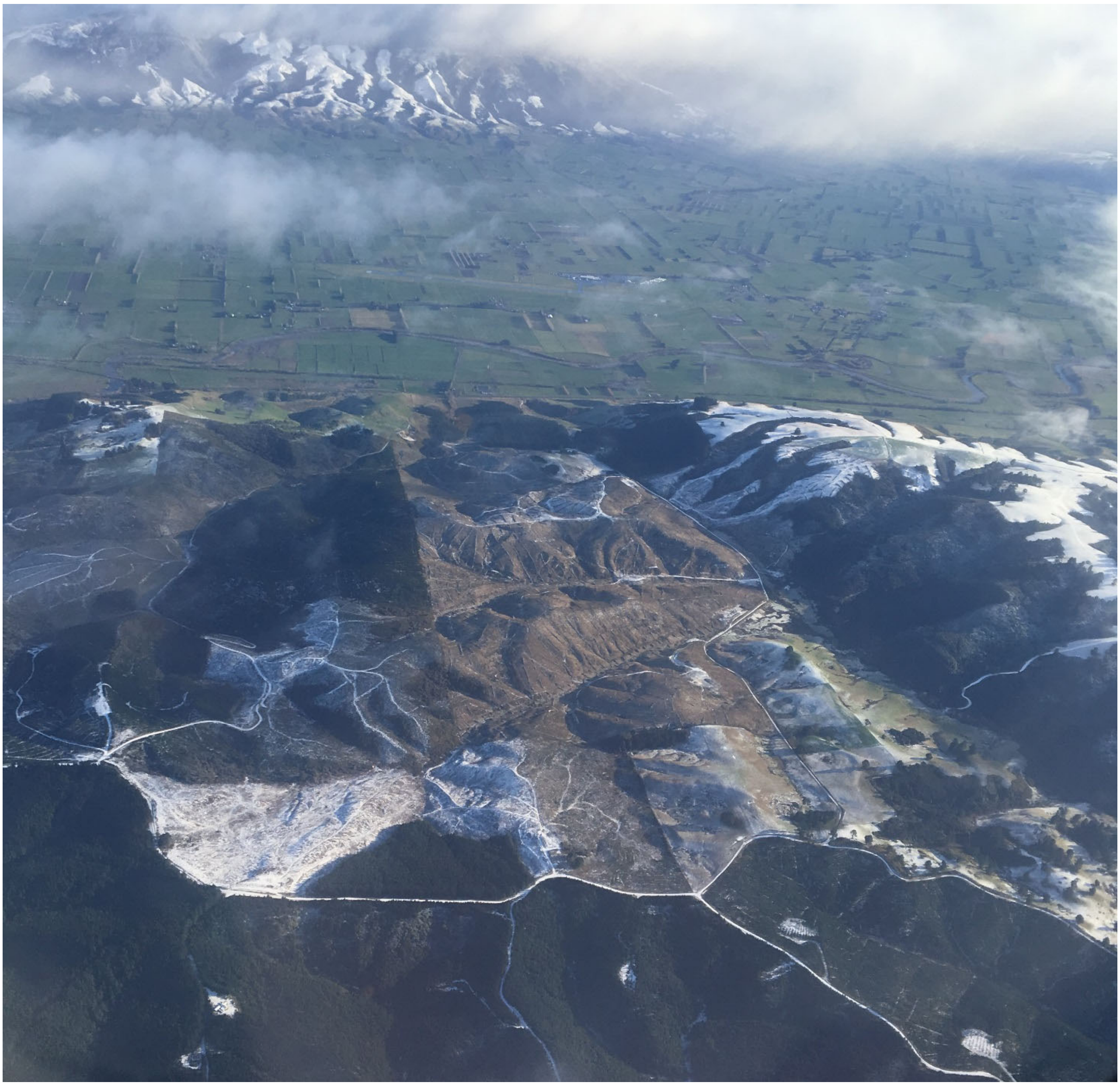

Dunedin City Council

Waste Futures Phase 2 – Work Stream 3. Extended Water Quality and Quantitative Human Health Risk Assessment

20 June 2022

The Power of Commitment

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Executive Summary

Overview

Dunedin City Council is proposing a new landfill at Smooth Hill in southwest Dunedin as part of the Waste Futures Project. GHD previously supported the application for resource consent by undertaking an assessment of landfill performance and assessment of effects to groundwater and surface water. During the hearing for the proposed landfill a number of submitters outlined concern regarding the potential for contaminants present in landfill leachate, in particular persistent organic pollutants, to impact the water quality of Ōtokia Creek and the ability of the Brighton community to undertake recreational activities and food gathering from the creek.

This report has been prepared in response to submitter concerns, with the assessment undertaken to provide quantitative predictions of surface water quality within the headwaters and additional downstream locations of the Ōtokia Creek. This extended water quality analysis includes consideration of a broader range of contaminants, a 'worst case' leachate discharge scenario and a quantitative human health risk assessment (QHHRA).

Extended Water Quality Assessment

Landfill liner systems are designed to minimise leakage of leachate to ground, however imperfections in the liner can occur during manufacture and installation, and liner failure may occur between 100 – 400 years following landfill closure. The extended water quality assessment considered the following scenarios with respect to leachate leakage:

1. Landfill closure scenario: reflects a conservative analysis of leachate loss under unexceptional conditions.
2. Liner failure scenario: simulates exceptional failure of the entire HDPE liner over a period of only 50 years, as well as delay of 5 years to implement mitigation measures following identification of the leachate liner issue.

The landfill liner failure scenario conservatively assumes that the integrity of the HDPE liner progressively fails at a rate of approximately 3,700 m^2/yr and that leachate leakage reports immediately to the wetland present within the designation, transport via groundwater which would otherwise take many years to flow from the landfill to surface water.

The range of contaminants considered has been expanded to include organic contaminants not typically measured or reported in landfill leachate and incorporates priority contaminants that are considered to be mobile, persistent and that demonstrate potential for bioaccumulation and biomagnification, such as PFAS.

To predict the rates of leachate discharge under the landfill liner failure scenario a simplistic and conservative mixing model was developed using GoldSim. Due to the notable differences in chemistry between groundwater and landfill leachate, the increasing leachate leakage were predicted to be detected within the first year of the liner failure scenario. Leachate loss to surface water was predicted to peak at approximately 180 m^3/yr at 6 years, following which mitigation measures implemented; this compared to the predicted conservative landfill closure scenario rate of 1.4 m^3/yr.

The GoldSim model was used to predict downstream surface water quality at discrete locations extending from the designation down Ōtokia Creek to Brighton. The natural processes that may attenuate contaminant distribution, such as adsorption, chemical reactions, microbial reactions, or bioassimilation were not considered, ensuring that the water quality predictions were very conservative.

For the landfill liner failure scenario the modelled contaminant concentrations in surface water downstream of the proposed landfill were predominantly below the screening level water quality criteria for human health and ecosystem protection. Contaminants exceeding the screening criteria included:

– Zinc and manganese, which were predicted to occur at concentrations similar to the adopted baseline condition for surface water
– Nitrate, which while predicted to exceed the ORC Regional Plan (2022) water quality criteria at a number of downstream locations in the liner failure scenario, did not result in change to the attribute state for nitrate outlined in the National Policy Statement for Freshwater Management 2020 (MfE, 2020).
– The PFOS concentrations predicted to occur for the liner failure scenario exceed the draft ecological water quality guideline for the protection of 99% of freshwater species outlined in HEPA (2020) at downstream

locations, with the exception of north of Big Stone Road (location 5) and the Lower Ōtokia Creek Marsh (location 6). The potential risks to human health associated with PFAS compounds were assessed in the QHHRA. Bioaccumulation in aquatic food chains in the downstream receiving environments has been evaluated in more detail in a qualitative ecological risk assessment (ERA).

Quantitative Human Health Risk Assessment

The human health risk assessment was undertaken to predict the impact of PFAS on surface water users downstream of the proposed landfill for the landfill liner failure scenario, with this intended to provide a highly conservative upper bound for potential risk to the community. Methodology and guidance from a number of references have been adopted to ensure a robust assessment. This includes guidance from Ministry for the Environment (MfE, 2011), Food Standards Australia New Zealand (FSANZ, 2017), Heads of EPAs Australia and New Zealand (HEPA, 2020) and Ministry of Health (MoH, 2018). The risk assessment methodologies were adopted from EnHealth (2012a;b) and the National Environmental Protection Council (NEPC, 2013) to assess exposure and human health risks.

The assessment considered the risks associated with ingesting PFAS compounds from a range of activities about which submitters expressed concern. Additional exposure pathways were also considered, and the cumulative risk determined assuming exposure via all pathways. The pathways include:

– Use of the Ōtokia Creek for frequent recreational use.
– The gathering and consumption of food from Ōtokia Creek, such as eel and water cress.
– Consumption of homegrown produce (fruit and vegetables) irrigated with water from Ōtokia Creek.
– Livestock watering and consumption of livestock and/or livestock products (e.g., eggs, milk, meat).

The rates of ingestion for each pathway are very conservative and reflect high rates of exposure much above those of the average person. Based on these very conservative assumptions the risk assessment calculated that near to Brighton the Hazard Index (HI) is 0.05 for PFOS + PFHxS and 0.0002 for PFOA compounds compared to an acceptable threshold of 1.

Assuming the same activities at the man-made pond immediately downstream of the landfill, the HI is predicted to be 0.4, and is low and acceptable.

This means that even where the worst-case scenario for landfill liner failure is realised, the potential risks to human health remain are predicted to remain within the acceptable human health thresholds.

Qualitative Ecological Risk Assessment

A qualitative risk assessment was undertaken to predict the impact of PFAS to aquatic ecology downstream of the proposed landfill for the liner failure leachate discharge scenario.

The results of the water quality assessment indicate that all estimated downstream concentrations of PFOS are well below the 95% freshwater species protection value (HEPA, 2020), providing a high level of confidence that PFOS discharges from the landfill are unlikely to adversely affect lower trophic level aquatic organisms within the Ōtokia Creek. However, a number of locations in the upper reaches of the creek estimate concentrations of PFOS exceeding the 99% freshwater species protection value (HEPA, 2020), therefore the potential for bioaccumulation in aquatic food chains was further evaluated within the ecological risk assessment.

A weight of evidence approach was adopted to consider multiple lines of evidence, as recommended by ANZ (2018) for risk assessments of aquatic environments. This approach considered potential receptors, parameter toxicity and exposure, including background and bioaccumulation trends.

The assessment results are summarised as follows:

– PFOS concentrations in the lower reaches of Ōtokia Creek following a liner failure event are very low and do not exceed the HEPA (2020) ecological water quality guidelines for protection of 99% of species. This suggests that PFOS discharges from the landfill are unlikely to adversely affect higher trophic level aquatic organism in the lower reaches of Ōtokia Creek.
– The upper reaches of Ōtokia Creek have intermittent flow and the habitat conditions have recently been assessed as suboptimal for freshwater macroinvertebrates and fish. In the absence of diverse and abundant

communities of lower trophic organisms in the upper reaches of the creek, secondary poisoning of higher trophic level organisms is unlikely to occur at the low PFOS concentrations predicted following a liner failure event.

– The PFAS NEPM PFOS species protection values are likely to increase in the future, potentially by more than an order of magnitude, as a result of additional studies published since the guidelines were derived in 2015. The PFOS concentrations estimated downstream of the landfill exceed the current 99% species protection (HEPA, 2020) value by less than an order of magnitude.

The available evidence does not suggest that PFOS concentrations downstream of the landfill following assessed liner failure are likely to result in adverse effects to the aquatic environment.

This report is subject to, and must be read in conjunction with, the limitations set out in section 1.4 and the assumptions and qualifications contained throughout the Report.

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1. Introduction

Dunedin City Council (DCC) has embarked on the Waste Futures Project to develop an improved comprehensive waste management system for Dunedin. As part of the project, the Council has confirmed the need to develop a new landfill to replace the current Green Island Landfill, which is envisaged to reach full capacity in the next few years. Final closure could be around 2028 depending on closure strategy adopted by the Council.

The Smooth Hill site in southwest Dunedin has been identified as the preferred location, and an assessment of effects on the environment (AEE) was prepared by Boffa Miskell. The AEE was supported by a number of technical assessment reports, including an Assessment of Effects to Groundwater prepared by GHD Limited (GHD).

The Council lodged applications for resource consents for Smooth Hill landfill with both the Otago Regional Council (ORC) and DCC in August 2020 based on the original concept design. The applications were accepted by both Councils in October 2020. ORC and DCC both subsequently requested further information on the applications under section 92 of the RMA in October 2020. In response to the section 92, and following a revision to the waste stream estimate by DCC, an updated landfill design was subsequently developed and the AEE, concept design and technical assessment reports were updated in 2021.

A hearing was held between 17 – 24 May 2022, during which a number of submitters indicated that there remains community concern regarding the potential for contaminants present in the landfill leachate to impact the water quality of Ōtokia Creek and the ability of the Brighton community to undertake recreational activities and food gathering from the creek. It is understood that of most concern to the community is the potential for exposure to mobile contaminants, such as per- and polyfluoroalkyl substances (PFAS).

1.1 Background

To support the initial application for resource consent under the Regional Plan for discharge of contaminants to land and water, GHD prepared the following technical assessment report:

> *Waste Futures Phase 2 – Work Stream 3. Smooth Hill Landfill Assessment of Effects to Groundwater. Prepared for Dunedin City Council. August 2020 (Updated May 2021). (Appendix 8 of the Boffa Miskell AEE (2021)).*

The groundwater report included an assessment of effects to water quality using a combination of site-specific water quality data, collected during site investigation programmes at the Smooth Hill site (November 2019 – March 2021), and landfill leachate data recorded at other New Zealand landfills (CAE, 2000). Subsequent to the preparation of the assessment of effects to Groundwater (GHD, 2021), the modelling of landfill performance was updated to reflect the most up to date liner design. The assessment of effects to water quality was therefore updated in response to the change in landfill liner design, and to include additional site-specific water quality data collected between August 2021 and January 2022. The results were presented in the Statement of Evidence of Anthony Hans Peter Kirk (Kirk, 2022).

Due to the very low rates of landfill leachate leakage expected to occur from the landfill and the existing impacts on groundwater quality, the potential degradation of groundwater water quality due to leachate leakage has been predicted to be limited. For a number of key parameters, including inorganic nitrogen, an improvement of existing water quality has been predicted to occur.

Impacts of leachate discharges on the water quality of Ōtokia Creek has been predicted to be negligible, in the context of the very small contribution of groundwater to the creek flow and the limited influence of leachate on groundwater.

The contaminants considered in this assessment included those typically encountered in municipal landfill leachate and are typically referenced in landfill guidance.

1.2 Purpose of this report

To address submitter concerns regarding potential impacts to water quality, and at the request of hearing Commissioners, GHD have undertaken this assessment to expand the current Smooth Hill landfill water quality assessment (GHD, 2021; Kirk, 2022) to include analysis of a broader range of contaminants, additional discharge scenarios and a quantitative human health risk assessment (QHHRA).

This report should be read in conjunction with the assessments presented in GHD (2021) and Kirk (2022).

1.3 Scope

1.3.1 Extended water quality assessment

The water quality assessments presented by GHD (2021) and Kirk (2022) have been expanded to provide quantitative predictions of surface water quality within the headwaters and additional downstream locations of the Ōtokia Creek. The extended analysis includes consideration of a broader suite of potential contaminants, including persistent organic pollutants, with a focus on PFAS that have the potential to bio accumulate and impact upon human health.

In addition to the previously provided conservative scenario for landfill liner leakage the assessment has been extended to include a reasonable ‘worst case’ scenario for landfill leachate discharges, to provide an upper bound (extremely conservative) for potential contaminant discharges. This considers rapid degradation of the landfill high density polyethylene (HDPE) liner and a conservatively high threshold for identifying issues and when mitigation could be put in place.

1.3.2 Quantitative human health risk assessment

Using the results of the extended water quality assessment (Section 1.3.1) a QHHRA has been presented within this report to evaluate the potential risks to human health from possible exposure to the contaminants that may be present within landfill leachate. This includes:

- Identification of the contaminant receptors and potential exposure pathways.
- Review of contaminants of concern, including persistent organic pollutants, and identification of risk limiting contaminants for detailed analysis. This includes selection of appropriate dose response information if available.
- Quantitative prediction of exposure to contaminants from landfill leachate, via the relevant pathways.
- Analysis of risk to human health associated with the contaminant exposure.

This analysis extends to the Brighton community and the coastal environment and includes consideration of contaminant mass and bioaccumulation.

1.4 Limitations

This report: has been prepared by GHD for Dunedin City Council and may only be used and relied on by Dunedin City Council for the purpose agreed between GHD and Dunedin City Council as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Dunedin City Council 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.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD as described throughout this report. GHD disclaims liability arising from any of the assumptions being incorrect.

Accessibility of documents

If this report is required to be accessible in any other format, this can be provided by GHD upon request and at an additional cost if necessary.

The opinions, conclusions and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular site conditions, such as the location of buildings, services and vegetation. As a result, not all relevant site features and conditions may have been identified in this report.

1.5 Assumptions

In undertaking this assessment a broad range of assumptions have been made, with supporting information regarding these assumptions provided within the relevant sections of this report. In representing a natural system and predicting the outcomes of potential events, significant simplification of the processes involved have been made. To respond to the inherent uncertainty created by such simplification, assumptions are typically conservative; giving a level of confidence that the predicted impacts are greater than would likely occur. As with all predictive assessments there is potential for actual outcomes to differ from those predicted.

2. Landfill leachate discharge scenarios

2.1 Introduction

The landfill liner system is intended to minimise leakage of leachate to ground. The primary containment layer is the HDPE membrane and this is used in both Type 1 and Type 2 liner systems. The HDPE liner is practically impermeable and strict quality control measures are used to confirm liner integrity during placement. However, for the purposes of assessing environmental effects, assessment to date (presented within GHD (2021) and updated in Kirk (2022)) predicts a level of leakage through the membrane based on the assumption that multiple imperfections in the liner occur during manufacture and installation. Where leakage occurs, the rate of loss is also constrained to the extent practicable by use of an underlying compacted clay layer, as for a Type 1 liner, and through intimate contact of the HDPE with the underlying geosynthetic clay layer (GCL) for a Type 2 liner. For the Smooth Hill landfill, a Type 1 liner is proposed for the side slopes and a Type 2 liner is proposed for the landfill base.

The rate of leachate leakage is largely controlled by the head of leachate on top of the liner. The minimum leachate collection system requirement in the WasteMINZ (2018) technical guidelines states that the leachate head is not to exceed 300 mm above the liner.

The rate of leachate generation, head of leachate and leakage is estimated using the industry standard Hydrologic Evaluation of Landfill Performance (HELP) software. The data inputs required include landfill design, material properties and weather conditions.

The rate of leakage of landfill leachate has been assessed for the following two scenarios:

1. Conservative landfill closure scenario (as presented within GHD (2021) and updated in Kirk (2022)). This scenario reflects a conservative analysis of leachate loss under unexceptional conditions.
2. A 'worst case' liner failure scenario, simulating progressive failure of the landfill HDPE liner and delayed response to implementing mitigation. This scenario reflects the exceptional failure of the liner over a short timeframe and significant delays in identifying and mitigating the effects of the resulting leachate discharge. To reduce doubt regarding the potential for adverse outcomes, this scenario is considered to be sufficiently conservative in its representation of liner failure and response as to reflect an outcome greater than is plausible.

2.2 Landfill closure scenario

The most up to date estimation of landfill leakage following landfill closure is presented in Kirk (2022). The assessment provides a conservative prediction of landfill leachate discharge due to adoption of high levels of HDPE manufacturing and installation defects and poor placement quality. Numbers of defects were chosen from the range of values presented in Berger & Schroeder (2013) as follows:

– Manufacturing defects are typically reported in the range of 1 – 2 pinholes per hectare. For the purpose of assessment pinhole density of 2 / hectare was adopted.
– Installation defects depend on the quality of the installation, with reported defect density ranges presented in Table 2.1. For the purpose of assessment 25 holes / hectare was adopted.
– Placement quality is represented within the HELP model as the degree of contact between defects in the HDPE and the underlying soils or GCL, which limit the rates of leachate leakage. A 'poor' placement quality was adopted to reflect a less well-prepared soil surface and/or geomembrane adjacent to the defect. This assumption provides a larger gap between HDPE and underlying soils or GCL, allowing greater spreading and leakage of leachate (Berger and Schroeder, 2013).

Table 2.1 Geomembrane installation quality and defect density (Berger and Schroeder, 2013)

Installation quality	Installation defect density (number / ha)
Excellent	Up to 2
Good	2 – 10
Fair	10 – 25
Poor	25 – 50*
* Higher defect densities have been reported for older landfills with poor installation operations and materials; however, these high densities are not characteristic of modern practice	

Assessment of the conservative landfill closure scenario provided a predicted rate of landfill leachate leakage of 1.4 m^3/yr.

The remainder of the documented assessment will focus on the methodology, results and findings of the water quality (Section 4) and human health risk assessment (Section 5) for the liner failure scenario.

2.3 Liner failure scenario

The serviceable life of the landfill liner is a function of many factors that include the quality of materials, quality and any performance additives to HDPE, the quality of the installation contractors work, quality control and monitoring during installation, adequate liner protection, careful placement of the first lifts of the waste, heat development and contamination in waste placed in the body of the landfill, and movement and/or shear of the liner. These matters are carefully controlled through detailed design, peer review, construction monitoring, and landfill management practices. Under ideal conditions HDPE liners may last 400 years before loss of leachate containment. Under more typical conditions liner failure can be expected to be less, and under particularly adverse conditions, with poor installation and landfill operation, this may be less than 100 years.

The liner failure scenario considers the following:

1. **Landfill leachate leakage** (Section 2.3.1) – Failure of the HDPE liner over a period of 50 years following landfill closure.
2. **Leachate Composition and contaminants of potential concern** (Section 2.3.2) – contaminant concentrations in leachate are towards the upper end of those reported for municipal solids landfills.
3. **Detection of leachate discharges** (Section 2.3.3) – A conservatively high threshold for detecting the influence of landfill leachate in groundwater downgradient of the landfill.
4. **Duration to mitigate discharges** (Section 2.3.4) – A five-year period following identification of increasing leachate discharges to undertake risk assessment and implement mitigation to protect the receiving environment.

2.3.1 Landfill leachate leakage

For the liner failure scenario complete degradation of the HDPE liner, across the base and slopes of the landfill, is assumed to progressively occur over a 50-year period. The initial leachate leakage rates are taken as those of the closure scenario (detailed in Section 2.2). To provide the maximum rate of leakage where the HDPE liner is not present (assumed to be at 50 years), the HELP models developed for the landfill closure scenario were reconfigured to remove the HDPE liner. All other features of the landfill design, such as the cover and liner properties, remained as outlined for the landfill closure scenario. The HELP modelling result for this maximum rate of leachate leakage without the HDPE liner is presented in Section 2.4.

Simulation of the progressive degradation of the landfill liner over the 50-year period, the associated increase in leachate leakage and its impact on groundwater and surface water quality, was carried out using a transient water and contaminant mass balance model for the developed in GoldSim (https://www.goldsim.com/Web/Applications) (Section 2.3.3). The water balance model incorporated the HELP model results and simulated the incremental increase in leakage over 50 years from the initial landfill closure rate, to the maximum rate without the HDPE liner.

2.3.2 Leachate composition and contaminants of concern

Leachate quality adopted for the water quality assessment (GHD, 2021) was the upper quartile of that provided in New Zealand guidance (CAE, 2000), with these representing those contaminants present at relatively elevated concentrations in landfill leachate. This range of contaminants and associated concentrations has been considered further in the extended water quality assessment.

Organic contaminants not typically measured or reported in landfill leachate have also been considered. For the purpose of risk assessment, it is standard practice to refine the list of potential contaminants to focus on priority contaminants; those most likely to present a risk to the environment and human health. Selection of priority organic contaminants has been carried out to identify the appropriate risk limiting contaminants for consideration. Additionally, submitter concerns regarding exposure to PFAS compounds have been considered, with the adoption of such organic contaminants within the list of considered contaminants of potential concern.

As the discharge of landfill leachate is considered to be ground and groundwater, the leachate will be subject to significant attenuation in the migration to surface water. Such attenuation can include biodegradation, volatilisation, adsorption, etc. For this reason, priority organic contaminants were identified considered to be those that are:

– Mobile – those contaminants known to have limited potential to adsorb to soils and organic matter.
– Persistent – those contaminants that demonstrate limited susceptibility to biodegradation or chemical reaction that reduces the contaminant mass and net toxicity.
– Non-volatile – those contaminants that will not lose contaminant mass via vapour.
– Bioaccumulative – those contaminants that can enter the ecological and human food chain via aquatic flora and fauna.
– Low threshold for risk – those contaminants with notably low risk-based water quality or exposure criteria, representing the potential for increased risk through exposure to even very small amounts.

An example of the screening process and exclusion of particular organic contaminants from further assessment, is provided in the consideration of the following potential organic contaminants:

– Polychlorinated biphenyls (PCBs) - while highly toxic and persistent in the environment, PCBs are very strongly adsorbed to organic matter in soil and they are not considered to be meaningfully mobile in groundwater.
– Polycyclic aromatic hydrocarbons (PAHs) – of the group of potential contaminants, those of notable toxicity, such as benzo[a]pyrene, are relatively immobile in groundwater. The smaller PAH compounds are only moderately mobile and relatively minor toxicity. They also demonstrate greater volatility and potential for biodegradation.
– Chlorinated solvents (such as vinyl chloride) – while mobile and relatively toxic, chlorinated compounds are volatile and degrade via chemical reactions. Contaminant mass is rapidly reduced in surface water environments.

Of the range of persistent organic contaminants associated with landfill leachate, PFAS compounds (in particular PFOS and PFOA) have the lowest adopted exposure criteria while meeting the other requirements of contaminant screening. For this reason, relevant PFAS compounds are considered to provide a conservative proxy for risks associated with other organic contaminants in the extended water quality assessment and human health risk assessment. Additional information relating to PFAS compounds and the properties of these is provided in Section 5.

Of the thousands of PFAS compounds that have been developed, studies to date have focussed on only a few key compounds developed in significant amounts and with known presence in the environment. At the time of reporting, toxicity studies have primarily focussed on two compounds PFOS and PFOA. Concentrations of PFAS compounds in landfill leachate have been sourced from Gallen *et al.,* (2017) and are the 95% percentile concentrations from monitoring of leachate at 27 landfills in Australia. Specific PFAS compounds included in the assessment include:

– perfluoroalkyl sulfonates: PFOS and PFHxS.
– perfluoroalkyl carboxylates: PFOA, PFHxA, PFNA, PFHpA, PFDA, PFUdA and PFDoDa

Adopted concentrations of potential leachate contaminants and leachate indicators, such as sodium and chloride, are provided in the results tables in Appendix B.

2.3.3 Detection of leachate discharges

The liner failure scenario considers increasing leachate discharge via groundwater to the wetland immediately downstream of the landfill. Due to reductions in groundwater flow beneath the landfill, under this scenario, leachate will make up an increasing proportion of groundwater migrating to the wetland.

Groundwater from beneath the landfill flows to the alluvial and organic sediments of the wetland within the gully floor of the designation. As surface water flow only occurs within the designation during and following periods of catchment run-off, mixing of any groundwater with surface water predominantly occurs only as run-off infiltrates the sediments. As such, groundwater from the designation becomes significantly diluted at the interface between groundwater and surface water within the wetlands.

The human-made constructed pond located approximately 300 m downstream of the designation is considered to be the point of complete mixing for groundwater and surface water from the designation. At this location, any groundwater migrating downstream through the wetland sediments is expected to become fully mixed with surface water. Downstream of the pond, the influence of the landfill in the liner failure scenario is considered to be limited to surface water.

Warning of increasing leachate discharges is provided by routine monitoring of groundwater and is evidenced as increasing concentrations of leachate indicator parameters. Monitoring of groundwater wells positioned immediately downgradient of the landfill allows detection of increasing leachate influence before meaningful impacts to surface water quality in the wetlands and un-named tributary of the Ōtokia Creek.

For the influence of leachate on groundwater to be detected, the concentrations of indicator parameters must be sufficiently elevated above background levels that they can be statistically confirmed as deviating from the baseline condition. For the liner failure scenario, the following approach to detecting increasing leachate influence has been adopted:

1. Groundwater quality is represented by the mean of samples collected from the downgradient monitoring well BH01A.
2. Trigger levels are calculated from BH01A dataset as the mean plus three standard deviations (99.7% of background data below this value assuming normal distribution) for the following leachate indicator parameters:
   - Alkalinity
   - Hardness
   - Electrical conductivity
   - Sodium
   - Potassium
   - Chloride
   - Sulphate
   - Total inorganic nitrogen
3. Discharged leachate is fully mixed with the catchment groundwater flow rate to the wetland (2,200 m^3/year) (GHD, 2021).
4. Fully mixed groundwater quality is compared to trigger levels and exceedances identified.

The approach to detecting increasing leachate influence is considered to be conservative for the following reasons:

– All leachate is assumed to remain within the shallow groundwater system, rather than infiltrate to deeper groundwater and be lost from the local hydrological environment.

– Leachate is allowed to be diluted by the full groundwater volume within the designation, before being tested against the trigger levels. This equates to testing within the wetland sediments at the designation boundary. Estimates of groundwater flow time from the landfill to this location are in the order of 25 years. Monitoring wells immediately downgradient of the landfill will provide an earlier opportunity to detect leachate where it is closer to source and less diluted, with estimates of groundwater flow from the landfill footprint to the nearest monitoring well in the order of 3 years.

– The influence of leachate can be determined from a shift in average conditions, such as by trend analysis, rather than exceedance of infrequent maximum conditions. Improvement in groundwater quality, as predicted (Kirk, 2022) also provides the means of re-setting limits to lower values than adopted in this scenario.
– No attenuation of contaminants is considered, with these assumed to report immediately to the receiving environment, such that the effects are realised within the same time period as landfill leachate detection.

2.3.4 Mitigation measures

Where groundwater trigger levels are exceeded, indicating the increasing influence of leachate leakage, it is reasonably expected that actions will be undertaken in response. These include, but are not limited to:

– Sampling for the full suite of contaminants of concern considered appropriate for the landfill.
– Undertaking of a detailed risk assessment to determine whether the conditions encountered present a meaningful risk to the receiving environment and users of it.
– Implementation of mitigation measures if needed to manage the risk associated with the discharge.

The liner failure scenario assumes a long timeframe of five years, from first identification through to implementing mitigation of the discharge. During this period liner degradation is assumed to continue, resulting in increasing leachate discharge and immediately increasing effects to groundwater and surface water quality.

The hydrogeological conditions beneath the landfill and within the designation are constrained by the topography and the low permeability of the underlying Henley Breccia. Shallow groundwater flow beneath the landfill has a clearly defined flow path to the wetland, with the fine-grained low permeability layer within the breccia prompting flow to a central point at the landfill toe. If needed, mitigation can be readily achieved by groundwater interception along the flow path, prior to groundwater entering the wetland. A number of relatively simple technologies exist and are commonly used for such groundwater interception, such as well pointing, perimeter dewatering wells and groundwater interception trenches. Additional mitigations, such as physical barriers can also be used to further reduce effects to the wetland, if needed. Examples include grout curtains and bentonite walls.

The rate of discharge at the conclusion of the five-year period to implement mitigation, is taken as the worst-case leachate leakage rate for the liner failure scenario and the corresponding effects to water quality. It is assumed that following this time further increases in leachate discharge will not occur.

The assumptions regarding mitigation are considered to be conservative for the following reasons:

– The rate of liner degradation assumed (50 years) is considered to be extraordinarily rapid in the context of modern liner conditions, with the whole of landfill extent of failure an unlikely occurrence, where failures are more commonly localised issues. The rate of degradation assumed results of a very high maximum discharge after the five-year period before mitigation can be implemented.
– The assumption of immediate impacts to surface water does not reflect the very long timeframes for groundwater and contaminant transport at the site. This, together with contaminant attenuation processes both within the Henley Breccia and the organic sediments of the wetland, is expected to significantly delay the occurrence of impacts to surface water by many years, allowing greater time for mitigation.
– Should emergency mitigation works be needed in the event liner failure, they could be investigated, designed and implemented within a relatively short timeframe (less than a year). This is due to the relatively simplistic nature of the groundwater interception technologies and the constrained hydrogeological conditions.

2.4 Leachate discharge scenario results

The conservatively estimated rate of leachate discharge for the landfill closure and liner failure scenarios are presented in Table 2.2.

The results of the landfill closure scenario are considered to represent potential leachate leakage after placement of the final capping layer. The assessment of this scenario provided the following key findings:

1. The rates of leachate generation are relatively low, due to the dry climate in the vicinity of Dunedin.

2. Due to the relatively high slope of the base liner (4% compared to the more typical 2%), the leachate head on the liner is small; this limits the potential rates of leachate leakage.
3. Annual rates of leachate leakage have been conservatively predicted to be 1.4 m^3/year after closure of the landfill.

For the landfill liner failure scenario, the predicted rates of leachate increase annual by approximately 36 m^3/yr, with this significant increase due to the large area of liner assumed to fail each year (approximately 3,700 m^2/yr). The detection of impacts to groundwater, detectable from background groundwater quality, is predicted to occur very soon after the increase in discharge (at model year 1 of liner degradation) as a function of the significant differences in chemistry between leachate and groundwater. Of the leachate indicator parameters tested, and following the assumed significant dilution in groundwater, the following parameters increased in concentration almost immediately to greater than assumed trigger levels:

– Electrical conductivity
– Sodium
– Potassium

Total inorganic nitrogen exceeded the adopted groundwater trigger level by model year 4 of liner degradation.

After detection of increasing leachate discharges, the rates of leachate discharge increased over the subsequent 5 model years it is assumed is required to prepare for mitigation, with rates peaking at model year 6 at 181.5 m^3/year. Beyond this period, leachate discharges are considered to be mitigated.

No other leachate indicator parameters tested exceeded the adopted groundwater trigger levels within the 6 years of increased discharge.

No leachate indicators within surface water exceeded the adopted surface water trigger levels.

The complete removal of the HDPE liner (the upper bound for the landfill liner failure scenario) is predicted by the HELP modelling to be 1,790 m^3/year, or <5% of leachate generated following landfill closure.

The surface water quality (Section 4) and human health risk assessment (Section 5) for the landfill closure scenario presents the conservatively expected impacts from the Smooth Hill landfill and is provided as comparison to the landfill liner failure scenario.

Table 2.2 Estimated rate of leachate discharge

Leachate discharge scenario	Predicted peak leachate discharge (m^3/year)
Conservative landfill closure	1.4
Landfill liner failure	181.5

3. Ōtokia Creek hydrology

3.1 Methodology

The initial water quality assessments presented in GHD (2021) and Kirk (2022) considered mixing of leachate leakage with shallow groundwater, however did not assess how contaminant concentrations may change after discharge to surface water and migration downstream in the Ōtokia Creek. This was due to the limited impact leachate was predicted to have on groundwater.

To provide additional assessment of effects to surface water quality, the hydrology of the Ōtokia Creek has been considered, with average surface water flow utilised in the GoldSim water and contaminant mass balance model to provide prediction of average surface water quality. The adoption of average flow is considered appropriate in the context of the annual averaging of contaminant exposure required in health risk assessment.

Estimates of mixing of groundwater with surface water at the edge of the landfill designation, within the valley floor marsh wetland, were made using the two following methodologies:

1. HELP model predicted runoff within the designation
2. NZ River Maps mean flow statistics

3.1.1 HELP model predicted runoff and groundwater discharge

The HELP model was structured to provide representation of the 'existing environment' as described in Technical Appendix C of the GHD (2021) groundwater assessment. The GHD (2021) scenario assessed a surface vegetation of 'poor grass' to simulate scrub coverage at the site. To understand the potential variability in average flow within the designation catchment over time, as the pine plantation cycles through tree growth and harvesting, the USDA Soil Conservation Service (SCS) runoff curve number (CN) (1985) and hydraulic conductivity of the topsoil within the HELP model were adjusted to reflect two additional scenarios:

– Bare soil:
  - CN: 96.48 (HELP computed CN using slope gradient, slope length, soil texture and vegetation type).
– Mature forestry:
  - Hydraulic conductivity of the soil increased by half an order of magnitude to account for macro pores and leaf litter.
  - CN: 77.0 (SCS (1986) CN for 'Woods' with soil group D (poor infiltration) and good hydrologic condition (protected from grazing, and litter and brush adequately cover the soil)).

Estimated groundwater discharge to the Ōtokia Creek under existing conditions has been adopted from the GHD (2021) groundwater assessment.

3.1.2 NZ River Maps

NZ River Maps (Whitehead and Booker, 2020) is an interactive online tool that provides predictions of hydrological regimes at ungauged sites. To achieve this, site measurements of each variable were combined with environmental data in a machine-learning model to identify the relationship between each response variable and the environment. These relationships were then applied to all reaches of the national digital river network to make predictions of the response variable.

The tool was used to extract mean flow along different reaches of the Ōtokia Creek downstream of the proposed Smooth Hill landfill. In addition to consideration of the mean flow at the northern edge of the landfill designation, five further locations downstream of the landfill have been considered, including the human-made constructed pond approximately 300 m downstream of the designation and the Lower Ōtokia Creek Marsh in Brighton.

3.2 Results

The predicted range of runoff within the designation catchment, estimated using the HELP model for the bare soil and mature forestry scenarios, is presented in Table 3.1. As evaporation has already been accounted for, the combined runoff and groundwater discharge provides an estimate of the annual average surface water flow within the headwaters of the Ōtokia Creek at the point where it crosses the designation boundary. Comparison of the HELP predicted results to those provided for the designation by NZ River maps indicates that the mean flow reported on NZ River Maps at this location (Table 3.1) provides a reasonable indication of annual flow for the creek. Given the variable land use throughout the remainder of the catchment, the NZ River Maps tool has been adopted as the preferred methodology for estimating mean Ōtokia Creek flow at additional downstream locations, as presented in Table 3.2 and Figure 3.1. Flow duration curves for each of the locations are presented in Appendix A.

Table 3.1 Hydrology results comparison at edge of landfill designation

Location along Ōtokia Creek	Catchment area at location (ha)	1. HELP model runoff(1) and groundwater discharge(2)	2. NZ River Maps
			Ōtokia Creek mean flow (m^3/yr) (3)
1 – Northern edge of landfill designation	69.2	176,056 – 345,927	203,723
1) Range of results representing forestry life cycle (mature forest to bare soil post-deforestation) 2) GHD, 2021 3) Whitehead and Booker, 2020			

Table 3.2 Hydrology along Ōtokia Creek

Location along Ōtokia Creek	Catchment area at location (ha)	Ōtokia Creek mean flow (m^3/yr) (1)
1 – Northern edge of landfill designation	69	203,723
2 – Constructed Pond	80	239,522 (2)
3 – McLaren Gully Road Culvert	190	454,749
4 – East of McLaren Gully Road	498	1,208,775
5 – North of Big Stone Road	2012	5,361,120
6 – Lower Ōtokia Creek Marsh	2560	6,874,848
1) Whitehead and Booker, 2020 2) Location 2 is on the same stream reach as Location 1, therefore mean flow at Location 2 has been linearly adjusted based on its distance along the reach.		

Paper Size ISO A4

0 500 1,000 1,500

Meters

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

N

Dunedin City Council
Smooth Hill Landfill

Otokia Creek Hydrology Assessment Locations

Project No. **12529451**
Revision No. **0**
Date **02/06/2022**

FIGURE 3.1

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Print date: 16 Jun 2022 - 14:27

Data source: World Imagery: Otago Regional Council, Maxar. GHD- hydrology assessment locations, regional catchment boundary, watercourse, landfill designation, watercourse, landfill operational extend.
Created by: schen4

4. Extended water quality assessment

4.1 Introduction

The water quality assessment presented in GHD (2021) and updated in Kirk (2022) estimated the impact to shallow groundwater quality following mixing with leachate discharge after closure of the landfill. This extended water quality assessment adopts the same methodology of water quality mixing, without consideration of attenuation processes that may remove contaminant mass. The assessment is also extended from the landfill to the Ōtokia Creek and Brighton.

The leachate discharge scenarios assessed are presented in Section 2 and consider the conservatively expected impact from the Smooth Hill landfill (landfill closure scenario) as well as potential failure of the landfill HDPE liner.

4.2 Modelling methodology

A simplistic mixing model was developed using the GoldSim software to predict contaminant flux of leachate leakage for the two discharge scenarios, followed by mixing with groundwater and surface water. The closed landfill scenario only considered PFAS, as the water quality assessments presented by GHD (2021) and Kirk (2022) did not identify any risks to the environment from mixing of leachate within groundwater prior to discharge to surface water. The following input data was used within the GoldSim model:

– Leachate discharge (Section 2.4)
  1. Closed landfill scenario
  2. Liner failure scenario
– Leachate composition (Appendix B)
  - Conservatively high parameter concentrations were adopted from leachate sample results from eight New Zealand municipal waste landfills (CAE, 2000;). Mercury concentration was adopted from the maximum leachate concentration recorded at Redvale landfill (T&T, 2019).
  - PFAS values are the 95% percentile (mean plus 1.96 standard deviations) of leachate concentrations recorded at 27 Australian landfills accepting a range of waste types including MSW, commercial and industrial (C&I) and construction and demolition (C&D) (Gallen *et al.,* 2017).
– Ōtokia Creek surface water flow (Table 3.2 and Figure 3.1).
  - Mean surface water flow from six locations, including the northern edge of the landfill designation, constructed pond and the Lower Ōtokia Creek Marsh (Whitehead and Booker, 2020).
– Existing groundwater quality (Appendix B)
  - All parameters excluding mercury, boron and PFAS were derived using average groundwater parameter concentrations from samples collected within the alluvium (BH01A) across five sampling events carried out between November 2019 and January 2022).
  - Adopted mercury concentration assumed 50% of the typical laboratory detection limit.
– Background PFAS concentrations of 0.1 ng/l for PFOS, PFHxS and PFOA were adopted from PDP (2018). The sum of perfluoroalkyl sulfonates and perfluoroalkyl carboxylates were taken as 0.2 ng/l respectively.
  - Adopted boron concentration of 0.01 mg/l/
– Existing surface water quality (Appendix B)
  - All parameters excluding mercury and PFAS were derived using average concentrations from samples collected within the Smooth Hill designation and between the designation and the McLaren Gully Road culvert across five sampling events carried out between July 2020 and January 2022).
  - Adopted mercury concentration assumed 50% of the typical laboratory detection limit.
  - Background PFAS concentrations of 0.1 ng/l for PFOS, PFHxS and PFOA, adopted from PDP (2018). The sum of perfluoroalkyl sulfonates and perfluoroalkyl carboxylates were taken as 0.2 ng/l respectively.

- Adopted boron concentration of 0.01 mg/l

The water quality assessment did not consider geochemical equilibrium or microbial reactions which may remove contaminant mass through precipitation of minerals, or the process of adsorption which can bind contaminants to aquifer materials. Likewise, contaminant mass removed from water by bioassimilative processes is not considered in the prediction of downstream water quality, providing a degree of conservative double counting of contaminant mass in the consideration of exposure via both water ingestion and aquatic food gathering.

Predicted water quality results were screened against Tier 1 (generic) water quality criteria and relevant regulations and guidance. Those contaminants exceeding the relevant risk based criteria, and presented potential risk to human health via assimilation into the food chain or recreational water use, were further considered within the QHHRA provided in Section 5.

4.3 Water quality Tier 1 screening assessment

For the purpose of screening water quality results, water quality criteria for both ecological and human health endpoints, for contaminants of potential concern in discharges from the landfill, have been selected from the following:

– Screening levels relevant to the assessment of potential risks to downstream ecology have been sourced from the Australia and New Zealand Government (ANZG, 2018) *Guidelines for fresh and marine water quality* and HEPA (2020) *PFAS National Environmental Management Plan*. The 95% species protection values (freshwater), which are appropriate for slightly to moderately disturbed environments, have been adopted for the majority of the chemicals with the 99% species protection values (freshwater) adopted for chemicals with the potential to result in secondary (food chain) toxicity in aquatic environments, in accordance with the approaches recommended by ANZG (2018) and HEPA (2020). This includes the draft criteria for PFAS compounds.

– The Otago Regional Plan: Water for Otago (ORC, 2022) considers the use, development and protection of the freshwater resources of the Otago region. Guideline values from the following schedules have been adopted in the screening levels assessment:
  - Schedule 15: Good Water Quality: Receiving water numerical limits and targets for achieving good quality water (Receiving water group 2).
  - Schedule 16A: Discharge Thresholds: Permitted activity discharge thresholds for water quality by discharge threshold area (Discharge threshold Area 2).

– The *Drinking Water Standards for New Zealand* (MoH, 2018) were adopted in the screening levels assessment of the risks to downstream human health. Only the heath guideline values were adopted to reflect potential for ingestion during recreational activities; aesthetic guideline values were not considered given that surface water is not used for potable supply.

– Australian Government National Health and Medical Research (NHMRC, 2022) *Australian Drinking Water Guidelines* (DWG) were adopted in the screening levels assessment of the risks to downstream human health from PFOA and the sum of PFOS and PFHxS. These health guideline values were adopted to reflect potential for ingestion during recreational activities.

– The NHMRC (2008) *Guidelines for Managing Risks in Recreational Water* were adopted in the screening level assessment of the risks associated with the recreational use of downstream surface water. For all parameters excluding PFAS, a recreational guideline value was derived under the conservative assumption that recreation would contribute equivalent of 10% drinking water consumption. The screening levels provided by NHMRC (2019) *Guidance on PFAS in recreational water* were adopted for PFAS.

4.3.1 Approach to assessing human health pathways not specifically incorporated into the published screening levels

The current and future beneficial uses of Ōtokia Creek surface water may include a variety of recreational activities (e.g. swimming, fishing) and agricultural uses (e.g. livestock watering and irrigation) that are not specifically addressed in the range of available screening levels. The MoH (2018) DWG and NHMRC (2019) values have been used to provide a screening level assessment of the chemical exposure risks that could occur in association with a variety of potable and non-potable downstream users, including recreation, the consumption of aquatic biota, irrigating fruit and vegetables and watering domestic livestock. This is considered appropriate on the basis that the NHMRC (2022) DWG incorporate the following:

– assume the consumption of 2 L of water per day across a lifetime of exposure.
– assume that only 10% of a person's exposure to a chemical comes from drinking water, with up to 90% assumed to come from other pathways.
– represent the concentrations of a chemical in water that Australian regulators have determined is safe when used for drinking and other domestic purposes for a lifetime.

Due to the tendency for PFAS to biomagnify in aquatic and terrestrial food chain, the potential exists that the consumption of biota could be the primary exposure pathway for these compounds in the downstream environment. In the absence of screening levels specific to these pathways, PFAS exposure risks in the downstream environment have been assessed via a QHHRA (Section 5).

4.4 Results

Estimated surface water concentrations along the Ōtokia Creek following mixing with leachate leakage, as estimated using the GoldSim mixing model, are presented in Appendix B. The landfill closure scenario considered only PFAS concentrations at the northern edge of the designation. For water quality assessment of other leachate contaminants during the landfill closure scenario please refer to the assessment presented in GHD (2021), updated by Kirk (2022). The results are presented alongside existing groundwater and surface water concentrations and relevant screening levels as discussed in Section 4.3.

Across the range of chemicals of potential concern (CoPC) included in the extended water quality assessment, the modelled concentrations in downstream surface water were predominantly below the adopted screening levels. These results indicate that leachate from the landfill under both the landfill liner failure and the conservative closed landfill scenarios represents low risk to downstream surface water users and aquatic ecology.

Note that adjustment of the ammoniacal nitrogen water quality criteria, outlined in the ORC Regional Plan (2022), from the listed pH 8 condition to a more neutral pH of 7, is required to provide assessment of potential ecotoxicity in the wetland and and Ōtokia Creek. Under these conditions the predicted ammoniacal nitrogen concentrations do not exceed the water quality criteria.

The following parameters exceeded the relevant screening level criteria for the landfill liner failure scenario:

– Zinc is predicted to exceed the ecological guideline water quality for protection of 95% of freshwater species (0.008 mg/l - ANZG, 2018) during the liner failure scenario, with this due to present exceedance of the criteria. The maximum predicted increase in surface water concentration at the edge of the designation is 0.001 mg/l is a function of an approximately 10% increase in the adopted zinc concentration for surface water. It is noted that the predicted concentrations do not exceed the ecological water quality guideline for protection of 80% of freshwater species (0.031 mg/l – ANZG, 2018), which is considered to better reflect the disturbed nature of the creek due to forestry activities.
– Nitrate nitrogen is predicted to exceed the ORC Regional Plan (2022) water quality criteria at a number of downstream locations during the liner failure scenario. Following mixing with surface water, nutrient transformation between nitrogen species is considered likely to result in nitrification of ammonia, converting ammoniacal nitrogen to nitrate. Comparison of predicted nitrate concentration, assuming both no and complete nitrification of ammoniacal nitrogen, against the NPSFM (2020) attribute states is presented in Table 4.1. The increase in nitrate is not predicted to result in a change in attribute band for this parameter, suggesting the influence of this increase is unlikely to be significant, particularly in the context of the conservatism applied in the landfill liner failure scenario.
– Manganese is predicted to exceed the New Zealand Drinking Water Standards (MoH, 2018) at all downstream locations during the liner failure scenario. However, concentrations are similar to those recorded within the existing surface water. The effects of leachate discharge are therefore not considered to be meaningful.
– The PFOS concentrations predicted to occur for the liner failure scenario exceed the draft ecological water quality guideline for the protection of 99% of freshwater species provided by HEPA (2020) at all downstream locations, with the exception of north of Big Stone Road (location 5) and the Lower Ōtokia Creek Marsh

(location 6). The potential for bioaccumulation in aquatic food chains in the downstream receiving environments has been evaluated in more detail in a qualitative ecological risk assessment (ERA) (Section 6).

Outside of PFAS compounds, selected as the priority organic contaminant for consideration of human health and ecotoxicity risk, no other contaminants have been identified through the water quality screening as discharging as landfill leachate in sufficient concentrations to represent meaningful risk to human health.

Table 4.1 Comparison of existing and estimated surface water concentrations of nitrate to the NPSFM (2020) attribute bands

Nitrate concentration	Existing surface water		Estimated surface water (Liner Failure scenario)		Estimated surface water (Liner Failure scenario) following complete ammoniacal nitrogen nitrification	
	Concentration (mg/l)	NPSFM attribute band -	Concentration (mg/l)	NPSFM attribute band	Concentration (mg/l)	NPSFM attribute band
Maximum concentration	1.1	B (Annual 95th percentile)	-	-	-	-
Median concentration (n=15)	0.097	A (Annual median)	0.19	A (Annual median)	0.86	A (Annual median)

5. Quantitative Human Health Risk Assessment

5.1 Introduction

This section presents a QHHRA for the predicted PFAS impacts to surface water downstream of the site. For the purpose of this QHHRA, the 'Assessment Area' is defined as the length of Ōtokia Creek and its un-named tributary, from the northern edge of landfill designation to the Lower Ōtokia Creek Marsh at Brighton.

The QHHRA has considered the range of potential beneficial uses of downstream surface water, including recreational uses, the harvesting and consumption of aquatic biota and the watering and consumption of livestock, livestock products and produce. The QHHRA is based on the PFAS concentrations predicted to occur in downstream surface water for the landfill liner scenario, as detailed in Section 4.

5.2 Framework and methodology

The QHHRA has been prepared with reference to the following guidance:

– Ministry for the Environment (MfE, 2011) *Methodology for deriving standards for contaminants in soil to protect human health*.
– Food Standards Australia New Zealand (FSANZ, 2017) *Report on Perfluorinated Chemicals in Food*.
– Heads of EPAs Australia and New Zealand (HEPA, 2020) *PFAS National Environmental Management Plan, over 2.0 (the "PFAS NEMP")*.
– Taumata Arowai (2021) *Drinking Water Standards for New Zealand* (draft).
– Ministry of Health (MoH, 2018) *Drinking water standards for New Zealand 2005* (revised 2018).

MfE (2011) provides the most recent guidance on conducting QHHRAs in New Zealand. MfE (2011) provides the exposure parameters that have been adopted in this QHHRA where applicable, but this document is principally concerned with exposure to contaminants in soil. Guidance provided by reputable international agencies has also been referenced where required and consistent with MfE (2011). In particular, the QHHRA methodologies detailed in the following guidelines have been adopted in this assessment, as relevant:

– EnHealth (2012a) *Australian exposure factor guidance*.
– EnHealth (2012b) *Environmental health risk assessment: guidelines for assessing human health risks from environmental hazards*.
– National Environmental Protection Council (NEPC, 2013) *National Environment Protection (Assessment of Site Contamination) Amendment Measure* 1999, as amended 2013 (the "ASC NEPM"):

Fundamental to the QHHRA process is the development of a Conceptual Site Model (CSM), which is a description of the plausible mechanisms ('pathways'), by which people ('receptors') may be exposed to chemicals in the environment ('sources'). Potential risks to human health cannot occur unless there is a complete Source-Pathway-Receptor (SPR) linkage associated with a source of contamination. Conversely, complete SPR linkages do not by default, indicate a receptor will be at risk; the risk assessment process is used to evaluate the extent of the potential risks.

The key steps in the QHHRA process are outlined in Figure 5.1 overleaf and can be summarised as follows:

– ***Issues identification:*** establishes the objectives of the QHHRA, evaluates the available data and establishes a preliminary CSM (Section 5.3).
– ***Toxicity assessment:*** establishes the relationships between PFAS exposure and potential health and ecological effects, using published toxicological information (Section 5.4).
– ***Exposure assessment:*** produces estimates of the PFAS exposure that may be experienced by the people using the Assessment Area (Section 5.5).

– ***Risk characterisation:*** combines the results of the toxicity assessment and exposure assessment, to provide numerical estimates of the potential health risks to relevant receptors (Section 5.6).
– ***Uncertainty and sensitivity assessment:*** evaluates the uncertainty associated with the QHHRA and sensitivity of the assessment outcomes to the various assumptions and inputs (Section 5.7).

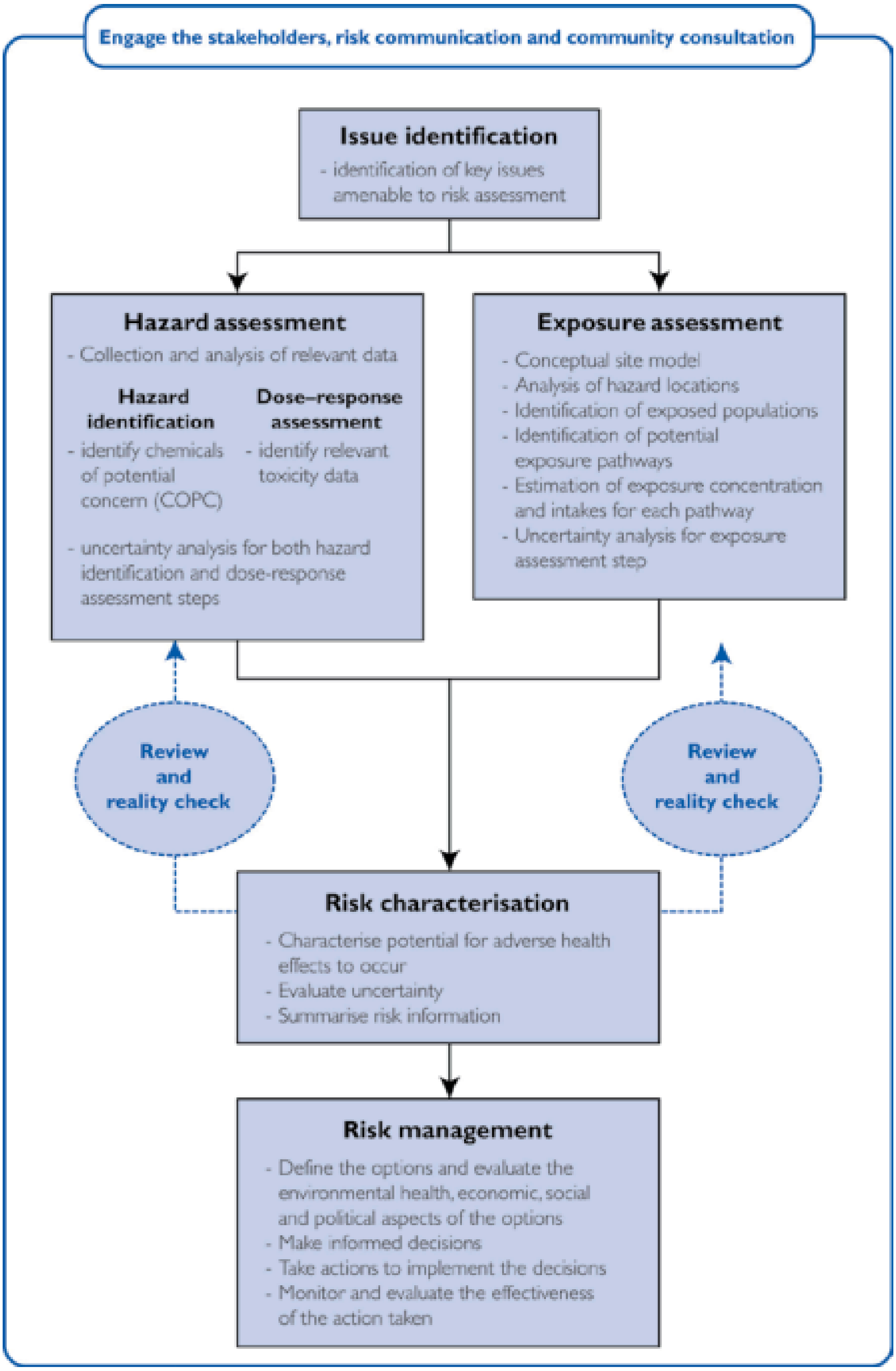

Figure 5.1 QHHRA methodology, sourced from enHealth (2012b)

5.3 Issues identification

The following discussion is focused on the sources, pathways and receptors that may be associated with the release of PFAS from the site into the Assessment Area.

5.3.1 Chemical of potential concern

The focus of this QHHRA is PFAS, due to tendency for some PFAS to biomagnify in aquatic and terrestrial food chains and the absence of screening levels specific to these pathways.

Scientists have identified thousands of individual PFAS compounds, but commercial laboratories only typically analyse a limited selection of these. The standard analytical suite focuses on the 28 individual PFAS that generally accounts for the majority of the PFAS mass in environmental samples and those that are understood to be the most persistent, bioaccumulative and toxic.

The groups of PFAS included in the standard analytical suite include the:

– perfluoroalkyl sulfonates (PFSA), of which PFOS and PFHxS are the most well-studied.
– perfluoroalkyl carboxylates (PFCA), of which PFOA is the most well-studied.
– fluorotelomers (FtS), including 8:2 FtS and 6:2 FtS.
– perfluoroalkyl sulfonamides.

Of the PFAS compounds included in the standard analytical suite, PFOS, PFHxS and PFOA are typically the dominant PFAS detected in environmental samples (HEPA, 2020). Studies monitoring PFAS concentration in human blood have reported that PFOS, PFOA and PFHxS are the predominant PFAS compounds to which people are generally exposed (EFSA, 2020). Many other PFAS compounds also ultimately breakdown into PFOS, PFHxS and/or PFOA. Consequently, PFOS, PFOA and PFHxS have been the focus of much of the scientific research undertaken on PFAS to date and are the compounds for which FSANZ (2017) has published health-based guidelines.

Given the regulatory and scientific focus on PFOS, PFHxS and PFOA these chemicals are the primary chemicals of potential concern (CoPC) for this QHHRA. For completeness, the broader group of PFAS compounds has been considered in the uncertainty and sensitivity analysis (Section 5.7).

5.3.2 Sources and migration pathways

The primary source of contamination considered in this QHHRA is the potential leaching of PFAS from the landfill into the underlying groundwater. As outlined in Section 2, consideration has been given in this assessment to the leachate of PFAS under predicted conservative operating conditions and following a failure of the landfill liner. The hydrogeology and hydrology of the site and Assessment Area suggest that any PFAS that leaches to groundwater would subsequently migrate towards to the Ōtokia Creek and move further downstream via surface water flow, ultimately discharging to the Lower Ōtokia Creek Marsh in Brighton.

PFAS are a large family of manufactured chemicals that have been used in New Zealand and around the world in a variety of commercial processes, household products and specialty applications. The persistence and mobility of some PFAS, combined with their widespread use have resulted in the presence of these compounds in the environment across the globe. A site-specific assessment of the existing PFAS concentrations in Ōtokia Creek has not been undertaken, but it is anticipated that a variety of sources external to the site contribute to the presence of PFAS in this waterway. Potential sources include wastewater treatment facilities, facilities that store and use aqueous film forming foam (AFFF) and urbane stormwater runoff.

5.3.3 Receptors and exposure pathways

The identified human users of the Assessment Area include:

– Users of the Ōtokia Creek who may come into direct contact with PFAS impacted sediment and surface water and may consume aquatic biota.
– Residents of properties adjacent to the Ōtokia Creek, who may ingest homegrown produce, poultry eggs, livestock meat or livestock milk watered with Ōtokia Creek surface water.

Table 5.1 presents a summary of the exposure scenarios relevant to the assessment of human and ecological exposures within the Investigation Area.

Table 5.1 Summary of receptors and exposure pathways

Receptor	Exposure scenario	Exposure media	Exposure pathways [1]
Human health receptors			
Users of Ōtokia Creek surface water	Beneficial use of extracted Ōtokia Creek surface water including: - Irrigation. - Livestock watering	Extracted surface water	Incidental ingestion of Ōtokia Creek surface water during beneficial use[1].
		Livestock	Domestic consumption of livestock or livestock products (e.g. eggs, meat, milk) watered with surface water
		Homegrown produce	Consumption of homegrown produce irrigated with extracted Ōtokia Creek surface water
	Use of Ōtokia Creek	Surface water	Incidental ingestion of Ōtokia Creek surface water during recreational activities (e.g. swimming)
		Aquatic biota	Consumption of aquatic biota (e.g., watercress, shellfish and eels)
[1] The primary exposure pathways of concern for human users of the Investigation relate to PFAS ingestion (see text below)			

The ingestion of surface water and food are the exposure routes of primary concern for human users of the Assessment Area, based on the following:

– Although the dermal absorption of PFAS can occur to a limited extent (refer to Section 5.4), dermal uptake makes a negligible contribution to PFAS exposure under normal circumstances. The dermal absorption of PFAS compounds by people coming into direct contact with surface water or groundwater is therefore not an exposure pathway of concern for this QHHRA.

– The majority of the PFAS compounds in the standard analytical suite are non-volatile and therefore the inhalation of PFAS vapours into the lungs of people using downstream surface water or extracted groundwater is expected to be limited. It is possible that dissolved PFAS could condense within the respiratory tract during activities such as irrigation, resulting in intake of dissolved PFAS. These kinds of exposures would however be negligible in comparison to the exposures that would be associated with pathways such as ingestion. Absorption by people following the inhalation of waterborne PFAS is therefore not an exposure pathway of concern for this QHHRA.

– Due to the bioaccumulative nature of PFAS, the incidental ingestion or inhalation of soil/dust in areas subject to irrigation with extracted Ōtokia Creek surface water would make a minimal contribution to PFAS exposure, relative to the intentional consumption of food.

5.3.4 Conceptual site model summary

In summary, based on the modelling and screening assessment (Section 4.4), the primary CoPC for this QHHRA are PFOS, PFHxS and PFOA. The PFAS exposure risks associated with the beneficial use of Ōtokia Creek surface water have been assessed in the detailed QHHRA including:

– Irrigation and consumption of homegrown produce (fruit and vegetables).

– Livestock watering and consumption of livestock and/or livestock products (e.g., eggs, milk, meat).

– Use of the Ōtokia Creek, including recreational use and the gathering and consumption of aquatic biota.

5.4 Toxicity assessment

A toxicity assessment determines whether human exposure to a chemical could cause an increase in the incidence of an adverse health condition (enHealth, 2012b). The outcomes of the toxicity assessment process are a set of toxicity criteria that are compared with exposure estimates to evaluate chemical exposure risks.

In accordance with enHealth (2012b), the toxicity assessment for this QHHRA includes two elements:

1. *Hazard Identification*, which examines the capacity of PFOS, PFHxS and PFOA to cause adverse health effects.
2. *Dose Response assessment*, which examines the quantitative relationships between PFOS, PFHxS and PFOA exposure and health effects.

Reference has been made primarily to the toxicological information published by FSANZ (2017). Consideration has also been given to pertinent information from the following sources:

– US Agency for Toxic Substances and Disease Registry (ATSDR).
– International Agency for Research on Cancer (IARC).
– European Food Safety Authority (EFSA).
– Published scientific literature.

5.4.1 Hazard identification

Numerous studies have been undertaken into the possible health effects of PFAS in humans. Most human studies attempt to identify a relationship between levels of PFAS in the blood and a health effect, but results to date (at the time of preparing this QHHRA) have been inconsistent. Additional difficulties arise when seeking to extrapolate from animal to human studies, as humans and animals have been found to react differently to exposure to PFOS and PFOA and differences in the toxicokinetics observed (ATSDR, 2021).

Acute toxicity

Acute exposures are typically defined as those occurring over a period of 14 days or less. Risk assessments generally focus on chronic effects, but acute effects can be important in some circumstances and should not be ignored in hazard identification process.

The limited data available for humans has not identified acute toxicity associated with exposure to PFOS, PFHxS or PFOA through inhalation, ingestion, dermal or ocular contact (ATSDR, 2021) and the potential PFAS concentrations in surface water downstream of the site have been predicted to be low (Section 4.4). Acute exposures have therefore not been considered further in this QHHRA.

Chronic toxicity – animal studies

Animal studies have indicated that chronic exposure of PFOS in mice, rats and monkeys can result in increased liver weight, liver cell hypertrophy, histopathological changes to lungs, decreased hormone levels and immunotoxicity (Bae, Kim, Schisterman, Barr, & Buck, 2015; FSANZ, 2017). Reproductive and developmental toxicity have also been observed in animal studies, but generally at doses similar or only marginally lower than that which also produced maternal toxicity (ATSDR, 2021; EFSA, 2020). EFSA (2020) concluded that PFOS has been shown to cause a reduced response to vaccination (T-cell dependent antibody response) at doses where no other toxicity was evident.

Limited animal studies have indicated that chronic exposure to PFHxS in rats can result in increases liver weights, histopathological changes to lungs and thyroid glands and haematological effects (Butenhoff, Chang, Ehresman, Chang, & York, 2009; FSANZ, 2017).

The predominant effects identified for PFOA in rodents have also been adverse effects on the liver, via a mechanism that FSANZ (2017) does not consider occurs in humans. Other effects of PFOA in animal studies include effects on body and organ weights, immunotoxicity and hypoglycaemia FSANZ (2017). Similarly, to PFOS, reproductive and developmental toxicity, including decreased offspring weights and neurodevelopmental effects have also been observed in animal studies for PFOA at doses lower than those associated with maternal toxicity (ATSDR, 2021).

Limited data is available to evaluate the toxicity of many of the other individual PFAS compounds, but ATSDR (2021) and EFSA (2020) identified animal toxicological studies on perfluoroalkyl carboxylates (PFCAs) – e.g., perfluorohexanoic acid (PFHxA), perfluorobutanoic acid (PFBA), and perfluoroheptanoic acid (PFHpA) – perfluoroalkyl sulfonates (PFSAs) including perfluorobutane sulfonic acid (PFBS) and perfluorooctane sulfonamide (FOSA). The toxic effects of compounds other than PFOS have generally been identified in animal studies undertaken on these compounds at doses several orders of magnitude higher than for PFOS and PFOA, but the dataset for these other compounds is limited (EFSA, 2020; ATSDR, 2021).

Chronic toxicity – epidemiological studies

Epidemiological studies typically involve the analysis of associations between PFAS exposure (e.g. concentrations in environmental matrices and humans) and human diseases and health endpoints.

The Australian Government commissioned an independent Expert Health Panel to identify potential health impacts associated with PFAS exposure and to identify priority areas for further research (Buckley, Sim, Douglas, & Håkansson, 2018). This panel found that scientific research indicated consistent links between human exposure to PFAS and the following health effects:

– Increased levels of cholesterol in the blood.
– Increased levels of uric acid in the blood.
– Reduced kidney function.
– Alterations in some indicators of immune response.
– Altered levels of thyroid hormones and sex hormones.
– Later age for starting menstruation in girls and earlier menopause in women.
– Lower birth weight in babies.

Notably, the differences in health effects reported in the scientific literature between people who have experienced high and low levels of PFAS exposure were generally small, with the health of the people with the highest exposure generally still within normal ranges for the general population. The Panel concluded that "*there is mostly limited or no evidence for any link with human disease*". These conclusions are generally consistent with those reported by FSANZ (2017) for epidemiological studies.

In a recent review undertaken by EFSA (2020) it was concluded that epidemiological studies provide evidence for an association between exposure to PFAS and increased serum levels of cholesterol. Associations between PFAS exposure and increased serum levels of the liver enzymes were also identified but the magnitude of these associations was small (~3%) and there were no associations identified with liver disease. EFSA (2020) also concluded that epidemiological studies provide insufficient evidence of associations between PFAS exposure and reproductive outcomes, neurodevelopment outcomes, growth in infancy or childhood, neurobehavioral, neuropsychiatric, cognitive outcomes, thyroid function, changes in kidney function or serum levels of uric acid.

Overall, all the reviewing bodies identified that there was limited epidemiological information available for compounds other than PFOS and PFOA.

Carcinogenicity

At the time of reporting, neither PFOS nor PFHxS had been classified as carcinogenic by the IARC. Increased liver tumour incidence has been reported in rats following exposure to PFOS, but this occurs at doses higher than those at which other effects have been observed (EFSA, 2020). The weight of evidence from *in vitro* and *in vivo* genotoxicity studies also suggests that this occurs through non-genotoxic mechanisms (EFSA, 2020; FSANZ, 2017). The ATSDR (2021) and EFSA (2020) also noted that human epidemiology studies did not find a consistent correlation between PFOS exposure and cancer incidence in occupational and general population studies.

Studies have shown that elevated PFOA serum levels have been associated with kidney and testicular cancer, and PFOA is classified by the IARC (2016) as '*possibly carcinogenic to humans*' (Group 2B). Occupational and community exposure studies have found increases in the risk of testicular and kidney cancer associated with PFOA (ATSDR, 2021). PFOA is however not deoxyribonucleic acid (DNA)-reactive and gives negative results in the majority of in vitro and in vivo genotoxicity tests, providing strong evidence that direct genotoxicity is not a mechanism of PFOA carcinogenesis (IARC, 2016).

Buckley *et al.* (2018) concluded that "*there is no current evidence that suggests an increase in overall cancer risk [in association with PFAS exposure]*" but notes the possible link of PFOA to increased incidence of kidney and testicular cancers. FSANZ (2017) concluded that the weight of evidence from a range of genotoxicity studies suggests that PFOS and PFOA are not genotoxic, which is consistent with the conclusions reached by EFSA (2020). EFSA (2020) also concluded that, although data for other PFAS are limited, structural similarities to PFOS and PFOA suggest that a direct genotoxic mode of action is unlikely.

Overall, the available toxicological information on PFAS suggests threshold toxicity as opposed to non-threshold toxicity. As such, a threshold approach has been adopted in this QHHRA for the PFAS dose response assessment, in line with the approach adopted by FSANZ (2017) and other international jurisdictions.

Toxicokinetics

Gastrointestinal absorption

In animal studies, PFOS and PFOA are rapidly and virtually completely absorbed (>95%) through the gastrointestinal tract. The limited data that is available for PFHxS also suggests rapid and virtually complete (>95%) gastrointestinal absorption (FSANZ, 2017). Similar patterns of gastrointestinal absorption have been reported for other PFSAs, including PFHxS, and for PFCAs including PFHxA, PFBA and PFHpA (EFSA, 2020). On this basis, it has been assumed that 100% of PFAS in water matrices (e.g., surface water and groundwater) may be absorbed into the gastrointestinal tract.

Dermal absorption

The functional groups of some PFAS compounds can dissociate into anions or cations in aqueous solution, depending upon pH. Due to their low acid dissociation constants, PFAS compounds such as PFOS and PFOA are predominantly present in a dissociated state in the aqueous phase, under typical environmental conditions (ITRC, 2022). The dermal permeability of chemicals is influenced by the state of ionization, with non-ionized forms of chemicals being more readily absorbed than the dissociated forms (USEPA, 2004). Hence, although limited data is available regarding the propensity of PFAS to be absorbed through the skin, it is expected that, under normal conditions, the dermal absorption of these compounds is negligible.

In two studies cited by ATSDR (2021) and EFSA (2020), 0.05% of the dose of PFOA applied to skin was absorbed under normal conditions. The estimated dermal penetration coefficients from these studies were approximately 1×10^{-6} centimetres per hour (cm/hour) (Fasano, et al., 2005) and 4.4×10^{-5} cm/hr (Franko, Meade, Frasch, Barbero, & Anderson, 2012), with the latter value estimated for PFOA dissolved in acetone and for skin pre-treated with glycerol, both of which may have enhanced PFOA absorption.

While dermal permeability data was not identified for PFOS or PFHxS, the dermal permeability of these compounds is also expected to be low under normal environmental and skin conditions.

Distribution and elimination

Following absorption, PFAS are widely distributed in the body, with the highest concentrations generally found in the liver, kidneys, and blood. PFAS can also be transferred to the foetus during pregnancy and to nursing infants. In vivo and in vitro studies suggest that PFSA and PFCA are not metabolised within the body (ATSDR, 2018).

Elimination of PFAS occurs primarily in the urine. In humans, the estimated half-lives for short-chain PFAS (such as PFBA and PFHxA) range from a few days to approximately one month, whereas for compounds with a long perfluoroalkyl chain length (such as PFOA, PFHxS or PFOS), it can be several years (EFSA, 2020). The estimated range of half-lives for elimination of PFOA, PFOS and PFHxS, as presented by Pizurro *et al.* (2019) are 2.3 to 8.5 years, 3.3 to 5.4 years and 5.3 to 15.5 years respectively.

5.4.2 Dose response assessment

Chronic health risks for threshold toxicants are assessed by comparing the estimated intake doses with toxicity reference values (TRVs). For threshold chemicals, TRVs are a measure of tolerable daily exposure and include values that are referenced by different agencies using a range of terms, including acceptable daily intake (ADI), tolerable daily intake (TDI), reference dose (RfD) or minimal risk level (MRL).

All of these values estimate the daily dose of a chemical to the human population (including sensitive subpopulations) that is likely to be without risk of deleterious non-cancer effects during a lifetime. TRVs for PFOS, PFHxS and PFOA are typically expressed in ng/kg of body weight/day.

The derivation of TRVs is a two-step process:

1. Defining a point of departure (POD).
2. Extrapolating from the POD for relevance to human exposure.

For threshold compounds the POD for the dose response assessment is typically the no-observed-adverse-effect level (NOAEL) or lowest-observed-adverse-effect level (LOAEL) derived from relevant animal or human data. To derive the TRVs for threshold health effects, the POD is typically adjusted downwards (i.e., made more conservative) to account for the uncertainty that is associated with extrapolation from experimental animals to humans and to account for the variability in the health responses of individuals. Downwards adjustments are also made to the POD in response to limitations in the available toxicological dataset (e.g., limited study durations or the absence of studies addressing specific potential endpoints) and when the POD is a LOAEL rather than a NOAEL. The adjustments are made using uncertainty factors (UF) of up to 10 for each potential source of uncertainty.

FSANZ (2017) developed TRVs for oral exposure to PFOS+PFHxS and PFOA, based upon the results of laboratory animal studies, with uncertainty factors applied to account for interspecies differences in toxicodynamics and differences between human populations. Due to the variability in half lives of these compounds by species, a pharmacokinetic modelling approach was used in conjunction with the NOAELs derived in animal studies to derive the following TRVs:

– For PFOS, FSANZ (2017) has recommended a TRV of 20 ng/kg bw/day based on decreased parental and offspring body weight gains in a multigeneration reproductive toxicity study in rats. The TRV was derived by applying pharmacokinetic modelling to the serum PFOS concentrations measured in experimental animals at the NOAELs in these and other critical studies, to calculate human equivalent doses (HED). An uncertainty factor of 30 was applied to the HED, which comprised a default factor of 3 to account for interspecies differences in toxicodynamics and a default factor of 10 for intraspecies differences in the human population.
– For PFHxS, there was insufficient toxicological and epidemiological information to derive a TRV. In the absence of a TRV, it is reasonable to conclude that the enHealth (2016) approach of using the TRV for PFOS is likely to be conservative and protective of public health as an interim measure. Effectively, this means that PFHxS and PFOS should be summed for the purposes of a dietary exposure assessment and risk characterisation.
– For PFOA FSANZ (2017) has recommended a TRV of 160 ng/kg bw/day based on fetal toxicity in a multigeneration reproductive and developmental toxicity study in mice. The TRV was derived by applying pharmacokinetic modelling to the serum PFOA concentrations measured in experimental animals at the NOAELs in these and other critical studies, to calculate HED. An uncertainty factor of 30 was applied to the HED, which comprised a default factor of 3 to account for interspecies differences in toxicodynamics and a default factor of 10 for intraspecies differences in the human population.

The FSANZ (2017) TRV adopted in this QHHRA is detailed in Table 5.2.

Table 5.2 Summary of adopted Toxicity Reference Values (FSANZ, 2017)

Chemical	Toxicity Reference Values
PFOS, PFHxS (sum)	20 ng/kg/day
PFOA	160 ng/kg/day

Dose response uncertainties

A variety of international jurisdictions have assessed the toxicity of PFOS and PFHxS and published TRVs. The TRVs established for PFOS and PFHxS by EFSA (2020) and ATSDR (2021) are lower than the values recommended by FSANZ (2017). The primary difference between the PFOS+PFHxS TRV derived by FSANZ (2017) and the values proposed by EFSA (2020) and ATSDR (2021) is the approach used to incorporate immunotoxicity, as follows:

– The TRV adopted by EFSA (2020) (0.63 ng/kg/day; applicable to the sum of PFOS, PFHxS, PFOA and PFNA) is based on two human epidemiological studies. A study with children on the Faroe Islands showed various associations between the serum levels of individual PFAS and the sum of these four compounds and antibody responses against diphtheria and tetanus vaccinations (Grandjean, et al., 2012). In addition, a more recent study on children from Germany (Abraham, et al., 2020) showed an inverse association between serum levels of PFOA and the sum of PFOA, PFNA, PFHxS and PFOS, and antibody responses against haemophilus influenzae type b, diphtheria, and tetanus in 1-year-old predominantly breastfed children.
– The PFOS TRV adopted by ATSDR (2021) (2 ng/kg/day) is based on similar toxicity endpoint to those referenced by FSANZ (2017) but an additional uncertainty factor of 10 was applied to account for the fact that immunotoxicity may be the most sensitive toxicity endpoint for PFOS exposure, as the serum PFOS levels associated with altered immune responses in animal studies are up to approximately 10 times lower than the serum concentration predicted to occur at the NOAEL for other critical endpoints.
– FSANZ (2017) acknowledged the potential immunotoxicity associated with exposure to PFAS exposure, noting that there are both positive and negative studies showing associations for increasing concentrations to compromise antibody production in humans. Based on a review of the available studies undertaken by Drew and Hagen (2016) however, FSANZ (2017) concluded that PFOS and PFOA effects on vaccine response are weak and not consistent for all vaccines. FSANZ (2017) also concluded that there is no convincing evidence for increased incidence of infectious disease associated with PFAS effects on human immune function, as the epidemiological studies that have observed decreased antibody response have not found significant increases in infection rates. In particular, Drew and Hagen (2016) noted that the NOAEL serum PFAS concentrations derived by Grandjean *et al.* (2012) are very low and that a number of environmental pollutants (e.g., polychlorinated biphenyls and mercury) could have been associated with altered levels of various antibodies in children.

Overall, the approach adopted by FSANZ to the potential immunotoxicity of PFOS+PFHxS is more pragmatic than that recently adopted by EFSA (2020) and ATSDR (2021). FSANZ[1] has undertaken a review of recent studies concerning the potential of PFAS to affect the human immune system. The review evaluated the relationship between PFAS and immune response to vaccinations, susceptibility to infections, and hypersensitivity responses, including allergy. The review concluded that new epidemiological studies provide some evidence of statistical associations between PFAS blood levels and impaired vaccine response, increased susceptibility to infectious disease and hypersensitivity responses but that causal relationships could not be established. At the time of reporting, based on this review, FSANZ did not consider immunomodulation as a suitable critical endpoint for quantitative risk assessment for PFAS and therefore the FSANZ (2017) TRVs are considered appropriate and have been adopted in this QHHRA.

5.5 Exposure assessment

The aim of the exposure assessment process is to produce estimates of the PFAS exposure that may be experienced by people using the Ōtokia Creek, with the receptors identified from general understanding of the environmental and land-use setting, and information provided in submissions on the Smooth Hill landfill. In this stage of the QHHRA, the understanding of potential sources, pathways for exposure and receptors referred to as the conceptual site model (CSM) is used to generate exposure assumptions for each exposure pathway, which are used in conjunction with site-specific exposure point concentrations and exposure modelling algorithms to estimate intakes of contaminants by the exposed receptors.

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1 https://www.foodstandards.gov.au/publications/Documents/PFAS%20and%20Immunomodulatory%20Review%20and%20Update%202021.pdf

Potential human health risks within the Assessment Area have primarily been sourced from the guidance provided by MfE (2011). Exposure parameters presented in national and international guidance documents and published reports and based on reasonable, professional judgement regarding realistic exposure scenarios have also been used to select appropriate exposure inputs, for scenarios not specifically addressed by MfE (2011).

5.5.1 Exposure scenarios

The CSM identified that Ōtokia Creek surface water may be used for a variety of purposes including:

– Livestock watering and the possible domestic consumption of livestock products (meat, milk and eggs).
– Irrigation and the possible domestic consumption of fruit and vegetables.
– Recreational purposes, such as swimming and the gathering and consumption of aquatic biota.

The QHHRA has assessed the potential combined PFOS+PFHXS and PFOA exposure that may occur in association with all of these exposure pathways.

5.5.2 Background exposure to PFAS

Overview

Exposures to PFOS+PFHxS and PFOA may be associated with releases attributable to identified sources of contamination, as well as impacts that originate from other sources in the wider environment and exposure in occupational settings. Typical sources of PFAS exposure in New Zealand are as follows:

Specific identifiable sources

– **Point sources**: Near facilities where PFAS have been extensively used (e.g. Defence bases or major airports) high PFAS levels may be found in the environment. To date, substantial sources of PFAS contamination, external to the site, have not been identified in the Investigation Area.
– **Occupational exposure:** Historically, PFAS was a major component of products such as firefighting foams and therefore a number of occupational groups (e.g., firefighters) experienced higher PFAS exposures than the general population. These kinds of exposures have however decreased in recent years, as PFAS is phased out of these kinds of products.

General sources

– **Household products**: PFAS are widely used in many common household products and specialty applications and therefore most people living in developed nations have some PFAS in their body that is related to the day-to-day use of products containing PFAS. Concentrations of PFOS in blood serum have been decreasing over time, following a reduction in production and use of PFOS containing products (ATSDR, 2021; EFSA, 2020).
– **Wider environmental sources:** Due to the widespread distribution, mobility and persistence of PFAS in the environment, these compounds are ubiquitous in the waterways of urban environment and are frequently found in potable and non-potable water supplies and in the human food chain. For most people, food is the primary source of exposure to PFAS (EFSA, 2020).

Consistent with the guidance provided by MfE (2011), these other sources of exposure should be included in the QHHRA. It is standard practice internationally to include a factor in the development of water quality standards, termed the Relative Source Contribution (RSC). The drinking water standards presented in the PFAS NEMP were derived in association with a default RSC of 0.1, which assumes that a person gets only 10% of their daily PFAS exposure from drinking water, with the other 90% assumed to come from other sources (e.g. food, soil). The use of an RSC of 10% is not however appropriate for use in a QHHRA such as this, that incorporates site-specific estimates of PFAS exposure via multiple pathways.

Background exposure studies

A variety of studies have been undertaken within New Zealand and internationally on background PFAS exposures. Key studies are summarised herein.

Based on Australian biomonitoring data collected between 2010 and 2011, a report prepared by the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE, 2017) estimated a background intake rate of 0.89 ng/kg per day for PFOS. This value represents approximately 4.5% of the TRV presented in Section 5.4.2.

A recent study undertaken on the general population in Norway by Poothong *et al.* (2020), assessed the relative PFAS exposure associated with the ingestion of food and drinks, inhalation of air, ingestion of dust and dermal absorption. Although a high degree of variability was noted between study participants and PFAS exposures were generally very low, diet was the predominant exposure pathway. For PFOS 95% and 3% of the total PFOS intake came from dietary intakes and air inhalation, respectively, with dust ingestion and dermal absorption contributing less than 1% of the PFOS total intake.

EFSA (2020) undertook an evaluation on the risks to human health related to the presence of PFAS in food, which included measuring the PFAS concentration in over 90,000 food samples from 16 countries. This study indicated that the mean PFAS concentrations measured in food were of the most relevance to the assessment of PFAS exposures at a population level and the lower bound exposure estimates aligned most closely to the available data on PFAS concentrations in human blood. The mean lower bound dietary PFAS exposure estimates across surveys and age groups were generally similar and can be summarised as follows:

– PFOS: 0.23 – 2.6 ng/kg/day (1.2% to 13% of the TRV presented in Section 5.4.2).
– PFHxS: 0.04 - 0.36 ng/kg/day (0.2% to 1.8% % of the TRV presented in Section 5.4.2).

The groups with the highest dietary exposures, when expressed in units of ng/kg/day were young children and the very elderly. Seafood was the primary source of PFAS exposure in the majority of the populations studied, with PFAS concentrations in freshwater fish being greater than those in marine fish. EFSA (2020) reported that dietary PFAS exposure was dominated by PFOS, PFHxS, PFOA and PFNA, with these compounds contributing to 46% of total dietary PFAS exposure.

A dietary exposure assessment was undertaken for PFAS by New Zealand Food Safety (2018), including the PFAS testing of 12 food groups (vegetables, dairy product, meats, takeaway foods and seafood). A single PFAS, perfluorohexanoic acid (PFHxA), was found in a beef rump steak sample, with no samples reporting detections of PFOS, PFHxS or PFOA. An assessment of exposure of to PFOS, PFHxS and PFOA, undertaken using hypothetical concentrations up to the analytical limit of reporting (LOR) concluded that there was negligible dietary exposure or dietary exposure risk. The theoretical upper bound mean exposure PFOS+PFHxS exposure estimates did not exceed 12% of the TRV for any of the population cohorts, while that for PFOA was below 1% of the TRV.

Similarly, the *24th Australian Total Diet Study (ATDS)* (FSANZ, 2016) included the analysis of PFAS in a range of foods sampled from a range of different retail outlets representing the buying habits of most of the community. The ATDS reported no detections for PFOA and only two detections for PFOS out of 50 foods tested and the concentrations of PFOS were at very low levels (1 part per billion). On this basis, FSANZ (2017) concluded that dietary exposure to PFAS from the general food supply is likely to be low, with substantial PFAS exposure from food generally only likely to occur at PFAS contaminated sites.

Thompson *et al.* (2010) outline a pharmacokinetic modelling approach to characterize exposure of Australians to PFOS. Key parameters for this model include the elimination rate constants and the volume of distribution within the body and the serum concentrations of PFOS measured in the Australian population. The pharmacokinetic modelling estimated PFOS intake rates of between 1.1 – 2.3 ng/kg/day, for males and females aged 11 to 75 years (*note that these values were presented in a corrigendum to the primary paper*). The average intake rate of 1.5 ng/kg/day represents 7.4% of TRV presented in Section 5.4.2. The authors of the paper note that physiological differences between adults and children mean that the children (<11 years), who were not included in the study, could demonstrate higher chemical intake rates than adults when expressed per unit of body weight.

Background exposure estimates

Overall, the available studies suggest that background exposures to PFAS in the general New Zealand population are likely to be very low and that the background exposures that do occur are likely to occur primarily via the dietary pathway. The background exposure estimates for PFOS+PFHxS, made based on the studies outlined above range from negligible (New Zealand Food Safety, 2018; dietary exposure to PFOS+PFHxS and PFOA in New Zealand) to 14.8% (EFSA, 2020; upper end of the range of mean dietary exposures estimates across survey and age groups in Europe).

A background exposure assumption of 10% has been adopted in this QHHRA, as a reasonable representation of the long-term background exposures that may be experienced by the New Zealand population.

5.5.3 Bioavailability

Bioavailability is the proportion of the intake of a substance, which is absorbed into the body. 'Bioavailability' can be separated into two distinct elements:

1. The ability of the substance to be liberated from a medium (e.g., plant or meat) within the gut or lung - often referred to as the bio-accessibility.
2. The ability of the substance to enter the bloodstream and be taken up by the body organs, once it has entered the lung or gut - this is often referred to as bioavailability (NEPC, 2013).

The toxicity data derived from experiments involving direct oral administration of PFAS to an animal or human intrinsically incorporates bioavailability as defined in Point 2 above. There has been limited research into bioaccessibility of PFAS in different media and therefore a conservative assumption of 100% bioaccessibility has been adopted in this assessment.

5.5.4 Exposure parameters

The approaches outlined by MfE (2011) have been used to select exposure assessment inputs that are adequately protective of people using the Ōtokia Creek downstream from the site, as follows:

– General physical characteristics and dietary ingestion rates have been sourced from MfE (2011), enHealth (2012a; 2012b) and FSANZ (2017).
– Dietary ingestion rates for aquatic biota have been sourced from reports prepared by the National Institute of Water and Atmospheric Research (NIWA, 2011), Ministry for Primary Industries (MPI, 2018) and Toxconsult (2013).
– MfE (2011) provides behavioural and exposure duration assumptions for standard exposure scenarios and these have also been adopted in this assessment for the rural residential exposure setting.
– Professional judgement and consideration of the site-setting has been used to select exposure parameters relevant to the production and consumption of home-grown livestock products, which are not specifically addressed by MfE (2011).

The exposure parameters incorporated into the QHHRA are detailed in Appendix C. Site-specific parameters are discussed in Section 5.5.5 below. The uncertainty associated with key exposure parameters has been evaluated in the sensitivity analysis (Section 5.7).

5.5.5 Exposure assessment calculation

Non-potable water intake

Users of Ōtokia Creek surface water may potentially ingest small volumes of water during activities such as swimming or irrigation. The incidental ingestion of water would generally be expected to make only a minor contribution to overall water intake.

enHealth (2012b) recommends average incidental ingestion rates of 25 mL/hr and 50 mL/hr respectively for adults and children swimming. These values have been adopted in this QHHRA in conjunction with the assumption that users of the Ōtokia Creek may spend up to 1 hr per day undertaking activities that may involve the incidental ingestion of surface water.

Watering domestic chickens

The CSM (Section 5.3) identified that people may be exposed to PFAS in surface water via the consumption of eggs laid by domestic chickens watered from the Ōtokia Creek. This Source-Pathway-Receptor linkage has therefore been included in this QHHRA.

The relationship between water sourced from the creek and the PFAS exposure that is associated with domestically produced chicken eggs has been estimated using the methodology presented by US EPA (2005). This guidance document provides an approach for estimating concentrations in chicken eggs, based on the measured concentrations in their diet (grain, water and incidental soil ingestion). For this QHHRA, it is assumed that chickens would be fed with commercially bought feed (not associated with water sourced from the creek). PFAS concentrations in the soil in the areas used by the chickens are also assumed to be low.

The critical factor determining the influence of PFAS concentrations in water on the PFAS concentration in chicken eggs, is the efficiency with which PFAS is transferred from the water consumed by laying chickens to their eggs. The Australian Department of Defence (2017a) completed a study in association with the RAAF BASE Williamtown (NSW) PFAS Investigation, examining the relationship between the PFAS concentrations in chicken eggs and the PFAS concentrations in their drinking water. The study involved 119 hens that were provided drinking water with different concentrations of PFAS. The outcomes of this study were adopted in this assessment were as follows:

– The amount of PFOS transferred to eggs each day was estimated, on average, to be equal to the amount of PFOS ingested by a chicken via their drinking water each day, with the majority of PFOS transferred to the yolk.
– Approximately 70% of PFHxS consumed by the hen each day via their drinking water was transferred to the egg.
– Approximately 45% of PFOA consumed by the hen each day via their drinking water was transferred to the egg.

The egg transfer factor estimated by DoD (2017a) for PFOS aligns with those reported for both PFOS and PFHxS in a study undertaken by Kowalczyk *et al.* (2020) on the transfer of these compounds from feed into chicken eggs. Therefore, the DoD (2017a) transfer factor for PFOS has been adopted for both PFOS and PFHxS in this HHRA.

The egg consumption rates recommended by MfE (2011) have been used to estimate the human exposure risks associated with the consumption of domestically produced eggs. These inputs equate to double the average egg consumption rates reported for New Zealand, this value being arbitrarily chosen as being a more likely estimate for those households that run poultry. It has been assumed that rural/residential households could source up to 25% of their fruit and vegetables from household sources, in accordance with the MfE (2011) default assumption.

A detailed description of the egg transfer modelling algorithms and the modelling inputs and outputs is provided in Appendix C.

Irrigating fruit and vegetables

The CSM (Section 5.3) identified that users of the Ōtokia Creek may be exposed to PFAS in surface via the consumption of fruit and/or vegetables irrigated in domestic gardens. This Source-Pathway-Receptor linkage has therefore been included in the QHHRA.

The critical factor determining the influence of PFAS concentrations in irrigation water on the PFAS concentrations in domestically produced fruit and vegetables, is the efficiency with which PFAS is transferred from the water to the irrigated plants. The DoD (2017b) completed a study in association with the RAAF Base Williamtown PFAS Investigation, examining the relationship between the PFAS concentrations in fruit and vegetables and the PFAS concentrations in irrigation water. The study involved a 120-day greenhouse trial where seven plant species, including fruit and vegetables, were grown in greenhouses and irrigated with water containing different PFAS concentrations.

The study developed transfer factors (mg/kg plant per mg/L water) for five of the vegetable species, as follows:

– PFOS: from 0.8 (alfalfa) to 8.1 (radish), with an average of 2.5.
– PFHxS: from 1.4 (lettuce) to 6.9 (beets) with an average of 3.8.
– PFOA: from 1.9 (lettuce) to 9.7 (radish), with an average of 4.9.

The mean transfer factors estimated in a separate study by Felitzer *et al.* (2014) for zucchini and cabbage were lower than those estimated by DoD (2017b) at 0.2 and 0.3 respectively for PFOS and 0.3 for both vegetable types for PFHxS. The higher transfer factors estimated by DoD (2017b) may be related to the elevated salinity of the water used in the study.

The DoD (2017b) study did not yield sufficient data to develop transfer factors for fruit but it was noted that samples of fruit taken during the broader study of the Williamtown area had lower concentrations of the PFAS than the leafy vegetables. This result is consistent with those reported by Felitzer *et al.* (2014), who estimated a mean transfer factor for tomatoes (0.03) that was an order of magnitude lower than those reported for zucchini and cabbage.

The average transfer factors identified by DoD (2017b) have been adopted in this HHRA, to estimate the relationship between the PFAS concentrations in irrigation water and domestically produced fruits and vegetables. This approach is likely to be conservative, given the results obtained by Felitzer *et al.* (2014).

The total fruit and vegetable consumption rates recommended by MfE (2011) have been used to estimate the human exposure risks associated with the consumption of domestically produced plants. It has been assumed that rural/residential households could source up to 25% of their fruit and vegetables from household sources, in accordance with the MfE (2011) default assumption.

A detailed description of the plant transfer modelling algorithms and the modelling inputs and outputs is provided in Appendix C.

Stock watering

Downstream of the site, livestock (cattle or sheep) may be exposed to PFAS by drinking creek water. Individuals living downstream of the site that produce and butcher livestock or consume domestically produced milk may therefore be exposed to PFAS via this Source-Pathway-Receptor linkage.

A critical factor determining the influence of PFAS concentrations in water on the PFAS concentrations in the livestock consuming it, is the efficiency with which PFAS is transferred from the water to livestock blood. Drew *et al.* (2021) studied the accumulation of PFAS in the serum of cattle and sheep raised on a hobby farm impacted by PFAS. The predominant source of PFAS exposure identified in this study was water, with grass and soil making minimal contributions to total PFAS exposure. This finding aligns with the outcomes of an as yet unpublished study in Victoria, Australia (Mikkonen, A, 2022).

Drew *et al.* (2021) derived transfer factors for cattle and sheep by dividing steady state serum PFAS concentration by the PFAS concentration in water, with the average values as follows:

– Cattle: 140 and 65 ng/mL serum per µg/L of water intake for PFOS and PFHxS respectively, with negligible transfer of PFOA from drinking water to serum.
– Sheep (non-pregnant or lactating ewes): 20 and 30 ng/mL serum per µg/L of water intake for PFOS and PFHxS respectively.

The accumulation of PFOS and PFHxS from water by sheep was lower than for cattle, likely due to sheep typically drinking less water per unit body weight than cattle. This HHRA has therefore focused on PFAS bioaccumulation in cattle rather than sheep, as a conservative approach. The transfer factors estimated by Drew *et al.* (2021) for cattle have been adopted, as the extent to which PFAS is transferred to animals will reflect on-farm practices and the setting of the Drew *et al.* (2021) is well aligned with the exposure scenarios present downstream of the site.

Another critical factor determining the influence of PFAS concentrations in water on the PFAS concentrations in the livestock consuming it, is the efficiency with which PFAS is transferred from the blood to edible meats. A study undertaken by Kowalczyk *et al.* (2013) has demonstrated that there are clear relationships between the concentrations of PFAS in the blood of dairy cows and the concentrations of PFAS in their meat, offal and milk. The ratios of the average PFOS and PFHxS concentrations in meat/offal/milk and serum, as reported in this study have been adopted in this assessment as follows:

– PFOS: 0.076 (meat), 1.06 (liver and kidneys - average) and milk (0.013) mg/kg per mg/L serum.
– PFHxS: 0.046 (meat), 0.19 (liver and kidneys – average) and milk (0.007) mg/kg per mg/L serum.

The 90th percentile meat and offal consumption rates reported by FSANZ (2017) have been used to estimate the human exposure risks associated with the consumption of livestock watered with water sourced from the creek downstream of the site, to reflect the relatively high meat consumption rates that may occur when animals are butchered for homegrown consumption. It has also been assumed that households could source up to 25% of their meat from household sources, in accordance with the MfE (2011) default assumption for rural/residential properties.

A detailed description of the livestock transfer modelling algorithms and the modelling inputs and outputs is provided in Appendix C.

Aquatic biota consumption

The CSM (Section 5.3) identified that users of the Ōtokia Creek may be exposed to PFAS in surface via the consumption of aquatic biota. This Source-Pathway-Receptor linkage has therefore been included in the QHHRA.

Bioconcentration and bioaccumulation both occur when the concentration of a chemical builds up in the tissues of an organism faster than it is removed. Bioconcentration refers specifically to the absorption of the chemical directly from an abiotic media, whereas bioaccumulation also incorporates the absorption of the chemical from food. Bioconcentration and bioaccumulation are quantified as follows:

– Bioconcentration is quantified via a bioconcentration factor (BCF), which defined as the concentration of a substance in the tissue of an aquatic organism divided by the concentration in water.
– Bioaccumulation is quantified via a bioaccumulation factor (BAF), which is also defined as the concentration of a substance in the tissue of an aquatic organism divided by the concentration in water, in scenarios where both abiotic media and food chain exposures contribute to chemical exposure.

In this QQRA, the potential for PFAS to bioaccumulate in aquatic biota tissue has been estimated using BAFs, sourced from the published scientific literature and publicly accessible reports. A variety of species inhabit the Otokia Creek and may be subject to human consumption, including short and long-fin eels, fish, (e.g., kokopu, bully fish), freshwater shrimp and aquatic plants such as watercress. For simplicity, single animal and plant species have been selected to represent this Source-Pathway-Receptor linkage.

MfE (2018) provides a summary of the BAF estimated for a variety of aquatic species, on the basis of New Zealand studies that incorporated co-located PFAS concentrations in surface water and biota. All of these studies were reported in consultants reports that are not publicly available. The BAF data presented by MfE (2018) for freshwater environments is summarised in Table 5.3. MfE (2018) does not provide BAF for freshwater aquatic plants.

Table 5.3 Summary of BAF data reported by MfE (2018)

Organism type	BAF (L/kg)	
	PFOS+PFHxS	PFOA
Freshwater fish	23 - 591	Not detected
Freshwater eel	9 - 727	4 - 69

The data presented by MfE (2018) demonstrates that long fin eels can be particularly susceptible to PFAS bioaccumulation and eels have therefore been selected as the indicator for the assessment of the human health risks associated with the bioaccumulation of PFAS in aquatic animals. This aligns with the characteristics of these organisms, with the following factors expected to contribute to their sensitivity to PFAS bioaccumulation[2]:

– Lifespan: longfin eels can live for several decades
– Habitat: longfin eels can inhabit freshwater environments, well inland, with limited potential for flushing
– Foraging habits: long fin eels forage predominantly on the substrate, in close association with sediment, where PFAS can accumulate
– Diet: long fin eels are predominantly carnivorous, feeding on insects, worms and snails as juveniles and fish, crustaceans and birds as adults.

Watercress has been selected as the indicator species for the assessment of the huma health risks associated with the bioaccumulation of PFAS in aquatic plants.

[2] https://www.doc.govt.nz/nature/native-animals/freshwater-fish/eels/

A review of publicly available data has been undertaken to identify studies that report co-located PFAS concentrations in surface water and eels and to estimate BAF from this data. BAF have been calculated based on the mean PFAS concentrations measured in eel fillets and surface water. It is noted that PFAS in sediment and in the diet will also contribute to the concentrations measured in eel tissue but that the estimated BAF values provide a snapshot of the levels of PFAS bioaccumulation that can be expected in eel populations in different environments.

PFAS bioaccumulation data specific to watercress was not identified for watercress and therefore the BAF relevant to freshwater aquatic plants generally were considered.

The range of identified BAF are summarised in Table 5.4

Table 5.4 Summary of mean PFAS BAF calculated from the published literature for eels

Study	PFOS BAF (L/kg)	PFHxS BAF (L/kg)	PFOA BAF (L/kg)
Eels			
RAAF Base East Sale PFAS Investigation (DoD, 2017c)	**7470**	174	**168**
Unpublished New Zealand study, referenced by MfE (2018)	727		Not detected
Field study after an AFFF airport at an airport in the Netherlands, described by Kwadijk *et al.* (2010; 2014)	234 - 3236	112 - **354**	12- 13
Field study in a captive (pond) environment in China, described by Wang *et al.* (2013)	1100	No data	59
Field study of canals, rivers and streams in Belgium, as described by Teunen *et al.* (2021)	7067	No data	No data
Freshwater aquatic plants			
RAAF Base East Sale PFAS Investigation (DoD, 2017c)	**1162**	**141**	**48**
Freshwater mecocosm study undertaken with macrophytes by Pi *et al.* (2017)	90	28	28
Bold values indicate the BAF adopted in the QHHRA			

Due to the relatively high level of uncertainty associated with this input parameter, the upper end of the range of identified BAF have been adopted in the QQHRA, including values derived from the data collected in the Heart of Morass wetland, which is an inland surface water body that receives surface water runoff from RAAF Base East Sale in Victoria, Australia. It is considered that these values are likely to overestimate PFAS bioaccumulation in a waterbody such as the Ōtokia Creek, which will be subject to greater levels of surface water flow and flushing.

The New Zealand Total Diet Study (MPI, 2018) identified that the mean fresh fish consumption rates for New Zealand adults ranged from 14 – 23 g/day and mean consumption rates of 2 g/day and 3 g /day were identified for children and toddlers respectively. The total fish consumption rates (including canned and frozen fish) reported by MPI (2018) were 41 – 61 g/day for adults, 13 g/day for children and 9 g/day for toddlers.

Dietary surveys undertaken by NIWA (2011) estimated maximum and mean eel consumption rates of 93.3 g/day and 9.6 g/day respectively for TeArawa iwi adults. A maximum eel consumption rate of 20 g/day as estimated for for Arowhenua iwi adults via a community consultation process, Toxconsult (2013) identified that the long-term average eel consumption rate for adults harvesting eels from the Kopeopeo Canal was 68 g/day. No specific data on eel ingestion by children could be found in the literature.

As eel have been used in this QHHRA to provide an indication of the PFAS exposure risks that may be associated with the consumption of aquatic animals, the long term average eel consumption rate estimated by Toxconsult (2013) has been used to estimate the human exposure risks associated with the adult consumption of aquatic animals gathered from within the Ōtokia Creek. Given that the adopted intake rate (68 g/day) is well above the mean total fish consumption rates reported for the New Zealand population (41 – 61 g/day: MPI, 2018) and that this consumption rate has been used in conjunction with the BAF for eels, this approach is considered conservative for the assessment of PFAS exposure risks for all aquatic animals.

In the absence of eel consumption rates specific to children, the mean total fish consumption rate reported by MPI (2018) for children has been adopted in this QHHRA for this receptor group. In conjunction with the use of a BAF specific to eels, this approach is considered likely to be conservative.

Dietary surveys undertaken by NIWA (2011) estimated maximum and mean watercress consumption rates of 90 g/day and 15.8 g/day respectively for Te Arawa iwi adults and the mean value was adopted for this QHHRA to represent long term consumption patterns. No consumption data for watercress by children was found in the literature and therefore this exposure pathway was assessed using 50% of the mean consumption rate for leafy vegetables reported by FSANZ (2017) for young children (2 – 6 years).

It has also been assumed that households could source 75% of the total aquatic animals and plants consumed from the Ōtokia Creek, as a conservative approach.

A detailed description of the aquatic biota modelling algorithms and the modelling inputs and outputs is provided in Appendix C.

5.5.6 Exposure point concentrations

Exposure point concentrations (EPCs) are the predicted chemical concentrations in surface water that have been used in the QHHRA to estimate exposure levels. The PFOS, PFHxS and PFOA concentrations predicted to occur downstream of the site in the water quality assessment (Section 4) have been adopted as the EPCs in this QHHRA. The values from the following locations have been used:

– The man-made pond located approximately 300 m downstream of the edge of the landfill designation, which represents the closest permanent waterbody to the landfill designation (Location 2).
– Ōtokia Creek, north of Big Stone Road (Location 5), which represents the downstream portion of the waterway near the community of Brighton.

5.6 Risk characterisation

5.6.1 Methodology

The purpose of the risk characterisation process is to combine the results of the toxicity and exposure assessments to provide numeric estimates of the potential health risks associated with the possible future release of PFAS from the site into the Ōtokia Creek.

In this QHHRA, potential PFOS+PFHxS and PFOA exposure risks at the predicted worst-case PFAS concentrations in Ōtokia Creek surface water have been estimated by comparing the estimated intakes (calculated via the methodology outlined in Section 5.5) with the threshold TRVs values established in Section 5.4. The ratio of the estimated intake to the TRV for each exposure pathway, is termed a Hazard Quotient (HQ) and all the HQs have been summed to derive an overall Hazard Index (HI). The equations used to derive HI and HQ are detailed in Appendix C.

An HQ equal to 1 represents a scenario where intake estimates are equal to the threshold TRV. In accordance with the approach recommended by MfE (2011), a target HQ equal to 1 has been used to assess exposure risks.

5.6.2 Results

The calculated HIs for adult and child users of Ōtokia Creek surface water are presented in Appendix C and summarised in Table 5.5. These values represent the cumulative PFAS exposure risks that would be occur if individuals were to use surface water for all the purposes identified in the CSM (Section 5.3.4)., including

– Irrigation and consumption of homegrown produce (fruit and vegetables).
– Livestock watering and consumption of livestock and/or livestock products (e.g., eggs, milk, meat).
– Use of the Ōtokia Creek, including recreational use and the gathering and consumption of aquatic biota.

Table 5.5 Summary of risk characterisation outcomes

Receptors	Hazard Indices		
	PFOS+PFHxS	PFOA	Total
Risk characterisation for the estimated worst-case surface water concentrations at the constructed pond (location 2)			
Adults	0.4	0.002	0.4
Children (Toddlers)	0.4	0.002	0.4
Risk characterisation for the estimated worst-case surface water concentrations in the lower reaches of Ōtokia Creek (location 6)			
Adults	0.05	0.0002	0.05
Children (Toddlers)	0.05	0.0002	0.05

The HI estimated for adult and child users were below the acceptable threshold of 1, across the range of likely future beneficial use patterns and considering the worst-case release estimates made in Section 4.4 for a complete failure scenario. These results provide a level of confidence that the release of PFAS from the site represents a low and acceptable exposure risk to people using Ōtokia Creek surface water.

The relative contribution of the various exposure pathways on the risk characterisation outcomes for each exposure pathway are summarised in Table 5.6. Across the range of exposure settings and for both adult and child users of Ōtokia Creek surface water, the potential for PFAS to bioaccumulate in aquatic animals was associated with the majority of the estimated PFAS exposure risk.

Table 5.6 Summary of relative pathway contribution to PFAS exposure estimates

Exposure pathway	Relative contribution to risk estimate			
	Constructed Pond (location 2)		Ōtokia Creek north of Big Stone Road (location 5)	
	Adult	Child	Adult	Child
Incidental water consumption	0%	0%	0%	0%
Poultry watering and egg consumption	0%	0%	0%	0%
Irrigation and produce consumption	0%	1%	0%	0%
Stock watering and meat consumption	1%	1%	1%	1%
Stock watering and offal consumption	1%	0%	1%	0%
Stock watering and livestock consumption	1%	3%	1%	2%
Aquatic animal consumption	93%	88%	94%	90%
Aquatic plant consumption	4%	6%	4%	5%

5.7 Uncertainty and sensitivity analysis

5.7.1 Uncertainty analysis

The uncertainty analysis identifies the assumptions and data gaps associated with the QHHRA. The main areas of uncertainty identified for this assessment include:

– Exposure assessment, including diversity in the communities living downstream of the site, diversity in the water use patterns of individuals and the challenges associated with predicting water quality downstream of the site.
– Toxicity assessment, including the range of TRV adopted internationally for PFOS+PFHxS.
– Risk characterisation, including the use of conservative modelling approaches and assumptions.

The approaches used to reduce the uncertainty associated with this QHHRA have been to use site-specific data wherever possible and to adopt conservative assumptions from reputable Australian and international agencies, in the absence of site-specific data. Health conservative assumptions applied in this assessment include:

- The conservatism detailed in Section 2 relating to the landfill liner failure scenario.
- The use of MfE, enHealth and MPI human behavioural and physical characteristic assumptions.
- The use of toxicological data intended to be well below any threshold for adverse health effects (based on no-observed-adverse-effect levels, with a number of safety factors applied to account for issues such as variability within populations).
- The use of conservative modelling assumptions and approaches.
- The use of background exposure allocations that are likely to overestimate PFAS exposures for the majority of the populations assessed.

Given the factors outlined above, the uncertainty in this assessment has been generally taken into account by erring on the side of the over estimation of potential health risks.

Key areas of uncertainty, which could influence the outcomes of the HHRA include:

- Patterns of aquatic animal consumption.
- The BAF for aquatic biota
- Background exposure assumptions.
- The presence of PFAS other than PFOS+PFHxS in the environment.

The sensitivity of the assessment outcomes to these inputs is further evaluated in Section 5.7.2.

5.7.2 Sensitivity analysis

In a sensitivity analysis, the values of parameters suspected to drive the potential risks are varied and the degree to which changes in the input variables result in changes to the risk estimates are determined. A sensitivity analysis can therefore be used to help characterise uncertainty and to identify the key parameters influencing the assessment of risk. The sensitivity analysis process provides a ‘reality check’ for the data adopted in the risk assessment.

Methodology

The focus in the sensitivity analysis are the key areas of uncertainty detailed in Section 5.7.1. The sensitivity analysis has incorporated adult and child residents, as the risk-driving exposure pathways differ between these receptor groups.

Appendix C presents the results of the sensitivity analysis for key variables, including the following:

- The calculated HI across a realistic range of potential input variables.
- Changes in the HI according to the various inputs.
- An evaluation of the relative variable sensitivity.

Background exposure assumptions

A background exposure allocation of 0.1 has been adopted in this QHHRA, which the available data suggests is likely to be appropriate for the New Zealand population (Section 5.5.2). Background exposure allocations of up to 50% were considered in the sensitivity analysis, with HI<1 derived across the range of values considered. Despite the uncertainty that is associated with this variable, the available data suggests that the RSC should be well below 0.5. This provides a level of confidence that the risk characterisation estimates are likely to be protective of the PFAS exposures that could be experienced by general population living downstream of the site, under a worst-case failure scenario.

Sensitivity analysis results – aquatic biota consumption rates and bioaccumulation factors

Aquatic animal consumption is associated with more than 80% of the PFAS exposures estimated for adults and children in downstream areas. Consideration has therefore been given to the sensitivity of the risk characterisation estimates to the assumed aquatic biota consumption rates and BAF. The results of this analysis can be summarised as follows:

– Aquatic biota consumption rates specific to the Ōtokia Creek were not available at the time of reporting and therefore data relevant to New Zealand more broadly was adopted. Notably, the sensitivity analysis indicates that adoption of aquatic biota consumption rates well above what is considered likely to occur within this waterway did not result in HI estimates greater than 1.
– The BAF adopted in the QHHRA were the highest mean values identified in a review of publicly available studies. The use of BAF values double those identified in this review did not result in HI estimates greater than 1.

Overall, the sensitivity analysis undertaken for aquatic biota exposure parameters provides a level of confidence that the potential release of PFAS from the site is unlikely to be associated with a PFAS exposure risk to the general population using the downstream reaches of the Ōtokia Creek.

Sensitivity analysis results – other PFAS

This QHHRA has focused on the risks associated with human exposure to PFHxS+PFOS and PFOA in downstream surface water. As previously noted, PFHxS, PFOS and PFOA are the predominant PFAS compounds in the environment and the main PFAS to which people are exposed (EFSA, 2020). Compounds other than PFOS, PFHxS and PFOA could however be released from the landfill, including the PFCA compounds perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnDA) and perfluorododecanoic acid (PFDoDa). This creates a level of uncertainty as to the PFAS risk profile for the downstream environment.

To address this uncertainty, the FSANZ (2017) TRV can be used to evaluate the PFAS exposure risks that for PFAS compounds that are likely to have similar physicochemical properties or to degrade to similar stable endpoints. In the case of this QHHRA, the PFOA TRVs can be applied to the assessment of all of the PFCAs based on these compounds having similar structural properties (Buck, et al., 2011). This approach is likely to be conservative, as the limited toxicological data that has been published internationally on PFCA compounds other than PFOA generally indicates that they are less toxic and persistent than these primary compounds (Section 5.4).

A comparison between the PFOA and total PFCA concentrations predicted to occur downstream of the site and the HI values calculated for adult users of Ōtokia Creek surface water using PFOA and total PFCA concentrations are presented in Table 5.7. The HI calculated for the total PFCA concentrations were well below the threshold of 1, indicating that PFAS compounds other than PFOS, PFHxS and PFOA do not significantly affect the risk characterisation outcomes.

Table 5.7 Comparison of risk characterisation outcomes for adult surface water users for PFOA and total PFCAs

Location	Predicted surface water concentration (µg/L)		Hazard Indices	
	PFOA	Total PFCAs	PFOA	Total PFCAs
Farm Pond	0.0016	0.0087	0.002	0.008
Coast Farm	0.00017	0.00062	0.0002	0.0006

5.8 Summary of outcomes

Overall, the QHHRA concluded that the potential risks to human health were low and acceptable, under a theoretical future scenario whereby there was a failure of the landfill liner. The QHHRA was based on a the PFAS concentrations predicted to occur in a worst-case liner failure scenario and considered the potential for people to be exposure to PFAS in the downstream environment daily, via all of the following pathways:

– The ingestion of water while swimming in Ōtokia Creek.

– Consuming eggs from chickens provided water from Ōtokia Creek.
– Consuming fruit and vegetables watered from Ōtokia Creek.
– Consume meat from livestock watered from Ōtokia Creek.
– Consuming milk from cattle watered from Ōtokia Creek.
– Consuming eel meat and water cress harvested from Ōtokia Creek.

Based on this very conservative cumulative assessment, the risk characterisation estimates were well below the acceptable threshold of 1. This means that even in a worst-case liner failure scenario, potential risks to the most highly exposed individuals would be low and acceptable.

This conclusion has been made based on the available data and the uncertainties identified through the report. This QHHRA is subject to, and must be read in conjunction with, the limitations set out in Section 1.4 and the assumptions and qualifications contained throughout the report.

6. Qualitative ecological risk assessment

6.1 Introduction

This section presents a qualitative ecological risk assessment (ERA) for the PFAS impacts to downstream surface water predicted to occur under a potential future landfill liner failure scenario.

HEPA (2020) provides the following screening levels relevant to the assessment of PFOS exposure risk to aquatic ecology, downstream of the site:

– A 95% species protection value of 0.13 µg/L, relevant to the screening level assessment of the potential for direct toxicity in slightly to moderately disturbed waterways, such as the Ōtokia Creek; and
– A 99% species protection values of 0.00023 µg/L, relevant to the screening level assessment of the potential for toxicity to occur in association with indirect (food chain) exposures.

The PFOS concentrations predicted to occur downstream of the site following a liner failure are summarised in Table 6.1.

Table 6.1 Summary of predicted downstream PFOS concentrations (worst-case liner failure scenario)

Location	Predicted PFOS concentrations (µg/L)
1. Northern edge of landfill designation	0.00096
2. Constructed Pond	0.00083
3. McLaren Gully Road Culvert	0.00048
4. East of McLaren Gully Road	0.00024
5. North of Big Stone Road	0.00013
6. Lower Ōtokia Creek Marsh	0.00013
Adopted screening levels	
99% species protection level	0.00023
95% species protection level	**0.13**

The data in Table 6.1 demonstrates that the predicted downstream PFOS concentrations are well below the 95% species protection values. This result provides a high level of confidence that PFOS discharges from the site are unlikely to adversely affect lower trophic level aquatic organisms within the Ōtokia Creek.

Given the predicted exceedances of the 99% species protection levels in the upper reaches of the receiving environment potential however, the potential for bioaccumulation in aquatic food chains in the downstream receiving environments has been evaluated in more detail in this ERA.

A weight of evidence (WoE) assessment is a method for decision-making that involves consideration of multiple sources of information and lines of evidence. ANZG (2018) suggests the use of a WoE approach to ERA in aquatic environments, as this avoids relying solely on any one piece of information or line of evidence and facilitates risk-based decision in the context of complex ecological systems. The lines of evidence considered in an ERA can vary depending on the scenarios assessed and the amount and type of data available.

A WoE approach has been adopted in this assessment, with the lines of evidence assessed including the following:

– The nature of the receiving environment and susceptibility of the aquatic food chain to PFOS secondary poisoning.
– PFOS toxicity, including recent advances in the understanding of multi-generational toxicity.

Consideration has also been given to the magnitude of the predicted downstream concentrations in the context of the range of potential external sources of PFAS to the environment.

6.2 Receptors and exposure

6.2.1 Receptor identification

The water quality assessment provided the PFOS concentrations predicted to occur, for the landfill liner failure scenario, at the following locations:

1. *Northern edge of landfill designation*: This location is a valley floor marsh wetland, considered by Blakely (2022) to form the headwaters of the Ōtokia Creek. Upstream of this point, there are no clearly defined stream beds, with overland surface flow only occurring during prolonged rainfall events. These ephemeral flow paths are not considered to provide habitat for indigenous freshwater fish or macroinvertebrates (Blakely, 2022).
2. *Constructed Pond*: The pond is a human-made structure located approximately 300 m downstream of the edge of the landfill designation. The pond provides perennial habitat for eels, but as the surrounding watercourse is inferred to be intermittent the pond is expected to be disconnected from the catchment during low flow periods (Blakely, 2022).
3. *McLaren Gully Road Culvert:* This location is the section of Ōtokia Creek between the landfill designation and the McLaren Gully Road Culvert, approximately 1.3 km in length. Blakely (2022) described this location as including sections of channel and diffuse flow. Where present, the channel is approximately 200-300 mm wide, but with a total wetted width (within wetland vegetation) ranging from 1 to 2 m in most places. Where flow is diffuse, the defined channel is absent and wetted width is 5 – 10 m wide. In April 2021, following a prolonged period of dry weather, Blakely (2022) observed the channel for much of the 1.3 km length to be entirely dry. Blakely (2022) also observed thick black, anoxic sediment and iron deposits in areas close to McLaren Gully Road. Blakely (2022) classified the in-stream habitat conditions as suboptimal for freshwater species.
4. *East of McLaren Gully Road:* This location is the section of Ōtokia Creek downstream of McLaren Gully Road. Blakely (2022) described this location as a wetland-intermittent-stream system.
5. *North of Big Stone Road:* This location is the section of Ōtokia Creek upstream of the Big Stone Road. The creek at this location was described by Blakely (2022) as a linear-wetland intermittent-stream system, similar in appearance to the valley marsh wetland downstream of the landfill designation.
6. *Lower Ōtokia Creek Marsh:* This location is downstream of the confluence between the Ōtokia Creek and McColl Creek, where flow is perennial. The creek discharges to the Pacific Ocean approximately 1.5 km downstream at Brighton Beach. The Lower Ōtokia Creek Marsh is classified as a regionally significant wetland.

The predominant catchment land use along the Ōtokia Creek is forestry, with farming (livestock) and residential land uses occurring along the lower reaches of the waterway.

6.2.2 Exposure assessment

The potential for indirect (food chain) exposure risks to occur in the lower and upper reaches of Ōtokia Creek is evaluated qualitatively herein.

Lower reaches of Ōtokia Creek

As detailed in Section 6.1, the PFOS concentrations predicted to occur in the lower reaches of the Ōtokia Creek (Locations 5 and 6) following a liner failure event are very low and below the HEPA (2020) ecological water quality guidelines for the protection of 99% of species. The PFOS concentrations predicted to occur in Ōtokia Creek, downstream of McLaren Gully Road (Location 4) were also of a similar order of magnitude to the HEPA (2020) ecological water quality guidelines for the protection of 99% of species.

While the HEPA (2020) ecological water quality guidelines for the protection of 99% of species were not derived based on bioaccumulation endpoints, it is widely accepted that concentrations of this order of magnitude are unlikely to be associated with adverse impacts to aquatic food chains and HEPA (2020) suggests that they are appropriate for the screening level assessment of this Source-Pathway-Receptor linkage. These results therefore provide a line of evidence to suggest that PFOS discharges from the site are unlikely to adversely affect higher trophic level aquatic organisms via the aquatic food chain in the lower reaches of Ōtokia Creek.

Upper reaches of Otokia Creek

In the upper reaches of Ōtokia Creek (Locations 1 to 3) the PFOS concentrations predicted to occur following a liner failure event are also very low (<0.001 µg/L) but marginally exceed the HEPA (2020) ecological water quality guidelines for the protection of 99% of species. While PFOS bioaccumulation can occur at very low concentrations, particularly in enclosed freshwater settings that provide perennial habitat for omnivorous/carnivorous aquatic organisms, as demonstrated for example by Terechovs *et al.* (2019). For toxicity to higher trophic level species to occur via the aquatic food chain, the PFOS-impacted area needs to support a robust aquatic food chain, including diverse and abundant communities of lower trophic organisms (e.g. freshwater macroinvertebrates and fish) and high-quality habitat for high trophic level organisms (e.g. birds, mammals and reptiles). Lines of evidence that suggest that the secondary poisoning of higher trophic level organisms is unlikely to occur in the upper reaches of Ōtokia Creek include the following:

- The predominant land use along the upper reaches of Ōtokia Creek is forestry.
- Blakely (2022) indicated that the surface water flow paths at the edge of the landfill designation are receive only intermittent flow and do not provide habitat for indigenous freshwater fish or macroinvertebrates.
- Blakely (2022) indicated that the section of Ōtokia Creek between the landfill designation and the McLaren Gully Road Culvert receives only intermittent flow and classified the in-stream habitat conditions as suboptimal for freshwater species.
- The constructed pond is a man-made structure that is intermittently disconnected from the catchment during low flow periods (Blakely, 2022). Hence, while this structure may provide habitat for macroinvertebrates and eels, it is unlikely to be an environment from which higher trophic level organisms (e.g. carnivorous birds) rely upon in isolation as a food source.

Overall, the available lines of evidence do not suggest that the upper reaches of Ōtokia Creek is an environment in which secondary poisoning is likely to occur, particularly at the low PFOS concentrations that are predicted to occur.

6.3 Ecotoxicity assessment

6.3.1 Overview of PFOS ecotoxicity

The ecotoxicity dataset published for PFOS is primarily based on laboratory dose-response bioassays; that is, laboratory experiments where organisms are exposed to different concentrations of PFOS and the response (e.g., mortality, growth, reproduction) is measured. In laboratory ecotoxicity tests the highest concentration at which the measured response is not significantly different from the control is termed the No-Observed Effects Concentration (NOEC) and the lowest tested concentration at which the measured response is significantly different from controls is termed the Lowest-Observed Effects Concentration (LOEC).

A selection of the PFOS NOEC concentrations reported for freshwater species in the literature are summarised in Table 6.2.

Table 6.2 Summary of toxicity data for PFOS (aquatic organisms)

Taxonomic group	Laboratory study end point	PFOS NOEC range	References
Microalgae	Growth	5,300 to 150,000 µg/L	OECD (2002), Boudreau, *et al.* (2003a), Liu *et al.* (2008)
Macrophyte	Growth	200 to 11,400 µg/L	Hanson, *et al.* (2005), Boudreau, *et al.* (2003a)
Crustaceans	Reproduction, growth	8 to 6,000 µg/L	Boudreau, *et al.* (2003b), Li (2010), Ji, *et al.* (2008), Lu, *et al.* (2015)
Insects	Hatching, emergence, growth	2.3 to 100 µg/L	MacDonald, *et al.* (2004), Bots, *et al.* (2010), Mommaerts, *et al.* (2011)
Fish	Larval growth, reproduction	0.24[a] to 300 µg/L	Keiter, *et al.* (2012), Ankley, *et al.* (2004), Oakes, *et al.* (2005), Han & Fang, (2010), Ji, *et al.* (2008), Funkhouser (2014)
Amphibians	Reproduction, larval growth	10 to 300 µg/L	Lou, *et al.* (2013), Ankley, *et al.* (2004), Giesy, *et al.* (2010)

Note:

The chronic NOEC values presented represent the ranges identified in the ecotoxicological literature at the time of reporting. The values have not been adopted as PFAS assessment levels, nor do they necessarily represent the lowest concentrations at which adverse effects may be observed in an environmental setting.

[a] Converted NOEC from the LOEC value of 0.6 µg/L using a conversion factor of 2.5 as per recommended by Warne et al. (2018)

Given that PFOS can be highly persistent, environmental exposures are potentially long-term and multi-generational. A summary of a selection of NOEC reported for PFOS in multigeneration studies is provided in Table 6.3.

Table 6.3 Summary of multigeneration PFOS toxicity data for freshwater aquatic species

Taxonomic group	Species	Laboratory study end point	NOEC[a] (µg/L)	References
Mollusc	*P. pomilia*	Reproduction (F1 generation)	10,000	Funkhouser (2014)
Rotifer	*Brachionus calyciflorus*	Population growth	250	Zhang *et al.* (2013)
Insect	*Chironomus riparius*	Development (F6)	3.5	Marzialli *et al.* (2019)
Fish	*Oryzias latipes*	Reproduction (F1 generation)	10	Ji *et al.* (2008)
Fish	*Danio rerio*	Growth (F2 generation)	0.6 µg/L (LOEC)	Keiter, *et al.* (2012)
Fish	*Pimephales promelas*	Reproduction (F0)	230	Ankley *et al.* (2005)

[a] Except as indicated

PFOS exposure can result in developmental toxicity in fish, through effects on embryo and larval development, reproduction and stress response (Concawe, 2016). LOEC as low as 0.6 µg/L have been reported in fish studies, with this value identified in association with growth inhibition in a 180-day multigenerational study with the zebrafish *Danio rerio* (Keiter, et al., 2012). This value contrasts with the 50 µg/L NOEC for growth suppression derived in a five-month exposure using the same species (Wang M. C., 2011). The inconsistent NOEC values observed for the zebrafish serves as an example of the uncertainty associated with the PFOS toxicity thresholds for aquatic species. Notably, all of the ecotoxicity studies report NOEC which are several orders of magnitude higher than the PFOS concentrations predicted to occur downstream of the site following a worst-case liner failure scenario (Section 6.1).

The Keiter *et al.* (2012) LOEC has been questioned by Arblaster *et al.* (2017) due to the wide dosing range (i.e., 0.6, 100 and 300 µg/L) and limited replication (2 replicates per dose) used. Another uncertainty of this study is the lack of significant effects on growth at higher concentrations, as pointed by Ankley *et al.* (2021). This multigeneration test has been replicated with a more robust experimental design, including a narrower dosing range and 5 replicates per dose, by Gust *et al*. (2021). While definitive results have not been published yet, preliminary results (EPA, 2022) indicate a PFOS NOEC that is likely to be notably higher that the reported by Keiter *et al.* (2012).

6.3.2 Implications for the HEPA (2020) species protection levels

The SSD approach used to derive the PFAS NEMP ecological screening levels for water involves compiling the available ecotoxicological data and plotting a cumulative distribution function (i.e., burr or log logistic) against the concentrations at which effects on laboratory species are observed. Concentrations that are protective of a percentage of species (i.e., 1% of all species, 5% of all species, etc.) are extrapolated from the SSD.

The very low PFOS 99% species protection value (0.00023 µg/L) was derived because derived from the extreme tail end of the distribution. The PFOS freshwater guideline presented in the PFAS NEMP was based on 18 chronic ecotoxicity endpoints, including the LOEC of 0.6 ug/L for *Danio rerio*, reported by Keiter *et al.* (2012) as the lowest data point. The uncertainty associated with this data point and the gap to the next lowest data point (i.e., 4 ug/L for the fish Oryzias latipes, Ji et al. (2008) resulted in a poor fitting of the burr distribution). This principally affected the calculation of the 99% species protection value, which as a consequence is associated with a very high level of uncertainty and is below the laboratory limit of reporting (LoR) for all but super ultra-trace analyses.

At the time of reporting, it was widely acknowledged that the HEPA (2020) ecological water quality guidelines were subject to being revised. It is expected that the current values will ultimately be adjusted upwards, for the following reasons:

– The HEPA (2020) ecological water quality guidelines were derived in 2015. Studies published between 2015 to date have increased the size of the dataset.
– More multigeneration studies and new sensitive species have been added to the dataset and populated the lower section of the distribution curve.
– The notable influence of the Keiter *et al.* (2012) LOEC value could be reduced if the new and more robust experiment reports a higher value.
– Warne *et al.* (2018) revised the process used to derive water quality guidelines, including changes in the definitions of chronic and acute data and the presentation of a more detailed methodology to check for modality. This is anticipated to result in changes in the dataset and a reduction in the toxicity range.

Overall, the available evidence suggests that the HEPA (2020) ecological water quality guidelines for PFOS species protection values are likely to increase in the future, potentially by more than an order of magnitude. Notably the PFOS concentrations predicted to occur downstream of the site at Locations 1 to 4 exceed the current 99% species protection value by less than an order of magnitude.

6.4 Background levels

PFAS are a large family of manufactured chemicals that have been used in New Zealand and around the world in a variety of commercial processes, household products and specialty applications. The physical and chemical properties of PFAS impart oil and water repellency, temperature resistance and friction reduction, making them useful to consumers and industry. Known sources of PFAS to surface water include:

– Building materials (e.g., additives to wood-based materials, insulation, paints, plumbing materials)
– Paper products and packaging
– Surfactants
– Textiles, including carpet and furniture)
– Domestic products, including cosmetics, waxes
– Class B firefighting foams
– Discharges from wastewater treatment plants, including treated effluent and biosolids (ITRC, 2022).

The widespread use of PFAS and the persistence and mobility of some PFAS, have resulted in the presence of these compounds in the environment across the globe. PFAS concentrations in surface water are frequently elevated in surface water in the vicinity of know point sources of PFAS (e.g., facilities where class B firefighting foams are manufactured, stored or used). Although there has been limited data published specific to the background concentrations of PFAS in New Zealand, the extensive sampling undertaken for example in association with the Australian Department of Defence PFAS Investigation and Management Program[3] and Airservices National PFAS Management Program[4] airports have also identified that PFAS is widespread in freshwater, estuarine and marine environments not subject impacts from known PFAS point sources.

Hence, while PFAS are man-made chemicals, due to the diversity of purposes for which it has been used, it is not typically absent in aquatic environments in urban areas. It is important to consider the outcomes of the water quality modelling, which demonstrated relatively low concentrations (<0.001 µg/L), in the context of the variety of sources that may influence aquatic environments, particular in urban areas. The proposed monitoring programme for the landfill includes analysis of surface water for PFOS to develop a baseline against change can be detected.

6.5 Weight of evidence assessment

Overall, the available evidence does not suggest the PFOS concentrations predicted to occur downstream of the site following a liner failure event are likely to result in adverse effects to the aquatic environment. Key lines of evidence supporting this conclusion are as follows:

- The predicted downstream PFOS concentrations are well below HEPA (2020) 95% species water quality guidelines along the length of the waterway, providing a high level of confidence that PFOS discharges from the site are unlikely to be associated with direct toxicity to aquatic organisms.
- The PFOS concentrations predicted to occur in the lower reaches of the Ōtokia Creek (Locations 5 and 6) following a liner failure event are very low and below the HEPA (2020) ecological water quality guideline for the protection of 99% of species. The PFOS concentrations predicted to occur in Ōtokia Creek, downstream of McLaren Gully Road were also of a similar order of magnitude to the HEPA (2020) ecological water quality guidelines for the protection of 99% of species. These results therefore provide a line of evidence to suggest that PFOS discharges from the site are unlikely to adversely affect higher trophic level aquatic organisms via the aquatic food chain in the lower reaches of Ōtokia Creek.
- The upper reaches of Ōtokia Creek are ephemeral and the habitat conditions as suboptimal for freshwater macroinvertebrates and fish. In the absence of diverse and abundant communities of lower trophic organisms in the upper reaches of Ōtokia Creek that the secondary poisoning of higher trophic level organisms is unlikely to occur at the low PFOS concentration (<0.001 µg/L) predicted to occur following a liner failure event.
- The PFAS NEPM PFOS species protection values are likely to increase in the future, potentially by more than an order of magnitude. The PFOS concentrations predicted to occur downstream of the site at Locations 1 to 4 exceed the current 99% species protection value by less than an order of magnitude.

[3] https://defence.gov.au/Environment/PFAS/
[4] https://www.airservicesaustralia.com/community/environment/pfas/

7. Conclusions

Extension of the water quality assessment, to include consideration of failure of the landfill HDPE liner, has been carried out to understand the upper bound for potential effects to water quality which may be associated with the landfill. The landfill liner failure scenario is considered to be sufficiently conservative as to be outside the range of what could occur at. Notable areas of conservatism include:

- Loss of HDPE integrity at a rate of approximately 3,700 m^2/year with complete failure across the landfill footprint in 50 years.
- Lack of consideration of the long travel times for groundwater and leachate to the receiving environment, which provides many years to respond before meaningful effects to surface water would be realised.
- Assumptions of complete contaminant mass discharged entering surface water, without attenuation processes.

Under the conditions assessed for the landfill liner failure scenario, the highest rate of leachate discharge to surface water, before mitigation measures can be implemented, is conservatively predicted to be in the order of 180 m^3/yr. This compared with the 1.4 m^3/yr conservatively predicted for the landfill after closure presented in GHD (2021) and updated in Kirk (2022).

The impacts to surface water quality are not predicted to result in significant degradation of the wetland, with the majority of contaminants considered not exceeding the relevant water quality criteria. Where exceedance of this does occur, it is primarily a function of the existing condition of surface water.

PFOS is indicated as exceeding the draft 99% water quality guideline for the protection of 99% of species, however, in consideration of the basis for this criteria and the available evidence, it does not suggest the PFOS concentrations predicted to occur downstream of the site following a liner failure event are likely to result in adverse effects to the aquatic environment.

Further consideration of the risks to human health, through the appropriate QHHRA process, indicates that of the pathways considered, food gathering from the creek provides the greatest potential exposure to PFAS compounds both derived from the landfill and present due to background activities. However, the QHHRA concluded that the potential risks to human health were low and acceptable, even under the theoretical failure landfill liner failure scenario. This included consideration of cumulative exposure to the PFAS compounds across the following exposure pathways:

- The ingestion of water while swimming in Ōtokia Creek.
- Consuming eggs from chickens provided water from Ōtokia Creek.
- Consuming fruit and vegetables watered from Ōtokia Creek.
- Consume meat from livestock watered from Ōtokia Creek.
- Consuming milk from cattle watered from Ōtokia Creek.
- Consuming eel meat and water cress harvested from Ōtokia Creek.

For the conservative landfill closure scenario, which represents the expected outcome for landfill development, the impact on the receiving environment associated with discharge of the PFAS compounds assessed, is considered to be negligible.

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Appendices

Appendix A

Ōtokia Creek flow duration curves

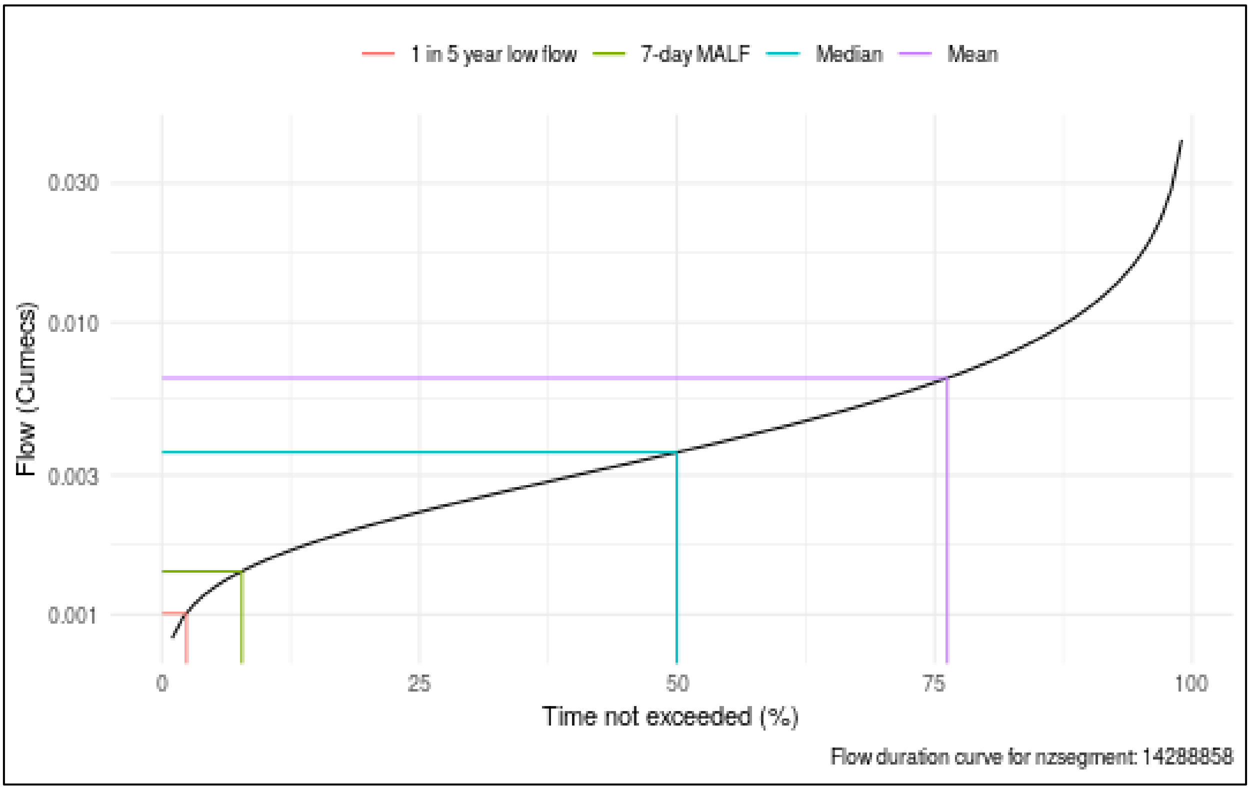

Figure A.1 ***Northern edge of designation and Constructed Pond (both locations along some reach of the creek) (Whitehead & Booker, 2020)***

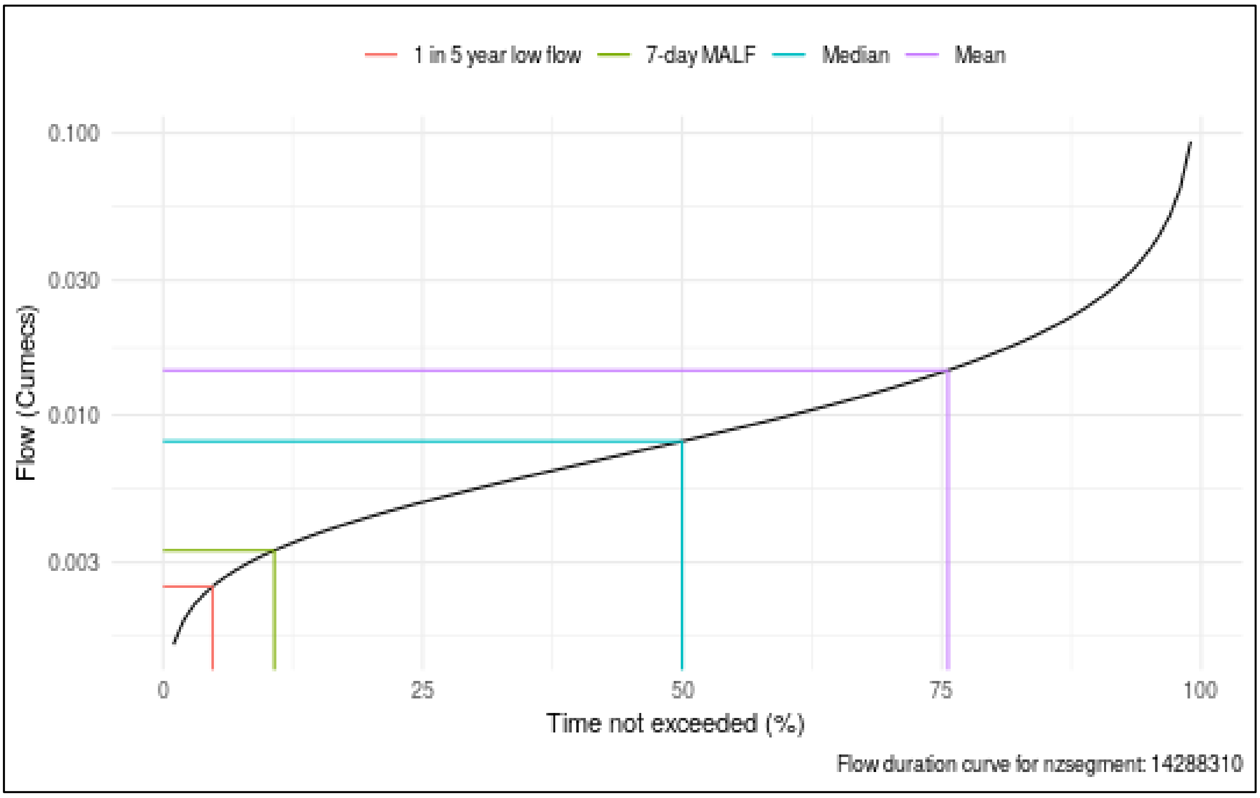

Figure A.2 ***McClaren Gully Road Culvert (Whitehead & Booker, 2020)***

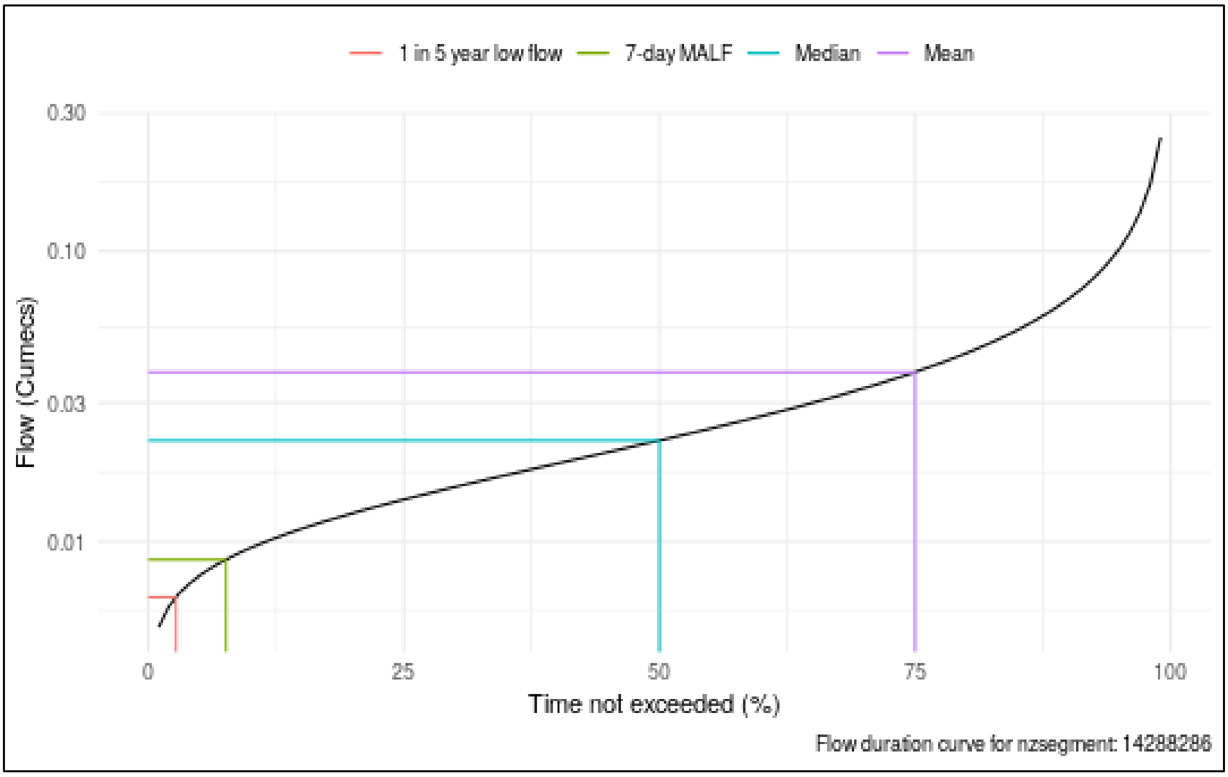

Figure A.3 East of McClaren Gully Road (Whitehead & Booker, 2020)

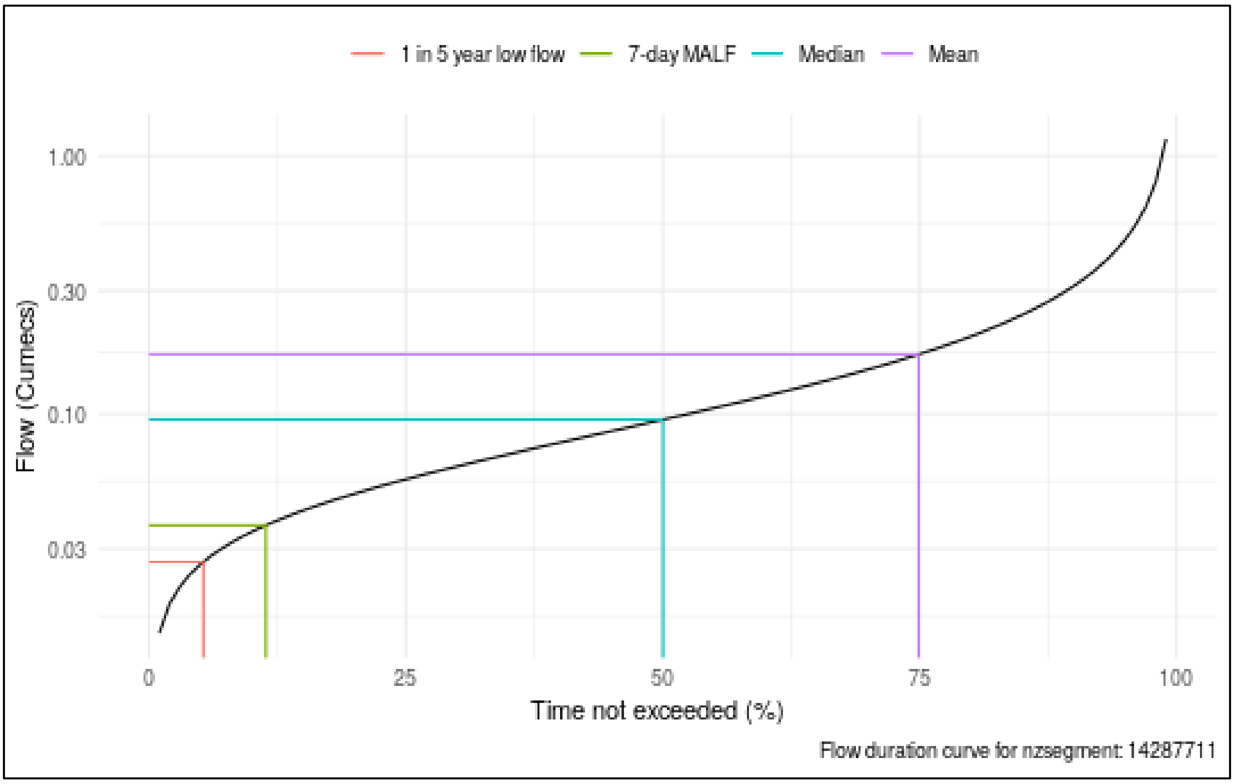

Figure A.4 North of Big Stone Road (Whitehead & Booker, 2020)

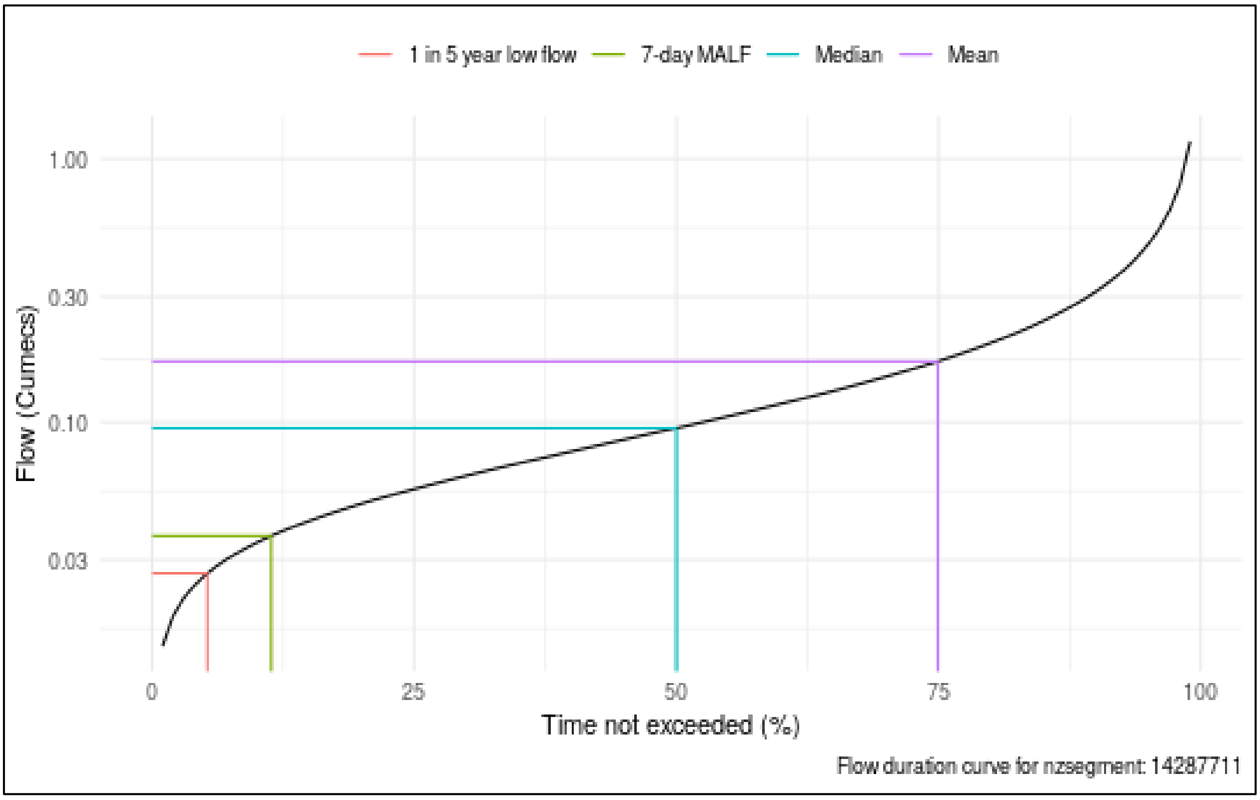

Figure A.5 ***Lower Ōtokia Creek Marsh (Whitehead & Booker, 2020)***

Appendix B

Water quality assessment results

		Ecological Water Quality Criteria	Adopted water quality			Ōtokia Creek Assessment Locations
Parameter	**Units**	**PFAS NEMP**	**Leachate**	**Groundwater**	**Surface Water**	**1. Northern edge of landfill designation**
PFOA	ug/l	**19**	1.976	0.0001	0.0001	0.00011
PFHxS	ug/l		4.131	0.0001	0.0001	0.00013
PFOS	ug/l	**0.00023**	**0.963**	0.0001	0.0001	0.00011

Water Quality Criteria References

HEPA (2020). National Chemicals Working Group of the Heads of Environmental Protection Agencies Australia and New Zealand. PFAS National Environmental Management Plan (NEMP). Version 2.0 - January 2020

bold and shaded indicates exceedance over screening values

Adopted Water Quality References

Leachate: PFAS values are the 95% percentile (mean plus 1.96 standard deviations) of leachate concentrations recorded at 27 Australian landfills accepting a range of waste types including MSW, commercial and industrial (C&I) and construction and demolition (C&D) (Gallen et al., 2017)

Groundwater: PFAS values are typical background concentrations reported by PDP (2018).

Surface water: PFAS values are typical background concentrations reported by PDP (2018).

		Drinking Water Quality Criteria		Adopted Water Quality			Ōtokia Creek Assessment Location
Parameter	**Units**	**Australian DWG**	**Recreational Guidelines**	**Leachate**	**Groundwater**	**Surface Water**	**1. Northern edge of landfill designation**
PFOA	µg/l	**0.56**	**10**	**1.976**	0.0001	0.0001	0.00011
PFHxS	µg/l			4.131	0.0001	0.0001	0.00013
PFOS	µg/l			0.963	0.0001	0.0001	0.00011
Sum of PFOS & PFHxS	µg/l	**0.1**	**2**	**5.094**	0.0002	0.0002	0.00024

Water Quality Criteria References

Recreational Guidelines - PFOA and sum of PFOS & PFHxS (Australian Government National Health and Medical Research Council (NHMRC, 2019) - All other parameters set assuming 10% of Australian DWG

Australian Government National Health and Medical Research Council (NHMRC, 2022). Australian Drinking Water Guidelines Version 3.7. All parameters assessed against Health Guideline Value. Aesthetic guideline values not considered.

bold and shaded and / or **red text** indicates exceedance over screening values

Adopted Water Quality References

Leachate: PFAS values are the 95% percentile (mean plus 1.96 standard deviations) of leachate concentrations recorded at 27 Australian landfills accepting a range of waste types including MSW, commercial and industrial (C&I) and construction and demolition (C&D) (Gallen et al., 2017)

Groundwater: PFAS values are typical background concentrations reported by PDP (2018).

Surface water: PFAS values are typical background concentrations reported by PDP (2018).

Table B3: Liner Failure Scenario
Ecological Water Quality Screening

		Ecological Water Quality Criteria				Adopted water quality			Ōtokia Creek Assessment Locations					
Parameter	**Units**	**ANZG**	**PFAS NEMP**	**ORC Schedule 16A**	**ORC Schedule 15**	**Leachate**	**Groundwater**	**Surface Water**	**1. Northern edge of landfill designation**	**2. Constructed Pond**	**3. McLaren Gully Road Culvert**	**4. East of McLaren Gully Road**	**5. North of Big Stone Road**	**6. Lower Ōtokia Creek Marsh**
Alkalinity	mg/l					473.0	426.2	21.5	21.9	21.9	21.7	21.6	21.5	21.5
Aluminium	mg/l	**0.055**				**7.9**			0.0070	0.0070	0.0032	0.0012	0.00027	0.00021
Ammoniacal Nitrogen	mg/l			**2 (3)**	**1 (3)**	**704.5**	0.0094	0.043	0.67	0.67	0.32	0.15	0.067	0.062
Arsenic	mg/l	**0.013 (1)**				**0.17**	0.00030	0.00065	0.00080	0.00080	0.00072	0.00068	0.00066	0.00065
Boron	mg/l	**0.37**				**12.3**	0.01	0.01	0.021	0.0209	0.0149	0.0118	0.01041	0.01032
Cadmium	mg/l	**0.0002**				**0.0063**	0.000077	0.000032	0.000037	0.000037	0.000034	0.000033	0.000032	0.000032
Calcium	mg/l					377.5	169	17.14	17.4	17.4	17.3	17.2	17.1	17.1
Chloride	mg/l					1733.5	91.3	53.1	54.7	54.7	53.8	53.4	53.2	53.2
Chromium	mg/l	**0.001 (2)**				**0.17**	0.00013	0.00032	0.00048	0.00048	0.00039	0.00035	0.00033	0.00032
Conductivity	S/cm					19975	0.0016	0.00033	17.8	17.8	8.0	3.0	0.68	0.53
Dissolved Reactive Phosphorus	mg/l			**0.035**	**0.01**	**3.4**	0.0013	0.0033	0.0064	0.0064	0.0047	0.0038	0.0034	0.0034
Iron	mg/l					183.0	0.033	0.82	0.98	0.98	0.89	0.85	0.83	0.82
Lead	mg/l	**0.0034**				**0.13000**	0.000025	0.00019	0.00031	0.00031	0.00024	0.00021	0.00019	0.00019
Magnesium	mg/l					193.8	58.3	7.9	8.1	8.1	8.0	7.9	7.9	7.9
Manganese	mg/l	**1.9**				**5.40**	0.31	0.61	0.61	0.61	0.61	0.61	0.61	0.61
Mercury	mg/l	**0.00006**				**0.0065**	0.00004	0.00004	0.000046	0.000046	0.000043	0.000041	0.000040	0.000040
Nickel	mg/l	**0.011**				**0.1900**	0.0043	0.0018	0.0020	0.0020	0.0019	0.0018	0.0018	0.0018
Nitrate Nitrogen	mg/l			**1**	**0.075**	**0.86**	**13.5**	**0.19**	**0.19**	**0.19**	**0.19**	**0.19**	**0.19**	**0.19**
Potassium	mg/l					630.0	6.5	2.0	2.6	2.6	2.3	2.1	2.0	2.0
Sodium	mg/l					36.0	82.7	29.9	30.9	30.9	30.4	30.1	29.9	29.9
Sulphate	mg/l					1165.0	170.1	25.5	25.8	25.8	25.6	25.5	25.5	25.5
Total Kjeldahl Nitrogen (TKN)	mg/l					1225.8	0.34	7.3	8.4	8.4	7.8	7.5	7.3	7.3
Total Hardness	mg/l					1410.3	695.0	60.6	61.9	61.9	61.2	60.8	60.7	60.6
Zinc	mg/l	**0.008**				**1.2**	0.0062	**0.0089**	**0.010**	**0.010**	**0.0094**	**0.0091**	**0.0089**	**0.0089**
PFOA	ug/l		**19**			1.976	0.0001	0.0001	0.0019	0.0019	0.00089	0.00040	0.00017	0.00015
PFHxS	ug/l					4.131	0.0001	0.0001	0.0038	0.0038	0.0017	0.00072	0.00024	0.00021
PFOS	ug/l		**0.00023**			**0.963**	0.0001	0.0001	**0.00096**	**0.00096**	**0.00048**	**0.00024**	0.00013	0.00013

Water Quality Criteria References
ORC (2022). Otago Regional Council. Regional Plan: Water for Otago. Schedule 15 (Receiving Water Group 2)
ORC (2022). Otago Regional Council. Regional Plan: Water for Otago. Schedule 16A: Discharge Thresholds for Discharge Threshold Area 2
ANZG (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Default guideline values for freshwater - protection: 95% of species (protection: 99% of species adopted for mercury)
HEPA (2020). National Chemicals Working Group of the Heads of Environmental Protection Agencies Australia and New Zealand. PFAS National Environmental Management Plan (NEMP). Version 2.0 - January 2020
bold and shaded and / or **red text** indicates exceedance over screening values
1 - Value for Arsenic (AsV) used
2 - Value for Chromium (CrVI)
3 - Values for Ammoniacal Nitrogen adjusted for receiving environment pH 7. ORC (2022) values derived for pH 8

Adopted Water Quality References
Leachate: All parameters excluding mercury and PFAS derived using the upper quartile of the highest concentrations recorded at eight consented municipal solid waste (MSW) Class 1 Landfills in New Zealand (CAE, 2000). Mercury value is the maximum concentration recorded from 26 leachate samples at Redvale Landfill, as reported by Tonkin & Taylor (2019). PFAS values are the 95% percentile (mean plus 1.96 standard deviations) of leachate concentrations recorded at 27 Australian landfills accepting a range of waste types including MSW, commercial and industrial (C&I) and construction and demolition (C&D) (Gallen et al., 2017)
Groundwater: All parameters excluding mercury and PFAS derived using average results from five sampling rounds at BH01A between November 2019 and January 2022. Mercury value is 50% of typical laboratory limit of detection. PFAS values are typical background concentrations reported by PDP (2018). Boron adopted concentration of 0.01 mg/l.
Surface water: All parameters excluding mercury and PFAS derived using average results from all surface water samples from five sampling rounds undertaken between July 2020 and January 2022. Mercury value is 50% of typical laboratory limit of detection. PFAS values are typical background concentrations reported by PDP (2018). Boron adopted concentration of 0.01 mg/l.

Table B4: Liner Failure Scenario
Drinking Water Quality Screening

		Drinking Water Quality Criteria			Adopted Water Quality			Ōtokia Creek Assessment Locations					
Parameter	**Units**	**New Zealand DWG**	**Australian DWG**	**Recreational Guidelines**	**Leachate**	**Groundwater**	**Surface Water**	**1. Northern edge of landfill designation**	**2. Constructed Pond**	**3. McLaren Gully Road Culvert**	**4. East of McLaren Gully Road**	**5. North of Big Stone Road**	**6. Lower Ōtokia Creek Marsh**
Alkalinity	mg/l				473	426.2	21.5	21.92	21.92	21.69	21.57	21.52	21.51
Ammoniacal Nitrogen	mg/l				704.5	0.0094	0.043	0.67	0.67	0.32	0.15	0.067	0.062
Arsenic	mg/l	**0.01**		**0.1**	**0.17**	0.00030	0.00065	0.00080	0.00080	0.00072	0.00068	0.00066	0.00065
Boron	mg/l	**1.4**		**14**	**12.3**	0.01	0.01	0.021	0.0209	0.0149	0.0118	0.01041	0.01032
Cadmium	mg/l	**0.004**		**0.04**	**0.0063**	0.000077	0.000032	0.000037	0.000037	0.000034	0.000033	0.000032	0.000032
Calcium	mg/l				377.5	169	17.14	17.4	17.4	17.3	17.2	17.1	17.1
Chloride	mg/l				1733.5	91.3	53.1	54.7	54.7	53.8	53.4	53.2	53.2
Chromium	mg/l	**0.05**		**0.5**	**0.17**	0.00013	0.00032	0.00048	0.00048	0.00039	0.00035	0.00033	0.00032
Conductivity	S/cm				19975	0.0016	0.00033	17.8	17.8	8.0	3.0	0.6766	0.5277
Dissolved Reactive Phosphoru	mg/l				3.4	0.0013	0.0033	0.0064	0.0064	0.0047	0.0038	0.0034	0.0034
Iron	mg/l				183	0.033	0.82	0.98	0.98	0.89	0.85	0.83	0.82
Lead	mg/l	**0.01**		**0.1**	**0.13**	0.000025	0.00019	0.00031	0.00031	0.00024	0.00021	0.00019	0.00019
Magnesium	mg/l				193.8	58.3	7.9	8.1	8.1	8.0	7.9	7.9	7.9
Manganese	mg/l	**0.4**		**4**	**5.4**	0.31	**0.61**	**0.61**	**0.61**	**0.61**	**0.61**	**0.61**	**0.61**
Mercury	mg/l	**0.007**		**0.07**	0.0065	0.00004	0.00004	0.000046	0.000046	0.000043	0.000041	0.000040	0.000040
Nickel	mg/l	**0.08**		**0.8**	**0.19**	0.0043	0.0018	0.0020	0.0020	0.0019	0.0018	0.0018	0.0018
Nitrate Nitrogen	mg/l	**50**		**500**	0.86	13.5	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Potassium	mg/l				630	6.5	2.0	2.6	2.6	2.3	2.1	2.0	2.0
Sodium	mg/l				36	82.7	29.9	30.9	30.9	30.4	30.1	29.9	29.9
Sulphate	mg/l				1165	170.1	25.5	25.8	25.8	25.6	25.5	25.5	25.5
Total Kjeldahl Nitrogen (TKN)	mg/l				1225.8	0.34	7.3	8.4	8.4	7.8	7.5	7.3	7.3
Total Hardness	mg/l				1410.3	695.0	60.6	61.9	61.9	61.2	60.8	60.7	60.6
Zinc	mg/l				1.2	0.0062	0.0089	0.010	0.010	0.0094	0.0091	0.0089	0.0089
PFOA	µg/l		**0.56**	**10**	**1.976**	0.0001	0.0001	0.0019	0.0019	0.00089	0.00040	0.00017	0.00015
PFHxS	µg/l				4.131	0.0001	0.0001	0.0038	0.0038	0.0017	0.00072	0.00024	0.00021
PFOS	µg/l				0.963	0.0001	0.0001	0.00096	0.00096	0.00048	0.00024	0.00013	0.00013
Sum of PFOS & PFHxS	µg/l		**0.07**	**2**	**5.094**	0.0002	0.0002	0.0047	0.0047	0.0022	0.00096	0.00037	0.00033
Sum of PFOA, PFHxA, PFHpA, PFNA, PFDA, PFUdA & PFDoDa	µg/l				9.370	0.0002	0.0002	0.0087	0.0087	0.0041	0.00177	0.00069	0.00062

Water Quality Criteria References

Recreational Guidelines - PFOA and sum of PFOS & PFHxS (Australian Government National Health and Medical Research Council (NHMRC, 2019) - All other parameters set assuming 10% of the drinking water standards.

Ministry for Health (2018). Drinking Water Standads for New Zealand 2005. Revised 2018. All parameters assessed Maximum Acceptable Value (MAV) for health significance. Aesthetic guideline values not considered.

Australian Government National Health and Medical Research Council (NHMRC, 2022). Australian Drinking Water Guidelines 6 2011. Version 3.7 Updated January 2022. All parameters assessed against Health Guideline Value. Aesthetic guideline values not considered.

bold and shaded and / or **red text** indicates exceedance over screening values

Adopted Water Quality References

Leachate: All parameters excluding mercury and PFAS derived using the upper quartile of the highest concentrations recorded at eight consented municipal solid waste (MSW) Class 1 Landfills in New Zealand (CAE, 2000). Mercury value is the maximum concentration recorded from 26 leachate samples at Redvale Landfill, as reported by Tonkin & Taylor (2019). PFAS values are the 95% percentile (mean plus 1.96 standard deviations) of leachate concentrations recorded at 27 Australian landfills accepting a range of waste types including MSW, commercial and industrial (C&I) and construction and demolition (C&D) (Gallen et al., 2017)

Groundwater: All parameters excluding mercury and PFAS derived using average results from five sampling rounds at BH01A between November 2019 and January 2022. Mercury value is 50% of typical laboratory limit of detection. PFAS values are typical background concentrations reported by PDP (2018). Boron adopted concentration of 0.01 mg/l.

Surface water: All parameters excluding mercury and PFAS derived using average results from all surface water samples from five sampling rounds undertaken between July 2020 and January 2022. Mercury value is 50% of typical laboratory limit of detection. PFAS values are typical background concentrations reported by PDP (2018). Boron adopted concentration of 0.01 mg/l.

Appendix C

QHHRA inputs and outputs

Assessment Area	Smooth Hill Landfill - Farm Pond
Exposure Scenario	Cumulative
Receptor Group	Children (2-6 years)
Chemicals of Potential Concern	PFOS+PFHxS
Exposure Media	Surface water

Total Hazard Index	-	**0.4**

Relevant exposure pathways	
Potable ingestion	No
Incidental ingestion	Yes
Poultry watering and egg consumption	Yes
Irrigation and produce consumption	Yes
Stock watering and meat consumption	Yes
Stock watering and offal consumption	Yes
Dermal contact	No
Stock watering and milk consumption	Yes
Aquatiic vertebrate consumption	Yes
Aquatic plant consumption	Yes

Parameter	Unit	Value	Details	Source
Water quality inputs				
Concentration in water	**µg/L**	**0.0047**	Predicted worst case surface water concentration at Farm Pond (no HDPE - complete failure)	Assumption
Concentration in water	**mg/L**	**4.70E-06**		
Percentage PFHxS (in PFOS+PFHxS)	**%**	**80%**	Distribution of PFOS/PFHxS predicted in downstream surface water samples	Site-specific
Risk calculations				
HI_{Total}	-	**3.93E-01**	$HI = \sum HQ_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$HQ_{Water\_Incidental}$	-	**1.00E-03**	$HQ_{Water\_incidental} = \frac{Intake_{Water\_incidental}}{TRV\ x\ (100\% - Background)}$	
HQ_{Eggs}	-	**6.61E-04**	$HQ_{Eggs} = \frac{Intake_{Eggs}}{TRV\ x\ (100\% - Background)}$	
HQ_{Garden}	-	**2.49E-03**	$HQ_{Garden} = \frac{Intake_{Garden}}{TRV\ x\ (100\% - Background)}$	
HQ_{Meat}	-	**5.79E-03**	$HQ_{Meat} = \frac{Intake_{Meat}}{TRV\ x\ (100\% - Background)}$	
HQ_{Offal}	-	**0.00E+00**	$HQ_{Offal} = \frac{Intake_{Offal}}{TRV\ x\ (100\% - Background)}$	
HQ_{Milk}	-	**1.20E-02**	$HQ_{Milk} = \frac{Intake_{Milk}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqVerts}$	-	**3.48E-01**	$HQ_{Aquatic\_Verts} = \frac{Intake_{Aquatic\_Verts}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqPklants}$	-	**2.34E-02**	$HQ_{Aquatic\_Plants} = \frac{Intake_{Aquatic\_Plants}}{TRV\ x\ (100\% - Background)}$	
Intake calculations				
$Intake_{Total}$	mg/kg/day	**7.08E-06**	$Intake_{Total} = \sum Intake_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$Intake_{Water\_Incidental}$	mg/kg/day	**1.81E-08**	$Intake_{Water\_nonpotable} = \frac{C_{Water}\ x\ IR_{Water\_nonpotable}\ x\ F_{Water\_nonpotable}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Eggs}$	mg/kg/day	**1.19E-08**	$Intake_{Eggs} = \frac{C_{Eggs}\ x\ IR_{Eggs}\ x\ F_{HG\_eggs}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Garden}$	mg/kg/day	**4.48E-08**	$Intake_{Garden} = \frac{C_{Garden}\ x\ IR_{Garden}\ x\ F_{HG\_garden}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Meat}$	mg/kg/day	**1.04E-07**	$Intake_{Meat} = \frac{C_{Meat}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Offal}$	mg/kg/day	**0.00E+00**	$Intake_{Offal} = \frac{C_{Offal}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Milk}$	mg/kg/day	**2.17E-07**	$Intake_{Milk} = \frac{C_{Milk}\ x\ IR_{Milk}\ x\ F_{Milk}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Verts}$	mg/kg/day	**6.26E-06**	$Intake_{Aquatic\_Verts} = \frac{C_{Aquatic\_Verts}\ x\ IR_{Aquatic\_Verts}\ x\ F_{HG\_Aquatic\_Verts}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Plants}$	mg/kg/day	**4.21E-07**	$Intake_{Aquatic\_Plants} = \frac{C_{Aquatic\_Plants}\ x\ IR_{Aquatic\_Plants}\ x\ F_{HG\_Aquatic\_Plants}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
Pathway contribution calculations				
$Contribution_{Ingestion\_IncidentalWater}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	Calculated based on MfE (2011) and ASC NEPM algorithms
$Contribution_{Homegrown\_Eggs}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_FruitVeg}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Meat}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Offal}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Milk}$	%	3%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Verts}$	%	88%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Plants}$	%	6%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	

General toxicity and exposure inputs				
TRV	mg/kg/day	0.00002	Based on developmental toxicity endpoints in animal studies	FSANZ (2017c)
$Background_{Ingestion}$ (Background)	%	10%	Conservative assumption, calculated on the basis dietary concentrations in Europe and serum concentrations in the Australian population	EFSA (2020), FSANZ (2017), Thompson *et al.* (2010)
Body weight (BW)	kg	13	Body weight of a child (2 years)	MfE (2011)
Averaging time (AT)	days	2190	Exposure duration x 365 days/yr	MfE (2011)
Exposure frequency (EF)	days/yr	365	Daily - local resident	MfE (2011)
Exposure duration (ED)	years	6	Childhood	MfE (2011)
Oral bioavailability (BIO)	-	1	Assumes that ingested PFAS is largely bioaccessible	OEH (2019)
Water consumption exposure inputs				
Ingestion rate ($IR_{Incidental}$)	L/day	0.050	Average daily incidental water ingestion rate. Represents the incidental ingestion that may be associated with the use of bore/creek water for activities such as bathing, filling swimming pools and sprinkler use	enHealth (2012)
Fraction of water sourced from bore/creek ($F_{W\_Incidental}$)	%	100%	Fraction of incidental water ingestion sourced from bore/creek	Assumption
Egg consumption exposure inputs				
Concentration in edible portion of egg (C_{Eggs})	mg/kg	3.9E-05	$C_{Egg} = \frac{TF_{Egg}\ x\ C_{Water}\ x\ IR_{Water\_chicken}\ x\ F_{Chicken\_water}\ x\ BIO}{LR\ x\ W_{egg}\ x\ F_{Edible}}$	DoD (2017a)
Water ingestion rate of chickens ($IR_{Chickens\_Water}$)	L/day	0.32	Average daily water consumption of a laying hen	ANZECC (2000)
Fraction of water sourced from bore/creek ($F_{Water\_Chickens}$)	%	100%	Conservative assumption - assumes poultry obtains all water requirements from the bore and/or creek	Assumption
Egg consumption rate (IR_{Egg})	kg/day	0.016	Double the average daily egg consumption rate reported for the New Zealand population (toddlers)	MfE (2011)
Edible fraction of egg (F_{Edible})	%	0.9	Approximate portion of an egg that is edible	MfE (2011)
Transfer factor to chicken eggs (TF_{Eggs})	mg/day edible egg per mg/day intake	1.1	A study undertaken by the Australian Department of Defence indicated that the amount of PFOS transferred to eggs each day is estimated, on average, to be equal to the amount of PFOS ingested by a chicken via their drinking water each day. Transfer rates for PFHxS and PFOA were lower, at 0.7 and 0.45 respectively.The defence study concludes that almost 100% of the transfer is to the edible portion and therefore the TF of 1 has been adjusted upwards according the the equation $1/F_{edible}$	DoD (2017a), Kowalczyk (2013)
Egg laying rate (LR)	eggs/day	0.8	Laying hens can produce up to approximately 300 eggs per year	Assumption
Egg weight (W_{egg})	kg/egg	0.060	Weight of a typical egg	MfE (2011)
Fraction of homegrown eggs (F_{HG_Eggs})	%	25%	MfE (2011) assumption for a rural/residential block	Assumption
Fruit and vegetable consumption exposure inputs				
Concentration in fruit and vegetables (C_{Garden})	mg/kg	1.7E-05	$C_{Garden} = TF_{Garden}\ x\ C_w$	DoD (2017b)
PFOS transfer factor to fruits and vegetables ($TF_{GardenPFOS}$)	L/kg	2.5	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFOS and irrigated vegetables of 2.5 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
PFHxS transfer factor to fruits and vegetables ($TF_{GardenPFHxS}$)	L/kg	3.8	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFHxS and irrigated vegetables of 3.8 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
Fruit and vegetable consumption rate ($C_{FruitVeg}$)	kg/day	0.14	Total fruit and vegetable consumption rates reported for the Australian population (1-3 years)	MfE (2011)
Fraction of homegrown fruit and vegetables ($F_{HG\_FruitVeg}$)	%	25%	Default assumption for rural/residential land uses	MfE (2011)
Meat and milk consumption exposure inputs				
Concentration in meat (C_{Meat})	mg/kg	2.1E-05	$C_{Meat} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Meat}$	Drew *et al.* (2021)
Concentration in offal (C_{Offal})	mg/kg	1.9E-04	$C_{Offal} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Offal}$	Drew *et al.* (2021)
Concentration in milk (C_{Milk})	mg/kg	3.4E-06	$C_{Milk} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Milk}$	Drew *et al.* (2021)
Meat (muscle) consumption rate (IR_{Muscle})	kg/day	0.085	90th percentile total meat consumption rate reported for the population (2-6 years). Representative of meat consumption rates for people on livestock-producing properties	FSANZ (2017)
Offal consumption rate (IR_{Offal})	kg/day	0.000	Substantial offal consumption has not been identified for children (2-6 years)	FSANZ (2017)
Milk consumption rate (IR_{Offal})	kg/day	1.097	90th percentile milk consumption rate reported for the population (2-6 years). Representative of milk consumption rates for people on livestock-producing properties	FSANZ (2017)
PFOS serum to meat concentration factor (CF_{Muscle})	L/kg	0.076	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS serum to offal concentration factor (CF_{Offal})	L/kg	1.06	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS serum to milk concentration factor (CF_{Milk})	L/kg	0.013	Describes the transfer from plasma to milk (mg/L meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to meat concentration factor (CF_{Muscle})	L/kg	0.046	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to offal concentration factor (CF_{Offal})	L/kg	0.19	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to milk concentration factor (CF_{Milk})	L/kg	0.007	Describes the transfer from plasma to offal (mg/L milk per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	140	Describes the relationship between the PFOS concentration in water and serum	Drew *et al.* (2021)
PFHxS transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	65	Describes the relationship between the PFHxS concentration in water and serum	Drew *et al.* (2021)
Fraction of water sourced from bore/creek (F_{Water_Stock})	%	100%	Conservative assumption - assumes livestock obtain all water requirements from the creek	Assumption
Fraction of homegrown meat (F_{HG_Meat})	%	75%	Represents the fact that stock produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption
Fraction of homegrown milk (F_{HG_Milk})	%	75%	Represents the fact that milk produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption

Aquatic biota consumption exposure inputs				
Concentration in aquatic vertebrates ($C_{Aquatic\_Verts}$)	mg/kg	8.4E-03	$C_{Aquatic\_Verts} = BAF_{Aquatic\_Verts}\ x\ C_w$	Burkhard (2020)
Concentration in aquatic plants ($C_{Aquatic\_Plants}$)	mg/kg	1.6E-03	$C_{Aquatic\_Plants} = BAF_{Aquatic\_Plants}\ x\ C_w$	Burkhard (2020)
PFOS bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	7470	Mean BAF reported for eel muscle	DoD (2017c)
PFHxS bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	354	Mean BAF reported for eel muscle	Kwadijk *et al.* (2010)
PFOS bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	1162	Mean BCF for aquatic plants	DoD (2017c)
PFHxS bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	141	Mean BCF for aquatic plants	DoD (2017c)
Aquatic vertebrate consumption rate ($IR_{Aquatic\_Verts}$)	kg/day	0.013	Mean total fish consumption rate for young children	MPI (2016)
Aquatic plant consumption rate ($IR_{Aquatic\_Plants}$)	kg/day	0.005	Half of the mean leafy vegetable consumption rate for young children	FSANZ (2017)
Fraction of locally grown aquatic vertebrates ($F_{HG\_Aquatic\_Verts}$)	%	75%	Represents the fact that locally caught aquatic biota may make a substantial contribution to the diet of local residents	Assumption
Fraction of locally grown aquatic plants ($F_{HG\_Aquatic\_Plants}$)	%	75%	Represents the fact that locally foraged aquatic vegetation may make a substantial contribution to the diet of local residents	Assumption

(aqua)	Value recommended by MfE, ASC NEPM, NHMRC, FSANZ or enHealth
(green)	Site-specific data or assumption
(yellow)	Assumption based on a published study or guideline
(orange)	Calculated value

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Assessment Area	Smooth Hill Landfill - Farm Pond
Exposure Scenario	Cumulative
Receptor Group	Children (2-6 years)
Chemicals of Potential Concern	PFOA
Exposure Media	Surface water

Total Hazard Index	**-**	**0.002**

Relevant exposure pathways	
Potable ingestion	No
Incidental ingestion	Yes
Poultry watering and egg consumption	Yes
Irrigation and produce consumption	Yes
Stock watering and meat consumption	Yes
Stock watering and offal consumption	Yes
Dermal contact	No
Stock watering and milk consumption	Yes
Aquatiic vertebrate consumption	Yes
Aquatic plant consumption	Yes

Parameter	Unit	Value	Details	Source
Water quality inputs				
Concentration in water	**μg/L**	**0.0019**	Predicted worst case surface water concentration at Farm Pond (no HDPE - complete failure)	Assumption
Concentration in water	**mg/L**	**1.90E-06**		
Risk calculations				
HI_{Total}	-	**2.07E-03**	$HI = \sum HQ_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$HQ_{Water\_Incidental}$	-	**5.07E-05**	$HQ_{Water\_incidental} = \frac{Intake_{Water\_incidental}}{TRV\ x\ (100\% - Background)}$	
HQ_{Eggs}	-	**1.50E-05**	$HQ_{Eggs} = \frac{Intake_{Eggs}}{TRV\ x\ (100\% - Background)}$	
HQ_{Garden}	-	**1.74E-04**	$HQ_{Garden} = \frac{Intake_{Garden}}{TRV\ x\ (100\% - Background)}$	
HQ_{Meat}	-	**0.00E+00**	$HQ_{Meat} = \frac{Intake_{Meat}}{TRV\ x\ (100\% - Background)}$	
HQ_{Offal}	-	**0.00E+00**	$HQ_{Offal} = \frac{Intake_{Offal}}{TRV\ x\ (100\% - Background)}$	
HQ_{Milk}	-	**0.00E+00**	$HQ_{Milk} = \frac{Intake_{Milk}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqVerts}$	-	**1.66E-03**	$HQ_{Aquatic\_Verts} = \frac{Intake_{Aquatic\_Verts}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqPlants}$	-	**1.64E-04**	$HQ_{Aquatic\_Plants} = \frac{Intake_{Aquatic\_Plants}}{TRV\ x\ (100\% - Background)}$	
Intake calculations				
$Intake_{Total}$	mg/kg/day	**2.98E-07**	$Intake_{Total} = \sum Intake_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$Intake_{Water\_Incidental}$	mg/kg/day	**7.31E-09**	$Intake_{Water\_nonpotable} = \frac{C_{Water}\ x\ IR_{Water\_nonpotable}\ x\ F_{Water\_nonpotable}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Eggs}$	mg/kg/day	**2.17E-09**	$Intake_{Eggs} = \frac{C_{Eggs}\ x\ IR_{Eggs}\ x\ F_{HG\_eggs}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Garden}$	mg/kg/day	**2.51E-08**	$Intake_{Garden} = \frac{C_{Garden}\ x\ IR_{Garden}\ x\ F_{HG\_garden}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Meat}$	mg/kg/day	**0.00E+00**	$Intake_{Meat} = \frac{C_{Meat}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Offal}$	mg/kg/day	**0.00E+00**	$Intake_{Offal} = \frac{C_{Offal}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Milk}$	mg/kg/day	**0.00E+00**	$Intake_{Milk} = \frac{C_{Milk}\ x\ IR_{Milk}\ x\ F_{Milk}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Verts}$	mg/kg/day	**2.39E-07**	$Intake_{Aquatic\_Verts} = \frac{C_{Aquatic\_Verts}\ x\ IR_{Aquatic\_Verts}\ x\ F_{HG\_Aquatic\_Verts}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Plants}$	mg/kg/day	**2.37E-08**	$Intake_{Aquatic\_Plants} = \frac{C_{Aquatic\_Plants}\ x\ IR_{Aquatic\_Plants}\ x\ F_{HG\_Aquatic\_Plants}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
Pathway contribution calculations				
$Contribution_{Ingestion\_IncidentalWater}$	%	2%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	Calculated based on MfE (2011) and ASC NEPM algorithms
$Contribution_{Homegrown\_Eggs}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_FruitVeg}$	%	8%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Meat}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Offal}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Milk}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Verts}$	%	80%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Plants}$	%	8%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	

General toxicity and exposure inputs				
TRV	mg/kg/day	0.00016	Based on developmental toxicity endpoints in animal studies	FSANZ (2017c)
$Background_{Ingestion}$ (Background)	%	10%	Conservative assumption, calculated on the basis dietary concentrations in Europe and serum concentrations in the Australian population	EFSA (2020), FSANZ (2017), Thompson *et al.* (2010)
Body weight (BW)	kg	13	Body weight of a child (2 years)	MfE (2011)
Averaging time (AT)	days	2190	Exposure duration x 365 days/yr	MfE (2011)
Exposure frequency (EF)	days/yr	365	Daily - local resident	MfE (2011)
Exposure duration (ED)	years	6	Childhood	MfE (2011)
Oral bioavailability (BIO)	-	1	Assumes that ingested PFAS is largely bioaccessible	OEH (2019)
Water consumption exposure inputs				
Ingestion rate ($IR_{Incidental}$)	L/day	0.050	Average daily incidental water ingestion rate. Represents the incidental ingestion that may be associated with the use of bore/creek water for activities such as bathing, filling swimming pools and sprinkler use	enHealth (2012)
Fraction of water sourced from bore/creek ($F_{W\_Incidental}$)	%	100%	Fraction of incidental water ingestion sourced from bore/creek	Assumption
Egg consumption exposure inputs				
Concentration in edible portion of egg (C_{Eggs})	mg/kg	7.0E-06	$C_{Egg} = \frac{TF_{Egg} \ x \ C_{Water} \ x \ IR_{Water\_chicken} \ x \ F_{Chicken\_water} \ x \ BIO}{LR \ x \ W_{egg} \ x \ F_{Edible}}$	DoD (2017a)
Water ingestion rate of chickens ($IR_{Chickens\_Water}$)	L/day	0.32	Average daily water consumption of a laying hen	ANZECC (2000)
Fraction of water sourced from bore/creek ($F_{Water\_Chickens}$)	%	100%	Conservative assumption - assumes poultry obtains all water requirements from the bore and/or creek	Assumption
Egg consumption rate (IR_{Egg})	kg/day	0.016	Double the average daily egg consumption rate reported for the New Zealand population (toddlers)	MfE (2011)
Edible fraction of egg (F_{Edible})	%	0.9	Approximate portion of an egg that is edible	MfE (2011)
Transfer factor to chicken eggs (TF_{Eggs})	mg/day edible egg per mg/day intake	0.5	A study undertaken by the Australian Department of Defence indicated that the amount of PFOS transferred to eggs each day is estimated, on average, to be equal to the amount of PFOS ingested by a chicken via their drinking water each day. Transfer rates for PFHxS and PFOA were lower, at 0.7 and 0.45 respectively.The defence study concludes that almost 100% of the transfer is to the edible portion and therefore the TF of 1 has been adjusted upwards according the the equation $1/F_{edible}$	DoD (2017a), Kowalczyk (2013)
Egg laying rate (LR)	eggs/day	0.8	Laying hens can produce up to approximately 300 eggs per year	Assumption
Egg weight (W_{egg})	kg/egg	0.060	Weight of a typical egg	MfE (2011)
Fraction of homegrown eggs (F_{HG_Eggs})	%	25%	MfE (2011) assumption for a rural/residential block	Assumption
Fruit and vegetable consumption exposure inputs				
Concentration in fruit and vegetables (C_{Garden})	mg/kg	9.3E-06	$C_{Garden} = TF_{Garden} \ x \ C_w$	DoD (2017b)
PFOA transfer factor to fruits and vegetables ($TF_{GardenPFOA}$)	L/kg	4.9	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFOA and irrigated vegetables of 4.9 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
Fruit and vegetable consumption rate ($C_{FruitVeg}$)	kg/day	0.14	Total fruit and vegetable consumption rates reported for the Australian population (1-3 years)	MfE (2011)
Fraction of homegrown fruit and vegetables ($F_{HG\_FruitVeg}$)	%	25%	Default assumption for rural/residential land uses	MfE (2011)
Meat and milk consumption exposure inputs				
Concentration in meat (C_{Meat})	mg/kg	0.0E+00	$C_{Meat} = TF_{Serum} \ x \ C_w \ x \ F_{Water\_stock} \ x \ CF_{Meat}$	Drew *et al.* (2021)
Concentration in offal (C_{Offal})	mg/kg	0.0E+00	$C_{Offal} = TF_{Serum} \ x \ C_w \ x \ F_{Water\_stock} \ x \ CF_{Offal}$	Drew *et al.* (2021)
Concentration in milk (C_{Milk})	mg/kg	0.0E+00	$C_{Milk} = TF_{Serum} \ x \ C_w \ x \ F_{Water\_stock} \ x \ CF_{Milk}$	Drew *et al.* (2021)
Meat (muscle) consumption rate (IR_{Muscle})	kg/day	0.085	90th percentile total meat consumption rate reported for the population (2-6 years). Representative of meat consumption rates for people on livestock-producing properties	FSANZ (2017)
Offal consumption rate (IR_{Offal})	kg/day	0.000	Substantial offal consumption has not been identified for children (2-6 years)	FSANZ (2017)
Milk consumption rate (IR_{Offal})	kg/day	1.097	90th percentile milk consumption rate reported for the population (2-6 years). Representative of milk consumption rates for people on livestock-producing properties	FSANZ (2017)
PFOA serum to meat concentration factor (CF_{Muscle})	L/kg	0.07	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA serum to offal concentration factor (CF_{Offal})	L/kg	1.2	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA serum to milk concentration factor (CF_{Milk})	L/kg	0	Describes the transfer from plasma to milk (mg/L meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	0	Negligible transfer of PFOA from drinking water to serum has been reported	Drew *et al.* (2021)
Fraction of water sourced from bore/creek (F_{Water_Stock})	%	100%	Conservative assumption - assumes livestock obtain all water requirements from the creek	Assumption
Fraction of homegrown meat (F_{HG_Meat})	%	75%	Represents the fact that stock produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption
Fraction of homegrown milk (F_{HG_Milk})	%	75%	Represents the fact that milk produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption

Aquatic biota consumption exposure inputs				
Concentration in aquatic vertebrates ($C_{Aquatic\_Verts}$)	mg/kg	3.2E-04	$C_{Aquatic\_Verts} = BAF_{Aquatic\_Verts} \times C_w$	Burkhard (2020)
Concentration in aquatic plants ($C_{Aquatic\_Plants}$)	mg/kg	9.1E-05	$C_{Aquatic\_Plants} = BAF_{Aquatic\_Plants} \times C_w$	Burkhard (2020)
PFOA bioaccumulation factor for aquatic invertebrates ($BAF_{Aquatic\_Inverts}$)	L/kg	45	Maximum BAF reported for molluscs	ITRC (2022)
PFOA bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	168	Mean BAF reported for eel muscle	DoD (2017c)
PFOA bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	48	Mean BCF for aquatic plants	DoD (2017c)
Aquatic vertebrate consumption rate ($IR_{Aquatic\_Verts}$)	kg/day	0.013	Mean total fish consumption rate for young children	MPI (2016)
Aquatic plant consumption rate ($IR_{Aquatic\_Plants}$)	kg/day	0.005	Half of the mean leafy vegetable consumption rate for young children	FSANZ (2017)
Fraction of locally grown aquatic vertebrates ($F_{HG\_Aquatic\_Verts}$)	%	75%	Represents the fact that locally caught aquatic biota may make a substantial contribution to the diet of local residents	Assumption
Fraction of locally grown aquatic plants ($F_{HG\_Aquatic\_Plants}$)	%	75%	Represents the fact that locally foraged aquatic vegetation may make a substantial contribution to the diet of local residents	Assumption

(green)	Value recommended by MfE, ASC NEPM, NHMRC, FSANZ or enHealth
(olive)	Site-specific data or assumption
(yellow)	Assumption based on a published study or guideline
(orange)	Calculated value

Assessment Area	Smooth Hill Landfill - Creek	
Exposure Scenario	Cumulative	
Receptor Group	Children (2-6 years)	
Chemicals of Potential Concern	PFOS+PFHxS	
Exposure Media	Surface water	

Total Hazard Index	-	**0.05**

Relevant exposure pathways	
Potable ingestion	No
Incidental ingestion	Yes
Poultry watering and egg consumption	Yes
Irrigation and produce consumption	Yes
Stock watering and meat consumption	Yes
Stock watering and offal consumption	Yes
Dermal contact	No
Stock watering and milk consumption	Yes
Aquatiic vertebrate consumption	Yes
Aquatic plant consumption	Yes

Parameter	Unit	Value	Details	Source
Water quality inputs				
Concentration in water	**µg/L**	**0.00037**	Predicted worst case surface water concentration at Brighton (no HDPE - complete failure)	Assumption
Concentration in water	**mg/L**	**3.70E-07**		
Percentage PFHxS (in PFOS+PFHxS)	**%**	**64%**	Distribution of PFOS/PFHxS predicted in downstream surface water samples	Site-specific
Risk calculations				
HI_{Total}	-	**4.93E-02**	$HI = \sum HQ_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$HQ_{Water\_Incidental}$	-	**7.91E-05**	$HQ_{Water\_incidental} = \frac{Intake_{Water\_incidental}}{TRV\ x\ (100\% - Background)}$	
HQ_{Eggs}	-	**5.21E-05**	$HQ_{Eggs} = \frac{Intake_{Eggs}}{TRV\ x\ (100\% - Background)}$	
HQ_{Garden}	-	**1.85E-04**	$HQ_{Garden} = \frac{Intake_{Garden}}{TRV\ x\ (100\% - Background)}$	
HQ_{Meat}	-	**5.76E-04**	$HQ_{Meat} = \frac{Intake_{Meat}}{TRV\ x\ (100\% - Background)}$	
HQ_{Offal}	-	**0.00E+00**	$HQ_{Offal} = \frac{Intake_{Offal}}{TRV\ x\ (100\% - Background)}$	
HQ_{Milk}	-	**1.22E-03**	$HQ_{Milk} = \frac{Intake_{Milk}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqVerts}$	-	**4.45E-02**	$HQ_{Aquatic\_Verts} = \frac{Intake_{Aquatic\_Verts}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqPlants}$	-	**2.69E-03**	$HQ_{Aquatic\_Plants} = \frac{Intake_{Aquatic\_Plants}}{TRV\ x\ (100\% - Background)}$	
Intake calculations				
$Intake_{Total}$	mg/kg/day	**8.88E-07**	$Intake_{Total} = \sum Intake_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$Intake_{Water\_Incidental}$	mg/kg/day	**1.42E-09**	$Intake_{Water\_nonpotable} = \frac{C_{Water}\ x\ IR_{Water\_nonpotable}\ x\ F_{Water\_nonpotable}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Eggs}$	mg/kg/day	**9.37E-10**	$Intake_{Eggs} = \frac{C_{Eggs}\ x\ IR_{Eggs}\ x\ F_{HG\_eggs}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Garden}$	mg/kg/day	**3.32E-09**	$Intake_{Garden} = \frac{C_{Garden}\ x\ IR_{Garden}\ x\ F_{HG\_garden}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Meat}$	mg/kg/day	**1.04E-08**	$Intake_{Meat} = \frac{C_{Meat}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Offal}$	mg/kg/day	**0.00E+00**	$Intake_{Offal} = \frac{C_{Offal}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Milk}$	mg/kg/day	**2.20E-08**	$Intake_{Milk} = \frac{C_{Milk}\ x\ IR_{Milk}\ x\ F_{Milk}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Verts}$	mg/kg/day	**8.01E-07**	$Intake_{Aquatic\_Verts} = \frac{C_{Aquatic\_Verts}\ x\ IR_{Aquatic\_Verts}\ x\ F_{HG\_Aquatic\_Verts}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Plants}$	mg/kg/day	**4.85E-08**	$Intake_{Aquatic\_Plants} = \frac{C_{Aquatic\_Plants}\ x\ IR_{Aquatic\_Plants}\ x\ F_{HG\_Aquatic\_Plants}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
Pathway contribution calculations				
$Contribution_{Ingestion\_IncidentalWater}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	Calculated based on MfE (2011) and ASC NEPM algorithms
$Contribution_{Homegrown\_Eggs}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_FruitVeg}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Meat}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Offal}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Milk}$	%	2%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Verts}$	%	90%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Plants}$	%	5%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	

General toxicity and exposure inputs				
TRV	mg/kg/day	0.00002	Based on developmental toxicity endpoints in animal studies	FSANZ (2017c)
$Background_{Ingestion}$ (Background)	%	10%	Conservative assumption, calculated on the basis dietary concentrations in Europe and serum concentrations in the Australian population	EFSA (2020), FSANZ (2017), Thompson *et al.* (2010)
Body weight (BW)	kg	13	Body weight of a child (2 years)	MfE (2011)
Averaging time (AT)	days	2190	Exposure duration x 365 days/yr	MfE (2011)
Exposure frequency (EF)	days/yr	365	Daily - local resident	MfE (2011)
Exposure duration (ED)	years	6	Childhood	MfE (2011)
Oral bioavailability (BIO)	-	1	Assumes that ingested PFAS is largely bioaccessible	OEH (2019)
Water consumption exposure inputs				
Ingestion rate ($IR_{Incidental}$)	L/day	0.050	Average daily incidental water ingestion rate. Represents the incidental ingestion that may be associated with the use of bore/creek water for activities such as bathing, filling swimming pools and sprinkler use	enHealth (2012)
Fraction of water sourced from bore/creek ($FW_{\_Potable}$)	%	0%	Fraction of potable water consumption sourced from bore/creek	Assumption
Fraction of water sourced from bore/creek ($F_{W\_Incidental}$)	%	100%	Fraction of incidental water ingestion sourced from bore/creek	Assumption
Egg consumption exposure inputs				
Concentration in edible portion of egg (C_{Eggs})	mg/kg	3.0E-06	$C_{Egg} = \frac{TF_{Egg}\ x\ C_{Water}\ x\ IR_{Water\_chicken}\ x\ F_{Chicken\_water}\ x\ BIO}{LR\ x\ W_{egg}\ x\ F_{Edible}}$	DoD (2017a)
Water ingestion rate of chickens ($IR_{Chickens\_Water}$)	L/day	0.32	Average daily water consumption of a laying hen	ANZECC (2000)
Fraction of water sourced from bore/creek ($F_{Water\_Chickens}$)	%	100%	Conservative assumption - assumes poultry obtains all water requirements from the bore and/or creek	Assumption
Egg consumption rate (IR_{Egg})	kg/day	0.016	Double the average daily egg consumption rate reported for the New Zealand population (toddlers)	MfE (2011)
Edible fraction of egg (F_{Edible})	%	0.9	Approximate portion of an egg that is edible	MfE (2011)
Transfer factor to chicken eggs (TF_{Eggs})	mg/day edible egg per mg/day intake	1.1	A study undertaken by the Australian Department of Defence indicated that the amount of PFOS transferred to eggs each day is estimated, on average, to be equal to the amount of PFOS ingested by a chicken via their drinking water each day. Transfer rates for PFHxS and PFOA were lower, at 0.7 and 0.45 respectively.The defence study concludes that almost 100% of the transfer is to the edible portion and therefore the TF of 1 has been adjusted upwards according the the equation $1/F_{edible}$	DoD (2017a), Kowalczyk (2013)
Egg laying rate (LR)	eggs/day	0.8	Laying hens can produce up to approximately 300 eggs per year	Assumption
Egg weight (W_{egg})	kg/egg	0.060	Weight of a typical egg	MfE (2011)
Fraction of homegrown eggs (F_{HG_Eggs})	%	25%	MfE (2011) assumption for a rural/residential block	Assumption
Fruit and vegetable consumption exposure inputs				
Concentration in fruit and vegetables (C_{Garden})	mg/kg	1.2E-06	$C_{Garden} = TF_{Garden}\ x\ C_w$	DoD (2017b)
PFOS transfer factor to fruits and vegetables ($TF_{GardenPFOS}$)	L/kg	2.5	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFOS and irrigated vegetables of 2.5 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
PFHxS transfer factor to fruits and vegetables ($TF_{GardenPFHxS}$)	L/kg	3.8	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFHxS and irrigated vegetables of 3.8 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
Fruit and vegetable consumption rate ($C_{FruitVeg}$)	kg/day	0.14	Total fruit and vegetable consumption rates reported for the Australian population (1-3 years)	MfE (2011)
Fraction of homegrown fruit and vegetables ($F_{HG\_FruitVeg}$)	%	25%	Default assumption for rural/residential land uses	MfE (2011)
Meat and milk consumption exposure inputs				
Concentration in meat (C_{Meat})	mg/kg	2.1E-06	$C_{Meat} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Meat}$	Drew *et al.* (2021)
Concentration in offal (C_{Offal})	mg/kg	2.2E-05	$C_{Offal} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Offal}$	Drew *et al.* (2021)
Concentration in milk (C_{Milk})	mg/kg	3.5E-07	$C_{Milk} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Milk}$	Drew *et al.* (2021)
Meat (muscle) consumption rate (IR_{Muscle})	kg/day	0.085	90th percentile total meat consumption rate reported for the population (2-6 years). Representative of meat consumption rates for people on livestock-producing properties	FSANZ (2017)
Offal consumption rate (IR_{Offal})	kg/day	0.000	Substantial offal consumption has not been identified for children (2-6 years)	FSANZ (2017)
Milk consumption rate (IR_{Offal})	kg/day	1.097	90th percentile milk consumption rate reported for the population (2-6 years). Representative of milk consumption rates for people on livestock-producing properties	FSANZ (2017)
PFOS serum to meat concentration factor (CF_{Muscle})	L/kg	0.076	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS serum to offal concentration factor (CF_{Offal})	L/kg	1.06	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS serum to milk concentration factor (CF_{Milk})	L/kg	0.013	Describes the transfer from plasma to milk (mg/L meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to meat concentration factor (CF_{Muscle})	L/kg	0.046	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to offal concentration factor (CF_{Offal})	L/kg	0.19	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to milk concentration factor (CF_{Milk})	L/kg	0.007	Describes the transfer from plasma to offal (mg/L milk per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	140	Describes the relationship between the PFOS concentration in water and serum	Drew *et al.* (2021)
PFHxS transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	65	Describes the relationship between the PFHxS concentration in water and serum	Drew *et al.* (2021)
Fraction of water sourced from bore/creek (F_{Water_Stock})	%	100%	Conservative assumption - assumes livestock obtain all water requirements from the creek	Assumption
Fraction of homegrown meat (F_{HG_Meat})	%	75%	Represents the fact that stock produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption
Fraction of homegrown milk (F_{HG_Milk})	%	75%	Represents the fact that milk produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption

Aquatic biota consumption exposure inputs				
Concentration in aquatic vertebrates ($C_{Aquatic\_Verts}$)	mg/kg	1.1E-03	$C_{Aquatic\_Verts} = BAF_{Aquatic\_Verts}\ x\ C_w$	Burkhard (2020)
Concentration in aquatic plants ($C_{Aquatic\_Plants}$)	mg/kg	1.9E-04	$C_{Aquatic\_Plants} = BAF_{Aquatic\_Plants}\ x\ C_w$	Burkhard (2020)
PFOS bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	7470	Mean BAF reported for eel muscle	DoD (2017c)
PFHxS bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	354	Mean BAF reported for eel muscle	Kwadijk *et al.* (2010)
PFOS bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	1162	Mean BCF for aquatic plants	DoD (2017c)
PFHxS bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	141	Mean BCF for aquatic plants	DoD (2017c)
Aquatic vertebrate consumption rate ($IR_{Aquatic\_Verts}$)	kg/day	0.013	Mean total fish consumption rate for young children	MPI (2016)
Aquatic plant consumption rate ($IR_{Aquatic\_Plants}$)	kg/day	0.005	Half of the mean leafy vegetable consumption rate for young children	FSANZ (2017)
Fraction of locally grown aquatic vertebrates ($F_{HG\_Aquatic\_Verts}$)	%	75%	Represents the fact that locally caught aquatic biota may make a substantial contribution to the diet of local residents	Assumption
Fraction of locally grown aquatic plants ($F_{HG\_Aquatic\_Plants}$)	%	75%	Represents the fact that locally foraged aquatic vegetation may make a substantial contribution to the diet of local residents	Assumption

	Value recommended by MfE, ASC NEPM, NHMRC, FSANZ or enHealth
	Site-specific data or assumption
	Assumption based on a published study or guideline
	Calculated value

Assessment Area	Smooth Hill Landfill - Creek
Exposure Scenario	Cumulative
Receptor Group	Children (2-6 years)
Chemicals of Potential Concern	PFOA
Exposure Media	Surface water

Total Hazard Index	**-**	**0.0002**

Relevant exposure pathways	
Potable ingestion	No
Incidental ingestion	Yes
Poultry watering and egg consumption	Yes
Irrigation and produce consumption	Yes
Stock watering and meat consumption	Yes
Stock watering and offal consumption	Yes
Dermal contact	No
Stock watering and milk consumption	Yes
Aquatiic vertebrate consumption	Yes
Aquatic plant consumption	Yes

Parameter	Unit	Value	Details	Source
Water quality inputs				
Concentration in water	**µg/L**	**0.00017**	Predicted worst case surface water concentration at Coast Farm (no HDPE - complete failure)	Assumption
Concentration in water	**mg/L**	**1.669E-07**		
Risk calculations				
HI_{Total}	-	**1.82E-04**	$HI = \sum HQ_{All\ pathways}$	Calculated - based on MfE(2011) and ASC NEPM algorithms
$HQ_{Water\_Incidental}$	-	**4.46E-06**	$HQ_{Water\_incidental} = \frac{Intake_{Water\_incidental}}{TRV\ x\ (100\% - Background)}$	
HQ_{Eggs}	-	**1.32E-06**	$HQ_{Eggs} = \frac{Intake_{Eggs}}{TRV\ x\ (100\% - Background)}$	
HQ_{Garden}	-	**1.53E-05**	$HQ_{Garden} = \frac{Intake_{Garden}}{TRV\ x\ (100\% - Background)}$	
HQ_{Meat}	-	**0.00E+00**	$HQ_{Meat} = \frac{Intake_{Meat}}{TRV\ x\ (100\% - Background)}$	
HQ_{Offal}	-	**0.00E+00**	$HQ_{Offal} = \frac{Intake_{Offal}}{TRV\ x\ (100\% - Background)}$	
HQ_{Milk}	-	**0.00E+00**	$HQ_{Milk} = \frac{Intake_{Milk}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqVerts}$	-	**1.46E-04**	$HQ_{Aquatic\_Verts} = \frac{Intake_{Aquatic\_Verts}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqPlants}$	-	**1.44E-05**	$HQ_{Aquatic\_Plants} = \frac{Intake_{Aquatic\_Plants}}{TRV\ x\ (100\% - Background)}$	
Intake calculations				
$Intake_{Total}$	mg/kg/day	**2.61E-08**	$Intake_{Total} = \sum Intake_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$Intake_{Water\_Incidental}$	mg/kg/day	**6.42E-10**	$Intake_{Water\_nonpotable} = \frac{C_{Water}\ x\ IR_{Water\_nonpotable}\ x\ F_{Water\_nonpotable}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Eggs}$	mg/kg/day	**1.90E-10**	$Intake_{Eggs} = \frac{C_{Eggs}\ x\ IR_{Eggs}\ x\ F_{HG\_eggs}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Garden}$	mg/kg/day	**2.20E-09**	$Intake_{Garden} = \frac{C_{Garden}\ x\ IR_{Garden}\ x\ F_{HG\_garden}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Meat}$	mg/kg/day	**0.00E+00**	$Intake_{Meat} = \frac{C_{Meat}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Offal}$	mg/kg/day	**0.00E+00**	$Intake_{Offal} = \frac{C_{Offal}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Milk}$	mg/kg/day	**0.00E+00**	$Intake_{Milk} = \frac{C_{Milk}\ x\ IR_{Milk}\ x\ F_{Milk}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Verts}$	mg/kg/day	**2.10E-08**	$Intake_{Aquatic\_Verts} = \frac{C_{Aquatic\_Verts}\ x\ IR_{Aquatic\_Verts}\ x\ F_{HG\_Aquatic\_Verts}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Plants}$	mg/kg/day	**2.08E-09**	$Intake_{Aquatic\_Plants} = \frac{C_{Aquatic\_Plants}\ x\ IR_{Aquatic\_Plants}\ x\ F_{HG\_Aquatic\_Plants}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
Pathway contribution calculations				
$Contribution_{Ingestion\_IncidentalWater}$	%	2%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	Calculated based on MfE (2011) and ASC NEPM algorithms
$Contribution_{Homegrown\_Eggs}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_FruitVeg}$	%	8%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Meat}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Offal}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Milk}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Verts}$	%	80%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Plants}$	%	8%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	

General toxicity and exposure inputs				
TRV	mg/kg/day	0.00016	Based on developmental toxicity endpoints in animal studies	FSANZ (2017c)
$Background_{Ingestion}$ (Background)	%	10%	Conservative assumption, calculated on the basis dietary concentrations in Europe and serum concentrations in the Australian population	EFSA (2020), FSANZ (2017), Thompson *et al.* (2010)
Body weight (BW)	kg	13	Body weight of a child (2 years)	MfE (2011)
Averaging time (AT)	days	2190	Exposure duration x 365 days/yr	MfE (2011)
Exposure frequency (EF)	days/yr	365	Daily - local resident	MfE (2011)
Exposure duration (ED)	years	6	Childhood	MfE (2011)
Oral bioavailability (BIO)	-	1	Assumes that ingested PFAS is largely bioaccessible	OEH (2019)
Water consumption exposure inputs				
Ingestion rate ($IR_{Incidental}$)	L/day	0.050	Average daily incidental water ingestion rate. Represents the incidental ingestion that may be associated with the use of bore/creek water for activities such as bathing, filling swimming pools and sprinkler use	enHealth (2012)
Fraction of water sourced from bore/creek ($F_{W\_Incidental}$)	%	100%	Fraction of incidental water ingestion sourced from bore/creek	Assumption
Egg consumption exposure inputs				
Concentration in edible portion of egg (C_{Eggs})	mg/kg	6.2E-07	$C_{Egg} = \frac{TF_{Egg} \times C_{Water} \times IR_{Water\_chicken} \times F_{Chicken\_water} \times BIO}{LR \times W_{egg} \times F_{Edible}}$	DoD (2017a)
Water ingestion rate of chickens ($IR_{Chickens\_Water}$)	L/day	0.32	Average daily water consumption of a laying hen	ANZECC (2000)
Fraction of water sourced from bore/creek ($F_{Water\_Chickens}$)	%	100%	Conservative assumption - assumes poultry obtains all water requirements from the bore and/or creek	Assumption
Egg consumption rate (IR_{Egg})	kg/day	0.016	Double the average daily egg consumption rate reported for the New Zealand population (toddlers)	MfE (2011)
Edible fraction of egg (F_{Edible})	%	0.9	Approximate portion of an egg that is edible	MfE (2011)
Transfer factor to chicken eggs (TF_{Eggs})	mg/day edible egg per mg/day intake	0.5	A study undertaken by the Australian Department of Defence indicated that the amount of PFOS transferred to eggs each day is estimated, on average, to be equal to the amount of PFOS ingested by a chicken via their drinking water each day. Transfer rates for PFHxS and PFOA were lower, at 0.7 and 0.45 respectively.The defence study concludes that almost 100% of the transfer is to the edible portion and therefore the TF of 1 has been adjusted upwards according the the equation $1/F_{edible}$	DoD (2017a), Kowalczyk (2013)
Egg laying rate (LR)	eggs/day	0.8	Laying hens can produce up to approximately 300 eggs per year	Assumption
Egg weight (W_{egg})	kg/egg	0.060	Weight of a typical egg	MfE (2011)
Fraction of homegrown eggs (F_{HG_Eggs})	%	25%	MfE (2011) assumption for a rural/residential block	Assumption
Fruit and vegetable consumption exposure inputs				
Concentration in fruit and vegetables (C_{Garden})	mg/kg	8.2E-07	$C_{Garden} = TF_{Garden} \times C_w$	DoD (2017b)
PFOA transfer factor to fruits and vegetables ($TF_{GardenPFOA}$)	L/kg	4.9	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFOA and irrigated vegetables of 4.9 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
Fruit and vegetable consumption rate ($C_{FruitVeg}$)	kg/day	0.14	Total fruit and vegetable consumption rates reported for the Australian population (1-3 years)	MfE (2011)
Fraction of homegrown fruit and vegetables ($F_{HG\_FruitVeg}$)	%	25%	Default assumption for rural/residential land uses	MfE (2011)
Meat and milk consumption exposure inputs				
Concentration in meat (C_{Meat})	mg/kg	0.0E+00	$C_{Meat} = TF_{Serum} \times C_w \times F_{Water\_stock} \times CF_{Meat}$	Drew *et al.* (2021)
Concentration in offal (C_{Offal})	mg/kg	0.0E+00	$C_{Offal} = TF_{Serum} \times C_w \times F_{Water\_stock} \times CF_{Offal}$	Drew *et al.* (2021)
Concentration in milk (C_{Milk})	mg/kg	0.0E+00	$C_{Milk} = TF_{Serum} \times C_w \times F_{Water\_stock} \times CF_{Milk}$	Drew *et al.* (2021)
Meat (muscle) consumption rate (IR_{Muscle})	kg/day	0.085	90th percentile total meat consumption rate reported for the population (2-6 years). Representative of meat consumption rates for people on livestock-producing properties	FSANZ (2017)
Offal consumption rate (IR_{Offal})	kg/day	0.000	Substantial offal consumption has not been identified for children (2-6 years)	FSANZ (2017)
Milk consumption rate (IR_{Offal})	kg/day	1.097	90th percentile milk consumption rate reported for the population (2-6 years). Representative of milk consumption rates for people on livestock-producing properties	FSANZ (2017)
PFOA serum to meat concentration factor (CF_{Muscle})	L/kg	0.07	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA serum to offal concentration factor (CF_{Offal})	L/kg	1.2	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA serum to milk concentration factor (CF_{Milk})	L/kg	0	Describes the transfer from plasma to milk (mg/L meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	0	Negligible transfer of PFOA from drinking water to serum has been reported	Drew *et al.* (2021)
Fraction of water sourced from bore/creek (F_{Water_Stock})	%	100%	Conservative assumption - assumes livestock obtain all water requirements from the creek	Assumption
Fraction of homegrown meat (F_{HG_Meat})	%	75%	Represents the fact that stock produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption
Fraction of homegrown milk (F_{HG_Milk})	%	75%	Represents the fact that milk produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption

Aquatic biota consumption exposure inputs				
Concentration in aquatic invertebrates ($C_{Aquatic\_Inverts}$)	mg/kg	7.5E-06	$C_{Aquatic\_Inverts} = BAF_{Aquatic\_Inverts} \times C_w$	Burkhard (2020)
Concentration in aquatic vertebrates ($C_{Aquatic\_Verts}$)	mg/kg	2.8E-05	$C_{Aquatic\_Verts} = BAF_{Aquatic\_Verts} \times C_w$	Burkhard (2020)
Concentration in aquatic plants ($C_{Aquatic\_Plants}$)	mg/kg	8.0E-06	$C_{Aquatic\_Plants} = BAF_{Aquatic\_Plants} \times C_w$	Burkhard (2020)
PFOA bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	168	Mean BAF reported for eel muscle	DoD (2017c)
PFOA bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	48	Mean BCF for aquatic plants	DoD (2017c)
Aquatic vertebrate consumption rate ($IR_{Aquatic\_Verts}$)	kg/day	0.013	Mean total fish consumption rate for young children	MPI (2016)
Aquatic plant consumption rate ($IR_{Aquatic\_Plants}$)	kg/day	0.005	Half of the mean leafy vegetable consumption rate for young children	FSANZ (2017)
Fraction of locally grown aquatic vertebrates ($F_{HG\_Aquatic\_Verts}$)	%	75%	Represents the fact that locally caught aquatic biota may make a substantial contribution to the diet of local residents	Assumption
Fraction of locally grown aquatic plants ($F_{HG\_Aquatic\_Plants}$)	%	75%	Represents the fact that locally foraged aquatic vegetation may make a substantial contribution to the diet of local residents	Assumption

	Value recommended by MfE, ASC NEPM, NHMRC, FSANZ or enHealth
	Site-specific data or assumption
	Assumption based on a published study or guideline
	Calculated value

Assessment Area	Smooth Hill Landfill - Farm Pond
Exposure Scenario	Cumulative
Receptor Group	Adults
Chemicals of Potential Concern	PFOS+PFHxS
Exposure Media	Surface water

Total Hazard Index	-	**0.4**

Relevant exposure pathways	
Potable ingestion	No
Incidental ingestion	Yes
Poultry watering and egg consumption	Yes
Irrigation and produce consumption	Yes
Stock watering and meat consumption	Yes
Stock watering and offal consumption	Yes
Dermal contact	No
Stock watering and milk consumption	Yes
Aquatiic vertebrate consumption	Yes
Aquatic plant consumption	Yes

Parameter	Unit	Value	Details	Source
Water quality inputs				
Concentration in water	**µg/L**	**0.0047**	Predicted worst case surface water concentration at Farm Pond (no HDPE - complete failure)	Assumption
Concentration in water	**mg/L**	**4.70E-06**		
Percentage PFHxS (in PFOS+PFHxS)	**%**	**80%**	Distribution of PFOS/PFHxS predicted in downstream surface water samples	Site-specific
Risk calculations				
HI_{Total}	-	**3.64E-01**	$HI = \sum HQ_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$HQ_{Water\_Incidental}$	-	**9.33E-05**	$HQ_{Water\_incidental} = \frac{Intake_{Water\_incidental}}{TRV\ x\ (100\% - Background)}$	
HQ_{Eggs}	-	**4.21E-04**	$HQ_{Eggs} = \frac{Intake_{Eggs}}{TRV\ x\ (100\% - Background)}$	
HQ_{Garden}	-	**1.43E-03**	$HQ_{Garden} = \frac{Intake_{Garden}}{TRV\ x\ (100\% - Background)}$	
HQ_{Meat}	-	**2.79E-03**	$HQ_{Meat} = \frac{Intake_{Meat}}{TRV\ x\ (100\% - Background)}$	
HQ_{Offal}	-	**3.54E-03**	$HQ_{Offal} = \frac{Intake_{Offal}}{TRV\ x\ (100\% - Background)}$	
HQ_{Milk}	-	**2.64E-03**	$HQ_{Milk} = \frac{Intake_{Milk}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqVerts}$	-	**3.38E-01**	$HQ_{Aquatic\_Verts} = \frac{Intake_{Aquatic\_Verts}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqPlants}$	-	**1.48E-02**	$HQ_{Aquatic\_Plants} = \frac{Intake_{Aquatic\_Plants}}{TRV\ x\ (100\% - Background)}$	
Intake calculations				
$Intake_{Total}$	mg/kg/day	**6.55E-06**	$Intake_{Total} = \sum Intake_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$Intake_{Water\_Incidental}$	mg/kg/day	**1.68E-09**	$Intake_{Water\_nonpotable} = \frac{C_{Water}\ x\ IR_{Water\_nonpotable}\ x\ F_{Water\_nonpotable}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Eggs}$	mg/kg/day	**7.57E-09**	$Intake_{Eggs} = \frac{C_{Eggs}\ x\ IR_{Eggs}\ x\ F_{HG\_eggs}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Garden}$	mg/kg/day	**2.57E-08**	$Intake_{Garden} = \frac{C_{Garden}\ x\ IR_{Garden}\ x\ F_{HG\_garden}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Meat}$	mg/kg/day	**5.03E-08**	$Intake_{Meat} = \frac{C_{Meat}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Offal}$	mg/kg/day	**6.37E-08**	$Intake_{Offal} = \frac{C_{Offal}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Milk}$	mg/kg/day	**4.75E-08**	$Intake_{Milk} = \frac{C_{Milk}\ x\ IR_{Milk}\ x\ F_{Milk}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Verts}$	mg/kg/day	**6.09E-06**	$Intake_{Aquatic\_Verts} = \frac{C_{Aquatic\_Verts}\ x\ IR_{Aquatic\_Verts}\ x\ F_{HG\_Aquatic\_Verts}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Plants}$	mg/kg/day	**2.66E-07**	$Intake_{Aquatic\_Plants} = \frac{C_{Aquatic\_Plants}\ x\ IR_{Aquatic\_Plants}\ x\ F_{HG\_Aquatic\_Plants}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
Pathway contribution calculations				
$Contribution_{Ingestion\_IncidentalWater}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	Calculated based on MfE (2011) and ASC NEPM algorithms
$Contribution_{Homegrown\_Eggs}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_FruitVeg}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Meat}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Offal}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Milk}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Verts}$	%	93%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Plants}$	%	4%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	

General toxicity and exposure inputs				
TRV	mg/kg/day	0.00002	Based on developmental toxicity endpoints in animal studies	FSANZ (2017c)
$\text{Background}_{\text{Ingestion}}$ (Background)	%	10%	Conservative assumption, calculated on the basis dietary concentrations in Europe and serum concentrations in the Australian population	EFSA (2020), FSANZ (2017), Thompson *et al.* (2010)
Body weight (BW)	kg	70	Adult body weight	MfE (2011)
Averaging time (AT)	days	8760	Exposure duration x 365 days/yr	MfE (2011)
Exposure frequency (EF)	days/yr	365	Daily - local resident	MfE (2011)
Exposure duration (ED)	years	24	Adulthood resident duration	MfE (2011)
Oral bioavailability (BIO)	-	1	Assumes that ingested PFAS is largely bioaccessible	OEH (2019)
Water consumption exposure inputs				
Ingestion rate ($IR_{Incidental}$)	L/day	0.025	Average daily incidental water ingestion rate. Represents the incidental ingestion that may be associated with the use of bore/creek water for activities such as bathing, filling swimming pools and sprinkler use	enHealth (2012)
Fraction of water sourced from bore/creek ($F_{W\_Incidental}$)	%	100%	Fraction of incidental water ingestion sourced from bore/creek	Assumption
Egg consumption exposure inputs				
Concentration in edible portion of egg (C_{Eggs})	mg/kg	3.9E-05	$C_{Egg} = \frac{TF_{Egg}\ x\ C_{Water}\ x\ IR_{Water\_chicken}\ x\ F_{Chicken\_water}\ x\ BIO}{LR\ x\ W_{egg}\ x\ F_{Edible}}$	DoD (2017a)
Water ingestion rate of chickens ($IR_{Chickens\_Water}$)	L/day	0.32	Average daily water consumption of a laying hen	ANZECC (2000)
Fraction of water sourced from bore/creek ($F_{Water\_Chickens}$)	%	100%	Conservative assumption - assumes poultry obtains all water requirements from the bore and/or creek	Assumption
Egg consumption rate (IR_{Egg})	kg/day	0.0548	Double the average daily egg consumption rate reported for the New Zealand population (adults)	MfE (2011)
Edible fraction of egg (F_{Edible})	%	0.9	Approximate portion of an egg that is edible	MfE (2011)
Transfer factor to chicken eggs (TF_{Eggs})	mg/day edible egg per mg/day intake	1.1	A study undertaken by the Australian Department of Defence indicated that the amount of PFOS transferred to eggs each day is estimated, on average, to be equal to the amount of PFOS ingested by a chicken via their drinking water each day. Transfer rates for PFHxS and PFOA were lower, at 0.7 and 0.45 respectively.The defence study concludes that almost 100% of the transfer is to the edible portion and therefore the TF of 1 has been adjusted upwards according the the equation $1/F_{edible}$	DoD (2017a), Kowalczyk (2013)
Egg laying rate (LR)	eggs/day	0.8	Laying hens can produce up to approximately 300 eggs per year	Assumption
Egg weight (W_{egg})	kg/egg	0.060	Weight of a typical egg	MfE (2011)
Fraction of homegrown eggs (F_{HG_Eggs})	%	25%	MfE (2011) assumption for a rural/residential block	Assumption
Fruit and vegetable consumption exposure inputs				
Concentration in fruit and vegetables (C_{Garden})	mg/kg	1.7E-05	$C_{Garden} = TF_{Garden}\ x\ C_w$	DoD (2017b)
PFOS transfer factor to fruits and vegetables ($TF_{GardenPFOS}$)	L/kg	2.5	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFOS and irrigated vegetables of 2.5 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
PFHxS transfer factor to fruits and vegetables ($TF_{GardenPFHxS}$)	L/kg	3.8	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFHxS and irrigated vegetables of 3.8 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
Fruit and vegetable consumption rate ($C_{FruitVeg}$)	kg/day	0.432	Total fruit and vegetable consumption rates reported for the New Zealand males (25+ years)	MfE (2011)
Fraction of homegrown fruit and vegetables ($F_{HG\_FruitVeg}$)	%	25%	Default assumption for rural/residential land uses	MfE (2011)
Meat and milk consumption exposure inputs				
Concentration in meat (C_{Meat})	mg/kg	2.1E-05	$C_{Meat} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Meat}$	Drew *et al.* (2021)
Concentration in offal (C_{Offal})	mg/kg	1.9E-04	$C_{Offal} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Offal}$	Drew *et al.* (2021)
Concentration in milk (C_{Milk})	mg/kg	3.4E-06	$C_{Milk} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Milk}$	Drew *et al.* (2021)
Meat (muscle) consumption rate (IR_{Muscle})	kg/day	0.221	90th percentile total meat consumption rate reported for the population (2+ years). Representative of meat consumption rates for people on livestock-producing properties	FSANZ (2017)
Offal consumption rate (IR_{Offal})	kg/day	0.032	90th percentile offal consumption rate reported for the population (2+ years). Representative of the upper end of the offal consumption rates for people on livestock-producing properties	FSANZ (2017)
Milk consumption rate (IR_{Offal})	kg/day	1.295	90th percentile total milk consumption rate reported for the population (2+ years). Representative of milk consumption rates for people on livestock-producing properties	FSANZ (2017)
PFOS serum to meat concentration factor (CF_{Muscle})	L/kg	0.076	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS serum to offal concentration factor (CF_{Offal})	L/kg	1.06	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS serum to milk concentration factor (CF_{Milk})	L/kg	0.013	Describes the transfer from plasma to milk (mg/L meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to meat concentration factor (CF_{Muscle})	L/kg	0.046	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to offal concentration factor (CF_{Offal})	L/kg	0.19	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to milk concentration factor (CF_{Milk})	L/kg	0.007	Describes the transfer from plasma to offal (mg/L milk per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	140	Describes the relationship between the PFOS concentration in water and serum	Drew *et al.* (2021)
PFHxS transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	65	Describes the relationship between the PFHxS concentration in water and serum	Drew *et al.* (2021)
Fraction of water sourced from bore/creek (F_{Water_Stock})	%	100%	Conservative assumption - assumes livestock obtain all water requirements from the creek	Assumption
Fraction of homegrown meat (F_{HG_Meat})	%	75%	Represents the fact that stock produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption
Fraction of homegrown milk (F_{HG_Milk})	%	75%	Represents the fact that milk produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption

Aquatic biota consumption exposure inputs				
Concentration in aquatic invertebrates ($C_{Aquatic\_Inverts}$)	mg/kg	4.9E-03	$C_{Aquatic\_Inverts} = BAF_{Aquatic\_Inverts}\ x\ C_w$	Burkhard (2020)
Concentration in aquatic vertebrates ($C_{Aquatic\_Verts}$)	mg/kg	8.4E-03	$C_{Aquatic\_Verts} = BAF_{Aquatic\_Verts}\ x\ C_w$	Burkhard (2020)
Concentration in aquatic plants ($C_{Aquatic\_Plants}$)	mg/kg	1.6E-03	$C_{Aquatic\_Plants} = BAF_{Aquatic\_Plants}\ x\ C_w$	Burkhard (2020)
PFOS bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	7470	Mean BAF reported for eel muscle	DoD (2017c)
PFHxS bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	354	Mean BAF reported for eel muscle	Kwadijk *et al.* (2010)
PFOS bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	1162	Mean BCF for aquatic plants	DoD (2017c)
PFHxS bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	141	Mean BCF for aquatic plants	DoD (2017c)
Aquatic vertebrate consumption rate ($IR_{Aquatic\_Verts}$)	kg/day	0.068	Maximum eel consumption rate reported for the adult population	NIWA (2011)
Aquatic plant consumption rate ($IR_{Aquatic\_Plants}$)	kg/day	0.015	Mean watercress consumption rate for the Te Arawa iwi population (adults)	NIWA (2011)
Fraction of locally grown aquatic vertebrates ($F_{HG\_Aquatic\_Verts}$)	%	75%	Represents the fact that locally caught aquatic biota may make a substantial contribution to the diet of local residents	Assumption
Fraction of locally grown aquatic plants ($F_{HG\_Aquatic\_Plants}$)	%	75%	Represents the fact that locally foraged aquatic vegetation may make a substantial contribution to the diet of local residents	Assumption

(teal)	Value recommended by MfE, ASC NEPM, NHMRC, FSANZ or enHealth
(green)	Site-specific data or assumption
(yellow)	Assumption based on a published study or guideline
(orange)	Calculated value

Assessment Area	Smooth Hill Landfill - Farm Pond
Exposure Scenario	Cumulative
Receptor Group	Adults
Chemicals of Potential Concern	PFOA
Exposure Media	Surface water

Total Hazard Index	**-**	**0.002**

Relevant exposure pathways	
Potable ingestion	No
Incidental ingestion	Yes
Poultry watering and egg consumption	Yes
Irrigation and produce consumption	Yes
Stock watering and meat consumption	Yes
Stock watering and offal consumption	Yes
Dermal contact	No
Stock watering and milk consumption	Yes
Aquatiic vertebrate consumption	Yes
Aquatic plant consumption	Yes

Parameter	Unit	Value	Details	Source
Water quality inputs				
Concentration in water	**µg/L**	**0.0019**	Predicted worst case surface water concentration at Farm Pond (no HDPE - complete failure)	Assumption
Concentration in water	**mg/L**	**1.90E-06**		
Risk calculations				
HI_{Total}	-	**1.83E-03**	$HI = \sum HQ_{All\ pathways}$	Calculated - based on MfE (2011) andASC NEPM algorithms
$HQ_{Water\_Incidental}$	-	**4.71E-06**	$HQ_{Water\_incidental} = \frac{Intake_{Water\_incidental}}{TRV\ x\ (100\% - Background)}$	
HQ_{Eggs}	-	**9.56E-06**	$HQ_{Eggs} = \frac{Intake_{Eggs}}{TRV\ x\ (100\% - Background)}$	
HQ_{Garden}	-	**9.98E-05**	$HQ_{Garden} = \frac{Intake_{Garden}}{TRV\ x\ (100\% - Background)}$	
HQ_{Meat}	-	**0.00E+00**	$HQ_{Meat} = \frac{Intake_{Meat}}{TRV\ x\ (100\% - Background)}$	
HQ_{Offal}	-	**0.00E+00**	$HQ_{Offal} = \frac{Intake_{Offal}}{TRV\ x\ (100\% - Background)}$	
HQ_{Milk}	-	**0.00E+00**	$HQ_{Milk} = \frac{Intake_{Milk}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqVerts}$	-	**1.62E-03**	$HQ_{Aquatic\_Verts} = \frac{Intake_{Aquatic\_Verts}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqPlants}$	-	**1.04E-04**	$HQ_{Aquatic\_Plants} = \frac{Intake_{Aquatic\_Plants}}{TRV\ x\ (100\% - Background)}$	
Intake calculations				
$Intake_{Total}$	mg/kg/day	**2.64E-07**	$Intake_{Total} = \sum Intake_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$Intake_{Water\_Incidental}$	mg/kg/day	**6.79E-10**	$Intake_{Water\_nonpotable} = \frac{C_{Water}\ x\ IR_{Water\_nonpotable}\ x\ F_{Water\_nonpotable}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Eggs}$	mg/kg/day	**1.38E-09**	$Intake_{Eggs} = \frac{C_{Eggs}\ x\ IR_{Eggs}\ x\ F_{HG\_eggs}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Garden}$	mg/kg/day	**1.44E-08**	$Intake_{Garden} = \frac{C_{Garden}\ x\ IR_{Garden}\ x\ F_{HG\_garden}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Meat}$	mg/kg/day	**0.00E+00**	$Intake_{Meat} = \frac{C_{Meat}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Offal}$	mg/kg/day	**0.00E+00**	$Intake_{Offal} = \frac{C_{Offal}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Milk}$	mg/kg/day	**0.00E+00**	$Intake_{Milk} = \frac{C_{Milk}\ x\ IR_{Milk}\ x\ F_{Milk}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Verts}$	mg/kg/day	**2.33E-07**	$Intake_{Aquatic\_Verts} = \frac{C_{Aquatic\_Verts}\ x\ IR_{Aquatic\_Verts}\ x\ F_{HG\_Aquatic\_Verts}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
Pathway contribution calculations				
$Contribution_{Ingestion\_IncidentalWater}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	Calculated based on MfE (2011) and ASC NEPM algorithms
$Contribution_{Homegrown\_Eggs}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_FruitVeg}$	%	5%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Meat}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Offal}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Milk}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Verts}$	%	88%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Plants}$	%	6%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake\ _{Total}}\ x\ 100\%$	

General toxicity and exposure inputs				
TRV	mg/kg/day	0.00016	Based on developmental toxicity endpoints in animal studies	FSANZ (2017c)
$Background_{Ingestion}$ (Background)	%	10%	Conservative assumption, calculated on the basis dietary concentrations in Europe and serum concentrations in the Australian population	EFSA (2020), FSANZ (2017), Thompson *et al.* (2010)
Body weight (BW)	kg	70	Adult body weight	MfE (2011)
Averaging time (AT)	days	8760	Exposure duration x 365 days/yr	MfE (2011)
Exposure frequency (EF)	days/yr	365	Daily - local resident	MfE (2011)
Exposure duration (ED)	years	24	Adulthood resident duration	MfE (2011)
Oral bioavailability (BIO)	-	1	Assumes that ingested PFAS is largely bioaccessible	OEH (2019)
Water consumption exposure inputs				
Ingestion rate ($IR_{Incidental}$)	L/day	0.025	Average daily incidental water ingestion rate. Represents the incidental ingestion that may be associated with the use of bore/creek water for activities such as bathing, filling swimming pools and sprinkler use	enHealth (2012)
Fraction of water sourced from bore/creek ($F_{W\_Incidental}$)	%	100%	Fraction of incidental water ingestion sourced from bore/creek	Assumption
Egg consumption exposure inputs				
Concentration in edible portion of egg (C_{Eggs})	mg/kg	7.0E-06	$C_{Egg} = \frac{TF_{Egg} \; x \; C_{Water} \; x \; IR_{Water\_chicken} \; x \; F_{Chicken\_water} \; x \; BIO}{LR \; x \; W_{egg} \; x \; F_{Edible}}$	DoD (2017a)
Water ingestion rate of chickens ($IR_{Chickens\_Water}$)	L/day	0.32	Average daily water consumption of a laying hen	ANZECC (2000)
Fraction of water sourced from bore/creek ($F_{Water\_Chickens}$)	%	100%	Conservative assumption - assumes poultry obtains all water requirements from the bore and/or creek	Assumption
Egg consumption rate (IR_{Egg})	kg/day	0.0548	Double the average daily egg consumption rate reported for the New Zealand population (adults)	MfE (2011)
Edible fraction of egg (F_{Edible})	%	0.9	Approximate portion of an egg that is edible	MfE (2011)
Transfer factor to chicken eggs (TF_{Eggs})	mg/day edible egg per mg/day intake	0.5	A study undertaken by the Australian Department of Defence indicated that the amount of PFOS transferred to eggs each day is estimated, on average, to be equal to the amount of PFOS ingested by a chicken via their drinking water each day. Transfer rates for PFHxS and PFOA were lower, at 0.7 and 0.45 respectively.The defence study concludes that almost 100% of the transfer is to the edible portion and therefore the TF of 1 has been adjusted upwards according the the equation $1/F_{edible}$	DoD (2017a), Kowalczyk (2013)
Egg laying rate (LR)	eggs/day	0.8	Laying hens can produce up to approximately 300 eggs per year	Assumption
Egg weight (W_{egg})	kg/egg	0.060	Weight of a typical egg	MfE (2011)
Fraction of homegrown eggs (F_{HG_Eggs})	%	25%	MfE (2011) assumption for a rural/residential block	Assumption
Fruit and vegetable consumption exposure inputs				
Concentration in fruit and vegetables (C_{Garden})	mg/kg	9.3E-06	$C_{Garden} = TF_{Garden} \; x \; C_W$	DoD (2017b)
PFOA transfer factor to fruits and vegetables ($TF_{GardenPFOA}$)	L/kg	4.9	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFOA and irrigated vegetables of 4.9 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
Fruit and vegetable consumption rate ($C_{FruitVeg}$)	kg/day	0.432	Total fruit and vegetable consumption rates reported for the New Zealand males (25+ years)	MfE (2011)
Fraction of homegrown fruit and vegetables ($F_{HG\_FruitVeg}$)	%	25%	Default assumption for rural/residential land uses	MfE (2011)
Meat and milk consumption exposure inputs				
Concentration in meat (C_{Meat})	mg/kg	0.0E+00	$C_{Meat} = TF_{Serum} \; x \; C_w \; x \; F_{Water\_stock} \; x \; CF_{Meat}$	Drew *et al.* (2021)
Concentration in offal (C_{Offal})	mg/kg	0.0E+00	$C_{Offal} = TF_{Serum} \; x \; C_w \; x \; F_{Water\_stock} \; x \; CF_{Offal}$	Drew *et al.* (2021)
Concentration in milk (C_{Milk})	mg/kg	0.0E+00	$C_{Milk} = TF_{Serum} \; x \; C_w \; x \; F_{Water\_stock} \; x \; CF_{Milk}$	Drew *et al.* (2021)
Meat (muscle) consumption rate (IR_{Muscle})	kg/day	0.221	90th percentile total meat consumption rate reported for the population (2+ years). Representative of meat consumption rates for people on livestock-producing properties	FSANZ (2017)
Offal consumption rate (IR_{Offal})	kg/day	0.032	90th percentile offal consumption rate reported for the population (2+ years). Representative of the upper end of the offal consumption rates for people on livestock-producing properties	FSANZ (2017)
Milk consumption rate (IR_{Offal})	kg/day	1.295	90th percentile total milk consumption rate reported for the population (2+ years). Representative of milk consumption rates for people on livestock-producing properties	FSANZ (2017)
PFOA serum to meat concentration factor (CF_{Muscle})	L/kg	0.07	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA serum to offal concentration factor (CF_{Offal})	L/kg	1.2	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA serum to milk concentration factor (CF_{Milk})	L/kg	0	Describes the transfer from plasma to milk (mg/L meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	0	Negligible transfer of PFOA from drinking water to serum has been reported	Drew *et al.* (2021)
Fraction of water sourced from bore/creek (F_{Water_Stock})	%	100%	Conservative assumption - assumes livestock obtain all water requirements from the creek	Assumption
Fraction of homegrown meat (F_{HG_Meat})	%	75%	Represents the fact that stock produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption
Fraction of homegrown milk (F_{HG_Milk})	%	75%	Represents the fact that milk produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption

Aquatic biota consumption exposure inputs				
Concentration in aquatic invertebrates ($C_{Aquatic\_Inverts}$)	mg/kg	8.6E-05	$C_{Aquatic\_Inverts} = BAF_{Aquatic\_Inverts}\ x\ C_w$	Burkhard (2020)
Concentration in aquatic vertebrates ($C_{Aquatic\_Verts}$)	mg/kg	3.2E-04	$C_{Aquatic\_Verts} = BAF_{Aquatic\_Verts}\ x\ C_w$	Burkhard (2020)
Concentration in aquatic plants ($C_{Aquatic\_Plants}$)	mg/kg	9.1E-05	$C_{Aquatic\_Plants} = BAF_{Aquatic\_Plants}\ x\ C_w$	Burkhard (2020)
PFOA bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	168	Mean BAF reported for eel muscle	DoD (2017c)
PFOA bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	48	Mean BCF for aquatic plants	DoD (2017c)
Aquatic vertebrate consumption rate ($IR_{Aquatic\_Verts}$)	kg/day	0.068	Maximum eel consumption rate reported for the adult population	NIWA (2011)
Aquatic plant consumption rate ($IR_{Aquatic\_Plants}$)	kg/day	0.015	Mean watercress consumption rate for the Te Arawa iwi population (adults)	NIWA (2011)
Fraction of locally grown aquatic vertebrates ($F_{HG\_Aquatic\_Verts}$)	%	75%	Represents the fact that locally caught aquatic biota may make a substantial contribution to the diet of local residents	Assumption
Fraction of locally grown aquatic plants ($F_{HG\_Aquatic\_Plants}$)	%	75%	Represents the fact that locally foraged aquatic vegetation may make a substantial contribution to the diet of local residents	Assumption

(turquoise)	Value recommended by MfE, ASC NEPM, NHMRC, FSANZ or enHealth
(green)	Site-specific data or assumption
(yellow)	Assumption based on a published study or guideline
(orange)	Calculated value

Assessment Area	Smooth Hill Landfill - Creek
Exposure Scenario	Cumulative
Receptor Group	Adults
Chemicals of Potential Concern	PFOS+PFHxS
Exposure Media	Surface water

Total Hazard Index	-	**0.05**

Relevant exposure pathways	
Potable ingestion	No
Incidental ingestion	Yes
Poultry watering and egg consumption	Yes
Irrigation and produce consumption	Yes
Stock watering and meat consumption	Yes
Stock watering and offal consumption	Yes
Dermal contact	No
Stock watering and milk consumption	Yes
Aquatiic vertebrate consumption	Yes
Aquatic plant consumption	Yes

Parameter	Unit	Value	Details	Source
Water quality inputs				
Concentration in water	**µg/L**	**0.00037**	Predicted worst case surface water concentration at Coast Farm (no HDPE - complete failure)	Assumption
Concentration in water	**mg/L**	**3.73E-07**		
Percentage PFHxS (in PFOS+PFHxS)	**%**	**64%**	Distribution of PFOS/PFHxS predicted in downstream surface water samples	Site-specific
Risk calculations				
HI_{Total}	-	**4.68E-02**	$HI = \sum HQ_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$HQ_{Water\_Incidental}$	-	**7.39E-06**	$HQ_{Water\_incidental} = \frac{Intake_{Water\_incidental}}{TRV\ x\ (100\% - Background)}$	
HQ_{Eggs}	-	**3.33E-05**	$HQ_{Eggs} = \frac{Intake_{Eggs}}{TRV\ x\ (100\% - Background)}$	
HQ_{Garden}	-	**1.06E-04**	$HQ_{Garden} = \frac{Intake_{Garden}}{TRV\ x\ (100\% - Background)}$	
HQ_{Meat}	-	**2.81E-04**	$HQ_{Meat} = \frac{Intake_{Meat}}{TRV\ x\ (100\% - Background)}$	
HQ_{Offal}	-	**4.35E-04**	$HQ_{Offal} = \frac{Intake_{Offal}}{TRV\ x\ (100\% - Background)}$	
HQ_{Milk}	-	**2.72E-04**	$HQ_{Milk} = \frac{Intake_{Milk}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqVerts}$	-	**4.40E-02**	$HQ_{Aquatic\_Verts} = \frac{Intake_{Aquatic\_Verts}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqVerts}$	-	**1.73E-03**	$HQ_{Aquatic\_Plants} = \frac{Intake_{Aquatic\_Plants}}{TRV\ x\ (100\% - Background)}$	
Intake calculations				
$Intake_{Total}$	mg/kg/day	**8.43E-07**	$Intake_{Total} = \sum Intake_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$Intake_{Water\_Incidental}$	mg/kg/day	**1.33E-10**	$Intake_{Water\_nonpotable} = \frac{C_{Water}\ x\ IR_{Water\_nonpotable}\ x\ F_{Water\_nonpotable}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Eggs}$	mg/kg/day	**6.00E-10**	$Intake_{Eggs} = \frac{C_{Eggs}\ x\ IR_{Eggs}\ x\ F_{HG\_eggs}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Garden}$	mg/kg/day	**1.91E-09**	$Intake_{Garden} = \frac{C_{Garden}\ x\ IR_{Garden}\ x\ F_{HG\_garden}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Meat}$	mg/kg/day	**5.07E-09**	$Intake_{Meat} = \frac{C_{Meat}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Offal}$	mg/kg/day	**7.83E-09**	$Intake_{Offal} = \frac{C_{Offal}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Milk}$	mg/kg/day	**4.89E-09**	$Intake_{Milk} = \frac{C_{Milk}\ x\ IR_{Milk}\ x\ F_{Milk}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Verts}$	mg/kg/day	**7.91E-07**	$Intake_{Aquatic\_Verts} = \frac{C_{Aquatic\_Verts}\ x\ IR_{Aquatic\_Verts}\ x\ F_{HG\_Aquatic\_Verts}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Plants}$	mg/kg/day	**3.11E-08**	$Intake_{Aquatic\_Plants} = \frac{C_{Aquatic\_Plants}\ x\ IR_{Aquatic\_Plants}\ x\ F_{HG\_Aquatic\_Plants}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
Pathway contribution calculations				
$Contribution_{Ingestion\_IncidentalWater}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	Calculated based on MfE (2011) and ASC NEPM algorithms
$Contribution_{Homegrown\_Eggs}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_FruitVeg}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Meat}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Offal}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Milk}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Verts}$	%	94%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Plants}$	%	4%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{\ Total}}\ x\ 100\%$	

General toxicity and exposure inputs				
TRV	mg/kg/day	0.00002	Based on developmental toxicity endpoints in animal studies	FSANZ (2017c)
$Background_{Ingestion}$ (Background)	%	10%	Conservative assumption, calculated on the basis dietary concentrations in Europe and serum concentrations in the Australian population	EFSA (2020), FSANZ (2017), Thompson *et al.* (2010)
Body weight (BW)	kg	70	Adult body weight	MfE (2011)
Averaging time (AT)	days	8760	Exposure duration x 365 days/yr	MfE (2011)
Exposure frequency (EF)	days/yr	365	Daily - local resident	MfE (2011)
Exposure duration (ED)	years	24	Adulthood resident duration	MfE (2011)
Oral bioavailability (BIO)	-	1	Assumes that ingested PFAS is largely bioaccessible	OEH (2019)
Water consumption exposure inputs				
Ingestion rate ($IR_{Incidental}$)	L/day	0.025	Average daily incidental water ingestion rate. Represents the incidental ingestion that may be associated with the use of bore/creek water for activities such as bathing, filling swimming pools and sprinkler use	enHealth (2012)
Fraction of water sourced from bore/creek ($F_{W\_Incidental}$)	%	100%	Fraction of incidental water ingestion sourced from bore/creek	Assumption
Egg consumption exposure inputs				
Concentration in edible portion of egg (C_{Eggs})	mg/kg	3.1E-06	$C_{Egg} = \frac{TF_{Egg} \ x \ C_{Water} \ x \ IR_{Water\_chicken} \ x \ F_{Chicken\_water} \ x \ BIO}{LR \ x \ W_{egg} \ x \ F_{Edible}}$	DoD (2017a)
Water ingestion rate of chickens ($IR_{Chickens\_Water}$)	L/day	0.32	Average daily water consumption of a laying hen	ANZECC (2000)
Fraction of water sourced from bore/creek ($F_{Water\_Chickens}$)	%	100%	Conservative assumption - assumes poultry obtains all water requirements from the bore and/or creek	Assumption
Egg consumption rate (IR_{Egg})	kg/day	0.0548	Double the average daily egg consumption rate reported for the New Zealand population (adults)	MfE (2011)
Edible fraction of egg (F_{Edible})	%	0.9	Approximate portion of an egg that is edible	MfE (2011)
Transfer factor to chicken eggs (TF_{Eggs})	mg/day edible egg per mg/day intake	1.1	A study undertaken by the Australian Department of Defence indicated that the amount of PFOS transferred to eggs each day is estimated, on average, to be equal to the amount of PFOS ingested by a chicken via their drinking water each day. Transfer rates for PFHxS and PFOA were lower, at 0.7 and 0.45 respectively.The defence study concludes that almost 100% of the transfer is to the edible portion and therefore the TF of 1 has been adjusted upwards according the the equation $1/F_{edible}$	DoD (2017a), Kowalczyk (2013)
Egg laying rate (LR)	eggs/day	0.8	Laying hens can produce up to approximately 300 eggs per year	Assumption
Egg weight (W_{egg})	kg/egg	0.060	Weight of a typical egg	MfE (2011)
Fraction of homegrown eggs (F_{HG_Eggs})	%	25%	MfE (2011) assumption for a rural/residential block	Assumption
Fruit and vegetable consumption exposure inputs				
Concentration in fruit and vegetables (C_{Garden})	mg/kg	1.2E-06	$C_{Garden} = TF_{Garden} \ x \ C_w$	DoD (2017b)
PFOS transfer factor to fruits and vegetables ($TF_{GardenPFOS}$)	L/kg	2.5	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFOS and irrigated vegetables of 2.5 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
PFHxS transfer factor to fruits and vegetables ($TF_{GardenPFHxS}$)	L/kg	3.8	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFHxS and irrigated vegetables of 3.8 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
Fruit and vegetable consumption rate ($C_{FruitVeg}$)	kg/day	0.432	Total fruit and vegetable consumption rates reported for the New Zealand males (25+ years)	MfE (2011)
Fraction of homegrown fruit and vegetables ($F_{HG\_FruitVeg}$)	%	25%	Default assumption for rural/residential land uses	MfE (2011)
Meat and milk consumption exposure inputs				
Concentration in meat (C_{Meat})	mg/kg	2.1E-06	$C_{Meat} = TF_{Serum} \ x \ C_w \ x \ F_{Water\_stock} \ x \ CF_{Meat}$	Drew *et al.* (2021)
Concentration in offal (C_{Offal})	mg/kg	2.3E-05	$C_{Offal} = TF_{Serum} \ x \ C_w \ x \ F_{Water\_stock} \ x \ CF_{Offal}$	Drew *et al.* (2021)
Concentration in milk (C_{Milk})	mg/kg	3.5E-07	$C_{Milk} = TF_{Serum} \ x \ C_w \ x \ F_{Water\_stock} \ x \ CF_{Milk}$	Drew *et al.* (2021)
Meat (muscle) consumption rate (IR_{Muscle})	kg/day	0.221	90th percentile total meat consumption rate reported for the population (2+ years). Representative of meat consumption rates for people on livestock-producing properties	FSANZ (2017)
Offal consumption rate (IR_{Offal})	kg/day	0.032	90th percentile offal consumption rate reported for the population (2+ years). Representative of the upper end of the offal consumption rates for people on livestock-producing properties	FSANZ (2017)
Milk consumption rate (IR_{Offal})	kg/day	1.295	90th percentile total milk consumption rate reported for the population (2+ years). Representative of milk consumption rates for people on livestock-producing properties	FSANZ (2017)
PFOS serum to meat concentration factor (CF_{Muscle})	L/kg	0.076	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS serum to offal concentration factor (CF_{Offal})	L/kg	1.06	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS serum to milk concentration factor (CF_{Milk})	L/kg	0.013	Describes the transfer from plasma to milk (mg/L meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to meat concentration factor (CF_{Muscle})	L/kg	0.046	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to offal concentration factor (CF_{Offal})	L/kg	0.19	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFHxS serum to milk concentration factor (CF_{Milk})	L/kg	0.007	Describes the transfer from plasma to offal (mg/L milk per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOS transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	140	Describes the relationship between the PFOS concentration in water and serum	Drew *et al.* (2021)
PFHxS transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	65	Describes the relationship between the PFHxS concentration in water and serum	Drew *et al.* (2021)
Fraction of water sourced from bore/creek (F_{Water_Stock})	%	100%	Conservative assumption - assumes livestock obtain all water requirements from the creek	Assumption
Fraction of homegrown meat (F_{HG_Meat})	%	75%	Represents the fact that stock produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption
Fraction of homegrown milk (F_{HG_Milk})	%	75%	Represents the fact that milk produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption

Aquatic biota consumption exposure inputs				
Concentration in aquatic invertebrates ($C_{Aquatic\_Inverts}$)	mg/kg	3.3E-04	$C_{Aquatic\_Inverts} = BAF_{Aquatic\_Inverts} \times C_w$	Burkhard (2020)
Concentration in aquatic vertebrates ($C_{Aquatic\_Verts}$)	mg/kg	1.1E-03	$C_{Aquatic\_Verts} = BAF_{Aquatic\_Verts} \times C_w$	Burkhard (2020)
Concentration in aquatic plants ($C_{Aquatic\_Plants}$)	mg/kg	1.9E-04	$C_{Aquatic\_Plants} = BAF_{Aquatic\_Plants} \times C_w$	Burkhard (2020)
PFOS bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	7470	Mean BAF reported for eel muscle	DoD (2017c)
PFHxS bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	354	Mean BAF reported for eel muscle	Kwadijk *et al.* (2010)
PFOS bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	1162	Mean BCF for aquatic plants	DoD (2017c)
PFHxS bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	141	Mean BCF for aquatic plants	DoD (2017c)
Aquatic vertebrate consumption rate ($IR_{Aquatic\_Verts}$)	kg/day	0.068	Maximum eel consumption rate reported for the adult population	NIWA (2011)
Aquatic plant consumption rate ($IR_{Aquatic\_Plants}$)	kg/day	0.015	Mean watercress consumption rate for the Te Arawa iwi population (adults)	NIWA (2011)
Fraction of locally grown aquatic vertebrates ($F_{HG\_Aquatic\_Verts}$)	%	75%	Represents the fact that locally caught aquatic biota may make a substantial contribution to the diet of local residents	Assumption
Fraction of locally grown aquatic plants ($F_{HG\_Aquatic\_Plants}$)	%	75%	Represents the fact that locally foraged aquatic vegetation may make a substantial contribution to the diet of local residents	Assumption

(teal)	Value recommended by MfE, ASC NEPM, NHMRC, FSANZ or enHealth
(green)	Site-specific data or assumption
(yellow)	Assumption based on a published study or guideline
(orange)	Calculated value

Assessment Area	Smooth Hill Landfill - Creek
Exposure Scenario	Cumulative
Receptor Group	Adults
Chemicals of Potential Concern	PFOA
Exposure Media	Surface water

Total Hazard Index	-	**0.0002**

Relevant exposure pathways	
Potable ingestion	No
Incidental ingestion	Yes
Poultry watering and egg consumption	Yes
Irrigation and produce consumption	Yes
Stock watering and meat consumption	Yes
Stock watering and offal consumption	Yes
Dermal contact	No
Stock watering and milk consumption	Yes
Aquatiic vertebrate consumption	Yes
Aquatic plant consumption	Yes

Parameter	Unit	Value	Details	Source
Water quality inputs				
Concentration in water	µg/L	0.00017	Predicted worst case surface water concentration at Coast Farm (no HDPE - complete failure)	Assumption
Concentration in water	mg/L	1.67E-07		
Risk calculations				
HI_{Total}	-	1.61E-04	$HI = \sum HQ_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$HQ_{Water\_Incidental}$	-	4.14E-07	$HQ_{Water\_incidental} = \frac{Intake_{Water\_incidental}}{TRV\ x\ (100\% - Background)}$	
HQ_{Eggs}	-	8.40E-07	$HQ_{Eggs} = \frac{Intake_{Eggs}}{TRV\ x\ (100\% - Background)}$	
HQ_{Garden}	-	8.76E-06	$HQ_{Garden} = \frac{Intake_{Garden}}{TRV\ x\ (100\% - Background)}$	
HQ_{Meat}	-	0.00E+00	$HQ_{Meat} = \frac{Intake_{Meat}}{TRV\ x\ (100\% - Background)}$	
HQ_{Offal}	-	0.00E+00	$HQ_{Offal} = \frac{Intake_{Offal}}{TRV\ x\ (100\% - Background)}$	
HQ_{Milk}	-	0.00E+00	$HQ_{Milk} = \frac{Intake_{Milk}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqVerts}$	-	1.42E-04	$HQ_{Aquatic\_Verts} = \frac{Intake_{Aquatic\_Verts}}{TRV\ x\ (100\% - Background)}$	
$HQ_{AqPlants}$	-	9.12E-06	$HQ_{Aquatic\_Plants} = \frac{Intake_{Aquatic\_Plants}}{TRV\ x\ (100\% - Background)}$	
Intake calculations				
$Intake_{Total}$	mg/kg/day	2.32E-08	$Intake_{Total} = \sum Intake_{All\ pathways}$	Calculated - based on MfE (2011) and ASC NEPM algorithms
$Intake_{Water\_Incidental}$	mg/kg/day	5.96E-11	$Intake_{Water\_nonpotable} = \frac{C_{Water}\ x\ IR_{Water\_nonpotable}\ x\ F_{Water\_nonpotable}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Eggs}$	mg/kg/day	1.21E-10	$Intake_{Eggs} = \frac{C_{Eggs}\ x\ IR_{Eggs}\ x\ F_{HG\_eggs}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Garden}$	mg/kg/day	1.26E-09	$Intake_{Garden} = \frac{C_{Garden}\ x\ IR_{Garden}\ x\ F_{HG\_garden}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Meat}$	mg/kg/day	0.00E+00	$Intake_{Meat} = \frac{C_{Meat}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Offal}$	mg/kg/day	0.00E+00	$Intake_{Offal} = \frac{C_{Offal}\ x\ IR_{Meat}\ x\ F_{Meat}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Milk}$	mg/kg/day	0.00E+00	$Intake_{Milk} = \frac{C_{Milk}\ x\ IR_{Milk}\ x\ F_{Milk}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Verts}$	mg/kg/day	2.04E-08	$Intake_{Aquatic\_Verts} = \frac{C_{Aquatic\_Verts}\ x\ IR_{Aquatic\_Verts}\ x\ F_{HG\_Aquatic\_Verts}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
$Intake_{Aquatic\_Plants}$	mg/kg/day	1.31E-09	$Intake_{Aquatic\_Plants} = \frac{C_{Aquatic\_Plants}\ x\ IR_{Aquatic\_Plants}\ x\ F_{HG\_Aquatic\_Plants}\ x\ BIO\ x\ EF\ x\ ED}{BW\ x\ AT}$	
Pathway contribution calculations				
$Contribution_{Ingestion\_IncidentalWater}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{Total}}\ x\ 100\%$	Calculated based on MfE (2011) and ASC NEPM algorithms
$Contribution_{Homegrown\_Eggs}$	%	1%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_FruitVeg}$	%	5%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Meat}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{Total}}\ x\ 100\%$	
$Contribution_{Homegrown\_Offal}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{Total}}\ x\ 100\%$	
$Contribution_{Milk}$	%	0%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Verts}$	%	88%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{Total}}\ x\ 100\%$	
$Contribution_{Aquatic\_Plants}$	%	6%	$Contribution_{Pathway} = \frac{Intake_{Pathway}}{Intake_{Total}}\ x\ 100\%$	

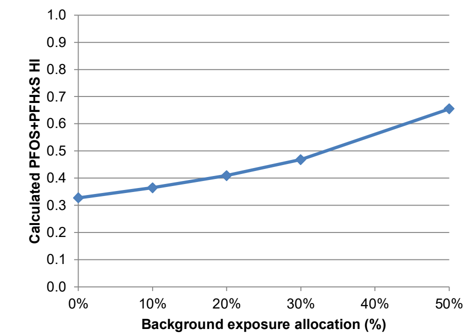
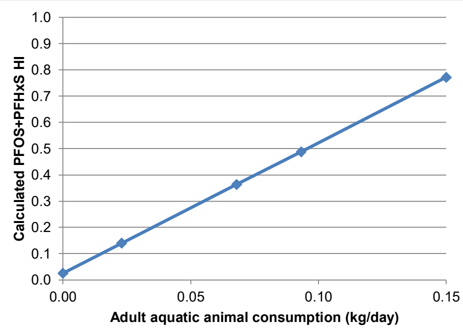
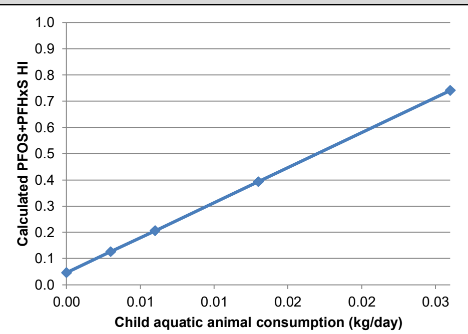
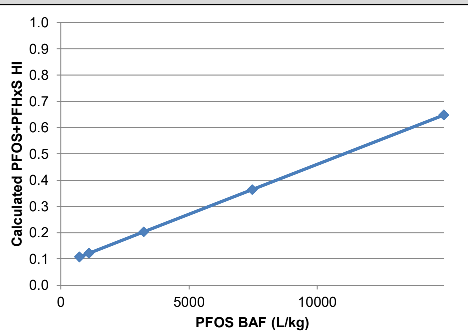
General toxicity and exposure inputs				
TRV	mg/kg/day	0.00016	Based on developmental toxicity endpoints in animal studies	FSANZ (2017c)
$Background_{Ingestion}$ (Background)	%	10%	Conservative assumption, calculated on the basis dietary concentrations in Europe and serum concentrations in the Australian population	EFSA (2020), FSANZ (2017), Thompson *et al.* (2010)
Body weight (BW)	kg	70	Adult body weight	MfE (2011)
Averaging time (AT)	days	8760	Exposure duration x 365 days/yr	MfE (2011)
Exposure frequency (EF)	days/yr	365	Daily - local resident	MfE (2011)
Exposure duration (ED)	years	24	Adulthood resident duration	MfE (2011)
Oral bioavailability (BIO)	-	1	Assumes that ingested PFAS is largely bioaccessible	OEH (2019)
Water consumption exposure inputs				
Ingestion rate ($IR_{Incidental}$)	L/day	0.025	Average daily incidental water ingestion rate. Represents the incidental ingestion that may be associated with the use of bore/creek water for activities such as bathing, filling swimming pools and sprinkler use	enHealth (2012)
Fraction of water sourced from bore/creek ($F_{W\_Incidental}$)	%	100%	Fraction of incidental water ingestion sourced from bore/creek	Assumption
Egg consumption exposure inputs				
Concentration in edible portion of egg (C_{Eggs})	mg/kg	0.0000	$C_{Egg} = \frac{TF_{Egg}\ x\ C_{Water}\ x\ IR_{Water\_chicken}\ x\ F_{Chicken\_water}\ x\ BIO}{LR\ x\ W_{egg}\ x\ F_{Edible}}$	DoD (2017a)
Water ingestion rate of chickens ($IR_{Chickens\_Water}$)	L/day	0.32	Average daily water consumption of a laying hen	ANZECC (2000)
Fraction of water sourced from bore/creek ($F_{Water\_Chickens}$)	%	100%	Conservative assumption - assumes poultry obtains all water requirements from the bore and/or creek	Assumption
Egg consumption rate (IR_{Egg})	kg/day	0.0548	Double the average daily egg consumption rate reported for the New Zealand population (adults)	MfE (2011)
Edible fraction of egg (F_{Edible})	%	0.9	Approximate portion of an egg that is edible	MfE (2011)
Transfer factor to chicken eggs (TF_{Eggs})	mg/day edible egg per mg/day intake	0.5	A study undertaken by the Australian Department of Defence indicated that the amount of PFOS transferred to eggs each day is estimated, on average, to be equal to the amount of PFOS ingested by a chicken via their drinking water each day. Transfer rates for PFHxS and PFOA were lower, at 0.7 and 0.45 respectively.The defence study concludes that almost 100% of the transfer is to the edible portion and therefore the TF of 1 has been adjusted upwards according the the equation $1/F_{edible}$	DoD (2017a), Kowalczyk (2013)
Egg laying rate (LR)	eggs/day	0.8	Laying hens can produce up to approximately 300 eggs per year	Assumption
Egg weight (W_{egg})	kg/egg	0.060	Weight of a typical egg	MfE (2011)
Fraction of homegrown eggs (F_{HG_Eggs})	%	25%	MfE (2011) assumption for a rural/residential block	Assumption
Fruit and vegetable consumption exposure inputs				
Concentration in fruit and vegetables (C_{Garden})	mg/kg	8.2E-07	$C_{Garden} = TF_{Garden}\ x\ C_w$	DoD (2017b)
PFOA transfer factor to fruits and vegetables ($TF_{GardenPFOA}$)	L/kg	4.9	A study undertaken by the Australian Department of Defence estimated average transfer factors for PFOA and irrigated vegetables of 4.9 L/kg. This value has been adopted across the range of potential homegrown produce	DoD (2017b)
Fruit and vegetable consumption rate ($C_{FruitVeg}$)	kg/day	0.432	Total fruit and vegetable consumption rates reported for the New Zealand males (25+ years)	MfE (2011)
Fraction of homegrown fruit and vegetables ($F_{HG\_FruitVeg}$)	%	25%	Default assumption for rural/residential land uses	MfE (2011)
Meat and milk consumption exposure inputs				
Concentration in meat (C_{Meat})	mg/kg	0.0E+00	$C_{Meat} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Meat}$	Drew *et al.* (2021)
Concentration in offal (C_{Offal})	mg/kg	0.0E+00	$C_{Offal} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Offal}$	Drew *et al.* (2021)
Concentration in milk (C_{Milk})	mg/kg	0.0E+00	$C_{Milk} = TF_{Serum}\ x\ C_w\ x\ F_{Water\_stock}\ x\ CF_{Milk}$	Drew *et al.* (2021)
Meat (muscle) consumption rate (IR_{Muscle})	kg/day	0.221	90th percentile total meat consumption rate reported for the population (2+ years). Representative of meat consumption rates for people on livestock-producing properties	FSANZ (2017)
Offal consumption rate (IR_{Offal})	kg/day	0.032	90th percentile offal consumption rate reported for the population (2+ years). Representative of the upper end of the offal consumption rates for people on livestock-producing properties	FSANZ (2017)
Milk consumption rate (IR_{Offal})	kg/day	1.295	90th percentile total milk consumption rate reported for the population (2+ years). Representative of milk consumption rates for people on livestock-producing properties	FSANZ (2017)
PFOA serum to meat concentration factor (CF_{Muscle})	L/kg	0.07	Describes the transfer from plasma to meat (mg/kg meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA serum to offal concentration factor (CF_{Offal})	L/kg	1.2	Describes the transfer from plasma to offal (mg/kg offal per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA serum to milk concentration factor (CF_{Milk})	L/kg	0	Describes the transfer from plasma to milk (mg/L meat per mg/L plasma)	Kowalczyk *et al.* (2013)
PFOA transfer factor to cattle serum (TF_{Serum})	mg/L serum per mg/L water	0	Negligible transfer of PFOA from drinking water to serum has been reported	Drew *et al.* (2021)
Fraction of water sourced from bore/creek (F_{Water_Stock})	%	100%	Conservative assumption - assumes livestock obtain all water requirements from the creek	Assumption
Fraction of homegrown meat (F_{HG_Meat})	%	75%	Represents the fact that stock produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption
Fraction of homegrown milk (F_{HG_Milk})	%	75%	Represents the fact that milk produced on individual agricultural properties may make a substantial contribution to the diet of property residents	Assumption

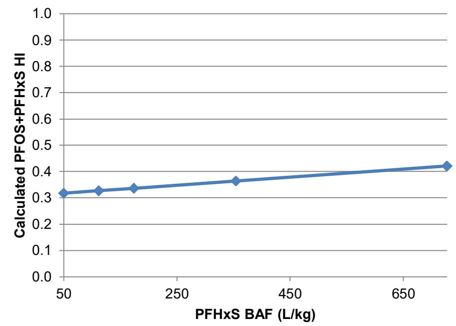
Aquatic biota consumption exposure inputs				
Concentration in aquatic invertebrates ($C_{Aquatic\_Inverts}$)	mg/kg	7.5E-06	$C_{Aquatic\_Inverts} = BAF_{Aquatic\_Inverts} \times C_w$	Burkhard (2020)
Concentration in aquatic vertebrates ($C_{Aquatic\_Verts}$)	mg/kg	2.8E-05	$C_{Aquatic\_Verts} = BAF_{Aquatic\_Verts} \times C_w$	Burkhard (2020)
Concentration in aquatic plants ($C_{Aquatic\_Plants}$)	mg/kg	8.0E-06	$C_{Aquatic\_Plants} = BAF_{Aquatic\_Plants} \times C_w$	Burkhard (2020)
PFOA bioaccumulation factor for aquatic vertebrates ($BAF_{Aquatic\_Verts}$)	L/kg	168	Mean BAF reported for eel muscle	DoD (2017c)
PFOA bioaccumulation factor for aquatic plants ($BAF_{Aquatic\_Plants}$)	L/kg	48	Mean BCF for aquatic plants	DoD (2017c)
Aquatic vertebrate consumption rate ($IR_{Aquatic\_Verts}$)	kg/day	0.068	Maximum eel consumption rate reported for the adult population	NIWA (2011)
Aquatic plant consumption rate ($IR_{Aquatic\_Plants}$)	kg/day	0.015	Mean watercress consumption rate for the Te Arawa iwi population (adults)	NIWA (2011)
Fraction of locally grown aquatic vertebrates ($F_{HG\_Aquatic\_Verts}$)	%	75%	Represents the fact that locally caught aquatic biota may make a substantial contribution to the diet of local residents	Assumption
Fraction of locally grown aquatic plants ($F_{HG\_Aquatic\_Plants}$)	%	75%	Represents the fact that locally foraged aquatic vegetation may make a substantial contribution to the diet of local residents	Assumption

(aqua)	Value recommended by MfE, ASC NEPM, NHMRC, FSANZ or enHealth
(green)	Site-specific data or assumption
(yellow)	Assumption based on a published study or guideline
(orange)	Calculated value

Sensitivity Analysis

Human Health Risk Characterisation - Farm Pond

Input Variable	Input Selection	HI	HI % Change	Graphical Representation	Relative Variable Sensitivity	Relative Variable Uncertainty in QHHRA
The influence of the background PFOS+PFHxS exposure allocation (%) on the HI for child surface water users						
50%	Five times the background exposure allocation estimated on the basis of the available data	0.7	93%		Moderate: The HI varied by ~100%across the range of potential background exposure assumptions	Moderate: There is limited data available regarding the background PFAS exposures experienced by the general population in New Zealand but it is anticipated to be low
30%	Three times the background exposure allocation estimated on the basis of the available data	0.5	38%			
20%	Two times the background exposure allocation estimated on the basis of the available data	0.4	20%			
10%	Background exposure assumption adopted this QHHRA; a conservative assumption made to address the uncertainty associated with the dietary PFAS exposures in New Zealand	0.4	7%			
0%	Representative of minimal background exposure - aligns with the background exposure estimates made by FSANZ (2017)	0.3	-4%			
Influence of adult aquatic animal consumption rate (kg/day) on the PFOS+PFHxS HI for surface water users						
0.150	Nominal high aquatic biota consumption rate	0.8	112%		Moderate: The HI decreased by ~100% if it was assumed that people consume minimal amounts of aquatic biota from the Otokia Creek	Moderate: Site-specific data on eel consumption rates was not available at the time of reporting but a number of surveys have been undertaken on other waterways
0.093	Toxconsult (2013) maximum eel consumption rate	0.5	34%			
0.068	Toxconsult (2013) long term average eel consumption rate	0.4	0%			
0.023	MPI (2018) mean fresh fish consumption rate for the New Zealand population	0.1	-62%			
0.0	Assumes no consumption of aquatic animals	0.0	-93%			
Influence of child aquatic animal consumption rate (kg/day) on the PFOS+PFHxS HI for surface water users						
0.026	Double the adopted eel consumption rate	0.7	89%		Moderate: The HI guidelines increased by ~90% if it was assumed that children consume twice as much eel caught from Otokia Creek	High: At the time of reporting limited information was available on child eel consumption rates
0.013	MPI (2018) total fish consumption rate for New Zealand children	0.4	0%			
0.006	Double the MPI (2018) fresh fish consumption rate for New Zealand children	0.2	-48%			
0.003	MPI (2018) fresh fish consumption rate for New Zealand children	0.1	-68%			
0.00	Assumes no aquatic animal consumption	0.05	-88%			
Influence of eel PFOS BAF on the PFOS+PFHxS HI for adult surface water users						
14940	Double the adopted BAF value	0.6	78%		Moderate: The HI varied by ~150% across the range of PFOS BAF considered	High: The BAF for PFOS in eel tissue will vary depending on site-specific factors
7470	Adopted value - derived from the data collected in a wetland in Victoria, Australia	0.4	0%			
3236	Upper end of the range of values reported in streams and canals downstream of a spill in the Netherlands (Kwadijk *et al.* , 2010; 2014)	0.2	-44%			
1100	Value reported by Wang *et al.* (2013) in a freshwater pond	0.1	-67%			
727	Value reported by MfE (2018) based on New Zealand data	0.1	-71%			

Input Variable	Input Selection	HI	HI % Change	Graphical Representation	Relative Variable Sensitivity	Relative Variable Uncertainty in QHHRA
Influence of eel PFHxS BAF on the PFOS+PFHxS HI for adult surface water users						
727	Value reported by MfE (2018) based on New Zealand data	0.4	16%		Low: The HI varied by <30% across the range of PFHxS BAF considered	High: The BAF for PFHxS in eel tissue will vary depending on site-specific factors
354	Upper end of the range of values reported in streams and canals downstream of a spill in the Netherlands (Kwadijk *et al.* , 2010; 2014)	0.4	0%			
174	Adopted value - derived from the data collected in a wetland in Victoria, Australia	0.3	-8%			
112	Lower end of the range of values reported in streams and canals downstream of a spill in the Netherlands (Kwadijk *et al.* , 2010; 2014)	0.3	-10%			
50	Nominal low PFHxS BAF value	0.3	-13%			
	Value adopted in the calculation of the water quality guideline					

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