such knowledge and understanding further develops and regulatory requirements become established. The opinions, conclusions and recommendations in this report are based on assumptions made by GHD described in this report; these include assumptions regarding the concentrations that will be encountered in soil and groundwater, the criteria that will apply, and the feasibility and applicability of particular management and treatment options with respect to PFC. Because of the evolving nature of this field there is considerable uncertainty regarding these various assumptions, and GHD disclaims liability arising from any of the assumptions being incorrect.

2. PFCs and the environment

2.1 Origin

PFCs are released into the environment through a wide range of commercial and industrial products; of particular relevance to aviation sites is the use of AFFF. Anthropogenic PFC chemicals, PFOS and PFOA, were historically used in AFFF due to their excellent thermal stability and hydrophobic properties.

Modern AFFF fire-fighting foams contain other PFCs called fluorotelomers such as 6:2 FtS and 8:2 FtS, which are considered less bioaccumulative and toxic than PFOS and PFOA, though still persistent in the environment (Seow 2013). Fluorotelomers are not made with, and cannot degrade to PFOS, though 8:2 FtS can degrade to PFOA in the environment (Danish EPA 2013, Seow 2013). There has been less research into the environmental impact of AFFF containing fluorotelomers than those containing PFOS and PFOA, but studies to date have indicated that while they have low environmental toxicity, environmental persistence is still of concern.

PFCs have been identified by the United States Environmental Protection Agency (US EPA) as ‘emerging contaminants’ on the basis either that the chemicals are characterised by a perceived, potential or real threat to human health and the environment, or by a lack of published health standards (USEPA 2014). The concern posed by these contaminants is reflected by Airservices decision to cease using AFFF foams for fire-fighting training at all of its locations. Airservices also ceased operational use of AFFF (other than at Darwin and Townsville joint user airports due to a request by the Australian Department of Defence).

There is global recognition of the potential impacts of PFCs on the environment and human health, particularly in the USA, Canada, the UK, Sweden, Norway, Germany and Australia (Seow 2013). As awareness grows of the environmental impacts resulting from PFOS and PFOA use, many countries have banned or restricted the use of PFCs in AFFF, particularly those containing PFOS (and PFOA precursors such as 8:2FtS). In May 2009 the Stockholm Convention was revised to ban PFOS production and use of PFOS and its salts, which, along with perfluorooctane sulphonyl fluoride, were restricted under Annex B as persistent organic pollutants (POPs). Australia has not yet ratified the PFOS POPs amendment.

PFC use in Australia has been monitored by the National Industrial Chemicals Notification and Assessment scheme (NICNAS). The use of PFOS-containing products in Australia has significantly decreased through a voluntary industry phase out agreement. Class B fire-fighting foams, paints and coatings containing PFOS have not been commercially available in Australia since December 2003 (CRC CARE[1] 2014a). It is not known whether existing stocks of these materials are still in use, though as noted above, it is understood that Airservices and Department of Defence have ceased use of AFFF containing PFOS.

In terms of the presence, extent and magnitude of PFC contamination and impacts on the environment, substantial information exists regarding this in North America, Europe, and Asia (CRC CARE 2014a). Limited information is currently available in Australia; however, studies are currently underway to better understand the extent and magnitude of PFC contamination. The Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) has recently commenced development of criteria and remediation guidance for PFOS and PFOA; this is expected to be completed early 2016.

[1] Cooperative Research Centre for Contamination Assessment and Remediation of the Environment

2.2 Physico-chemical properties

PFCs are highly stable organic compounds, both chemically and biologically, and hence are very persistent in the environment. Important physico-chemical properties in relation to environmental persistence and impacts are outlined below.

PFOS and PFOA

- They are artificially manufactured (i.e. they are not naturally occurring). PFOS and PFOA can also be formed from related substances or precursor compounds by microbial degradation or larger organism metabolism (e.g. rainbow trout transform perfluorinated acids to PFOS and PFOA) (CRC CARE 2014a). It is possible that as PFCs are gradually phased out, precursor transformation may contribute significantly to exposure (CRC CARE 2014a).
- They are chemically and biologically stable and hence persistent in the environment, resistant to biodegradation, atmospheric photooxidation, direct photolysis, and hydrolysis (US EPA 2014).
- PFOS and PFOA comprise a long carbon chain that is both lipid and water repellent. Each contains a charged hydrophilic head, and a hydrophobic and oleophobic perfluorocarbon tail (CRC CARE 2014a). PFOS is a perfluoroalkyl sulphonate, with a chain of eight carbon atoms, in which all of the carbon-hydrogen bonds are replaced by carbon-fluorine bonds (perfluorinated) (Environment Canada 2013). PFOA is a compound with an eight-carbon chain length, in which seven are perfluorinated. It belongs to the perfluorocarboxylic acids class of chemicals, and is often called “C8” (Seow 2013).
- The stability of PFOS and PFOA is due to the strength of the carbon-fluorine bonds; each fluorine atom is shielded by three electron pairs, and the carbon atoms are shielded by the fluorine atoms (CRC CARE 2014a).
- PFOS and PFOA are moderately soluble (CRC CARE 2014a) and have long half-lives in water with respect to hydrolysis (41 years and 92 years respectively (Hites, 2006) – but may be significantly longer) and are persistent in groundwater and surface waters (US EPA 2014).
- PFCs have been found to partition from the groundwater column into organic matter-rich sediments and soil particles due to their propensity to adsorb to organic carbon (Das et al 2010 – CERAR and CRC CARE 2014a).
- The vapour pressure for PFOS at 20^{o}C is 2.48×10^{-6} mm Hg and for PFOA is 0.017 mm Hg (US EPA 2014), and vaporisation appears to be of little concern. However, PFOS and PFOA can be transported long distances in air because of their high atmospheric half-lives (114 days and 90 days respectively) (US EPA 2014).
- PFOS and PFOA have been found to bioaccumulate and biomagnify in a range of species, and because of their persistence and accumulative effects, have been detected in higher trophic level animals such as fish and birds. PFOS has a higher tendency for bioaccumulation compared with PFOA due to its longer perfluoroalkyl chain length (eight carbon chain compared with seven carbon chain). PFOS has been shown to bioaccumulate and biomagnify in fish and piscivorous (fish-eating) birds. The biomagnification factor ranges from 1.4 to 17 in predatory birds and mammals (US EPA 2014)
- PFOS is the only PFC that has been shown to accumulate to levels of concern in fish tissue. The estimated kinetic bioconcentration factor in fish ranges from 1,000 to 4,000 (US EPA 2014).

- Consumption of fish and fishery products can be one of the primary sources of human exposure to PFOS, with other potential pathways being ingestion of other food and water, inhalation of contaminated air or contaminated dust, exposure to carpets treated with perfluoroalkyls (children), or use of commercial products such as fabric protectors (ATSDR 2009).

6:2FtS and 8:2FtS

- 6:2FtS is a fluorotelomer which has six fluorinated carbons and two methylene carbons in the fluoroalkyl chain. 8:2FtS has eight fully fluorinated carbons and two methylene carbons.
- 6:2FtS is considered to be less bioaccumulative and toxic than PFOS and PFOA. It has been shown to have low acute, sub-chronic and aquatic toxicity, and negative genetic and developmental toxicity. While not bioaccumulative and less biopersistent than PFOS, there are concerns regarding its persistence in the environment (Seow 2013).
- Fluorotelomers cannot degrade to PFOS and are not made from PFOA, though 8:2FtS can degrade to PFOA (Seow 2013).

2.3 Toxicity

Numerous studies have been conducted globally as to the toxicity of PFOS and PFOA. Key findings with respect to toxicity include the following:

- Toxicology studies show that PFOS and PFOA are readily absorbed after oral exposure and accumulate primarily in the serum, kidney and liver and have a half-life of approximately 4 years in humans (US EPA 2014).
- The toxic effect on humans from acute exposure is not known, as there is limited information available (US EPA 2014).
- While the long term adverse effects on humans are not yet well understood, due to the long half life of PFOS and PFOA in humans, continued exposure could increase body concentrations to levels that would cause adverse outcomes(US EPA 2009b).
- Animal studies have demonstrated a moderate acute oral toxicity, with potential adverse effects on the gastrointestinal tract, liver and thyroid levels (CRC CARE 2014a). PFOS is more toxic than PFOA (Danish EPA 2013). Potential developmental, reproductive and other systemic effects were identified in rodents through acute- and intermediate-duration oral studies. Exposure of rats to PFOS caused effects on the neuroendocrine system and liver tumours. Little information is available as to the ecological effects of PFOS and PFOA in the Australian environment.
- PFOS and PFOA bind to proteins (β-lipoproteins and liver fatty acid binding protein), preferentially partitioning to liver, blood and kidney tissue, and can interfere with fatty acid metabolism, and deregulate lipid and lipoprotein metabolism. They do not accumulate in fatty tissues because they exhibit both hydrophobic and lipophobic properties (Danish EPA 2013).
- The US EPA does not currently classify PFOS or PFOA as carcinogenic (US EPA 2014). The Danish EPA considers PFOS and four derivatives to have a harmonised classification[2] as carcinogenic, toxic to reproduction and acutely toxic (Danish EPA 2013). The Danish EPA (2013) has recommended that PFOA be classified for carcinogenicity, target organ toxicity, acute toxicity and eye irritation. Neither PFOS nor

[2] Classification of certain hazardous chemicals is harmonised throughout the European Union to ensure adequate risk management, in accordance with the Regulation (EC) No. 1272/2008 of the European Parliament and of the Council of 16 December 2008.

PFOA have been found to exhibit mutagenic properties, though high doses (2 mg/kg bw/day) may induce carcinogenicity in animals.

- When considering the toxicity of PFOS and PFOA, the source material must be considered as other constituents of AFFF may contribute to the toxicity (e.g. biological oxygen demand (BOD) and chemical oxygen demand (COD) in AFFF). A holistic approach is necessary to understand the likely impacts of contamination to the environment.

2.4 Fate and transport

PFOS and PFOA are widely distributed in the environment, detected in soil, sediment, surface waters and groundwater, both near point sources and in remote locations. Their persistence in the environment and moderate solubility means they can be transported long distances and between different media. PFOS and PFOA can be transported to surface waters and subsurface waters (i.e. groundwater) as a result of runoff and leaching.

Human exposure to PFOS and PFOA is considered to be mainly through oral ingestion of contaminated food and water. PFOS has been widely detected in human blood serum. Studies of blood sera in Australian residents (urban and rural areas) have found highest mean concentrations of PFOS and PFOA of 20.8 ng/mL and 7.6 ng/mL, respectively. Concentrations reported were equal to or higher than reported serum levels in Europe and Asia, and lower than in the US. PFOS concentrations in men and women increased with age. Males generally contained higher serum concentrations than females (CRC CARE 2014a). It is important to note that while an extensive assessment of PFCs in blood serum of Australian residents has been undertaken, temporal trends are lacking. While the impacts of PFOS on humans are recognised and experimental data is available, the long term effects of human exposure to PFOS have not been established.

International studies have detected PFOS and PFOA in a range of ecological receptors including molluscs, fish, birds and mammals, but limited information is available regarding the bioaccumulation in Australian wildlife. Studies have found that PFOS and PFOA concentrations in freshwater environments are often one to two orders of magnitude lower than the no observable effect concentration (NOEC) values (CRC CARE 2014a). The limiting factor when determining the impacts of PFOS and PFOA contamination on ecosystems is the bioaccumulation of contaminants across trophic levels.

3. Interim screening levels

There are currently no formally recognised investigation levels for PFCs in soil, groundwater or surface water in Australia. The following presents a summary and discussion of international guidance, and outlines interim screening levels that are suggested be used for making decisions on management options until such time that Australian regulatory guidance is available. Such guidance may well be available in the next few years, as CRC CARE has commenced the development of guidance relating to screening, remediation and management of PFOS and PFOA, in conjunction with Australian regulatory agencies and industry (CRC CARE 2014b).

The interim adoption of overseas guidance is consistent with the Australian Government's recent decision to utilise international systems, services or products that have been approved under a trusted international standard, in an effort to reduce duplicative regulation. This is intended to streamline, amongst other processes, the assessment of industrial chemicals as part of the NICNAS, channelling resources to higher risk industrial chemicals. While not directly related to the environmental and human health impacts of existing PFC contamination, the principles adopted in this framework are consistent with this approach (Australian Government Department of Prime Minister and Cabinet, 2015).

The application of these interim screening levels will be dependent on site-specific considerations. The decision making frameworks developed for each scenario (Sections 4 to 7) will facilitate selection of the relevant screening levels.

Note that the term "interim screening level" (ISL) has been adopted; in Australia, "Investigation Level" is the term applied for screening levels in the NEPM and has regulatory significance, and referring to the screening levels in this document as "investigation levels" may be rejected by the regulatory agencies. Interim screening levels protective of human health have been referred to as "health interim screening levels" (HISLs), and those protective of ecosystems as "ecological interim screening levels" (EISLs).

A summary of interim screening levels for PFOS, PFOA and 6:2FtS (where available) from published international guidance documents and the rationale behind selection of each screening level, is provided in Table 1. There is limited information available for 8:2FtS, however as it is a precursor product to PFOA, it is considered appropriate to adopt the PFOA screening levels. This assumes 100% degradation of 8:2FtS to PFOA, which is conservative.

Table 1 Interim screening levels (ISLs)

Exposure Scenario	PFOS	PFOA / 8:2FtS	6:2FtS	Source	Comments
SOIL					
Human health interim screening levels (HISLs) – residential (direct contact only)	6 mg/kg	16 mg/kg	60 mg/kg	USEPA Region 4 2009 (in US EPA 2014) Jarman et al 2014	US EPA Region 4 provides a residential soil screening level of 6 mg/kg for PFOS and 16 mg/kg for PFOA (US EPA 2014). This guideline is protective of human health via direct contact exposure (i.e. ingestion, dermal, dust inhalation) for a residential scenario. The US EPA does not provide a screening level for 6:2FtS. Jarman et al (2014) have carried out a toxicological assessment of 6:2FtS for drinking water and conclude that intakes of more than 10 fold over that for PFOS may be acceptable. On this basis, an interim screening value for 6:2FtS of 10 fold the PFOS value is proposed. It should be noted these screening levels do not protect against leaching into groundwater.
HISLs – industrial (direct contact only)	90 mg/kg	240 mg/kg	900 mg/kg		Criteria have not been published for commercial and industrial land use, and for this document a scaling factor has been applied to the residential criteria to derive screening levels for commercial/industrial land. The scaling factor allows for the differences in adult worker body weight, exposure time and duration of exposure compared with those that apply for residential exposure, which include children. The scaling factor varies with the contaminant, and depends on the contribution of risk from different pathways, i.e. oral, dermal and dust inhalation. Lipophilic chemicals such as DDT tend to absorb more through skin and the scaling factor is generally found to be in the order of 15. For PFCs a scaling factor of 15 is proposed. Note that these screening levels do not protect against leaching into groundwater; leachability is considered further in Section 4.
Ecological interim screening levels (EISLs) (terrestrial)	0.373 mg/kg (95% protection) 0.91 mg/kg (residential, 80% protection, low reliability) 4.71 mg/kg (commercial/industrial, 60% protection, low reliability)	3.73 mg/kg	NA	UK Environmental Agency 2009	Due to the lack of terrestrial data, the low reliability 'predicted no effect concentration' (PNEC) for soil calculated at 0.373 mg/L, which has been derived from a single earthworm bioassay using an application factor of 100 by the UK Environmental Agency (2009), has been selected as a conservative interim screening level for PFOS. The selection of this screening level is supported by the calculation of a PNEC of 0.22 mg/kg recommended for application to marine sediments in Norway (Bakke et al 2010). It would be expected that marine sediments would have a lower PNEC due to the lower amounts of organic carbon in the system when compared to terrestrial systems or freshwater sediments. The selected screening level for PFOS is shown to be conservative as the no effect concentration for sub-lethal endpoints in plants (shoot height and emergence) ranges from 3.91 mg/kg to 62.5 mg/kg (UK Environment Agency 2009). There are currently no terrestrial toxicity data to calculate screening levels for the protection of terrestrial ecosystems for PFOA and 6:2FtS. However, as the toxicity of PFOA and 6:2FtS have been shown to be lower than PFOS (Yang et al 2014), it would be expected that the ecological screening levels would be >0.373 mg/kg. Yang et al (2014) have calculated PNECs for PFOS and PFOA and reported a 12 to 14 fold difference between the PNECs. Therefore, to calculate a conservative PNEC for PFOA, a conservative interim screening value using 10 fold the PFOS PNEC is proposed. The low reliability PNEC for soil of 0.373 mg/kg is based on 95% protection of species. Based on the limited terrestrial ecotox data (only 4 data points with an additional professional judgement data point to get the five required to meet ANZECC 2000 requirements), using Burrlioz species sensitivity distribution software low reliability values were calculated for 80% species protection (urban residential in accordance with the NEPM, 0.91 mg/kg) and 60% species protection (commercial/industrial land use, 4.71 mg/kg). Using the data presented in the UK Environment Agency report the 95% species protection level was found to be 0.36 mg/kg. The appropriate interim screening level should be selected based on the current and future site land use (i.e. commercial/industrial – 60%, residential – 80%, or areas of ecological significance - note the NEPM defines the criteria for these areas as 99% species protection).
GROUNDWATER					
HISLs (drinking water only)	0.2 µg/L	0.4 µg/L	5.0 µg/L	USEPA Region 4 2009a (PFOS/PFOA) Jarman et al 2014 (6:2 FTS)	***Drinking water*** The US EPA has published a provisional guideline of 0.2 µg/L for PFOS and 0.4 µg/L for PFOA for drinking water (US EPA 2009a). A study on monkeys (Seacat et al 2002) was used to derive the PFOS/PFOA no-observed-adverse-effect level (NOAEL) of 0.03 mg/kg/d based on lower body weights, increased liver weight and other effects. The derivation allowed for 80% background contribution. Half-life clearance rates (bio-elimination) were measured (from rat studies) for PFOS and PFOA. It was found the PFOS half-life is higher than PFOA (i.e. more persistent in the body) and therefore the intake allowed dose is lower for PFOS resulting in the lower criterion. The State of Minnesota has established a health based drinking water guideline of 0.3 µg/L for PFOS and PFOA. These are based on the Seacat et al 2002 study of monkeys, but do not include the half-life studies in rats used by US EPA. While the derived values are similar, the US EPA's values include a wider range of toxicological considerations and have been selected for this document. Jarman et al (2014) proposed drinking water guidelines for 6:2FtS: below 5 µg/L requires no further action, 5 – 290 µg/L requires monitoring, above 290 µg/L requires management/remediation. The various values given are based on a drinking water endpoint protective of human health, and do not include allowance for other exposures or effects that might arise from use or disposal of water after use. ***Other beneficial uses*** Published criteria for other beneficial uses, such as primary contact recreation and industrial water use have not been identified, and are generally not likely to be limiting. Consequently, other beneficial uses of groundwater should be considered on a case by case basis. Protection of human health would also protect other, less sensitive beneficial uses. There are no criteria for human health for direct contact exposure to groundwater. Adopting the drinking water criteria would be an acceptable, conservative approach.
EISLs	In most cases the assessment of ecological impact will relate to the discharge of groundwater to a surface water, and impact on the aquatic ecosystems of the surface water (see below). In assessing risk to surface waters, consideration should be given to the flux of the chemical in groundwater, the resulting dilution that will occur in the surface water and the existing PFC levels in the surface water. This can then be compared to the surface water screening values below.				

Exposure Scenario	PFOS	PFOA / 8:2FtS	6:2FtS	Source	Comments
SURFACE WATER					
EISLs (toxicity effects on aquatic organisms)	6.66 µg/L	2900 µg/L	NA	Qi et al 2011 Giesy et al 2010	Qi et al (2011) have calculated a PNEC (95% species protection) of 6.66 µg/L following the same methodology as used in Australia, based on species sensitivity distribution. The UK Environmental Agency requires an annual average PFOS concentration of 1 µg/L in fresh surface waters and an annual average in marine systems of 2.5 µg/L (Seow 2013). The RIVM maximum acceptable concentration (MAC) for ecosystems for freshwater was calculated as 36 µg/L and a serious risk concentration (SRC) of 930 µg/L. The MAC for marine systems is 7.2 µg/L and the SRC is 930 µg/L (RIVM 2010). Environment Canada (2013) provided a draft guideline for PFOS in water of 6 µg/L, similar to Qi et al (2011). The methodology and input parameters for this guideline have not been reviewed in detail. Giesy et al (2010) propose an ecological toxicity criterion for PFOA, which appears to have been developed on a similar basis to ANZECC aquatic protection (species effect levels). There is insufficient information to determine a screening level for 6:2FtS; this is currently under review. Given the lower toxicity of 6:2FtS, it can be expected that PFOS and PFOA will be the limiting contaminants with respect to ecological toxicity.
HISLs (consumption of fish)	0.65 ng/L	300 ng/L	6.5 ng/L	RIVM 2010	RIVM (2010) presents a PFOS Maximum Permissible Concentration (MPC) of 0.65 ng/L based on protection of human health via consumption of seafood (i.e. the bioaccumulation in food chain), rather than a direct toxicological effect. As such, the RIVM MPC number should not be used for protection of aquatic species, but should be used in surface water where seafood is caught for consumption (e.g. fish, crabs, oysters, etc.). The criterion applies in the receiving water after dilution, and can apply to situations where there is groundwater discharge, rainfall run off from contaminated areas, and treated effluent discharging to a receiving water. Studies have found that PFOA is not as bioaccumulative as PFOS in fish; US EPA 2014 indicates that PFOS is the only PFC that has been identified as bioaccumulating to levels of concern in fish tissue. RIVM (2010) does not provide a criterion for PFOA. The RIVM PFOS criterion is based on a bioaccumulation factor of 14,000 L/kg, whereas BCF and BMF values for PFOA (27 L/kg and 2.7 respectively) reported by Environment Canada (2012) indicate a bioaccumulation factor of 72.9. On this basis PFOS is around 200 times more bioaccumulative than PFOA in fish. Allowing for a further factor of 2.6 to account for the differences in toxicity and pharmokinetics (as per the residential soil criteria) results in a total factor of around 500. Therefore a PFOA criterion of 300 ng/L is proposed. There are no readily available published guideline values for 6:2FtS for protection of human health via consumption of fish, therefore an interim screening level of 10 x PFOS screening level is proposed, based on the lower toxicity of 6:2FtS documented by Jarman et al 2014.
HISL (drinking water)	There are no specific guidelines for surface water use as drinking water; in this instance the groundwater drinking water ISLs would apply.				
NOTES: NA – not available					

4. Soil and sediment management

This section provides contamination management options and outlines a decision framework for selecting an appropriate management strategy for PFC contaminated soil (Scenario 1) and sediment (Scenario 4) generated during construction and maintenance works at leased federal airports.

The contamination management options may also be appropriate for the management of PFC contaminated slurry (such as soil or sediment with a high water content), although the slurry must first be dewatered (probably most cost-effectively through evaporation). Any excess PFC contaminated water derived from this dewatering should be managed in accordance with the framework provided in Section 5. Careful consideration needs to be given to the process adopted for drying the slurry and measures taken to prevent further contamination of soil and/or groundwater in the area where dewatering will take place.

The decision basis is outlined schematically in Figure 1.

Establishing which soil and sediment contamination management option is suitable and preferred requires consideration of the contamination risks, as well as airport operational and stakeholder requirements. The decision process considers:

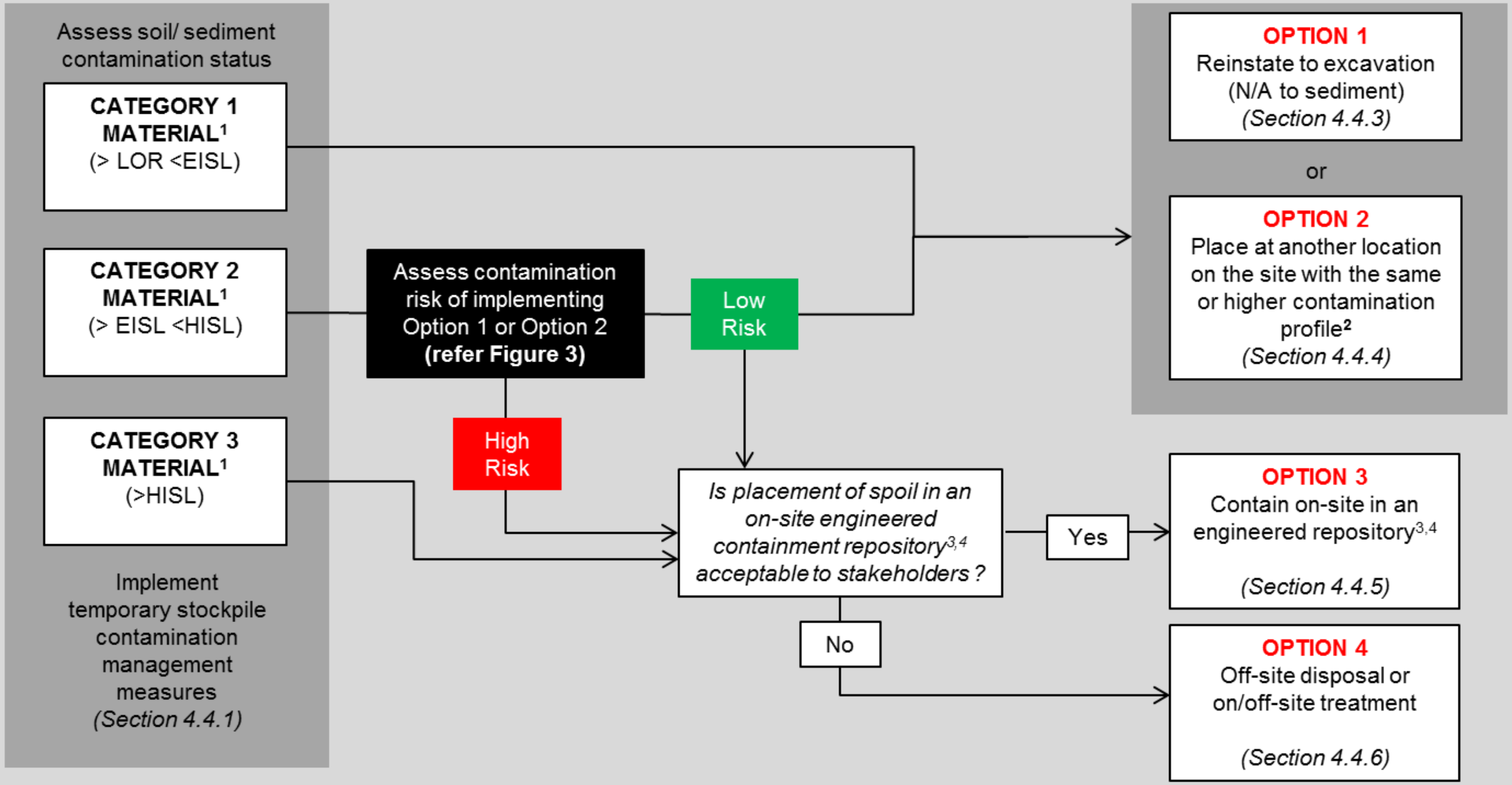
- The concentrations of PFCs and extent of contamination. Soil acceptance criteria outlined in Section 3 are used to define three categories of PFC contaminated soil that may be applied in the context of an airport setting.
- The acceptability of the approach to airport stakeholders, particularly from a regulatory and airport operational perspective.
- The nature of the construction works and how the contamination management approach will affect or be aligned with these works.
- The risk of contamination to human health and the environment following implementation of the management approach.

Figure 1 provides a decision process that integrates these elements leading to management Options 1, 2, 3 or 4, described in Section 4.4. The following sections explain the basis for development of the decision process, additional decision schematics and more detail on specific considerations relating to each of the options.

4.1 Overarching principles

The decision process presented in Figure 1 is specifically for management of contaminated soil arising from airport construction activities. It is not intended to be, and nor should it be used as a decision support tool where site remediation is the primary objective. As a result, the guidance is based on the following overarching principles:

- The protection of human health is paramount.
- The actions should not increase the extent of contamination or the risk posed by the contamination.
- Effort and resources are prioritised to more heavily contaminated areas where a greater risk reduction per dollar spent may be achieved.
- The actions should not preclude remediation of an area where the residual contamination poses an unacceptable risk and remediation will be required in the future.



1) Proposed soil/ sediment PFC waste classification categories for leased federal airports (refer Section 4.3) based on interim screening levels.
2) Spoil may only be placed or re-used at another area of the airport site where: (a) The PFC concentrations at that area are the same or greater than that of the spoil; (b) In doing so, the existing contamination risk profile of that area is not raised, taking into consideration all potential sources pathways and receptors; and (c)There are no other contaminants of concern that would drive the risk.
3) Defined as: (a) dedicated purpose built soil/sediment containment facility, or (b) a suitably engineered containment system integrated with other site infrastructure such as below pavements or other structures where fill material is required.
4) Consideration should be given to jurisdictional regulations where applicable. For example, a Works Approval (statutory approval required by the EP Act which permits construction) is required for a contaminated soil containment repository greater than 1,000m^3 in Victoria.

EISL – Ecological Interim Screening Level; HISL – Health Interim Screening Level, refer Table 1, Section 3.

Figure 1 Decision support tool for PFC contaminated soil and sediment at federally leased airport sites

- Criteria for decision making are consistent with the principles generally applied in the management of contaminated land in Australia or, where Australian guidance is not available, international published criteria.
- Implementation of this guidance using Options 1-3 will not result in remediation of the area. Information will need to be retained on the organisation's Contaminated Site Register to inform future management.

4.2 Understanding the risks arising from the contamination

To assist in understanding the risks arising from contamination, it is important to prepare a Conceptual Site Model (CSM) that describes the nature of the source of contamination and the pathways by which receptors (persons and the environment) might be affected by the contamination. The risk posed by contamination may be acceptable if the pathway between the source and receptor is not complete, or can be broken by management or remediation.

The potential linkages between the source, pathways and receptors are shown in Figure 2 below. Other pathways and receptors as well as pathways and receptors that are subsets of the above may also be present. The CSM presented here should be considered as a baseline and added to or amended as dictated by the specific characteristics of the site.

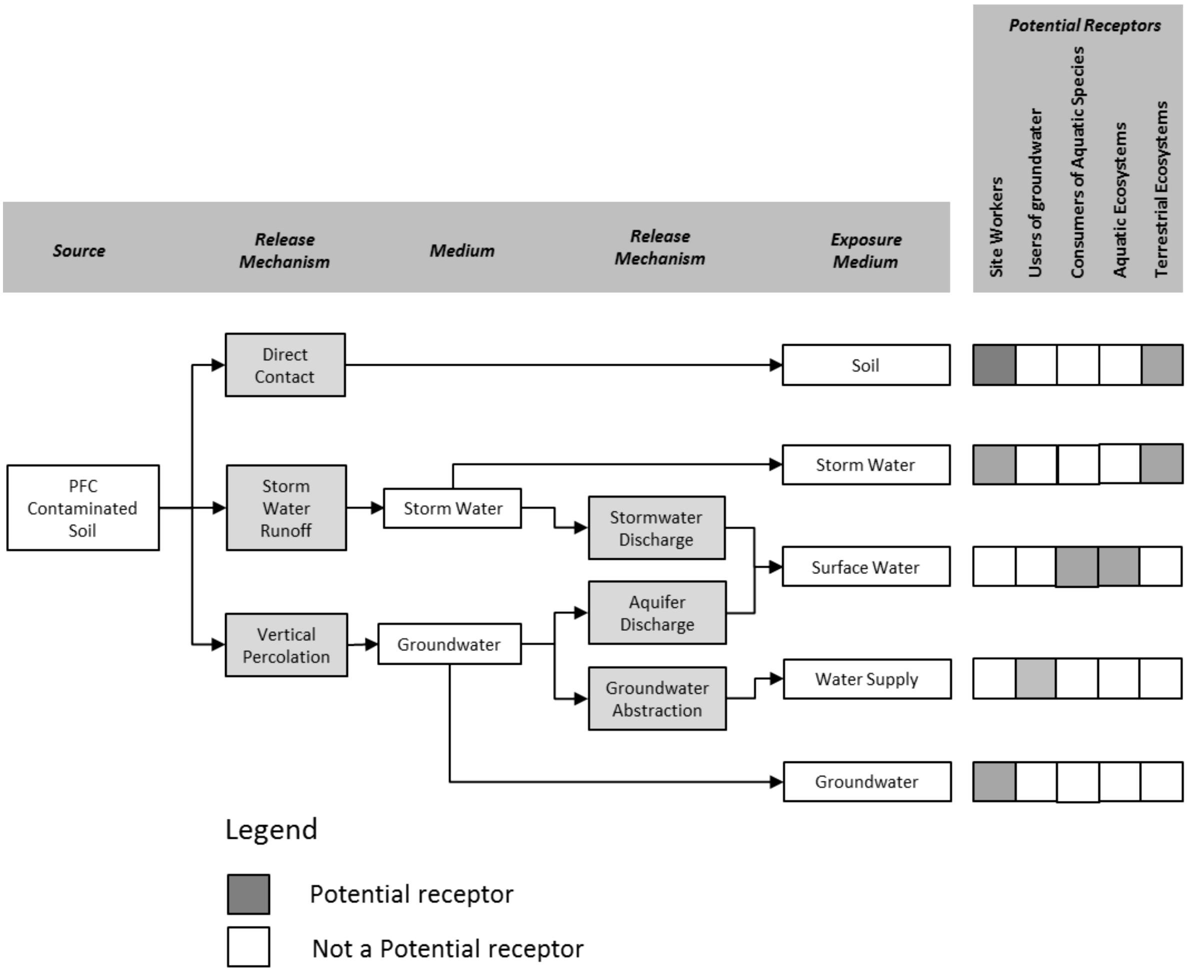


Figure 2 Conceptual site model

In Scenarios 1 and 4, the contamination source is defined as PFC contaminated soil or sediment that is to be excavated.

Management options for soil or sediment that has been excavated should consider the risks arising through the following contaminant transport pathways:

- *Direct contact* – where persons may be exposed directly to soil contamination if the contamination is exposed at the surface, or needs to be accessed during construction or maintenance activities.
- *Stormwater runoff* – rainfall or other runoff is contaminated as it runs over soil that is exposed at the surface. The contaminated runoff may discharge to a surface water body.
- *Vertical percolation to groundwater* – contamination leaches from soil to water as water migrates downward through soil to the water table, resulting in contaminated groundwater. The contaminated groundwater may be extracted for use, or may discharge to a surface water body.

The key on-site and off-site receptors are:

- Persons such as site workers who may come into direct contact with contaminated soil or water, off-site users of groundwater, and persons who may consume fish or other aquatic species.
- Ecosystems, including terrestrial ecosystems on-site, and aquatic ecosystems off-site.

4.3 Interim soil/ sediment PFC waste classification categories

4.3.1 Proposed soil and sediment waste classifications

For the purposes of this document, three (3) interim soil/sediment waste classification categories for PFC contaminated soil and sediment have been set using the criteria nominated in Table 1. These are set out in Table 2.

Table 2 Interim PFC waste classification categories for airports

PFC soil and sediment waste classification categories	Upper Limits	
Category 1 Material	*Concentration (mg/kg)*	*ASLP* (µg/L)[3]
PFOS	0.373[1]	-
PFOA	3.73[1]	-
Category 2 Material		
PFOS	90[2]	20[4]
PFOA	240[2]	40[4]
Category 3 Material		
PFOS	>90[2]	-
PFOA	>240[2]	-

NOTES:
1. UK Environmental Agency 2009 ecological investigation level.
2. USEPA Region 4 health screening level for a commercial/industrial land use.
3. Australian Standard Leaching Procedure.
4. Based on USEPA Region 4 2009 drinking water criteria with 100 fold attenuation factor applied.

4.3.2 Category 1 material

The derivation of criteria for Category 1 Material has followed a similar methodology to that adopted by EPA Victoria publication No. IWRG621 July 2009 *"Soil hazard categorisation and management, publication"* (EPA Victoria Publication IWRG621). This establishes criteria that are consistent with the "*Fill Material upper limits*" listed in EPA Victoria Publication IWRG621, where soil with contaminant concentrations below these criteria is considered to be acceptable for use on land where there are sensitive land uses. The EPA Victoria Fill Material upper limits are based on information sourced from various documents[3] (noting that the date of publication was 2009 and this predated the recent 2013 NEPM Variation).

For EPA Victoria Publication IWRG621, the basis for setting Fill Material upper limits has generally been: where residential human health investigation thresholds and soil ecological investigation thresholds are available, the more stringent of the two has been adopted. If no ecological investigation threshold has been identified, then the human health investigation threshold has been adopted as the Fill Material upper limit.

Using this approach, an equivalent Fill Material upper limit of 0.373 mg/kg and 3.73 mg/kg has been set for PFOS and PFOA respectively based on the most stringent of the criteria being the UK Environmental Agency 2009 ecological investigation level.

We note however, that the fate of soils impacted by PFCs and classified as Category 1 Material under this report, cannot be considered 'clean' and cannot be used in the same way as "Fill Material" in Victoria, for example (i.e. for any land use). The classification of Category 1 Material simply means it is suitable for management under the less conservative Options 1 or 2.

Material with no detectable PFCs can be used for any land use (assuming no other contaminants are present at unacceptable levels). However, this document was not designed to address such material and the reader is referred to State or Territory guidance.

In the context of this document, contaminated soil and sediment that meets the Category 1 criteria can be seen to present a low risk for relocation on-site.

4.3.3 Category 2 and 3 material

Two further PFC waste classification categories have been established as the basis for contamination management decisions at airport sites for soil and sediment containing concentrations of PFOS or PFOA that exceed the equivalent Fill Material upper limits.

Category 2 material containing concentrations of PFOS or PFOA exceeding the equivalent Fill Material upper limit, but below the health based interim screening levels for a commercial/industrial land use listed in Table 1 and leachate as determined by the ASLP test is below 100 times the USEPA Region 4 2009 drinking water criterion. This is equivalent to the 'Category C' classification in the EPA Victoria publication IWRG621, and defines material that is suitable for disposal at a municipal landfill. This material poses a potential ecological risk, but is unlikely to pose a risk to human health in the context of an airport setting except where sensitive land uses exist.

In the context of this document, contaminated soil and sediment that meets the Category 2 criteria can be expected to pose a low risk if disposed of at a landfill or on-site in areas of similar (or greater) contamination and this may be helpful in gaining approval for such disposal or deciding whether such disposal (if accepted by the landfill operator) is likely to pose a low risk.

[3] The EPA Victoria Fill Material upper limits for metals are based on the NEPM 1999 Ecological Investigation Levels (EILs); the upper limits for benzo(a)pyrene and total PAHs are based on Residential Health Investigations Levels (HIL-A) from NEPM 1999; and the upper limits for petroleum hydrocarbons (benzene, total BTEX and TPH) are based on the health limits specified in the 1994 NSW EPA Service Station guidelines.

Category 3 material containing concentrations of PFOS or PFOA greater than the Category 2 material criteria may be suitable for disposal in a secure landfill or require treatment.

In the context of this document, contaminated soil and sediment that exceeds the Category 2 criteria may pose a higher risk for disposal at a municipal landfill, and storage or treatment should be considered.

4.4 Contamination management options and decision process

4.4.1 Introduction

The objective of this guideline is to provide practical advice to manage the risk to human health and the environment from PFC contamination, and allow critical airport construction operations to occur.

For many contaminants *source removal* is preferred to reduce the risk resulting from the contamination; this avoids the requirement for on-going management and can avoid restrictions on construction work. However, in the case of PFCs, establishing whether source removal is necessary is complex in the absence of published criteria, and the available source removal options are limited by the high level of cost and uncertainty in the application of treatment technologies and the availability and basis for acceptance for landfill disposal.

Because of the limitations and uncertainties in source removal, the soil contamination management options outlined in this guidance which can be applied, should this be deemed necessary, have focused on *pathway control* and *receptor control* approaches, based on containment and on-site management.

The overarching principles outlined in Section 4.1 lead to four soil contamination management options as follows:

- Option 1 – Reinstate soil to excavation (soil only, not applicable to sediments).
- Option 2 – Place soil at another location on the site with the same or higher contamination risk profile.
- Option 3 – Contain spoil on-site in a location where it will be effectively contained.
- Option 4 – Off-site disposal or on/off-site treatment.

The decision process for selecting a management option outlined in Figure 1 is linked directly to the soil/sediment waste classification categories defined in Section 4.3.

Guidance relating to each option, together with guidance on the management of temporary and long-term stockpiling of soil that will be required, is outlined in the following sections.

4.4.2 Management of temporary stockpiles

The management of temporary or longer-term stockpiles of contaminated soil is likely to be required in the majority, if not all, instances where contaminated soil needs to be excavated. The handling and temporary stockpiling of contaminated spoil should include environmental management measures to prevent the spread of contamination.

In general, the requirements are:

- Stockpiles should be placed within plastic-lined and bunded areas to avoid contamination of the underlying soil and groundwater and uncontrolled runoff to adjacent land and waterways.
- Excavation and handling of contaminated soil during heavy rain or strong wind should be avoided where possible.

- All stockpiles that are likely to remain on-site for more than 24 hours should be covered with plastic or tarpaulins to minimise exposure to rain that could lead to the generation of contaminated water, erosion and windblown dust.
- Regular monitoring of the condition of stockpile coverings, bunding and lining (as practicable) must be undertaken.

Longer-term post-construction contamination management options are described in the following sections.

4.4.3 Option 1 - reinstatement to excavated area (soil only)

In circumstances where the excavation design, nature of the soils and method of construction allows, it may be acceptable to return PFC contaminated soil to the excavated area. This option is not relevant for sediments found in drains as they cannot be replaced in the drain from which they were excavated.

In general:

- Subject to the assumptions below, returning soil to an excavation is likely to be an acceptable approach where the concentrations of PFOS and PFOA are below the interim Fill criteria (Category 1).
- Determining whether this is an acceptable option for Category 2 soil (containing PFC concentrations above the interim Fill criteria but below the maximum criteria for landfill disposal) will depend on the level of risk that the contamination poses. Guidance on assessing the level of risk for Category 2 soil is provided in Section 4.5.
- In considering the applicability of Option 1, the underlying assumptions are that:
  - The area surrounding the excavation contains similar concentrations of PFCs to that of the excavated soil.
  - The excavated soil represents only a small portion of the total likely mass of the contamination in that area. This should be assessed on a case by case basis having regard to the contamination risk.
  - The excavation work is part of construction activities where site remediation or contamination management is not the key objective.
  - Return of the soil to the excavation does not raise the contamination risk profile of that area, taking into consideration change in the land use that may occur on completion of the construction activities.

In implementing this option, a Construction Environmental Management Plan (CEMP) for the works should be prepared which requires:

- Appropriate occupational hygiene controls to minimise exposure of workers to contaminants;
- Excavated soil to be returned to the same depth in the excavation from where it was removed where practicable;
- Surplus soil to be managed in accordance with Section 4.4.2; and
- The area where contamination remains to be recorded in a Site Contamination Register. Information recorded should include the location (including a map), volume of soil reinstated, details of the magnitude and nature of the contamination, and reference to the future management requirements (such as may be detailed in a site management plan).

4.4.4 Option 2 – place at another location on the site with the same or higher contamination risk profile

In cases where the excavation design, nature of the soils/sediments and method of construction allows, it may be acceptable to relocate PFC contaminated soil and sediment to another similarly contaminated area of the same site, providing that the contamination risk profile at the destination area is not increased.

This option is only acceptable for Category 1 and Category 2 soil and sediment (i.e. not acceptable for soil exceeding the interim health screening level for a commercial/industrial land use).

In considering the applicability of Option 2, the underlying assumptions are that:

- The area where the soil will be placed already contains similar concentrations of PFCs to that of the excavated soil, and that the material (once placed) will represent only a minor fraction of the total mass of the contamination already existing in that area. This should be assessed on a case by case basis having regard to the contamination risk.
- The excavation work is part of construction activities where site remediation or contamination management is not the key objective.
- Placement of the soil does not raise the contamination risk profile of the area where it is placed.
- There are no other chemical or physical characteristics of the soil/sediment (e.g. other contaminants or acid sulphate soil potential) that would give rise to an unacceptable risk.

Category 1 fill material

Where the concentrations of PFOS and PFOA in the soil or sediment are below the interim Fill criteria (Category 1) and the area of the site where the material is to be placed has similar or higher concentrations of PFCs, it can be expected that placement of the soil or sediment will pose a low risk.

Category 2 material

Whether it is acceptable to place contaminated soil or sediment containing PFC concentrations above the interim Fill criteria but below the maximum Category 2 soil criteria will depend on the level of risk that the contamination poses. Guidance on assessing the level of risk for Category 2 soil is provided in Section 4.5.

In implementing this option, a Construction Environmental Management Plan (CEMP) for the works should be prepared which requires:

- Appropriate occupational hygiene controls to minimise exposure of workers to contaminants;
- That the soil/sediment be placed and managed according to usual sediment and erosion control practices typical for stockpiled material. Soil and sediment must be placed such that any erosion and sedimentation that may lead to mobilisation of the material away from the designated area is prevented. In many circumstances revegetation may be an appropriate strategy to achieve this.
- The destination area must be recorded in a Site Contamination Register. Information recorded should include the location (including a map), volume of soil placed, details of the magnitude and nature of the contamination, and reference to the future management requirements (such as may be detailed in a site management plan).
- In some cases material for which the leachate concentrations exceed the Category 2 criteria may be treated to reduce leachability by addition of a stabilising agent, which may

reduce leaching of PFCs as measured by ASLP testing. This may result in the soil having an equivalent risk to Category 2 material and may permit a change of classification to Category 2.

4.4.5 Option 3 – on-site containment

Contaminated soil may be able to be managed by on-site containment where return of soil to the location from which it was excavated is not possible, or where the contamination risk of doing so is found to be unacceptable.

In general:

- The containment must be sufficient to prevent the exposure, release or leaching of contamination over the life of the development. It is useful to distinguish two containment strategies, although variations on these are possible:
  - Placement of the soil in another area where the site development works (such as road or runway paving, or a building) will achieve effective containment, preferably where contamination is already present and the relocation of contaminated soil does not lead to contamination of uncontaminated soil; or
  - Placement of the soil in a dedicated engineered containment cell (such as an on-site landfill) designed and sited with a primary intention to prevent the spread of contamination.

  The suitability of either of these approaches will be contingent on a number of site and stakeholder specific factors including the availability of suitable areas and approval requirements (particularly for an engineered containment cell). It is essential that any longer term management responsibilities also be identified and allocated. Consideration should also be given to jurisdictional (e.g. State) regulatory requirements.
- The intent of the containment system must be to prevent the release of PFCs to the environment. As PFCs are mobile, it is important to exclude rainfall from the soil and to prevent it being suspended in stormwater or leaching to groundwater. It may be possible to effectively achieve this by placing the soil in a location where it will be covered by a structure such as concrete paving or a building and the contaminated material is well clear of the groundwater.
- In the case of an engineered containment cell, the design of the cell should be consistent with the requirements for landfills (such as those outlined in the Victorian Best Practice Environmental Management (BPEM) for landfills), and should include a suitable cover and liner (such as a geosynthetic clay liner or hardstand) to prevent ingress of surface water and prevent leaching of contaminants to groundwater.
- The area selected for containment should be well away from drainage courses or areas prone to flooding. Where the facility is within a floodplain, additional engineering and management controls would be required to ensure that the facility will be protected from flooding, erosion by floodwaters or infiltration from a perched water table.
- Where the contaminated material can give rise to concentrations of PFCs that exceed the criteria for leaching that are commonly applied in setting acceptance criteria for landfills (such as those Table 2), or where greater certainty is required regarding avoiding future leaching problems, it may be desirable to add an amendment to the soil to reduce the level of leachability so that it does not exceed such criteria.

It is important to recognise that containment under an engineered structure such as pavement or a building may effectively render it inaccessible in the future and, before adopting this strategy, there should be:

- Consultation with the regulatory agency to confirm that such an approach does not contravene particular regulatory requirements and a risk-based approach can be taken; and
- A high level of certainty that leaching or release of contamination will not occur in the future.

4.4.6 Option 4 - off-site disposal or on-/off- site treatment

There are a number of technologies that may be suitable for treatment and disposal of PFC contaminated soils. Most of these technologies have not been commercially proven and can involve a high level of cost, but may be suitable and economically viable in some circumstances. The application of particular technologies is an ongoing consideration in the industry; this includes treatability studies and trials. Options that are currently being considered to address the issue by industry and regulators in Australia and abroad include:

- *Stabilisation* – treat contaminated soil to satisfy the requirements for containment or landfill acceptance using a product such as matCARE™ or RemBind™ to reduce the potential for leaching of PFCs. Cement can be used in conjunction with these products to prevent erosion and sedimentation of the soil. Test work suggests that stabilisation can prevent leaching over the long term, but it is not clear whether stabilisation will reduce the health risk and potential for ecological impact.
- *Thermal Desorption* – heat is used to increase the volatility of the PFCs such that they can be volatilised from the soil matrix, with the resulting gases treated at very high temperature to break down the PFCs and allow capture of the resulting fluoride in an air pollution control device (such as a scrubber). Thermal desorption of contaminated soil has been demonstrated on a commercial basis in Australia, although the upper limits for PFCs would need to be confirmed.
- *Incineration* - High temperatures (>1,200°C) are used to combust (in the presence of oxygen) the organic constituents in the soil. Internationally this option is recognised as being technically feasible. This method has been successful at sites in Queensland and Tasmania where incineration has been possible in cement kilns.
- *Chemical Oxidation* - This method has proved useful in the oxidation of many organic compounds and it is now being tested (at bench scale) overseas to address PFOS and PFOA. The most effective chemical oxidants trialled to date include “Fenton’s Reagent” (hydrogen peroxide plus an iron catalyst) and activated persulphate (activated by heat, UV, Fenton’s Reagent etc) have been trialled at bench scale with some success, although the large scale application of such compounds may be problematic. The application of such methods is highly dependent on the natural oxidant demand of the soil and the acceptability of the composition of the material after treatment, taking into account the residual PFCs, fluoride, and reagents that have been added.
- *Landfilling* - at a suitable secure landfill. The generally applicable requirements for acceptance of PFC contaminated soils at landfills have yet to be established, although acceptance at particular landfills may be possible on a facility-specific basis. The presence of PFCs in the leachate of Australian landfills and the level of concern relating to PFCs in landfills is in the process of being determined, and may inform this issue.

In summary, at the current time in Australia:

- There are no well-established commercially available treatment technologies for PFC contaminated soil.

- The acceptability of disposing of contaminated soil at established commercial landfills is uncertain and is likely to be state and facility specific.
- Considerable effort is being directed in the industry to determining acceptable options for treatment and disposal of PFC contaminated soil, and it is likely that options that have regulatory acceptance will become available in the next few years.
- If the decision process concludes that off-site disposal or on-/off- site treatment is the only suitable option, it will be necessary to undertake a detailed evaluation of the technologies and disposal options that are indicated may be viable, to determine which are acceptable and identify the preferred option.

4.5 Contamination management decision process and risk assessment

A risk assessment is required in circumstances where management Options 1 or 2 are to be considered for Category 2 soil, or when Option 2 is to be considered for Category 2 sediment.

In these circumstances, there is a potential ecological risk that must be considered and addressed. Category 2 soil contains concentrations of PFCs below the interim health based commercial/industrial levels and therefore can be considered to pose a low risk to human health in the context of an airport use.

A risk based decision framework is outlined in Figure 3. The process is divided into the key limiting contaminant migration pathways: direct contact, surface water and groundwater. The decision process considers the risk of each of these pathways being realised. In some cases the answer to these questions may be clear, while in others it may be necessary to undertake more detailed investigations to reach a conclusion. The risk assessment should also take into consideration site management controls and how these measures may impact the outcome. The response to a “HIGH” or “LOW” risk ranking should be as outlined in Figure 1 (Section 4.1).

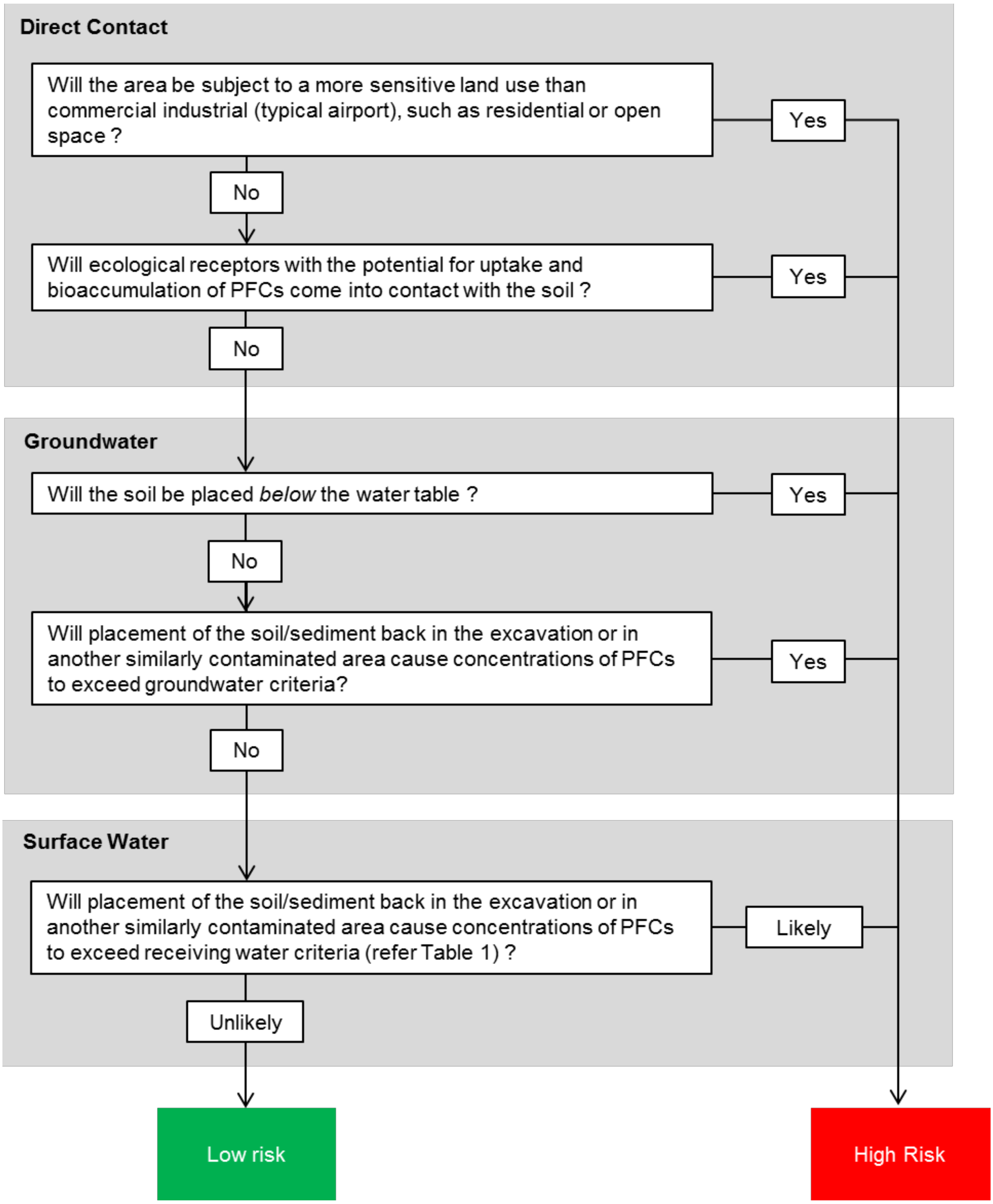


Figure 3 Decision-based risk assessment for re-use of Category 2 soil and sediment

5. PFC impacted water

5.1 Generation of PFC impacted water

Scenario 2 considers construction activities where interception of PFC contaminated groundwater will occur, and disposal of the contaminated groundwater as a waste stream is required. This may include, for example, situations in which excavations or other civil works are undertaken in areas of shallow groundwater, resulting in the need for dewatering. The situations in which PFC contaminated groundwater requires management may comprise either a:

- *Known event*: it is known during the planning or design phase that PFC contaminated groundwater will be encountered and will require management during construction. In this instance, it may be possible at the design stage to review the location and design of the works to determine whether it is possible to *avoid* intercepting groundwater and hence avoid the need to manage PFC contaminated groundwater; or
- *Unexpected encounter*: PFC contaminated groundwater is encountered unexpectedly during construction works and it is required to be removed from the works area. In this instance it can be assumed that management of groundwater will be essential.

Scenario 3 considers situations in which rainwater coming into contact with PFC contaminated infrastructure will result in a waste stream of PFC contaminated water.

Both these scenarios require the management of PFC contaminated water, and hence have been considered together. It is anticipated that in the majority, if not all instances the PFC contaminated water will need to be captured and contained, prior to final management decisions being made. Section 5.4.2 provides a discussion on the general requirements for temporary containment of contaminated water.

5.2 Conceptual site model

For Scenarios 2 and 3, the contamination source requiring management is defined as water that has been contaminated by PFCs, where the main contaminants of concern are PFOS and PFOA, though other PFCs including 6:2FtS and 8:2FtS may also be present.

The key contaminant transport pathways are generally:

- *Direct contact* – persons or animals may be exposed directly to contaminated water. If appropriate health and safety measures are adopted during handling, and environmental management measures are put in place to contain contaminated water, this is unlikely to occur.
- *Surface water discharge* – if contaminated water is discharged to surface water, aquatic ecosystems may be exposed to unacceptable levels of PFCs (refer to Section 2). Bioaccumulation of PFCs in aquatic species may occur. Depending on the level of dilution and the resulting concentrations in the receiving water, humans may be exposed to unacceptable concentrations of PFCs through consumption of fish species, or (less likely) recreational activities such as swimming. If contaminated water first discharges to a stormwater system, the water can be expected to ultimately discharge to a surface water and the issues relating to surface water discharge will apply.
- *Sewer discharge* – if contaminated water is disposed to sewer, most of the PFC contamination will accumulate in the sewage biosolids, with a minor fraction of the PFC contamination passing through to the treated effluent. The PFC concentration in the biosolids may limit the use or disposal of the biosolids, and the PFC contamination of the treated effluent, depending on the point of discharge, may result in issues relating to

discharge to a surface water body or discharge to land. It can be expected that there will be considerable dilution in the sewage, and the PFCs will pose a low risk to sewerage system workers.

- *Vertical percolation to groundwater* – should contaminated water be stored in a location removed from an existing PFC plume, or runoff from the excavation occur, the potential for leaching to underlying aquifers must be considered. Assuming appropriate management practices are followed during extraction, capture and storage, vertical percolation to groundwater may not occur.

The key on-site and off-site receptors to be considered are:

- Persons such as site workers who may come into direct contact with contaminated groundwater, persons who may consume fish or other aquatic species, and persons involved with the sewerage or stormwater systems.
- Ecosystems, including terrestrial ecosystems on-site (through direct contact), aquatic ecosystems of surface water bodies on-/off- site, aquatic ecosystems of stormwater receiving environments, terrestrial ecosystems of sewage biosolids disposal areas.

The primary risks to human health and ecological receptors are outlined in Section 2.

It has been assumed that:

- Groundwater extraction that may occur during construction works will generally be limited in both volume and duration, and as such will not have a significant impact on an existing groundwater PFC plume, and will be unlikely to alter the overall site risk profile. Should projects involve removal of significant volumes of water over long time frames, the implications of this on the hydrogeological regime and remaining contamination should be considered.
- Where PFC contaminated water arises from surface runoff, the water will be captured and contained. The management options discussed below are therefore intended to be applied once the PFC contaminated groundwater and/or surface water has been captured and contained.

5.3 Contaminated water management options

In determining disposal options for PFC contaminated water, the following questions arise:

1. Is the water of suitable quality to discharge directly to surface water, stormwater or sewer *without treatment?*
2. If the water is not of suitable quality for discharge without treatment, *can it be treated on-site*?
3. If the water is not of suitable quality for discharge without treatment and cannot be treated ons-ite, *can it be treated off-site, or retained on-site without treatment?*

From these questions, four management options have been identified:

- Option 1: disposal *without treatment* to surface water, stormwater or sewer.
- Option 2: *on-site treatment*, prior to discharge to surface water, stormwater or sewer.
- Option 3: *on-site containment or off-site treatment*.
- Option 4 – *recharge of water to the aquifer*. This would be subject to:

- Regulatory approval;
- The aquifer having been identified as already being contaminated by PFCs;
- Other chemicals in the water to be recharged not precluding aquifer recharge; and
- Recharge being conducted in a manner that does not impact surface water (e.g. through uncontrolled runoff).

Option 1 is a low cost option and options 2, 3 and 4 will generally have a higher cost.

5.4 Decision process and management options

5.4.1 Decision process

The following sections describe the decision making process for dealing with PFC contaminated water. The overall decision process is illustrated schematically in Figure 4. The detailed considerations relating to each option are discussed in the next sections.

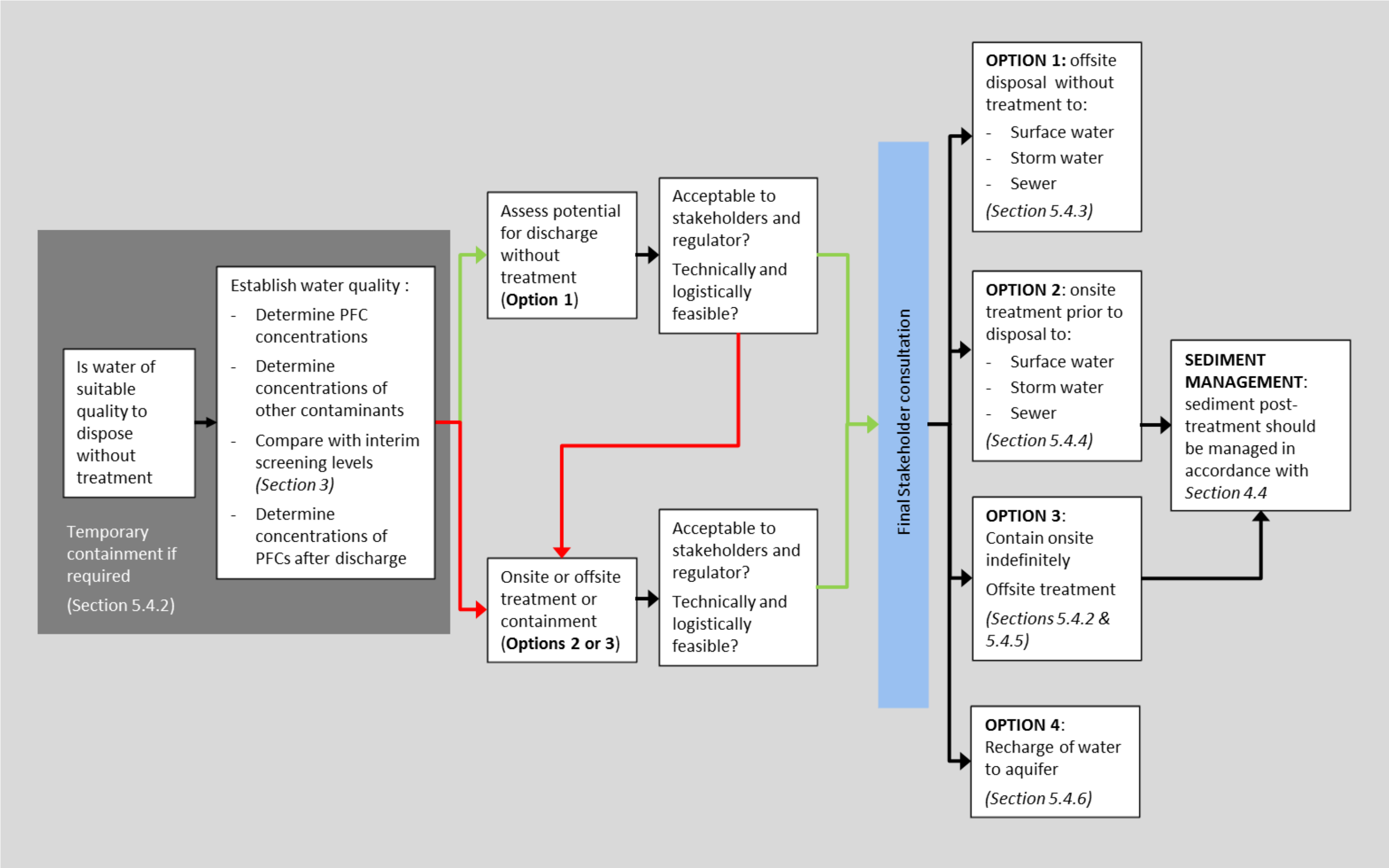


Figure 4 PFC contaminated water management options

5.4.2 Temporary containment of contaminated water

It is likely that the temporary containment of PFC contaminated water will be required in many instances where a waste stream is generated. The handling and temporary containment of contaminated water should include environmental management measures to prevent the spread of contamination (e.g. leaching, runoff, etc.). In general, the requirements are:

- Water must be contained within a tank, or dam or retention basin with an impermeable liner.
- Where water is to be contained for extended periods, the containment vessel must be covered to avoid rain infiltration and potential overflow.
- A capture system should be installed around the storage facility to prevent surface runoff in the event of overflow or failure. This may include bunding around a vessel, or an overflow runoff capture system surrounding a storage dam.
- Appropriate health and safety precautions should be implemented during handling of contaminated water.
- As the management options identified are dependent on the concentrations of PFCs, water samples should be collected and analysed for PFCs (and other contaminants of potential concern) to understand which contaminants are limiting and determine the disposal option that is acceptable.

5.4.3 Option 1 – discharge without treatment

Disposal of PFC contaminated water directly to surface water, stormwater or sewer without treatment will generally have a low cost and is likely to be the preferred option if acceptable. In evaluating whether this option is possible, the following considerations apply:

General considerations

- *Does the site setting and infrastructure make it feasible to discharge the PFC contaminated water to surface water, stormwater or sewer, if this were to be acceptable?*
- *Are PFC concentrations (in the receiving water body, post discharge) below the interim screening levels provided in* Section 3*?* Specific requirements relating to each water system are discussed below.
- *Is the direct disposal of impacted water acceptable to regulators or the sewerage authority (such as through a Trade Waste Agreement (TWA)), and is approval required?* This may vary between jurisdictions, and will be dependent on site-specific situations, and PFC concentrations.
- *Are the concentrations of contaminants other than PFCs (e.g. BOD, metals, hydrocarbons, etc.) acceptable for direct disposal?* It is assumed in the following discussion that PFCs are the limiting contaminants, but this may not be the case in some situations.

Surface water

- *Are PFC concentrations below the surface water ecological and human health interim screening levels?* These levels will generally apply within the water column of the surface water body, after dilution. In some cases such as where the discharge occurs through a shoreline and the shoreline ecosystems need to be protected, then the levels prior to dilution in the water body may apply.

  Assuming the concern is the bulk water, then dilution should be taken into consideration. Note that the levels that apply to waters where bioaccumulation of PFCs in edible fish or crustacea can occur are extremely low, and are unlikely to be satisfied unless there is a very high level of dilution (such as can occur if the discharge is small and is into a large receiving water such as a river, bay or ocean). Consideration should be given as to whether human consumption of fish or crustacea from the surface water body will occur, as these screening levels are the most stringent.

Is there a possible risk to human health via direct contact? In the absence of criteria for PFCs in recreational waters, the interim screening levels for drinking water can be adopted as providing a low risk for this beneficial use (Section 3).

Stormwater

- The considerations listed for surface water are relevant for stormwater. In the case where the PFCs are present in rainfall runoff, the concentrations may be highly diluted in mixing with other stormwater. Estimates of the likely dilution may be able to be determined by comparing catchment areas or stream flows.
- Where sites are harvesting stormwater for re-use, this water must be sampled and analysed for PFCs and compared to the groundwater criteria in Table 1 before re-use can be considered. Regulatory approval should also be sought.

Sewer

- *If the site has a Trade Waste Agreement (TWA) that allows for PFCs, are the PFC concentrations below the specified levels?* It is understood a number of Airservices sites have such TWAs in place (GHD 2014).
- *If there is not an existing TWA that allows for PFCs, will the sewerage authority grant a TWA that allows this?*
- *Can it be expected that the mass of PFCs in the PFC contaminated water proposed to be discharged to the sewer will not give rise to an unacceptable accumulation of PFCs in biosolids or an unacceptable concentration in the treated effluent?* Knowledge of the mass of biosolids generated, the volume of sewage effluent leaving the treatment plant and the mass of PFCs discharged to the sewerage system can provide an indication of whether this poses a low risk or not.

5.4.4 Option 2 – on-site treatment prior to discharge

Option 2 considers on-site containment and treatment to reduce PFC concentrations in the waste stream, and upon achieving reduced concentrations subsequent disposal to surface water, stormwater or sewer. This can be expected to be a higher cost option, both from a financial and logistical perspective.

Advances are being made in the treatment of PFC contaminated water. Technologies that may be viable from a financial, logistical and technical perspective include (from GHD 2014):

- Adsorption (e.g. activated carbon, MyCelx, MatCARE or ash); and
- Nanofiltration and reverse osmosis.

More advanced methods such as thermal phase reduction or photochemical treatment are developmental and are not considered to be commercially viable at the present time.

Depending on the composition of the water (such as whether there is a high load of other contaminants present like hydrocarbons or salts), pretreatment may be necessary and can involve, for example:

- Activated sludge treatment to remove BOD and suspended solids; and

- Filtration to remove suspended solids (e.g. with a variety of media including sand and membranes (microfiltration and ultrafiltration)).

Further information on remediation technologies is provided in GHD (2014). This report found that adsorption methods (activated carbon, ash, matCARE™, MyCelx) and advanced filtration methods (nanofiltration and reverse osmosis) to be worthy of further consideration. These methods involve separation and concentration of PFCs in a residual solid phase (sludge, filter medium such as a cartridge, or adsorbent) that must then be treated and disposed of. It is expected the process outlined in Section 4.4 for management of contaminated soils could be followed for management of residual solid phase.

When determining whether treatment is possible and selecting a suitable treatment method, consideration should be given to the initial concentrations of PFCs and other background organic and metal contaminants, the available time frames, volumes to be managed, and other site specific factors. For small volumes of contaminated groundwater treatment may not be financially viable. In this instance, if Option 1 is not viable, then Option 3 (Section 5.4.5) may provide an alternative.

The ultimate goal of treatment would be to achieve very low concentrations of PFCs that can be discharged to sewer, stormwater or surface waters. The objectives outlined for Option 1 (Section 5.4.3) above then apply.

5.4.5 Option 3 – containment or off-site treatment / disposal

On-site containment of contaminated water was discussed in Section 5.4.2. PFC contaminated water may also be consigned off-site for treatment and ultimate disposal. This may be at a licensed treatment facility. Considerations include:

- This could be a preferred option where volumes are low, irrespective of concentrations.
- The practicability will depend on the location of an appropriately licensed facility, and whether transport of the contaminated water will gain regulatory acceptance (if this is necessary). This would need to be ascertained on a case by case basis, as may vary in each state/territory.
- This option can avoid the environmental risk associated with the discharge of PFC contaminated water to a receiving water.
- The cost may be high and therefore unsuitable for large volumes.

5.4.6 Option 4 – aquifer recharge

Recharge of water to the aquifer. This would be subject to:

- Regulatory approval;
- The aquifer having been identified as being impacted by PFCs;
- Other chemicals in the water to be recharged not precluding aquifer recharge; and
- Recharge being conducted in a manner that does not impact surface water (e.g. through uncontrolled runoff).

6. Groundwater management

6.1 Introduction

The contamination of groundwater at airport sites has the potential to impact not only human health and ecological receptors on-site, but also receptors off-site through the ability of PFCs to migrate with the groundwater. Impact to off-site receptors in particular can lead to the involvement of State-based regulators.

The following guidance suggests management options based on the risks posed by known or potential groundwater contamination. A decision framework for selecting an appropriate contamination management response is also suggested.

The guidance is based on developing a Conceptual Site Model (CSM) that identifies the key contamination pathways and receptors of PFC-contaminated groundwater in the context of an airport setting.

6.2 Conceptual site model

6.2.1 Introduction

To assist in understanding the risks arising from groundwater contamination, a generic CSM has been prepared that describes the nature of the contamination, potential receptors (persons and the environment) and the pathways by which receptors might be affected by the contamination. The risk posed by contamination may be acceptable if the pathway between the source and receptor is not complete, or can be broken by management or remediation.

6.2.2 Contaminants of concern

The main contaminants of concern are PFOS and PFOA. It is recognised that other PFCs such as 6:2 FTS and 8:2FtS may also be present, however, PFOS and PFOA can generally be expected to be the limiting contaminants with regard to groundwater contamination and are the only PFCs where international assessment guidelines are well established.

6.2.3 Contaminant sources

PFCs can enter the groundwater by infiltration of rainwater through soils contaminated by PFCs. Sources of soil contamination are described in Section 2.1.

Where groundwater is impacted by PFCs and is extracted for irrigation, it may be distributed more widely over a site, thereby eventually impacting a wider area of groundwater.

6.2.4 Contaminant transport pathways

The fate and transport of PFCs in groundwater is described in Section 2.4. In summary, contamination leaches from soil to water as water migrates downward through soil to the water table, resulting in contaminated groundwater. The contaminated groundwater migrates with groundwater flow and diffusion and may discharge to surface water where it will be further diluted. Groundwater contaminated with PFCs may be extracted for use such as potable use, irrigation, stock watering, or filling a swimming pool. Where shallow groundwater is present, groundwater may discharge to stormwater drains and then to a stormwater discharge area (such as a surface water body).

6.2.5 Contaminant exposure pathways

The key contaminant exposure pathways for groundwater are:

- Human receptors (on-site and off-site):
  - Direct contact – where persons may be exposed directly to groundwater contamination through extractive use.
  - Indirect contact – where persons may be exposed to surface water impacted by discharging groundwater.
  - Ingestion of organisms impacted by PFCs (aquatic and terrestrial).
- Ecological receptors (on-site and off-site):
  - Natural aquatic ecosystems including water and sediments.
  - Aquaculture.

As outlined in Section 2.4, risks to human health mainly arise through drinking contaminated groundwater or eating organisms affected by contaminated groundwater. In terms of risks to ecological receptors, while contamination can give rise to direct toxic effects on ecosystems, the limiting factor can be the bioaccumulation of contaminants in fish or other species affecting persons or other animals that consume these fish or other species.

The potential linkages between the source, pathways and receptors are shown in Figure 5. Other pathways and receptors as well as pathways and receptors that are subsets of these may also be present.

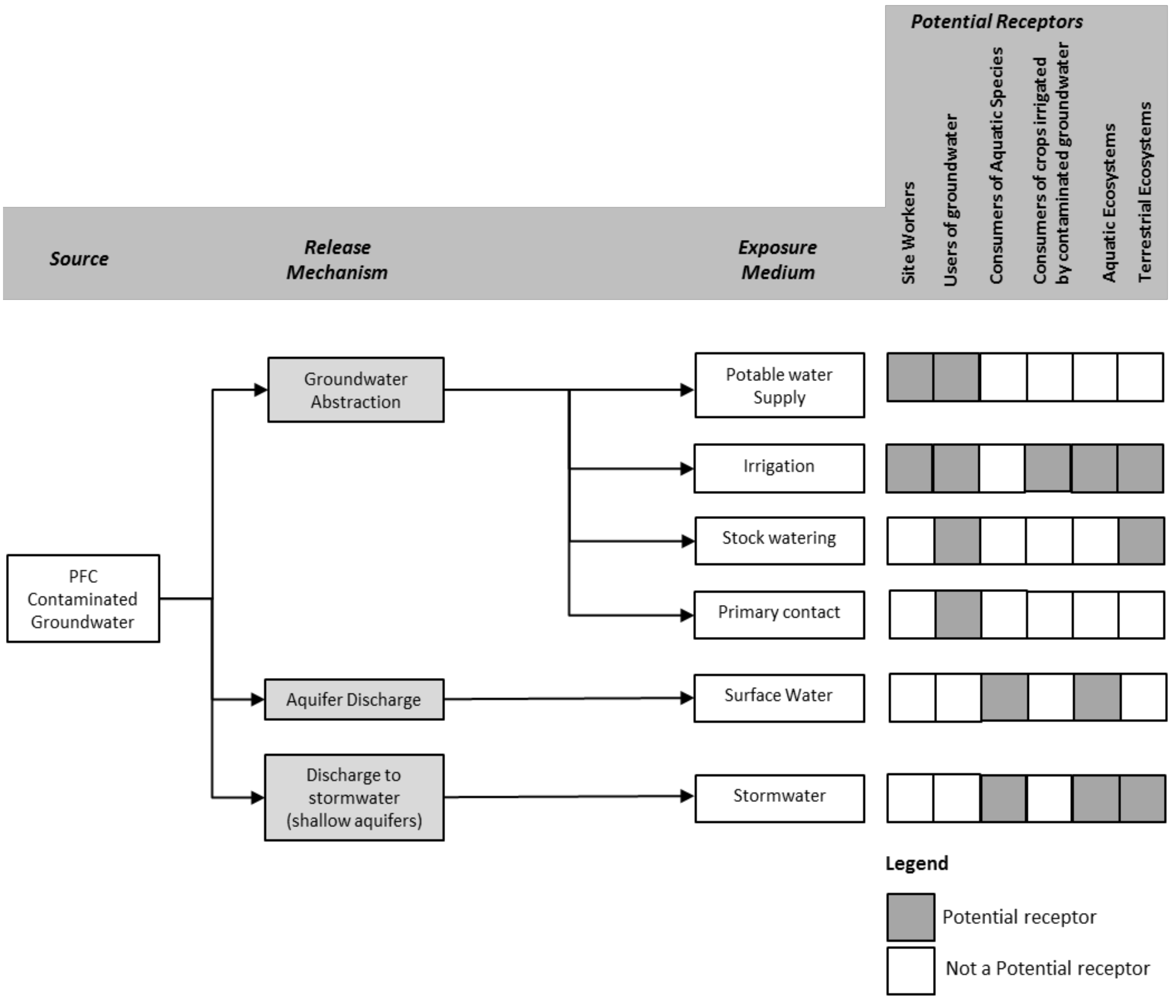


Figure 5 Groundwater conceptual site model

The CSM presented here should be considered as a generalised model, and added to or amended as dictated by the specific characteristics of the site.

In deriving a methodology to guide management of groundwater, a process has been used that first classifies a site based on the risk of contamination being present and having an adverse impact on receptors. This process involves a review of site-specific information and assumptions made in the generic CSM.

The results of the data assessment are used to develop risk profiles based on the following risk dimensions, which are defined in Sections 6.2.6, 6.2.7 and 6.2.8:

- Facility Risk Dimension;
- Setting Risk Dimension; and
- Beneficial Use Risk Dimension.

The decision process is shown in Figure 6.

6.2.6 Facility risk dimension

This dimension considers the probability that AFFF was used on the site based on past practices, site infrastructure and activities. Where AFFF was known to have been used, further risk aspects are then assessed. Where it can be demonstrated that AFFF was not used on a site, no further assessment work would be required and the risk ranking of the site would be designated ‘NIL’.

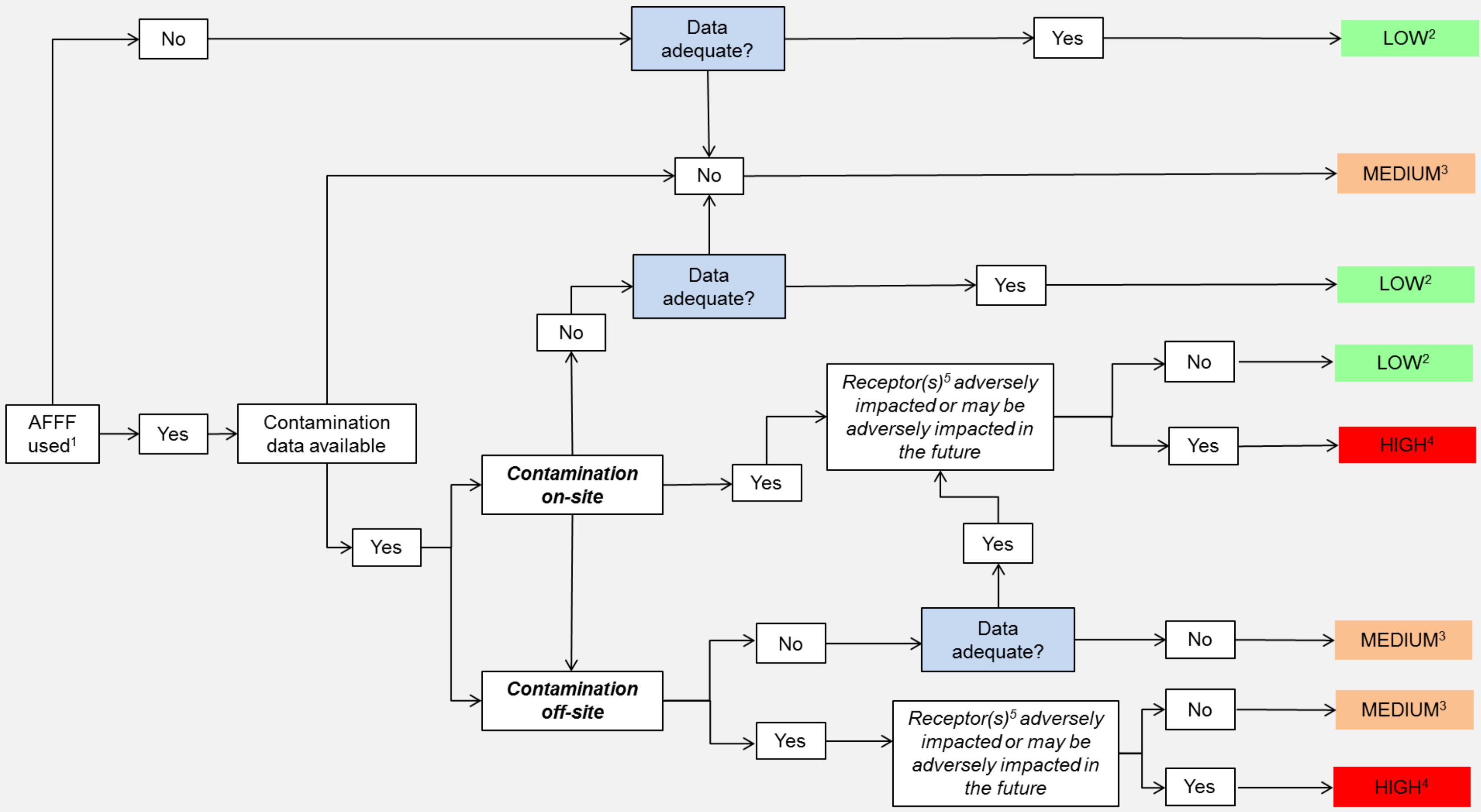
6.2.7 Setting risk dimension

This dimension assesses the geology, hydrogeology, land and groundwater beneficial uses, natural resource value, proximity to sensitive receptors (groundwater bores, surface waterbodies, fisheries, recreational areas), location of RAMSAR areas, use of resources (actual and potential).

For sites where AFFF has been shown to have been used, the environmental setting will determine the likelihood and significance of impact to on-site and off-site receptors. For example, sites with sandy aquifers and nearby receptors would be considered more likely to have contaminants migrate from within their boundaries.

For sites with little or no information, a judgement assessment of risk can be conducted. These sites are likely to be designated ‘MEDIUM’ risk to trigger further investigative work.

Discharge receptors can vary and result in significantly different levels of dilution of the dissolved PFCs. The impact of dissolved PFCs in rivers may be less than that discharging into a small lake or estuary. However, for the purpose of this guidance, all receptors are assumed to be vulnerable until site-specific investigations prove otherwise.



1. Assumes sufficient information exists to confirm AFFF was either used or not used
2. Low – Refer to Section 6.3.3
3. Medium – Refer to Section 6.3.2
4. High – Refer to Section 6.3.1
5. Receptor – includes extractive uses of groundwater, aquatic ecosystems, or other receptors as defined by regulatory bodies

Figure 6 Groundwater management decision process

6.2.8 Beneficial use risk dimension

This dimension assesses existing groundwater contamination data to quantify (or semi-quantify) the impact from PFCs in relation to on and off-site beneficial uses. Beneficial uses would be determined by local (State) or Federal legislation.

Where no data is available and a site has been shown to have used AFFF, the site would be designated ‘MEDIUM’ risk and further assessment work would be recommended.

The presence of PFCs in groundwater at concentrations in excess of investigation criteria that preclude groundwater beneficial uses would result in a site risk designation of ‘HIGH’. However, consideration of beneficial uses must include an assessment of the likelihood of such uses being realised in the foreseeable future. For example, there may be a risk to agricultural use of groundwater but there may be no extraction for agricultural purposes in the vicinity of the sites. In such a case however, this use may be realised in the future.

Where impact to off-site groundwater is confirmed, the site would also be designated ‘HIGH’ risk as there would be no control over the consequences of such contamination.

6.3 Groundwater management regimes by risk level

Once the risk ranking has been determined for a site, an appropriate management program can be established. This section provides guidance on the level and type of management recommended based on a high, medium and low risk site. Generally management involves ensuring an adequate monitoring well network is in place to confirm the level of risk, and once the monitoring network has been established and results obtained, a decision can then be made on the frequency of monitoring. This should be made in consultation with an experienced hydrogeologist and should also consider stakeholder inputs.

A flow chart showing the required management for high, medium and low risk sites is provided in Figure 7.

6.3.1 High risk sites

High risk sites are defined as those where:

- Actual impact to groundwater has occurred on-site in excess of adopted investigation criteria (as shown in Section 3) and beneficial uses of groundwater are adversely impacted.
- On-site receptor controlled by a third party (e.g. water authority) is impacted.
- On-site groundwater has been impacted and beneficial uses are precluded.
- Off-site impact identified and beneficial uses precluded.

Where off-site migration of contamination has occurred, or where an on-site receptor owned by a third party is impacted, external stakeholders such as State environmental agencies (EPAs) and local users of groundwater can influence management measures giving less control over the process.

RISK LEVEL	ON-SITE / OFF-SITE	WELL NETWORK	ANALYTICAL DETAILS	TRIGGER	CONTINGENCY
HIGH	ON-SITE	• Sources • Boundaries • Along plume length • Sufficient to assess flow direction and gradient and plume stability	• PFOS, PFOA • 6:2 FtS • 8:2 FtS • TOC • TDS, pH	Actual harm identified →	Implement remedial action
				Impacted on-site receptor controlled by a third party →	Implement remedial action
				Beneficial uses precluded →	Assess need for further GMEs. Re-assess risk and need for remedial action
	OFF-SITE	• Along plume length • At receptor(s) where possible	• PFOS, PFOA • 6:2 FtS • 8:2 FtS • TOC • TDS, pH	Impact at receptor wells →	Implement remedial action
				EPA notice →	Comply with notice
				Complaints →	Re-assess risk rating
MEDIUM	ON-SITE	• Sources • Boundaries • Sufficient to assess flow direction and gradient	• PFOS, PFOA • 6:2 FtS • 8:2 FtS • TOC • TDS, pH	Plume increasing (not stable) →	Re-assess risk rating
	OFF-SITE	• Assess presence of PFCs off-site if present in boundary wells on site	• PFOS, PFOA • 6:2 FtS • 8:2 FtS • TOC • TDS, pH	PFCs present →	Re-assess risk rating
LOW	ON-SITE	• Potential sources • Sufficient to assess flow direction and gradient	• PFOS, PFOA • 6:2 FtS • 8:2 FtS • TOC • TDS, pH	Impact identified →	Install additional wells to delineate plume and at site boundaries. Re-assess risk rating

Figure 7 Recommended groundwater management regimes by risk level

In summary:

- ***Groundwater well network*** – the groundwater well network should as a minimum include wells to assess groundwater concentrations, located to target each source area(s), sentinel wells at the site boundary(ies) downgradient of the source(s), adjacent to receptors on-site and off-site and along the plume length on-site and off-site. The network should be sufficient to assess the groundwater flow direction, hydraulic gradient and plume stability. Advice from an experienced contaminant hydrogeologist should be sought to advise on design of the network including location, depth and screened interval of the wells.
- ***Sampling methodology*** – bailing or low flow sampling would be appropriate depending on the aquifer properties and other contaminants of concern. The use of Teflon in sampling tubes or bailers should be avoided[4]. Consideration should be given to minimising the sediment load and suspended solids in the samples to avoid the potential for total concentrations of PFCs to be overstated. A consistent approach should be employed for every sampling event.
- ***Analyte suite*** - PFOS, PFOA, 6:2FtS, 8:2FtS, total organic carbon (TOC), total dissolved solids (TDS) and pH.

6.3.2 Medium risk sites

Medium risk sites are generally those where either no or incomplete contamination data exists, or where impacts have been observed but were not exceeding guidelines (as provided in Section 3) and not impacting off-site receptors.

In summary:

- ***Groundwater well network*** – the groundwater well network should as a minimum include wells assessing each source area(s), sentinel wells at the site boundary(ies) downgradient of the source(s), adjacent to receptors on-site and along the plume length. The network should be sufficient to assess groundwater flow direction, hydraulic gradient and plume stability. Advice from an experienced contaminant hydrogeologist should be sought.
- ***Sampling methodology*** – bailing or low flow sampling would be appropriate depending on the aquifer properties and other contaminants of concern. The use of Teflon in sampling tubes or bailers should be avoided. Consideration should be given to minimising the sediment load and suspended solids in the samples to avoid the potential for total concentrations of PFCs to be overstated. A consistent approach should be employed for every sampling event.
- ***Analyte suite*** - PFOS, PFOA, 6:2FtS, 8:2FtS, TOC, TDS, pH.

6.3.3 Low risk sites

Low risk sites are those that present no unacceptable risk to on-site or off-site receptors, either through the absence of a contaminant source (i.e. sites where AFFF has not be used), or where this has been demonstrated by adequate site-specific contamination data.

In summary:

- ***Groundwater well network*** – where no PFC source is present, no PFC-specific groundwater network is required. If a potential contaminant source is identified (i.e. AFFF

[4] ALS Sample Collection Pocket Guide, http://www.alsglobal.com/en/Our-Services/Life-Sciences/Environmental/News/New-Sample-Collection-Pocket-Guide-Environmental-Australia

has been used at or near the site) the groundwater well network should include wells assessing each potential source area(s) and others as necessary to determine the groundwater flow direction and hydraulic gradient. Advice from an experienced contaminant hydrogeologist should be sought.

- ***Sampling methodology*** – bailing or low flow sampling would be appropriate depending on the aquifer properties and other contaminants of concern. The use of Teflon in sampling tubes or bailers should be avoided. Consideration should be given to minimising the sediment load and suspended solids in the samples to avoid the potential for total concentrations of PFCs to be overstated. A consistent approach should be employed for every sampling event.
- ***Analyte suite*** **-** PFOS, PFOA, 6:2FtS, 8:2FtS, TOC, TDS, pH.

6.3.4 Triggers and contingencies

The groundwater management flowchart (Figure 7) also indicates observations that would trigger additional work at the site and possible contingency actions to avoid or mitigate risks. Effective implementation of appropriate contingency actions or controls can lead to a reduction of the risk profile of the site.

7. Managing PFC contaminated sites

Scenario 6 considers the management of publically accessible, non-operational areas that are impacted with PFCs, such as a decommissioned fuel depot. This may constitute areas of soil, groundwater and/or surface water that contain concentrations of PFCs above the interim screening levels provided in Section 3.

7.1 Management of contaminated sites in Australia

The management process for contaminated sites applies irrespective of whether the site is publicly accessible or not, and consideration of the potential for exposure of the public will be an important consideration in defining the site specific conceptual site model.

The process for management of PFC contaminated sites should follow that outlined in the NEPM, which is recognised as the primary national guidance document for the assessment of site contamination in Australia (NEPM 1999, as amended 2013, Explanatory Statement).

The NEPM includes two Schedules:

- Schedule A provides a general process for the assessment of site contamination.
- Schedule B comprises 10 technical guidelines about site assessment criteria, site investigations, laboratory analyses, human health and ecological risk assessment, groundwater assessment, community consultation, consultants and auditors, and health and safety.

Schedule A is of particular importance when making decisions as to the appropriate investigation management of PFC contaminated sites. It is important this work is conducted by persons with a thorough understanding of contaminated site assessment and management, particularly with respect to PFCs. Schedule A is provided in Figure 8, with each of the key steps discussed in the following sections.

7.2 Understanding the problem – investigation and laboratory analysis

The first step towards developing a management strategy for a PFC contaminated site is understanding the extent and magnitude of contamination. Soil, groundwater or surface water sampling (as appropriate) and laboratory analysis is essential in delineating the extent and magnitude of the problem and hence associated risks.

Schedules B2 and B3 of the NEPM provide detailed information on the design and implementation of a sampling and analysis plan and laboratory analysis.

7.3 Developing the conceptual site model

Schedule B2 of the NEPM provides information on the development of CSMs. Development of a site-specific CSM is an iterative process, with the complexity of the CSM corresponding to the scale and complexity of the known or potential impacts. As more information is gathered about a site and the contamination, the CSM can be further refined to allow remediation and management actions to be defined that are commensurate with the scale of the problem. Defining the CSM allows the most cost effective management approach to be determined, and minimises the chance of undertaking more or less work than required.

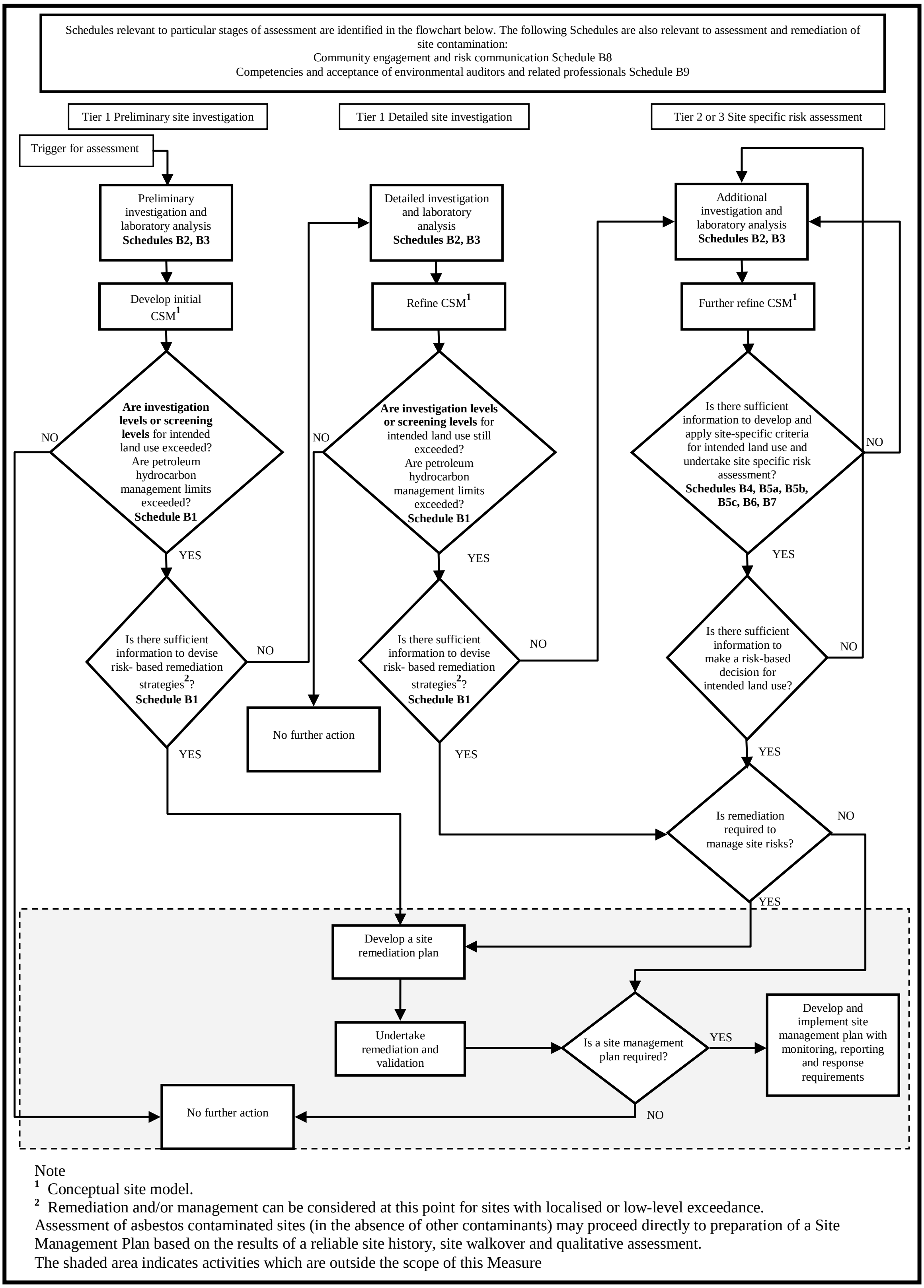


Figure 8 NEPM Schedule A – recommended general process for assessment of site contamination

The essential elements of a CSM are outlined in Section 4.3 of Schedule B2 of the NEPM. Briefly these include:

- Known and potential sources of contamination and contaminants of concern, including the mechanism of contamination (e.g. surface spill 'top down' which is most commonly the case for PFC contaminated sites, or a subsurface release such as from a corroded pipe).
- The media contaminated (e.g. soil, groundwater, surface water, sediments, air).
- Potential human and ecological receptors, such as site workers or the general public, users of groundwater at or removed from the site, and terrestrial and surface water ecological receptors.
- Potential exposure pathways; how humans or ecological receptors may become exposed to PFCs (e.g. direct contact through handling contaminated soil, ingestion of contaminated soil/dust, surface water runoff or contaminated groundwater discharge to surface water bodies, etc.). Once potential exposure pathways have been identified it needs to be determined whether the pathways are complete; if a pathway is incomplete the risk to receptors may be low despite the presence of contamination.

In developing and refining the CSM it is important to ensure that:

- the available data is representative (i.e. provides an accurate picture of the contamination, without biasing high or low);
- variability and uncertainty is identified (the extent and magnitude of contamination defined); and
- any identified data gaps are assessed for importance when determining management strategies for the site.

7.4 Interim screening levels

One of the early, key steps provided in Schedule A is determining whether a site is contaminated by comparing concentrations of the contaminant against criteria for the current and/or intended land use. The NEPM 2013 does not currently provide investigation levels for PFCs, and for the purposes of this Framework the interim screening levels in Section 3 should be applied. As highlighted in Section 3, such guidance may be available in the next few years, as CRC CARE has commenced the development of guidance relating to screening, remediation and management PFOS and PFOA, in conjunction with Australian regulatory agencies and industry (CRC CARE 2014b).

The interim screening levels should be regarded as concentrations of PFCs above which further investigation and evaluation is required, providing the basis of a Tier 1 risk assessment, in which the risk to potential receptors can be evaluated.

As in the NEPM, the interim screening levels are not clean-up goals or response levels. The intent is to trigger *a risk-based approach to management* if exceeded, rather than be default remediation criteria; which in many cases would be an overly conservative response. For example, elevated concentrations of PFCs in soil may be identified; however, if the Tier 1 risk assessment identifies a low risk to potential receptors it may be acceptable to retain the contamination on-site and implement ongoing management measures.

7.5 Developing remediation and management strategies

Contamination management and remediation strategies are outside the scope of the NEPM, though a generic framework is provided in Schedule A (refer Figure 8) which outlines the typical process for determining whether remediation is required, and the steps undertaken to complete remediation. Strategies for managing soil, sediment and groundwater PFC contamination are outlined in Sections 4, 5 and 6 of this report.

8. Case studies

This section outlines four hypothetical case studies in which AFFF contaminated soil, water and sediment requires management. In each case study the contamination management decision processes outlined throughout this framework are followed, with reference to the relevant sections of the framework. It is important when considering these case examples that the relevant sections of the framework are also referred to, as they contain further details that inform and are imperative to the decision making process.

8.1 Case 1: removal of underground storage tank

8.1.1 Issue

- An underground storage tank (UST) at a fuel farm requires removal and is situated in the vicinity of a former AFFF tank.
- The soil in the vicinity of the UST is moderately contaminated with PFCs.
- Groundwater is contaminated.
- How do we deal with the soil?

8.1.2 Decision process for soil

- Assess interim soil PFC waste classification based on Table 2 (Section 4.3.1).
- Consider which management option is logistically possible based on Figure 1 (Section 4.1).

Soil waste classification

Sample	PFOS (mg/kg)	PFHxS[1] (mg/kg)	Soil Category
Shallow	12	1	Category 2 (< Industrial use HISL of 90 mg/kg, refer Table 1)
Deep	0.06	0.06	Category 1 (< Sensitive use HISL of 6 mg/kg, refer Table 1)
Note 1. Perfluorohexanesulfonic acid			

8.1.3 Management option

Option	Option possible?
Option 1: reinstate to excavation	Yes – based on Category 1 and 2 classification
Option 2: place at another location on the site with the same or higher contamination profile	Yes – based on Category 1 and 2 classification, but subject to risk assessment (Figure 3). See Section 8.1.4
Option 3: contain on-site in an engineered repository	Yes
Option 4: off-site disposal or on/off-site treatment	Yes

Further input to decision process is groundwater contamination in the area.

Groundwater

PFOS (µg/L)	PFOA (µg/L)	PFHxS[1] (µg/L)	ISLs exceeded (Section 3, Table 1)
600	165	2,240	Drinking water (0.2 µg/L) Ecological (aquatic) (6.66 µg/L) Human consumption of fish (0.65 ng/L)
Note 1. Perfluorohexanesulfonic acid			

8.1.4 Determine the risks arising from the contamination (Section 4.5, Figure 3)

Risk consideration	Yes / No	Comments
Land use: will the area (where contamination will be placed) be subject to a more sensitive land use?	No	Acceptable risk
Ecological receptors: will ecological receptors with the potential for uptake and bioaccumulation of PFCs come into contact with the soil	No	Assumes material will be placed below surface. Acceptable risk
Groundwater: Will the soil be placed below the water table?	No	Acceptable risk
Groundwater: will placement of the soil back into the excavation or another area cause concentrations of PFCs to exceed the groundwater criteria (refer Table 1)?	No	Will not make situation worse in vicinity of UST, but there is less certainty as to what the situation will be in another location; caution should be exercised. Acceptable risk
Surface water: will placement of the soil back into the excavation or another area cause concentrations of PFCs to exceed receiving water criteria (refer Table 1)?	Unlikely	Acceptable risk

8.1.5 Conclusions

- Options 1 and 2 have low risk; however, the acceptability of these options is dependent on stakeholders.
- If Option 2 is proposed, it will be necessary to confirm the risk to groundwater if the material is placed at another location.
- Option 3 and 4 have low risk and are also possible; if stakeholders do not allow Options 1 or 2 then these should be considered.

8.1.6 Reality check

- Selection of any of Options 1 through 4 will result in a low risk to human health, low risk to surface water, and a low risk to groundwater in the same location and elsewhere if similar concentrations present.
- If Options 1 or 2 are selected, contamination will have to be managed in the future and the impacted site must be recorded on the contaminated site register.

8.2 Case 2: fire station upgrade

8.2.1 Issue

- A fire station truck apron is to be lowered, generating approximately 700 m^3 PFC contaminated fill/soil to manage.
- A possible solution would be to place the fill/soil at an old Fire Training Ground. The Fire Training Ground is close to the site boundary and groundwater contamination is likely to have moved off-site.
- No groundwater data.

8.2.2 Decision process for soil

- Assess interim soil PFC waste classification based on Table 2 (Section 4.3.1).
- Consider which management option is logistically possible based on Figure 1 (Section 4.1).

Soil waste classification

Sample	PFOS (mg/kg)	PFOA (mg/kg)	Soil Category
Fire station	0.024	0.006	Category 1 (PFOS and PFOA)
Fire training ground	2.24 (ASLP 250 µg/L)	0.06 (ASLP 5.26 µg/L)	Category 3 (PFOS, based on ASLP) Category 2 (PFOA, based on ASLP)

8.2.3 Management option (Section 4.5, Figure 3)

Option	Option possible?
Option 1: reinstate to excavation	No (not logistically possible from engineering perspective)
Option 2: place at another location on the site with the same or higher contamination profile	Yes (subject to risk assessment)
Option 3: contain on-site in an engineered repository	Yes
Option 4: off-site disposal or on/off-site treatment	Yes

8.2.4 Determine the risks arising from the contamination (Section 4.5, Figure 3)

Risk consideration	Yes / No	Comments
Land use: will the area (where contamination will be placed) be subject to a more sensitive land use?	No	Acceptable risk
Ecological receptors: will ecological receptors with the potential for uptake and bioaccumulation of PFCs come into contact with the soil	No	No on-site receptors. Acceptable risk
Groundwater: Will the soil be placed below the water table?	Not known	Preferable for soil to be placed above the water table. Acceptable risk
Groundwater: will placement of the soil back into the excavation or another area cause concentrations of PFCs to exceed the groundwater criteria (refer Table 1)?	No	Contaminated soil is Category 1, containing lower concentrations than the Fire Training Ground. It would pose a low risk and be unlikely to increase groundwater contamination at the Fire Training Ground. Acceptable risk
Surface water: will placement of the soil back into the excavation or another area cause concentrations of PFCs to exceed receiving water criteria (refer Table 1)?	Unlikely	Contaminated soil is Category 1 and poses a low risk. Acceptable risk

8.2.5 Conclusion

- Option 1 is not logistically possible as the area needs to be lowered, not filled.
- Options 2, 3 and 4 are possible:
  - Option 2, disposal at the Fire Training Ground is low risk, but management of the area may be required in the future and the impacted site must be recorded on the contaminated site register;
  - Option 3, on-site repository is subject to stakeholder acceptance; and
  - Option 4, off-site disposal may be cost prohibitive or not accepted at waste disposal facility.

8.2.6 Reality check

- The soil excavated from the fire station poses a low risk, and could be relocated to old Fire Training Ground, which is already contaminated with higher concentrations of PFCs.
- Future management of the Fire Training Ground is likely to be required, and placement of lightly contaminated soil in the area (i.e. Category 1 material) would need to avoid increasing the amount of soil requiring future management.

8.3 Case 3: minor infrastructure works

8.3.1 Issue

- A separator, tanks and pipeline are to be installed at a waste water treatment plant. Treated water is to go to an off-site municipal wastewater treatment plant.
- A minor quantity of PFC contaminated soil is to be excavated (50 m^3) and requires disposal.
- Works may involve the collection of PFC contaminated groundwater, which will require disposal.
- The site is potentially going to be redeveloped in the future and the development may include sensitive residential land use.

8.3.2 Decision process for soil

- Assess interim soil PFC waste classification based on Table 2 (Section 4.3.1).
- Consider which management option is logistically possible based on Figure 1 (Section 4.1).

Soil waste classification

Sample	PFOS (mg/kg)	PFOA (mg/kg)	Soil Category
Soil	3.1	0.1	Category 2 (< industrial use HSIL of 90 mg/kg PFOS)
Sediment	0.2	0.01	Category 1 (< sensitive use ESIL of 6 mg/kg PFOS)

Other considerations:

Groundwater

PFOS (µg/L)	PFOA(µg/L)	ISLs exceeded (Section 3, Table 1)
25.1	1.49	Drinking water (0.2 µg/L) Ecological (6.66 µg/L) Human consumption of fish (0.65 ng/L)

Surface water off bitumen

PFOS (µg/L)	PFOA (µg/L)	ISLs exceeded (Section 3, Table 1)
4.3	7.8	Drinking water (0.2 µg/L) Human consumption of fish (0.65 ng/L)

Surface water off pad

PFOS (µg/L)	PFOA (µg/L)	ISLs exceeded (Section 3, Table 1)
10.5	6.4	Drinking water (0.2 µg/L) Ecological (6.66 µg/L) Human consumption of fish (0.65 ng/L)

8.3.1 Management option (Section 4.5, Figure 3)

Option	Option possible?
Option 1: reinstate to excavation	No (not logistically possible)
Option 2: place at another location on the site with the same or higher contamination profile.	Yes, if development will not occur for many years. In this instance review and management would be required prior to any future development. No, if development to sensitive use is in immediate future.
Option 3: contain on-site in an engineered repository	Potentially
Option 4: off-site disposal or on/off-site treatment	Yes

8.3.2 Determine the risks arising from the contamination (Section 4.5, Figure 3)

Risk consideration	Yes / No	Comments
Land use: will the area (where contamination will be placed) be subject to a more sensitive land use?	Yes	Future residential use. Acceptable risk if on-site disposal will not preclude future use potential.
Ecological receptors: will ecological receptors with the potential for uptake and bioaccumulation of PFCs come into contact with the soil	No	No (not currently on-site). Acceptable risk.
Groundwater: Will the soil be placed below the water table?	Not known	Depth to groundwater not known. Unknown risk
Groundwater: will placement of the soil back into the excavation or another area cause concentrations of PFCs to exceed the groundwater ISLs (refer Table 1)?	Yes	Potentially; depends on the location and level of contamination. Concentrations in groundwater at excavation location already exceed ISLs. Acceptable risk if placed back in excavation. Unknown risk if placed in another location.
Surface water: will placement of the soil back into the excavation or another area cause concentrations of PFCs to exceed receiving water ISLs (refer Table 1)?	Unlikely	Assumes material will be placed below the surface, or contained to prevent leaching. Acceptable risk

8.3.3 Conclusions

- Option 1: not logistically possible.
- Option 2: not viable due to the risk posed to groundwater and future development.
- Options 3 and 4 are possible:
  - Option 3: on-site temporary storage/repository is low risk, but depends on stakeholder acceptance. Longer term management of contaminated material would be required.
  - Option 4: off-site disposal is low risk subject to acceptance by waste disposal facility.

8.3.4 Reality check

- The contaminated soil presents a low risk to human health for airport use; however, because of relatively short-term future development and risk of groundwater contamination placement of material elsewhere on the site is not viable.
- Temporary storage/containment on-site or off-site disposal are low risk.

8.3.5 Decision process for groundwater management

- Which options are possible for disposal of groundwater (Section 5.3)?

Option	Option possible?
Option 1: disposal without treatment to surface water, stormwater or sewer	No - surface water and stormwater. Possible – sewer (subject to any licence agreements or regulatory requirements)
Option 2: on-site treatment, prior to discharge to surface water, stormwater or sewer	Yes
Option 3: on-site containment or off-site treatment	Yes

Decision process for managing contaminated water (Section 5.4, Figure 4)

Aspect	Yes / No	Outcome
Do PFC concentrations exceed ISLs (Section 2, Table 1)?	Yes	Direct discharge is not acceptable
Is discharge without treatment logistically/technically feasible?	Not applicable	PFC concentrations preclude this option.
On-site or off-site treatment or containment acceptable to stakeholders?	Yes	Acceptable option.
On-site or off-site treatment or containment logically feasible	Yes	Acceptable option.

8.3.6 Conclusion

- Option 1: direct discharge without treatment is not acceptable.
- Option 2: potentially acceptable, but it would be necessary to check the likely concentrations of PFOS in off-site WWPT effluent and biosolids. As the quantity of groundwater requiring disposal is small, it is likely these concentrations would be very low, which lends support to this management option.
- Option 3: potentially acceptable, but not required if Option 2 is acceptable.

8.3.7 Reality check

- PFOS concentrations in water for disposal might be in the order of 10 µg/L. Assuming 90% of PFOS is retained in municipal WWTP biosolids and a 50:1 dilution of municipal effluent in marine receiving water, this requires the volume of effluent from the municipal WWTP to be at least 40 fold greater than the volume of effluent leaving the site, in order to comply with 0.65 ng/L receiving water (HISL for human health consumption of fish, refer Section 3, Table 1). Based on an example for a treatment plant that serves 72 000 persons, with a flowrate of 19 ML/day and dry biosolids 1500 kg/day, the criteria for receiving water and biosolids are easily achieved.

8.4 Case 4: redevelopment of aircraft hangar

8.4.1 Issue

- An aircraft hangar site is to be redeveloped for use as dog kennels, administrative buildings and a garage.
- A small amount of PFC contaminated soil is to be disposed of.
- The site is currently not used, and is open to the general public as a recreational area. There is an adjacent playground and man-made lagoon.

8.4.2 Decision process for soil

- Determine interim soil PFC waste classification (Section 4.3.1, Table 2)
- Consider which management option is possible (Section 4.1, Figure 1)

Sample	PFOS (mg/kg)	PFOA (mg/kg)	Soil Category
Soil	4.21	0.041	Category 2 (less than PFOS residential use HISL 6 mg/kg) Less than EISL Commercial/industrial (4.71 mg/kg)
Sediment	1.5 (ASLP 2.61 µg/L)	0.01 (ASLP 0.08 µg/L)	Category 2 (based on ASLP)

Other considerations:

Groundwater

PFOS µg/L	PFOA µg/L	ISLs exceeded (Section 3, Table 1)
2460	60	Drinking water level (0.2 µg/L PFOS) Ecological level (6.66 µg/L PFOS) Human consumption of fish (0.65 ng/L PFOS)

Surface water lagoon

PFOS µg/L	PFOA µg/L	ISLs exceeded (Section 3, Table 1)
3.08	0.1	Drinking water level (0.2 µg/L PFOS) Ecological level (6.66 µg/L PFOS) Human consumption of fish (0.65 ng/L PFOS)

8.4.3 Management option (Section 4.5, Figure 3)

Option	Option possible?
Option 1: reinstate to excavation	No (not logistically possible)
Option 2: place at another location on the site with the same or higher contamination profile	Possible (depends on risk level)
Option 3: contain on-site in an engineered repository	Yes
Option 4: off-site disposal or on/off-site treatment	Yes

8.4.4 Determine the risks arising from the contamination (Section 4.5, Figure 3)

Risk consideration	Yes / No	Comments
Land use: will the area (where contamination will be placed) be subject to a more sensitive land use?	Yes	Acceptable risk if material inaccessible to humans or dogs (e.g. under buildings/hard stand area). Unacceptable risk if material left uncovered and accessible.
Ecological receptors: will ecological receptors with the potential for uptake and bioaccumulation of PFCs come into contact with the soil	Yes (current land use) No (proposed dog kennels and administration building)	Unacceptable risk for current land use (recreation). Acceptable risk for proposed land use, given ecological receptors unlikely to be present in dog kennels/administration buildings.

Risk consideration	Yes / No	Comments
Groundwater: Will the soil be placed below the water table?	Not known	Above the water table is preferable. Acceptable risk if soil placed above the water table.
Groundwater: will placement of the soil back into the excavation or another area cause concentrations of PFCs to exceed the groundwater criteria (refer Table 1)?	Yes	Groundwater is already contaminated with PFCs. Acceptable risk if material placed back into the excavation. Potentially unacceptable risk if material relocated, if in vicinity of uncontaminated groundwater.
Surface water: will placement of the soil back into the excavation or another area cause concentrations of PFCs to exceed receiving water criteria (refer Table 1)?	Unlikely	Lagoon is already contaminated. If PFC material is covered with hardstand material (e.g. under building) this would minimise runoff to surface water. Acceptable risk if material covered.

8.4.5 Conclusion

- Option 1: reinstatement to excavation is not logistically possible.
- Option 2: possible, if (a) material is covered to prevent access by dogs (assuming future land use as kennels) and to prevent surface run off to lagoon if placed in the development area, or (b) another suitable (already contaminated) location can be found on the airport site and the risk of Option 2 is found to be acceptable at that location (refer Figure 3).
- Option 3 and Option 4 are possible:
  - Option 3: on-site temporary storage or repository is low risk, but subject to stakeholder acceptance.
  - Option 4: off-site disposal is low risk.

8.4.6 Reality check

- The PFC contaminated soil poses a low risk to human health.
- Risk to dogs would need to be assessed through a site-specific risk assessment; it is not appropriate to apply the HISLs or EISLs to dogs given the different exposure assumptions and toxicity criteria for dogs compared with humans or ecosytems. Risk could be reduced to an acceptable level by preventing dogs coming into contact with contaminated soil (i.e. removing exposure pathway), such as through placing soil under a building/hard stand, or other suitable capping layer.
- PFC concentrations exceed ecological ISLs for current land use (recreation), however are below EISLs for proposed landuse (commercial/industrial). Material could be placed elsewhere on the site if it were covered (e.g. with hardstand material, or capping layer) to prevent dogs being exposed to PFCs, and to prevent surface runoff to lagoon.
- Soil must be placed in location with the same or greater groundwater contamination as origin, to avoid further impacting groundwater. Risk unacceptable if material placed in area of lesser groundwater contamination due to high leachability of PFCs.

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GHD

180 Lonsdale Street
Melbourne, Victoria 3000
T: (03) 8687 8000 F: (03) 8687 8111 E: melmail@ghd.com.au

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