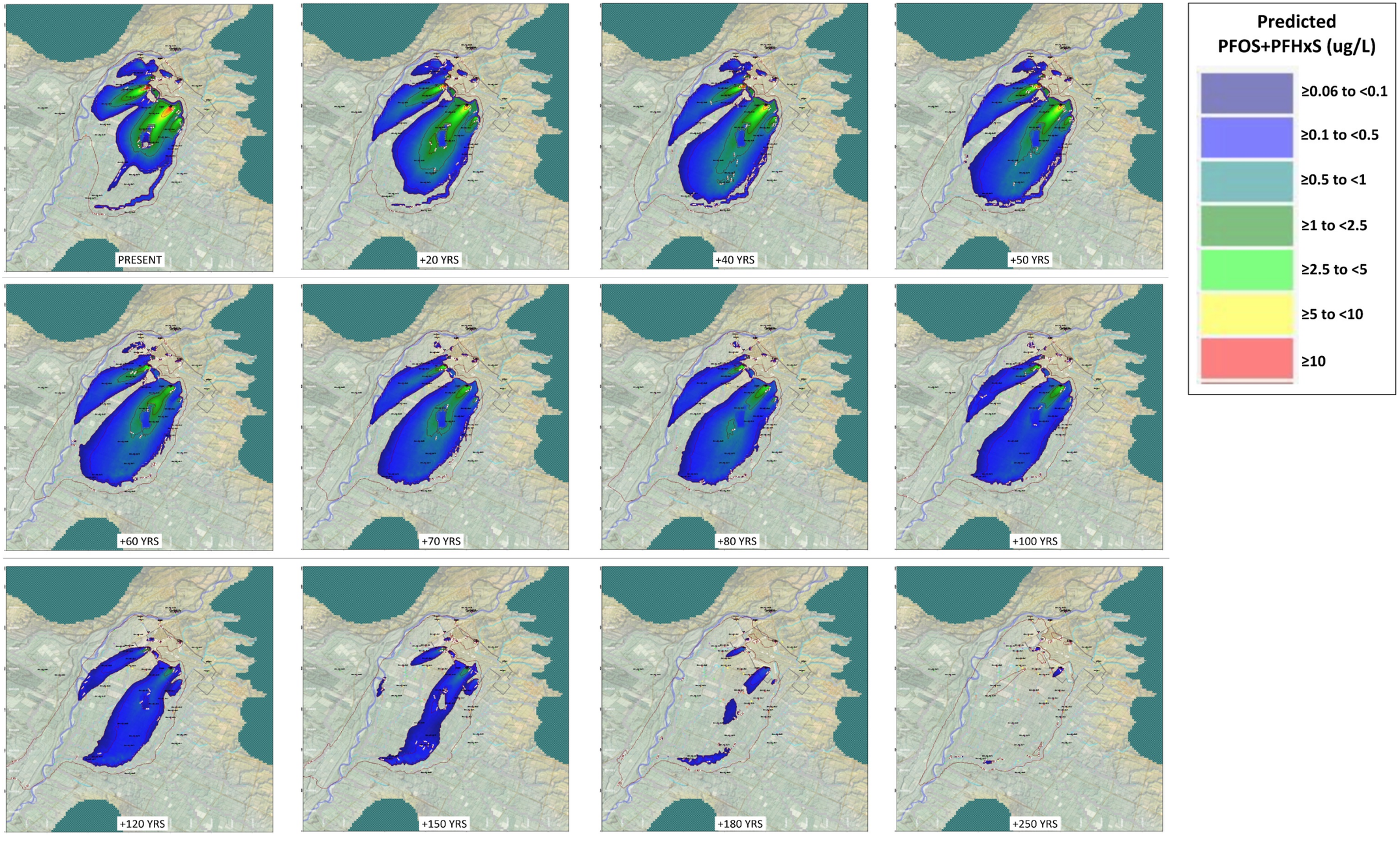

Diagram 9: Longer Source Depletion Future Plume Prediction (no retardation)

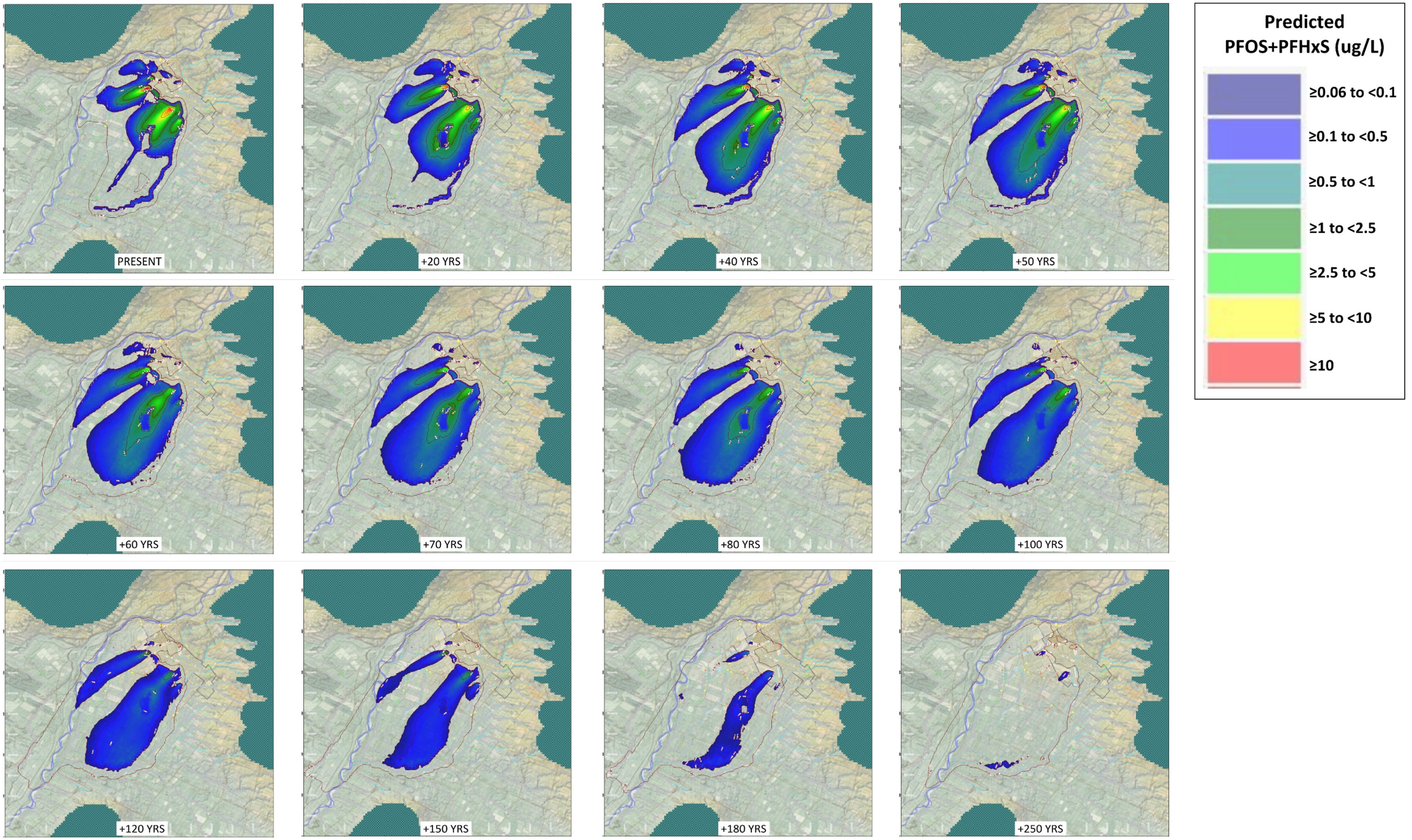

Diagram 10: Longer Source Depletion Future Plume Prediction (with retardation)

7.7 Plume Predictions - Discussion and Summary

A groundwater plume of PFOS + PFHxS has been modelled and interpreted based on all available observation data obtained during NZDF PFAS investigations. Mapping and interpretation of a PFOS + PFHxS plume has been utilised for the purposes of this project, rather than other PFAS species, due to the current relevance of these two species for drinking water toxicity guidelines, and because they are both terminal products. Other PFAS, many of which are not well understood, may behave differently.

The plume is sourced from at least 13 individual onsite Soil Source Zones. In theory, each Soil Source Zone is likely to be/have been producing an individual plume, but due to the geographical spread and nature of the groundwater flow system beneath the wider Ohakea site, these individual plumes have coalesced into essentially a single plume. Surface Water Source Zones have also been identified as key sources because they can transport contaminant mass, which can enter the groundwater system, long distances and quickly.

The existing plume (PFOS + PFHxS ≥0.06 ug/L) has an estimated area of 1100 ha to 1600 ha, and has an estimated total PFOS + PFHxS mass (in solution) between 50 kg to 70 kg. An estimated 'above detection' extent has also been developed for the existing plume, with an estimated area of approximately 3600 ha. Whilst these are considered best estimates, there are gaps in data and knowledge on the plume extent, concentration distribution, and geochemical processes. Consequently, there is significant uncertainty associated with the aforementioned estimates. However, despite the uncertainties, the general plume extent is reasonably well covered spatially by physical observation data, and the present-day plume is interpreted to be well constrained in the northern and eastern direction (and in the western direction to a lesser extent). This has enabled development of a predictive assessment which is considered 'fit *for purpose'* with respect to the project objectives.

Into the future, the plume is expected to continue migration and expansion before beginning a slow process of depletion. This is primarily because while the source is not being added to (i.e. AFFF containing PFOS is no longer used) ongoing leaching from soil is occurring. The individual 'arms' of the plume are generally expected to continue advancing in their current direction of travel – generally west through south-southwest from Base Ohakea - until they encounter a major groundwater discharge boundary (i.e. Rangitikei River or Makowhai Stream). Surface water, particularly the Rangitikei River and Makowhai Stream, are the primary receptors of the plume. The plume discharges to these receptors (and their tributaries) as baseflow.

The hydrogeological setting in which the plume resides provides control on the fate and form of the plume into the future. In general, higher topography and groundwater pressures exist north, east and south of the existing plume. This effectively bounds the plume from migrating much further afield in these directions. Rather, the plume is expected to migrate north-west through south-southwest towards into the aforementioned Rangitikei River and Makowhai Stream (the regional groundwater sinks). It must be noted that plume migration/transport under and beyond these surface water bodies is possible, but as these are the regional groundwater sinks, they are the ultimate receivers, and migration back into these surface water bodies would ultimately occur, albeit slightly further downgradient.

Shallow wells (i.e. <50 m depth) which abstract groundwater from within the extent of the plume and the plumes predicted future migration path are also likely to be receptors. Deep wells e.g. >100 m depth, are less likely to be receptors of the plume. This is because the plume is generally predicted to be present and remain in the top portion of the groundwater system e.g. top 40 m to 60 m of saturation. Significant groundwater abstraction and/or poorly sealed boreholes do however have the potential to locally 'drag' the plume to greater depths.

The 'best estimate' of the likely time period for the existing plume (PFOS + PFHxS >0.06 ug/L) to decrease below its current area is estimated at approximately 75 years (no retardation) to 100 years (with retardation). The time to halve the existing plume area (PFOS + PFHxS >0.06 ug/L) is estimated at approximately 95 years (no retardation) to 125 years (with retardation). Even in a theoretical scenario where all source zones are instantaneously removed, it is expected that the plume (PFOS + PFHxS ≥0.06 ug/L) would remain approximately the same area (as the existing plume) for at least the next 25 years (approximately). Consequently, all predictions and interpretations point towards the existing plume having a significant presence for time periods on the multi-decade scale.

A maximum future extent of 'above detection' or ≥0.001ug/L (PFOS + PFHxS) is estimated at approximately 4300 ha. This extent should be considered as a probability extent e.g. PFOS + PFHxS detection outside of this extent is considered unlikely, but not impossible. The timing of when this maximum extent could be reached is likely to be in the long-term future i.e. >50 years.

8.0 Summary and Conclusions

Investigations at Ohakea have identified PFAS in soil and water on base, as well as in the surrounding environment and neighbouring properties.

The sampling programme completed between 2015 and 2018 included several rounds of groundwater and surface water monitoring, and sampling soil, sediment, animal tissue and plant tissue in various locations within and in the vicinity of the site.

In summary:

- PFAS was detected in all media sampled with the exception of goat's milk.
- Exceedances of applicable guidelines and trigger values were observed for groundwater (drinking water), surface water, eggs, fish tissue and watercress.
- The maximum PFAS concentrations observed were for PFOS for all media on-site. Similarly, off-site the maximum PFAS concentration was for PFOS for all media, except groundwater and surface water. Maximum PFHxS concentrations were higher than PFOS in off-site groundwater and surface water.
- Comparison of the sample results on-site and off-side shows that a significant proportion of PFAS mass in groundwater remains on-site. Median sum of PFOS + PFHxS is an order of magnitude higher than the median of off-site samples. PFAS concentrations off-site generally decreased with distance from the base with the exception of PFHxS.
- There is potentially significantly greater mass of PFAS (particularly PFOS) in the unsaturated soil than in the groundwater on-site.
- In general, PFAS concentrations in surface water decreased with increasing distance from the Base. The exception to this is the Makowhai Stream, where the lowest concentrations of PFOS were observed closest to the site, the highest concentrations approximately 1.5 km downstream from the base, before decreasing again downstream.
- Higher concentrations of PFOS were observed in the Makowhai Stream in summer months and lower concentrations in the wetter winter months.
- Evidence of transformation of PFAS was examined by comparing the molar concentration of PFAS from several groundwater wells extending south-west from the base. Some limited evidence of transformation of PFAS compounds in the plume was found.

Predictions have been made for the existing and future groundwater plume using 3D groundwater and flow and solute transport modelling:

- The existing plume (PFOS + PFHxS ≥0.06 ug/L) has an estimated area of 1100 ha to 1600 ha, and has an estimated total PFOS + PFHxS mass (in solution) in the order of 50 kg to 70 kg. An estimated 'above detection' extent has also been developed for the existing plume, with an estimated area of approximately 3600 ha. This estimate excludes other PFAS compounds. There is significant uncertainty associated with these estimates.
- Into the future, the plume is expected to continue migration and expansion before beginning a slow process of depletion. The plume is generally expected to continue advancing in the current direction of travel – generally west through south-southwest from Base Ohakea - until encountering a major groundwater discharge boundary (i.e. Rangitikei River or Makowhai Stream). Surface water is the primary receptor of the plume.
- The 'best estimate' of the likely time period for the existing plume (PFOS + PFHxS >0.06 ug/L) to decrease below its current area is estimated to be in the order of 75 years (no retardation) to 100 years (with retardation).
- The time to halve the existing plume area (PFOS + PFHxS >0.06 ug/L) is estimated to be greater than 100 years; best estimate 95 years (no retardation) to 125 years (with retardation).
- A maximum future extent of 'above detection' or ≥0.001ug/L (PFOS + PFHxS) is estimated at approximately 4300 ha, and predicted to occur >50 years into the future. This extent should be considered as a probability extent e.g. PFOS + PFHxS detection outside of this extent is considered unlikely, but not impossible.
- A prediction was also completed whereby the existing sources were assumed to have already completely depleted. This scenario is considered analogous to a 'Best Possible Case' estimate and its purpose is to provide a prediction which tends towards the fastest perceivable (but unlikely) plume depletion.
- Under this scenario plume depletion is likely to be significantly more rapid than for the 'best estimate' scenario, however plume depletion is still on the multiple decade scale.
- A longer source depletion prediction scenario where the existing sources were assumed to take longer to deplete than for the 'best estimate' scenario was also undertaken. This produced a plume with an overall similar shape and aerial extent (as per the 'best estimate'); however, plume depletion took significantly longer e.g. approximately twice the duration.

The following conclusions have been drawn following interpretation of the sample results and modelling of the groundwater plume:

- The results and the literature indicate that there is potentially significantly greater mass of PFAS in the unsaturated soil than in the groundwater. Leaching of PFAS from the unsaturated soil could potentially provide an ongoing and long term source of PFAS to groundwater.
- Surface water has been identified as an important pathway for the migration of PFAS into groundwater and vice versa. Surface water flow can move contaminants much faster than groundwater flow, and due to the strong connection between groundwater-surface water within the region, contaminant transport via surface water is a key influencing factor for the groundwater plume.
- Interconnectedness of groundwater and surface water is further illustrated in the Makowhai Stream where PFOS concentrations are lower near Ohakea, reaching their maximum approximately 1.5 km from the site, before decreasing with increasing distance from the site.

One potential mechanism for this pattern is the influence of groundwater discharge (to the Makowhai Stream) where PFOS concentrations in the stream are highest.

- The plume of PFAS-containing groundwater emanating from historic use of AFFF at RNZAF Base Ohakea is expected to be constrained in the longer term by topography and higher groundwater pressures to the north, east and south and by the Rangitikei River to the west. It is expected that shallow groundwater in the investigation area is prevented from moving further south than approximately the Makowhai Stream and is instead directed towards the Rangitikei River. Plume migration/transport under and beyond these surface water bodies is possible, but as these are the regional groundwater sinks, they are the ultimate receivers, and migration back into these surface water bodies would ultimately occur, albeit slightly further downgradient.
- The plume is expected to persist in concentrations > 0.06 ug/L for many decades.

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