IN THE MATTER OF	the Resource Management Act 1991
AND	
IN THE MATTER OF	applications for resource consents and notices of requirement in relation to the Ōtaki to North of Levin Project
BY	**WAKA KOTAHI NZ TRANSPORT AGENCY**
	Applicant

ŌTAKI TO NORTH OF LEVIN HIGHWAY PROJECT:

TECHNICAL ASSESSMENT G

HYDROGEOLOGY & GROUNDWATER

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Glossary

Term	Definition
Accretion	The gradual enlargement of an area of land through the natural accumulation of sediment deposited by a river, lake, or sea.
Active channel	A channel of a stream subject to change by prevailing discharges.
Aggradation	Accumulation of sediment on the channel bed or floodplain.
Annual Exceedance Probability (AEP)	The probability of a flood of a given magnitude being equalled or exceeded in any year, usually expressed as a percentage.
Aquifer	A water-bearing unit beneath the ground surface that can supply sufficient water to act as a water resource.
Flowing artesian pressure	Groundwater pressures such that the water would rise above the ground surface if it was not confined by a less permeable unit or a bore.
Average Recurrence Interval (ARI)	The average number of years expected between events of a given magnitude. Also known as the return period.
Baseflow	The flow in a channel derived from the slow drainage of soil water or groundwater. Maintains flow in a stream or river during periods between rainfall events.
Bedload	Coarse material that is transported along the bed of a river during floods. Excludes finer material that may be suspended within the water column. Moves at a rate significantly slower than the velocity of the water.
Confined aquifer	An aquifer located beneath a lower permeability unit that prevents the groundwater rising to a height equal to its confining pressure.
CPT	Cone Penetration Test – a subsurface investigation technique.
Degradation	The general lowering of the land/channel surface by natural processes of weathering and erosion.
Depression storage	Depressions in the surface topography of the land which can store precipitation that would otherwise become runoff.
Down-gradient	Further down the groundwater system where pressures are lower.
Dry weather flow	See baseflow.
Digital Terrain Model (DTM)	Term often used interchangeably with DEM (Digital Elevation Model). A DTM is a digital representation of the landscape allowing 3D analyses.
Effluent stream	A stream that gains water from the adjacent groundwater.
Floodplain	A relatively flat alluvial landform created largely by the contemporary flow regime of the river. The floodplain is inundated by flows greater than bankfull discharge and

	therefore subject to the periodic deposition of sediment and debris.
Hydraulic connection	A path that allows water to flow from one location to another either laterally or vertically.
Hydrograph	The changes in flow (either water level or volume) over time.
Hyetographs	The changes in rainfall intensity or depth over the duration of an event.
Infiltration capacity	The sustained rate that water can pass through the soil surface once any soil storage is saturated. Varies as a function of soil type and hydraulic properties.
Influent stream	A stream that loses water to the adjacent groundwater.
Interfluve	The dividing ridge between adjacent catchments.
Overbank flooding/flow	Occurs at flows above bankfull discharge when the channel can no longer contain the volume of runoff. Floodwater spills over the banks and starts to flow across the floodplain.
Overflow channel	A watercourse that is generally dry but conveys flood water that has overflowed the banks of a river. Generally, only flow during larger flood events.
Overland flow	Water that flows over the ground surface. May be caused either by the soil/regolith being saturated or when rainfall intensity exceeds the infiltration capacity.
Overland flow paths	The path taken by water flowing over the ground surface towards a river or stream.
Paleochannels	Old, abandoned, and generally inactive channels found on a floodplain. Paleochannels can also exist at depth creating a 3D mosaic of preferential flow paths for groundwater.
Phreatic surface	The top of the saturated zone (water table) in an unconfined aquifer.
Piedmont plain	An area of gently dipping terrain, formed largely by alluvial processes, that may develop between the hill country and the coast. Caused by a significant reduction in gradient and therefore energy to transport sediment.
Piezometric surface	The top of the groundwater if it was not confined and could reach equilibrium conditions.
Perched water table	A local, generally unconfined aquifer at a higher elevation than the regional groundwater system. Generally, form during rainstorm events when there is a permeability discontinuity in the soil profile eg, when a more permeable soil/regolith overlies relatively impermeable bedrock.
Perennial stream	A stream or reach of a stream that flows continuously throughout the year.
Piezometric contours	Lines of equal groundwater elevation if it was not confined and could reach equilibrium conditions.

Regolith	Unconsolidated material that overlies the bedrock. Includes any soil and weathered bedrock above the competent bedrock.
Runoff	Water flowing under the influence of gravity either across the ground surface or in open channels.
Saturated overland flow	Overland flow that occurs because the soil is saturated and acts as if the surface is sealed.
Sediment load	The material that is eroded and transported by a stream. Total load consists of dissolved load, suspended load, and bedload.
Sediment transport	The movement of sediment through a river system. See also bedload and suspended load.
Semi-confined aquifer	An aquifer beneath a hydrogeologic unit of lower permeability which limits direct hydraulic connection to the ground surface.
Soil moisture content	The water held in the soil, generally by capillary forces, at tensions greater the force of gravity which would allow groundwater to flow either vertically or laterally.
Specific yield	The volume of water obtained from an unconfined aquifer per unit volume of the aquifer.
Storativity	The volume of water released from an aquifer when there is a unit drop in pressure.
Streamflow	Comprises the movement of water under the influence of gravity in open channels of various sizes.
Storm runoff	Water which arrives rapidly after the onset of precipitation. Also see quickflow and direct runoff.
Subsurface flow	The flow of water beneath the ground surface.
Suspended load	Finer material that is transported within the water column and moves at approximately the speed of flow. Moves more often, faster, and further than bedload.
Thalweg	The line of deepest flow and generally highest velocity within a river or stream.
Throughflow	Water that infiltrates the soil surface and then moves laterally through the regolith towards a stream channel. Movement can occur either as unsaturated flow (particularly through macropores such as root channels or cracks within the soil) or as a saturated layer.
True right/left bank	The right/left bank of a river when looking downstream.
Unconfined aquifer	A water-bearing unit with a direct hydraulic connection to the ground surface above and where the groundwater level is equal to the phreatic surface.
Up-gradient	Further up the groundwater system where pressures are higher.
Water table	The top of the saturated zone (phreatic surface) in an unconfined aquifer.

EXECUTIVE SUMMARY

1. The Ōtaki to North of Levin Highway Project ("**Ō2NL Project**") will traverse several coalescing alluvial fans, formed by highly mobile rivers and streams of various sizes. The alluvium deposited by these rivers and streams ranges from coarse gravels to clay; depending on the size of the stream and the relative position of the thalweg (the deepest and fastest part of the channel) when the sediment was deposited. This already complex mosaic of alluvium is further complicated by the mobile nature of the rivers and streams, potential truncation of some stream channels by strike-slip motion on faults, fluctuating sea level, and changes in sediment supply from the headwaters.

2. This three-dimensional mosaic of largely sedimentary deposits hosts a groundwater system that contains both unconfined and confined aquifers and water-bearing units.

3. The design of the Ō2NL Project has been informed by several cultural, hydrological, and hydrogeological principles to avoid any potential adverse effects and to maximise environmental and community outcomes.

4. To identify and avoid any potential adverse effects of the Ō2NL Project on groundwater, and where this is not possible to mitigate potential adverse effects, comprehensive investigations were undertaken to gain a better understanding of the groundwater system beneath and adjacent to the proposed highway. Those investigations are summarised in *Appendix G.1* to this Technical Assessment. That appendix should be read in conjunction with this Technical Assessment if additional detail and explanation of specific matters is required.

5. The investigations included 63 boreholes, 77 test pits, 36 Cone Penetration Tests ("**CPTs**"), 57 monitoring bores, 10 hand auger holes, eight slug tests and nine soil infiltration tests. The findings were generally consistent with previous hydrogeological investigations and no atypical or unique conditions were identified.

6. In general, the water table mimics the topographic surface and ranges in depth from the ground surface to deeper than 20m. Springs and some wetlands occur where the water table intersects the ground surface, especially towards the northern and southern ends of the Ō2NL Project. The deepest groundwater levels generally occur at locations east of Levin (near Tararua Rd). The highest groundwater levels ranged from 0.5m to 2m below

the ground surface in areas near Queen Street East (east of Levin), east of Manakau Township, and adjacent to Manakau Stream.

7. Because of the stratified and variable nature of the alluvial sediments, there are often at least two water-bearing units at different depths. These water-bearing units are separated by aquitards of lower permeability material, generally silt or clay. The effective groundwater levels ie, pressures, in these water-bearing units can be significantly different.

8. At any location, both the deep and shallow bores screened in different water bearing units follow a very similar seasonal trend. This suggests that, despite its apparent complexity, the groundwater is acting as an interconnected system.

9. Comprehensive modelling, calibrated against the measured groundwater levels, allows prediction of daily groundwater levels back to 1971. This allows estimation of the maximum groundwater level likely to have been experienced over the past 50-years, and a range of design groundwater levels. This information was used to assist with the concept design of the Project to avoid any potential adverse effect on the groundwater system.

10. If the hydrological and hydrogeological principles are incorporated into the detailed design and construction of the Ō2NL Project, this will avoid any potential adverse effects on the groundwater system while also maximising environmental and community outcomes. Appropriate design of the selected Ō2NL alignment will ensure:

    (a) There will be no change in the existing water balance (rainfall or evapotranspiration) and therefore no adverse effect on groundwater supported wetlands and forests.

    (b) That any direct interaction with groundwater is avoided by constructing the Ō2NL highway above the maximum height of the water table, determined by comprehensive and detailed monitoring and modelling, wherever practicable.

    (c) Existing hydraulic connections will be maintained through the design of the stormwater system and surface hydraulic connections past the proposed Ō2NL highway. Also, the construction of the Ō2NL highway above the maximum elevation of the water table will avoid any effects on the existing groundwater flow paths. Maintaining both surface and subsurface hydraulic connections will therefore avoid adverse effects on groundwater supported wetlands and forests.

(d) Any potential effect on the hydraulic connection between surface water and groundwater under the immediate footprint of the proposed Ō2NL highway, caused by the ‘sealing’ of the existing ground surface, will be offset by the construction of swales and wetland treatment devices. These devices, adjacent to the Ō2NL highway, will maintain and potentially enhance the existing hydraulic connections. The devices will allow the infiltration and percolation of any excess rainfall to recharge the groundwater system. Consequently, there will be no adverse effect on groundwater supported wetlands and forests.

(e) Improved water quality, with respect to nutrient and pathogen loading, will occur through the change in land use from pastoral farming and specially designed and constructed wetlands to treat runoff from the proposed Ō2NL highway. This will result in a small improvement in the quality of both surface runoff and groundwater over time.

(f) That stormwater from the proposed Ō2NL highway will be collected by the network of swales, retention basins and wetlands to ensure no runoff will occur onto adjacent land containing existing private bore(s), wetlands, or streams.

11. There are 69 wetlands identified along the proposed highway alignment. The hydrological regime and sensitivity of each to the Project were assessed. Analysis of the proposed highway alignment, both vertical and lateral, identified seven wetlands or forest remnants that are connected to groundwater and within a zone where road cuts may intercept and reduce groundwater levels.

12. This analysis showed that overall, any potential effects of the Project on those wetlands are likely to be ‘less than minor’. In the few instances where more than minor effects are possible, these will be offset by the measures proposed in Technical Assessment J (Terrestrial Ecology).

13. Furthermore, while road cuts may reduce groundwater levels at these seven wetlands, it must be recognised that wetlands can be either formed from discharges of groundwater or be acting as recharge pathways to groundwater. Where the latter is true, reducing groundwater levels will not affect the water balance at the wetland.

14. Two sites may potentially be affected temporarily by dewatering required for culvert construction. Analysis of the potential effects of temporary dewatering on wetlands and forest remnants and any neighbouring bores shows that any effects will be of temporary, of short duration, and can be mitigated by standard construction techniques. Any effects of temporary dewatering can therefore be regarded as 'less than minor'.

15. Detailed analysis of the potential effects of groundwater mounding under and adjacent to the stormwater treatment devices east of Levin shows that any effects during events less than the maximum design event ie, the 1% AEP rainfall increased to allow for climate change, can be considered 'less than minor'. For larger events, it is likely that the entire ground would be saturated, and overland flow would occur. The proposed works will not exacerbate the existing situation.

16. The current conceptual earthworks design of the Ō2NL Project relies on a significant amount of additional fill, >1.5Mm³, above that anticipated to be won through cut activities.

17. From a list of approximately 36 potential material supply sites along the length of the Ō2NL Project, four were chosen for a more detailed assessment. Selection was on the basis of their proximity to the Project, geotechnical conditions, and performance against a range of environmental, cultural, and economic criteria including potential legacy outcomes.

18. Preliminary analysis shows that each of these four sites could be potentially developed to supply additional material for the Project without any adverse effect on surface water or groundwater resources, and without exacerbating the existing flood hazard. In most situations, the potential works would provide some small amount of flood mitigation. This would be greatest during smaller and more frequent events.

19. At least two of the sites, because of their hydrological characteristics, offer the potential following rehabilitation to leave an enduring legacy in the form of open-water ponds and wetlands.

20. While the investigations have allowed the identification and avoidance of potential adverse effects of the Ō2NL Project on the groundwater system, as with any hydrogeological investigation, there remains some small residual uncertainty. This uncertainty will be reduced as further investigations are undertaken, additional data collected, and the design of the Project refined.

21. To monitor for any unforeseen residual adverse effects on the groundwater system, a Groundwater Monitoring and Management Plan is proposed as a component of the proposed Construction Environment Management Plan. The Groundwater Monitoring and Management Plan will allow any potentially adverse residual effects to be mitigated, and remedied, if necessary.

INTRODUCTION

22. My full name is Dr John (Jack) Allen McConchie. I am currently employed as the Technical Director (Hydrology & Geomorphology) by SLR Consulting (NZ). I have been engaged by Waka Kotahi NZ Transport Agency (**Waka Kotahi**) to provide expert technical support in the areas of hydrology, hydrogeology, and groundwater in relation to the Ōtaki to North Levin State Highway (Ō2NL).

Qualifications and experience

23. I have the following qualifications and experience relevant to the Ō2NL Project. I hold a Bachelor of Science degree with First Class Honours (from Victoria University of Wellington) and a PhD (also from Victoria University of Wellington).

24. I am a **member** of **several** professional and relevant associations including the:

    (a) New Zealand Hydrological Society;

    (b) American Geophysical Union;

    (c) New Zealand Geographical Society;

    (d) Australia-New Zealand Geomorphology Group; and

    (e) Environment Institute of Australia and New Zealand.

25. I am a certified RMA hearings commissioner (2011-present) and have been an Independent Professional Adviser to Waka Kotahi since 2011.

26. I was the New Zealand Geographical Society representative on the Joint New Zealand Earth Science Societies' Working Group on Geopreservation. This Working Group produced the first geopreservation inventory; published as the New Zealand Landform Inventory.

27. Prior to the start of 2008, I was an Associate Professor with the School of Earth Sciences at Victoria University of Wellington. I taught undergraduate

courses in hydrology and geomorphology, and a postgraduate course in hydrology, hydrogeology, and water resources.

28. For more than 40 years my research and professional experience has focused on various aspects of hydrology, groundwater, and geomorphology, including: slope and surface water hydrology (including water quality), hydrometric analysis, groundwater dynamics, landscape evolution, and natural hazards. Within these fields I have edited one book. I have written, or co-authored, 10 book chapters and over 50 internationally refereed scientific publications, including several papers focusing on landscape evolution of the Horowhenua lowlands, groundwater dynamics and contamination at Manakau, and the risk from saline intrusion.

29. I have extensive experience responding to natural hazards; particularly flooding and slope instability. This includes: Cyclone Alison in the Ruahine Range (1975); the Hutt Valley rainstorm (1976); extensive landsliding in Wairarapa (1978); Cyclone Bola (1988); Waikato floods (1998); and the Manawatū floods (2004). Most recently I assisted with the North Canterbury Transport Infrastructure Recovery (NCTIR) Agency and the Flaxbourne-Ward community responses to mitigate the effects of the Kaikōura Earthquake (2016).

30. I have considerable experience working on major infrastructure projects including: the Hamilton North Bypass; Western Link Road; Kopu Bridge; Tauranga Eastern Link Road; Basin Bridge; Transmission Gully; Peka Peka to Ōtaki Expressway; Petone-Grenada Link Road; the realignment of SH3 at both Mt Messenger and Awakino Gorge; and Te Ahu a Turanga: Manawatū Tararua Highway. This experience gives me an in-depth understanding of climate, hydrology, and hydrogeology as they interact with infrastructure.

31. Finally, I have considerable local experience having worked on various hydrology and groundwater-related projects in and around Horowhenua and Manawatū over the past 20 years; including the Peka Peka to Ōtaki Expressway and Te Ahu a Turanga: Manawatū Tararua Highway. I provided technical evidence relating to the flood hazard and stormwater management at Tara-Ika (Horowhenua District Council's Plan Change 4) during hearings into the proposed change to the Horowhenua District Plan. I have provided technical advice to Horizons on several applications for resource consents involving works related to streams and rivers. This experience has given me

an in-depth understanding of climate, hydrology, and hydrological processes of the area to be traversed by the Ō2NL Project.

Code of conduct

32. I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court Practice Note 2014. This evidence has been prepared in compliance with that Code, as if it were evidence being given in Environment Court proceedings. Unless I state otherwise, this evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions I express.

Purpose and scope of evidence

33. This assessment provides a review of:

    (a) The core principles adopted by the Ō2NL Project that underpin and inform the hydrogeological investigations;

    (b) The hydrological and hydrogeological principles that inform the design and construction of the Ō2NL Project;

    (c) The hydrogeological setting and its implications for the Ō2NL Project;

    (d) The hydrogeological investigations undertaken with respect to the Ō2NL Project;

    (e) The findings of the hydrogeological investigations of relevance to the Ō2NL Project; and

    (f) How any residual adverse effects caused by the inherent uncertainty of groundwater investigations will be managed.

PROJECT DESCRIPTION

34. Waka Kotahi is giving notices of requirement ("**NoRs**") for designations to the Horowhenua District Council ("**HDC**") and the Kāpiti Coast District Council ("**KCDC**") and is applying for the necessary resource consents from Manawatū-Whanganui Regional Council ("**Horizons**") and Greater Wellington Regional Council ("**GWRC**") for the Ō2NL Project.

35. The Ō2NL Project involves the construction, operation, use, maintenance, and improvement of approximately 24km of new four-lane state highway

between Taylors Road (to the north of Ōtaki) and State Highway 1 (“**SH1**”) north of Levin.

36. The Ō2NL Project is part of the New Zealand Upgrade Programme (“**NZUP**”) and has the purpose to *“improve safety and access, support economic growth, provide greater route resilience, and better access to walking and cycling facilities.”* The Ō2NL Project provides the final northern link of the Wellington Northern Corridor that extends from Wellington International Airport to north of Levin.

37. The Ō2NL Project comprises the following key features):

(a) a grade separated diamond interchange at Tararua Road, providing access into Levin;

(b) two dual lane roundabouts located where Ō2NL crosses SH57 and where it connects with the current SH1 at Heatherlea East Road, north of Levin;

(c) four lane bridges over the Waiauti, Waikawa and Kuku Streams, the Ohau River and the North Island Main Trunk (“**NIMT**”) rail line north of Levin;

(d) a half interchange with southbound ramps near Taylors Road and the new Peka Peka to Ōtaki expressway to provide access from the current SH1 for traffic heading south from Manakau or heading north from Wellington, as well as providing an alternate access to Ōtaki.

(e) local road underpasses at South Manakau Road and Sorenson Road to retain local connections;

(f) local road overpasses to provide continued local road connectivity at Honi Taipua Road, North Manakau Road, Kuku East Road, Muhunoa East Road, Tararua Road (as part of the interchange), and Queen Street East;

(g) new local roads at Kuku East Road and Manakau Heights Road to provide access to properties located to the east of the Ō2NL Project;

(h) local road reconnections connecting:

(i) McLeavey Road to Arapaepae South Road on the west side of the Ō2NL Project;

(ii) Arapaepae South Road, Kimberley Road and Tararua Road on the east side of the Ō2NL Project;

(iii) Waihou Road to McDonald Road to Arapaepae Road/SH57;

(i) Koputaroa Road to Heatherlea East Road and providing access to the new northern roundabout;

(j) the relocation of, and improvement of, the Tararua Road and current SH1 intersection, including the introduction of traffic signals and a crossing of the NIMT;

(k) road lighting at conflict points, that is, where traffic can enter or exit the highway;

(l) median and edge barriers that are typically wire rope safety barriers with alternative barrier types used in some locations, such as bridges that require rigid barriers or for the reduction of road traffic noise;

(m) stormwater treatment wetlands and ponds, stormwater swales, drains and sediment traps;

(n) culverts to reconnect streams crossed by the Ō2NL Project and stream diversions to recreate and reconnect streams;

(o) a separated (typically) three-metre-wide SUP, for walking and cycling along the entire length of the new highway (but deviating away from being alongside the Ō2NL Project around Pukehou (near Ōtaki)) that will link into shared path facilities that are part of the PP2Ō expressway (and further afield to the Mackays to Peka Peka expressway SUP);

(p) spoil sites at various locations along the length of the Project; and

(q) five sites for the supply of bulk fill / earth material located near Waikawa Stream, the Ohau River and south of Heatherlea East Road.

38. Consequently, the Ō2NL Project has the potential to interact with the groundwater system and *vice versa*. To avoid any potential adverse effects of the Ō2NL Project, and to maximise the environmental and community outcomes, a comprehensive understanding of the groundwater system and its dynamics has been developed.

CORE PRINCIPLES

Cultural

39. Through the partnership process, the core (overarching) principles developed for the Ō2NL Project described in the CEDF[1] are to:

    (a) Tread lightly, with the whenua

    - Me tangata te whenua (treat the land as a person);
    - Kia māori te whenua (Let it be its natural self).

    (b) Create an enduring community legacy

    - Kia māori te whakaaro (normalise māori values);
    - Me noho tangata whenua ngā mātāpono (embed the principles in all things);
    - Tū ai te tangata, Tū ai te whenua, Tū ai te Wai (elevate the status of the people, land, and water).

40. These core principles flow from tikanga (te ao) māori cultural values. They define the framework for interaction between those working on the Ō2NL Project and for the relationship between the Project Team, the Ō2NL Project itself, and the natural world.

Hydrology & Groundwater

41. The development of the Ō2NL Project has also been informed by several hydrological and hydrogeological principles. These include:

    (a) Maintaining the existing water balance ie, the input, output and storage of water;

    (b) Avoiding any direct interaction with the groundwater system, where practical;

    (c) Maintaining existing hydraulic connections in both surface water and groundwater;

    (d) Maintaining, and where practical enhancing, the existing hydraulic connections between surface water and groundwater;

[1] Cultural and environmental design framework (Appendix Three to Volume II).

(e) Improving the quality of groundwater, where practical; and

(f) Maintaining, and where practical improving, the quality and quantity of groundwater entering Punahau / Lake Horowhenua.

EXISTING ENVIRONMENT

Hydrogeological setting

42. The proposed Ō2NL Project will traverse several coalescing alluvial fans, formed by highly mobile rivers and streams of various sizes (*Figure G.1*).

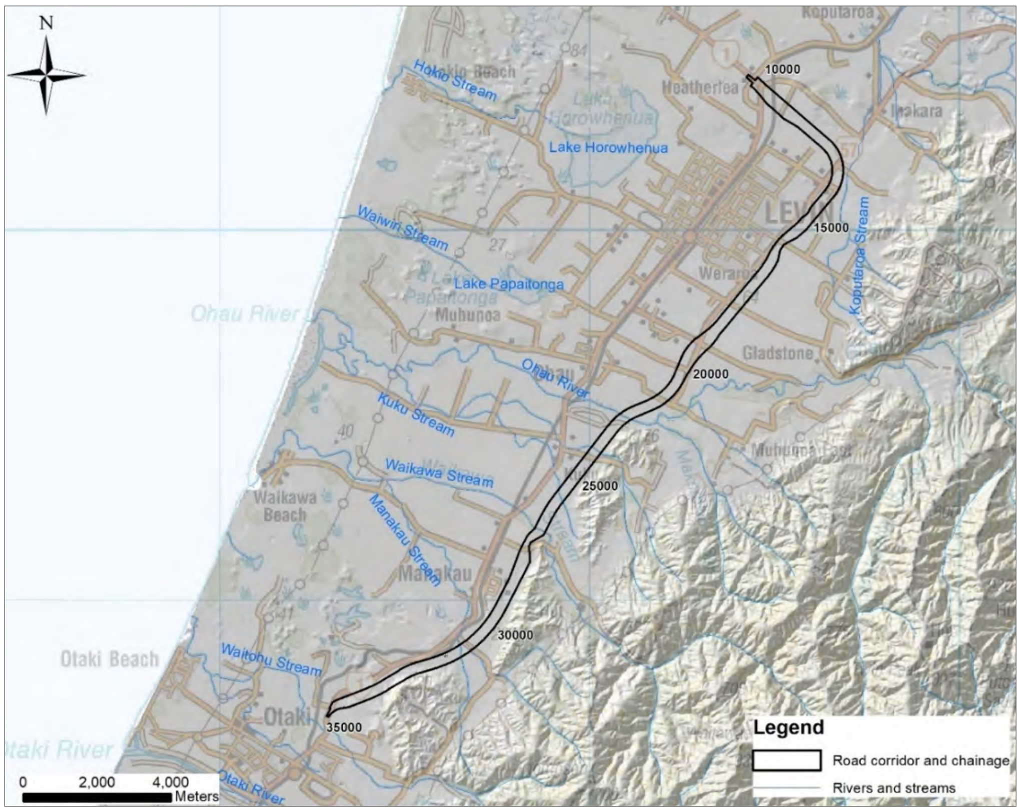

Figure G.1: The alignment of the Ō2NL Project and the various rivers and streams it will intersect. Chainages along the proposed highway are indicated.

43. The alluvium deposited by these rivers and streams ranges from coarse gravels to clay; depending on the size of the stream and the relative position of the thalweg (the deepest and fastest part of the channel) when the sediment was deposited. This already complex mosaic of alluvium is further complicated by the mobile nature of the rivers and streams, potential truncation of stream channels by strike-slip motion on faults, and changes in sediment supply from the headwaters.

44. At the same time as this sediment was being deposited, the sea level has fluctuated by 100-130m. This resulted in changes to the gradient of the

rivers and streams, and consequently the energy available to erode and transport sediment. Furthermore, changing sea levels caused significant differences in the distance of the coast from the hill country to the east. During glacial conditions the shoreline was about 30km west of its current ‘interglacial’ position. This affected the nature, energy, and location of marine processes.

45. Consequently, marine sediment is interfingered with the alluvium from the rivers and streams. While marine and finer sediment dominate closer to the coast, significant variability in material size and origin occurs throughout the Ō2NL Project area.

46. Climatic oscillations between glacial (with lower sea levels, steeper river gradients, reduced vegetation cover, and greater erosion) and interglacial (with conditions like today) periods have also affected conditions and therefore the nature of the sedimentary deposits.

47. Given the nature and origin of these sediments, they are relatively easily eroded and re-entrained by the same or similar processes that led to their original deposition. This means that, as well as the landscape accumulating sediment that reflects the conditions during deposition, these sediments have been randomly and preferentially eroded over time.

48. Finally, there is likely to have been both vertical and horizontal movement on the faults in the area. This has affected the depth to bedrock and some of the larger structural elements in the landscape, including the Poroutawhao Basement High that restricts groundwater flow westwards towards the coast in the vicinity of Punahau / Lake Horowhenua.

49. The net effect of the interaction of all these processes is an extremely complex three-dimensional mosaic of coarse to fine sediment, of either alluvial or marine origin, that forms a piedmont plain between the Tararua Range and the coast (*Figure G.2*).

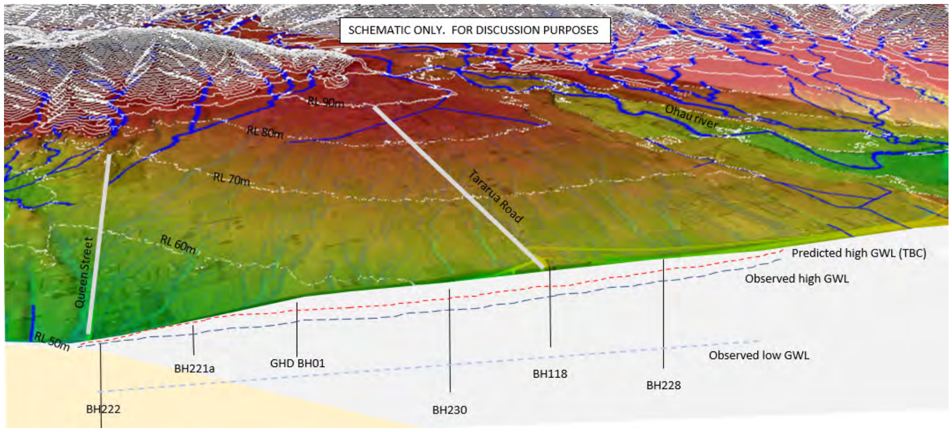

Figure G.2: **The Ō2NL Project will be constructed across a series of coalescing alluvial fans that form a piedmont plain between the Tararua Range and the coast.**

50. The result of the interaction of these processes, over time and throughout the Ō2NL Project area, is described in detail in Stantec (2021a&b).[2&3] The surficial geology described in these reports is summarised in *Figure G.3 & Table G.1.*

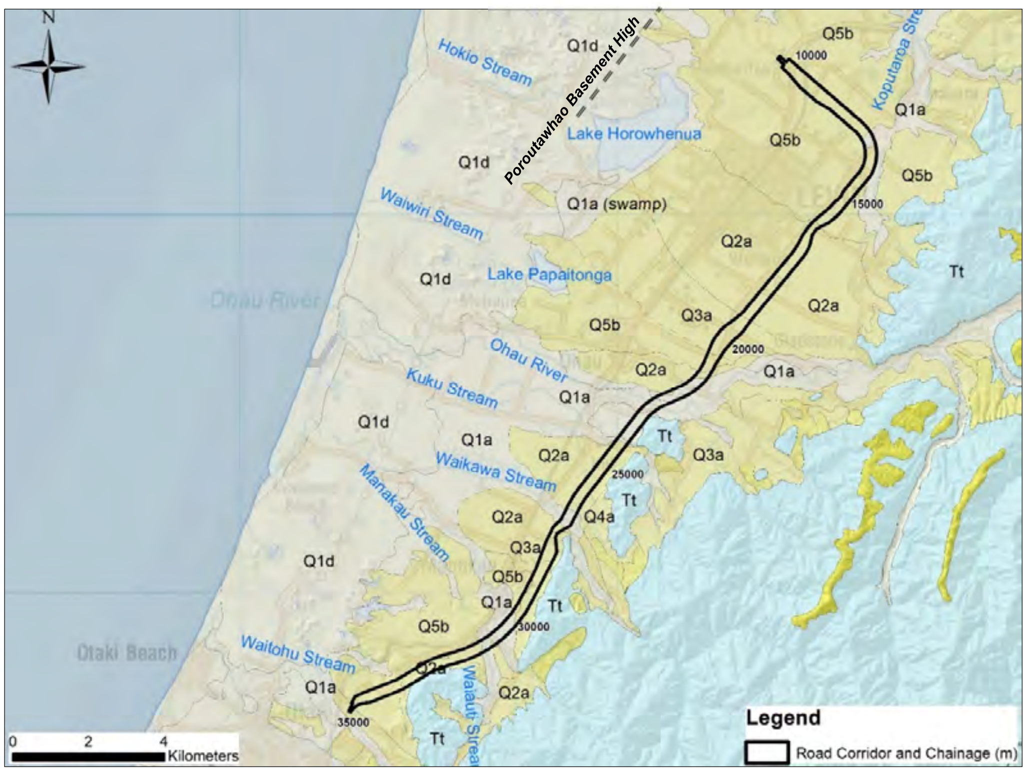

Figure G.3: **Geology in the vicinity of the Ō2NL Project. The different units are described in *Table G.1*.** Chainages along the proposed highway are indicated.

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2 Stantec (2021a). Geotechnical Factual Report. SH1 Ōtaki to North Levin. Prepared for Waka Kotahi. New Zealand Transport Agency. September 2021.

3 Stantec (2021b). SH1 Ōtaki to North Levin. Geotechnical Interpretation Report. Prepared for Waka Kotahi. NZ Transport Agency.

Table G.1: Geological units in the vicinity of the Ō2NL Project.

Unit	Formation name	Description
Q1a	Holocene river deposits	Alluvial gravel, sand, silt, mud, and clay with local peat, includes modern riverbeds.
Q2a	Late Pleistocene river deposits	Poorly to moderately sorted gravel with minor sand or silt underlying terraces; includes minor fan gravel.
Q3a	Late Pleistocene river deposits	Weathered; poorly sorted to moderately sorted gravel underlying loess-covered, commonly eroded, aggradational surfaces.
Q5b	Late Pleistocene shoreline deposits	Beach deposits consisting of marine gravel with sand; commonly underlying loess and fan deposits.
Q6a	Pleistocene Alluvium	Weathered; poorly sorted to moderately sorted gravel underlying loess-covered, commonly eroded, aggradational surfaces.
Tt	Basement (Wellington Greywacke)	Alternating sandstone, mudstone, poorly bedded. Conglomerate, basalt, chert.

Hydrological interactions

51. While the focus of this Technical Assessment is the groundwater system, it is important to recognise the various interactions of a wide range of hydrological processes that affect the groundwater (*Figure G.4*).

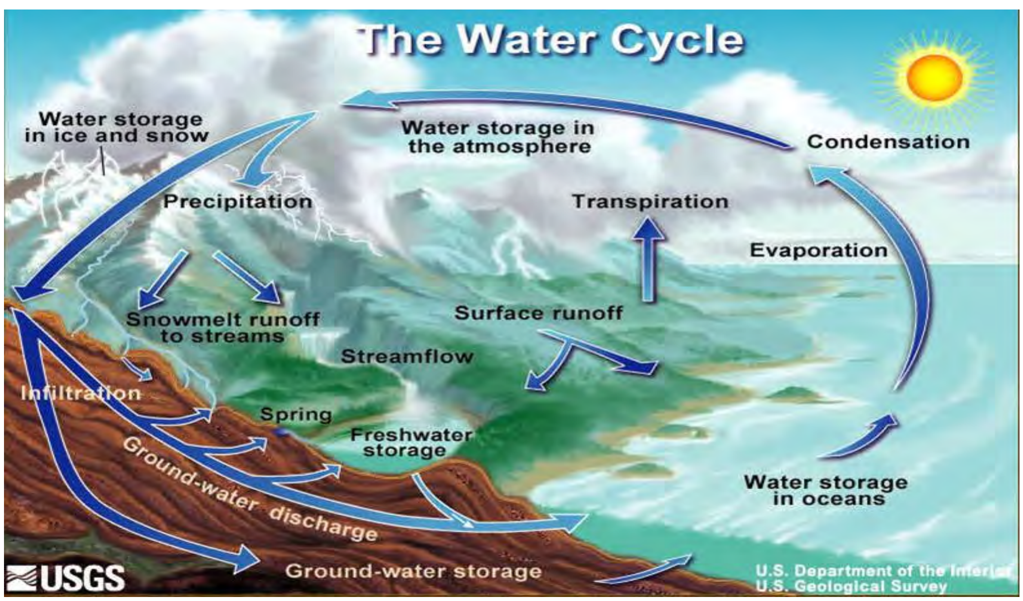

Figure G.4: Interaction of various hydrological processes and systems.

52. For example, in the Ō2NL Project area, rainfall directly affects streamflow and groundwater recharge. Streamflow also affects groundwater recharge by infiltration and percolation through the channels of the various rivers and streams. Groundwater then sustains springs and augments streamflow when it intersects the ground surface. Both streamflow and groundwater provide inflows to Punahau / Lake Horowhenua and Lake Papaitonga, which then provide streamflow to the Hokio and Waiwiri Streams respectively. Several rivers and streams in the area also have both ‘losing’ and ‘gaining’ reaches (ie, they either lose water to or, gain water from, groundwater) depending on the hydrogeology and hydraulic gradient between the river and adjacent groundwater.

53. Consequently, when considering the groundwater system, it is important that this system and its dynamics are placed in the context of the wider hydrological processes.

Groundwater management zones

54. Approximately 70% of the Ō2NL Project is located within the Horowhenua Groundwater Management Zone ("**HGMZ**"), administered by Horizons. Relatively short lengths of the Ō2NL Project in the north and south lie within the Manawatū Groundwater Management Zone ("**MGMZ**") and Ōtaki Groundwater Management Zone ("**ŌGMZ**"); managed by Horizons and the GWRC respectively (*Figure G.5*).

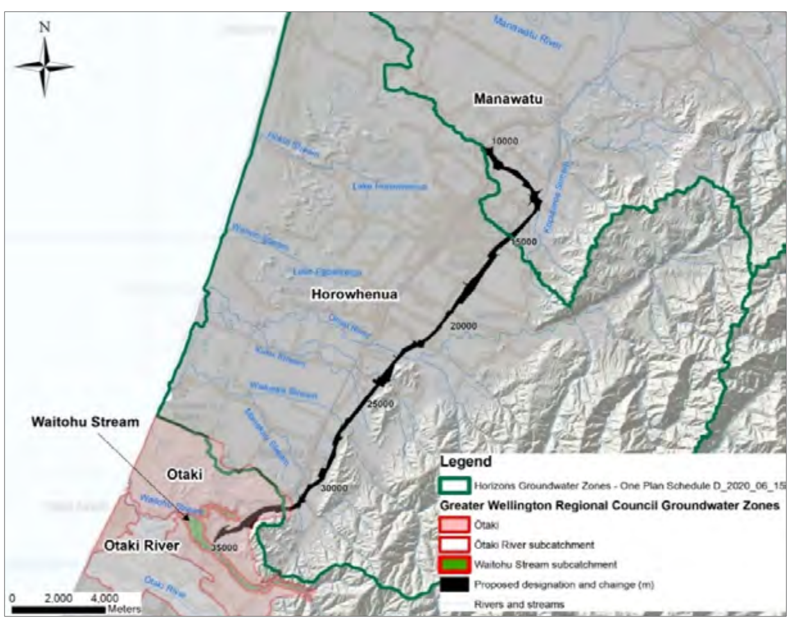

Figure G.5: Groundwater Management Zones, within the two territorial authorities, traversed by the Ō2NL Project. Chainages along the proposed highway are indicated. (Sources: Horizons & GWRC)

Horowhenua Groundwater Management Zone ("HGMZ")

55. The HGMZ covers 388km^2 and extends from the foothills of the Tararua Range to the coast. Groundwater occurs within a multi-layered, unconfined and semi-confined (leaky) aquifer system.

56. Unconfined aquifers, with a direct hydraulic connection to the ground surface, are present across the entire HGMZ. These range in thickness from 5-40m, with the water table, ie, the top of the saturated zone, ranging from the ground surface to a depth of 30m.

57. The unconfined aquifers are often underlain by silt and clay and up to four semi-confined aquifers which become progressively more confined with depth.

58. The aquifer system (unconfined and semi-confined) may extend from 15m to more than 300m below ground and is underlain by low permeability Tararua Range greywacke basement.

Water balance

59. The two principal inflows to the groundwater system are rainfall infiltration through the ground surface and leakage through the beds of various rivers and streams, but principally the Ohau River.

60. East of Levin, high soil infiltration rates result in little runoff with almost all rainfall (minus evapotranspiration) being stored in the soil or recharging groundwater. Groundwater inflows from deeper aquifers and the greywacke bedrock to the east are probably minor sources of groundwater.[4]

61. The principal outflows from the groundwater system are discharges to the sea and leakage into rivers, lakes, and streams. Abstractions from bores also constitute a significant component of the water balance, although this is likely to have a strong seasonal signature; ie, to be highest in late summer.

Groundwater flow direction

62. Groundwater beneath the Ō2NL Project flows generally in an east-west direction, from the Tararua Range towards the coast. The piezometric surface (top of the groundwater) tends to mimic the topography, with groundwater flow being normal to the piezometric contours. Groundwater

[4] Gyopari (2005). Horowhenua Lakes Assessment of Groundwater – Surface Water Interaction. Prepared for Horizons Regional Council.

discharges into the Tasman Sea and through hydraulically connected surface water bodies such as Punahau / Lake Horowhenua and various spring fed streams (*Figure G.6*).[5]

63. Near the Tararua Range, groundwater flows downwards into deeper semi-confined sand and gravel aquifers because of the positive hydraulic gradient. However, near the coast and Punahau / Lake Horowhenua, the vertical hydraulic gradient reverses and groundwater flow is upwards from the semi-confined aquifers into the shallow overlying unconfined aquifers and hydraulically connected surface water bodies (*Figure G.7*).

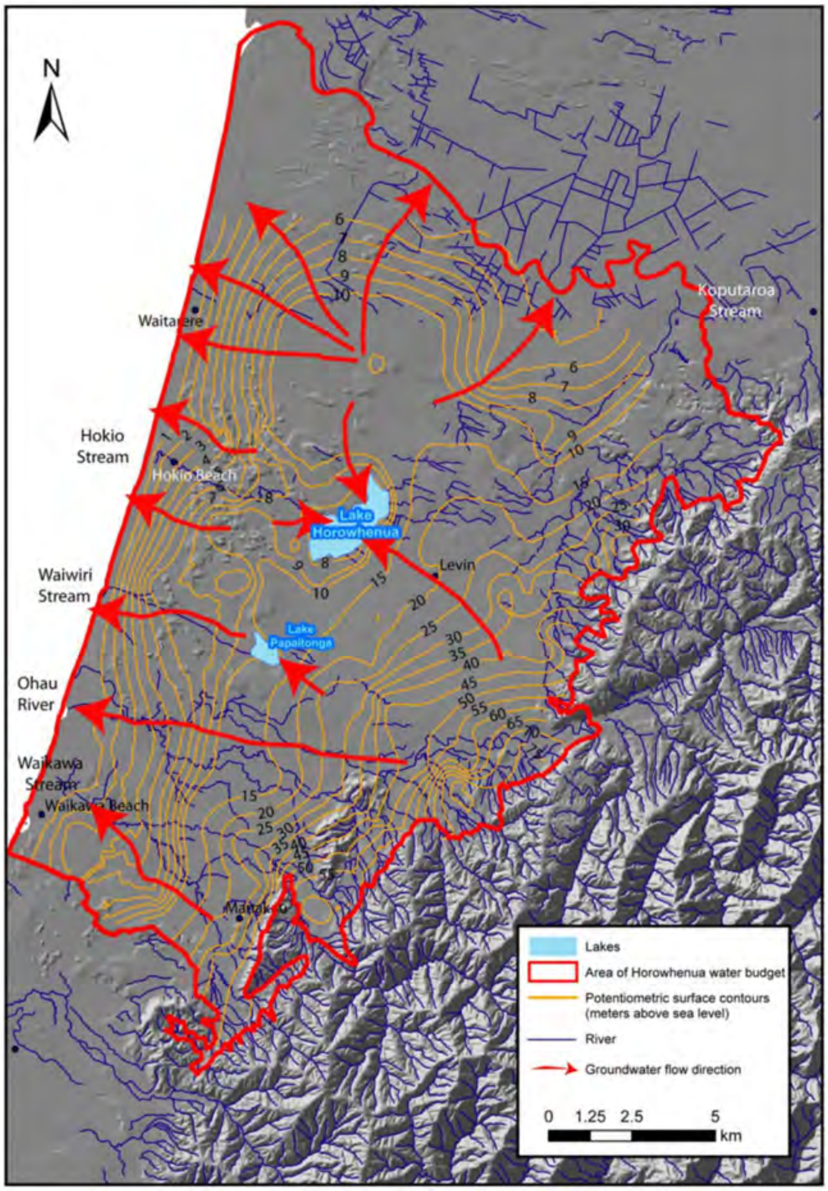

Figure G.6: Groundwater flow direction in the HGMZ. (Source: White *et al.*, 2010)[5]

[5] White, P., Zarour, H., Meilhac, C., and Green, S. (2010). Horowhenua water resources: water budget and groundwater surface water interaction. GNS Science Consultancy Report. 2010/22.

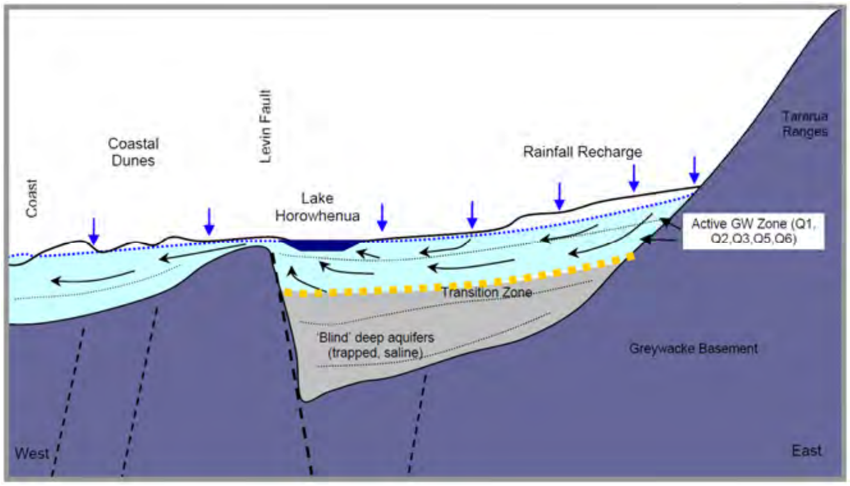

Figure G.7: **Schematic illustration of the nature of groundwater flow and the interaction of surface and subsurface flow east of Levin**. (Source: Gyopari, 2005)[4]

Groundwater levels

64. Groundwater levels within the HGMZ show a seasonal pattern, with the highest groundwater levels in late winter-spring and lowest water levels in late summer-autumn. This pattern is typical of rainfall recharged groundwater. Groundwater levels in various bores range from artesian, ie, the effective water level is above ground, to approximately 40m below the ground, depending on the aquifer and location. Typically, groundwater levels are deeper near the Tararua Range and shallower near the coast. The seasonal variation ranges from approximately 1-15m, with larger variation east of Levin where the groundwater is deepest (*Figure G.8*).

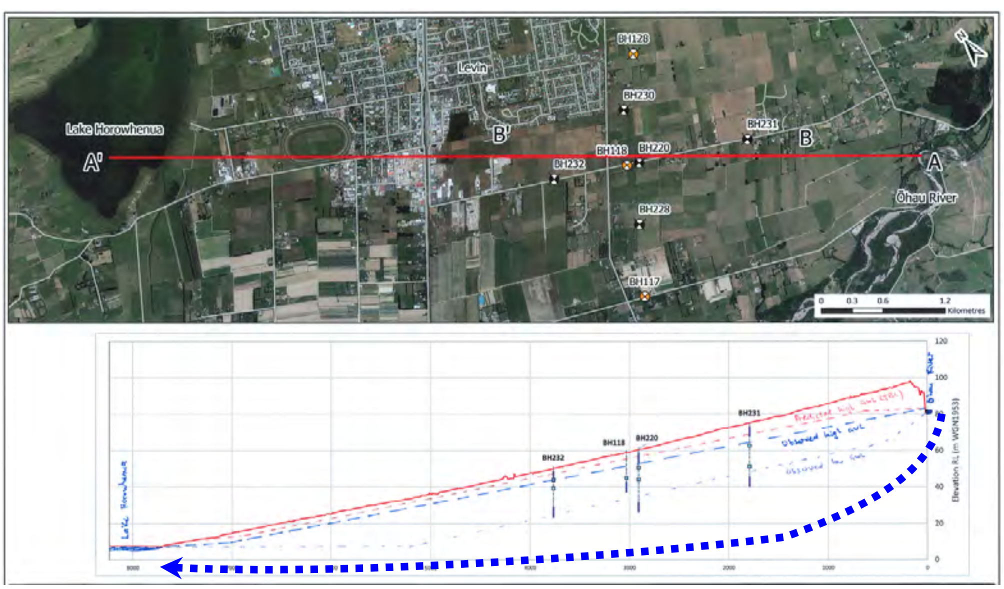

Figure G.8: **Simplified flow path of groundwater movement from the Tararua Range to the coast.**

Surface water drainage

65. The HGMZ has few natural surface water features. This is most noticeable between the Ohau River and Koputaroa Stream where the piedmont plain is composed of alluvium with very high permeability. Consequently, there is little or no surface runoff and almost all rainfall recharges the groundwater system.[6]

Groundwater / surface water interaction

66. The main surface water bodies are the Ohau River and Lakes Horowhenua and Papaitonga. Smaller streams include the Waiauti, Waikawa, Kuku and Koputaroa. All these surface water features interact with the groundwater system, either receiving or contributing water depending on the hydrogeology and hydraulic gradient. Many of the streams also have adjacent influent and effluent reaches, that lose or gain water from groundwater respectively, depending on the hydrogeology and hydraulic gradient between the stream and adjacent groundwater.

Punahau / Lake Horowhenua

67. A major groundwater discharge point is Punahau / Lake Horowhenua. While different studies have produced various estimates of groundwater discharge to the lake, they all agree that groundwater provides the principal inflow.

68. A water balance for Punahau / Lake Horowhenua estimated that 36-63% of lake inflow is from seepage of groundwater through the lakebed and shoreline.[7] This estimate excludes groundwater from spring-fed streams flowing into the lake and therefore the total groundwater input is likely to be greater than indicated above. The groundwater capture zone for Punahau / Lake Horowhenua extends from north of Levin to Lake Papaitonga and east to the Tararuas.[8]

69. In the most recent Punahau / Lake Horowhenua Groundwater Model, groundwater inflow is estimated to average 531.2L/s, or 54% of the total inflow.[9]

[6] Zarour, H. (2008). Groundwater resources in the Manawatu–Wanganui Region: technical report to support policy development (2008/EXT/948). Retrieved from Palmerston North, New Zealand.
[7] PDP (2019): Lake Horowhenua water balance assessment and quantification of uncertainties – 2019 Update. Prepared for Horizons Regional Council. October 2019.
[8] PDP (2017): Coastal lakes groundwater capture zones investigation. Report prepared for Horizons Regional Council. August 2017. Horizons report 2017/EXT/1549.
[9] PDP (2021): Lake Horowhenua groundwater model. Report prepared for Horizons Regional Council. October 2021. Horizons report 2022/EXT/1758.

70. Groundwater moving through permeable gravel and sand intersects the impermeable Poroutawhao Greywacke Basement High east of Punahau / Lake Horowhenua. This forces the groundwater upwards through the base of the lake. The lake also receives flow from spring-fed streams, including Arawhata (largest), Mangaroa, and Patiki Streams. The Queen Street Drain, the flow regime of which is dominated by the runoff of stormwater, also discharges into the lake.

Lake Papaitonga

71. Lake Papaitonga is the largest lake in Horowhenua that occurs to the west of the Levin Fault. Lake inflow, although it has not been quantified, is likely dominated by groundwater from springs in a series of deeply entrenched gullies in the sandstone terrace on the eastern side of the lake. Diffuse spring discharge may also occur through the bed of the lake. The lake's groundwater capture zone crosses the Ō2NL Project alignment just south of Levin.[10]

Ohau River

72. Seepage losses from the Ohau River, through the bed and banks of the channel, is a major source of surface water recharge to the groundwater system. It directly recharges water-bearing units within the younger alluvium, with groundwater then flowing into the deeper semi-confined and confined aquifers.[11 & 12]

Springs

73. There are numerous springs formed by groundwater discharging to the ground surface (*Figure G.9*).

74. Most of these springs, however, are located a significant distance down-gradient of the Ō2NL Project; which is about half-way between the Tararua Range and the coast.

75. Many of the springs are located within or adjacent to surface drainage features, or along the eastern edges of Lakes Punahau / Horowhenua and

[10] PDP (2017): Coastal lakes groundwater capture zones investigation. Report prepared for Horizons Regional Council. August 2017. Horizons report 2017/EXT/1549.
[11] Zarour, H. (2008). Groundwater resources in the Manawatu–Wanganui Region: technical report to support policy development (2008/EXT/948). Retrieved from Palmerston North, New Zealand.
[12] Gyopari, M. (2005). Horowhenua Lakes: assessment of groundwater – surface water interaction. Report prepared for Horizons Regional Council. Retrieved from Wellington, New Zealand.

Papaitonga. The rest are clustered mainly around Koputaroa Stream (*Figure G.9*).

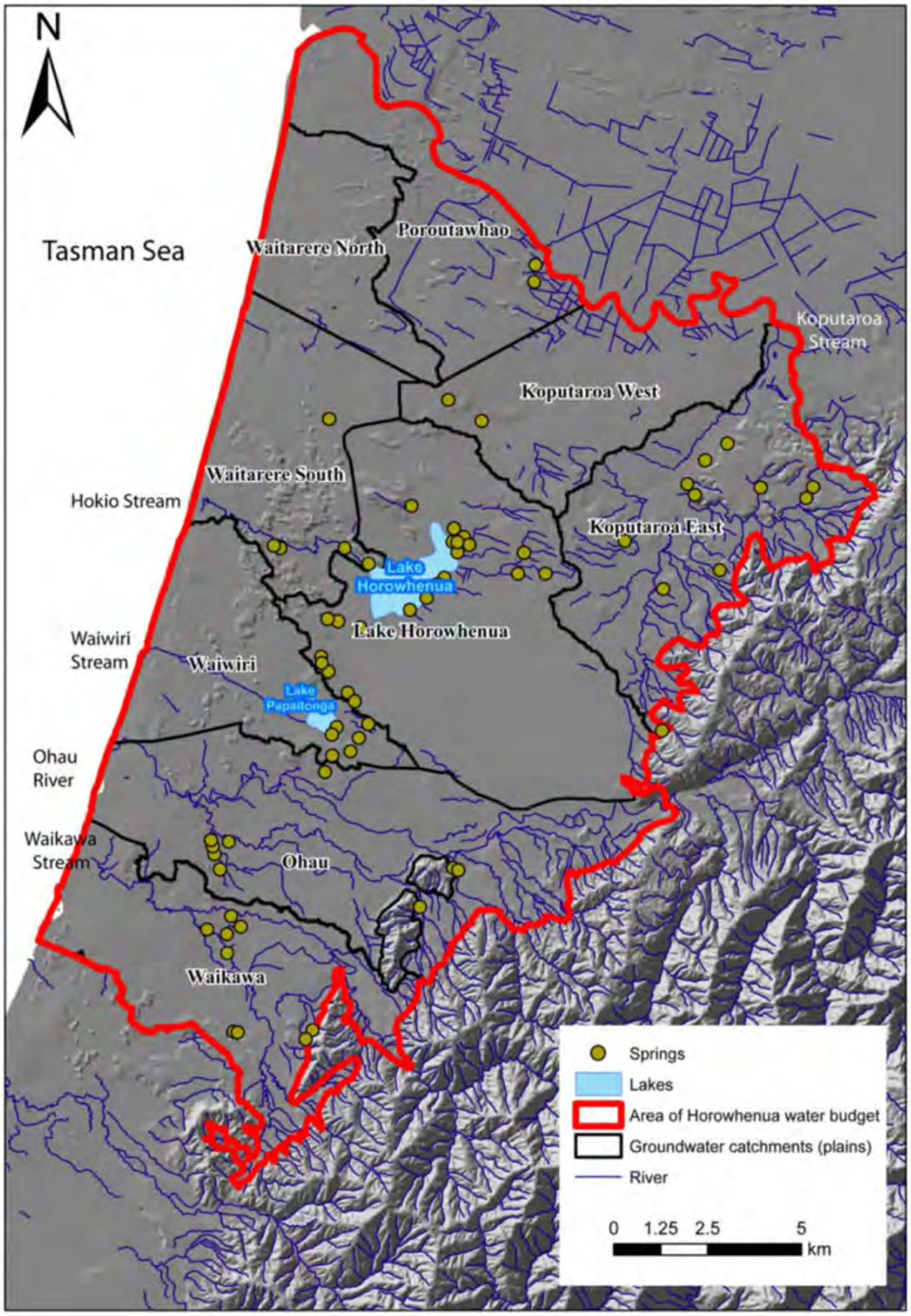

Figure G.9: Springs within the HGMZ. (Source: White *et al.*, 2010)[5]

Existing bores and groundwater abstraction

76. In 2022, there were 986 bores within the HGMZ listed in Horizons' bore database.[13] While the maximum depth is 277.3m, these bores are generally relatively shallow, with a median depth of approximately 20m. The bores are

[13] Data obtained in 2022 from Horizons bore database that is accessible via their online data portal.

generally low yielding (<5L/s) and few have consent to abstract more than $50m^3$/day (0.6L/s).[13]

77. In 2021, there were 46 permitted groundwater abstractions within the HGMZ listed in Horizons' resource consent database.[14] Consented takes were mainly for agriculture irrigation/water supply (62%), horticultural irrigation/water supply (29%) and recreational irrigation/industrial use (9%). Non-consented shallow groundwater, with abstraction under the Horizons One Plan Permitted Activity Rule, is used extensively for domestic and stock water supply.

Groundwater quality

78. The groundwater is generally high in nutrients, and shallow groundwater in unconfined aquifers is prone to microbiological contamination from intensive land uses; particularly those involving animal husbandry.

79. The average nitrate-nitrogen concentration in groundwater is 10.3mg/L,[15] compared to the NZ drinking water standard of 11.3mg/L. The average phosphate concentration is 0.2mg/L. The groundwater is also relatively high in iron and manganese, with average total concentrations of 4.5mg/L and 0.3mg/L respectively.

*Manawatū Groundwater Management Zone ("**MGMZ**")*

80. The Ō2NL Project north of Levin extends into the southern edge of the MGMZ. The MGMZ hosts most of the regions' bores. The groundwater is used extensively for municipal, industrial, agricultural, and domestic water supply. Groundwater flows through a sequence of quaternary sediments towards the coast, with vertical movement limited by interbedded silts and clays. Preferential flow occurs through moderate-high yielding gravel and sand lenses. Beneath and adjacent to the Ō2NL Project, the MGMZ is characterised by shallow groundwater, springs, and wetlands, and the Koputaroa Stream catchment.

*Ōtaki Groundwater Management Zone ("**ŌGMZ**")*

81. The southern end of the Ō2NL Project, where it adjoins the PP2Ō Project, extends into the ŌGMZ. The ŌGMZ has three main aquifers. These include

[14] Data obtained in 2021 from Horizons resource consent database that is accessible via their online data portal.
[15] Data obtained in 2021 from Horizons bore water quality database.

an unconfined aquifer to a depth of 10m, and two semi-confined aquifers. These extend from 10-20m, with the other being deeper than 20m.

82. The unconfined aquifer consists of river gravels, sand and silt overlain by up to four metres of sand, silt and clay deposited during floods in the Ōtaki River. Adjacent to the Ōtaki River, constant reworking of alluvial sediments has resulted in an unconfined, high-yielding riparian aquifer. This is hydraulically connected to the Ōtaki River. Piezometric contours show groundwater within the unconfined aquifer flows northwest towards the coast. The unconfined aquifer is predominantly recharged by losses from the Ōtaki River and land surface recharge from rainfall.

83. The largest surface water features towards the southern end of the Ō2NL Project are the Ōtaki River and Waitohu Stream, approximately 2.3km and 600m south of the Ō2NL Project respectively. Both surface water bodies show significant interaction with the unconfined aquifer, losing water downstream of the Tararua Range and gaining appreciable base flow in their lower reaches near the coast.

Groundwater bores

Community water supplies

84. A search of both the Horizons and GWRC online data portals in September 2021, a review of Schedule M2 – Drinking Groundwater Protection Areas of GWRC's proposed Natural Resources Plan, and a review of information held by ESR (2001),[16] identified three 'community' water supplies in the wider vicinity of the Ō2NL Project (*Table G.2*).

85. Only one of these water supply schemes lies within the proposed designation for the Ō2NL Project ie, the Glenmorgan Water Supply Scheme. The Project passes through the inferred groundwater capture zone of the Tatum Park bores but is significantly north of the Ōtaki bore and its inferred capture zone. The Waitohu catchment also lies between the Project and the capture zone for the Ōtaki bore (*Figure G.10*).

[16] ESR (2021). Drinking-water Register for New Zealand. Retrieved August 29, 2021, from https://www.esr.cri.nz/our-services/consultancy/water-quality-and-sanitation/register-of-suppliers/

Table G.2: Community water supplies in the wider vicinity of the Ō2NL Project.

Regional Council	Groundwater Take Consent	ESR (2001)	Relationship to Ō2NL Project
Horizons	None identified	• Serves the Tatum Park Holiday Conference Centre • Supplies less than 25 persons • Category: Self supplied • Source: G01860 Tatum Park Bore 1 • Source: G01476 Tatum Park Bore 2	The Ō2NL Project crosses the Source Protection Zone 2 marked by Horizons for Tatum Park 1 Bore (Horizons Bore ID – 362101) and Tatum Park 2 Bore (Horizons Bore ID – 362541). Both bores are approximately 700m west of the Project. Source Protection Zone 2 may be affected by microbiological contamination under the existing environment.
Horizons	GWRC consent WGN140067	None. Not listed as a registered supply	Glenmorgan Water Supply Scheme. A community supply to 47 households based on discussions with landowners.
GWRC	None identified	• Population served: Otaki Township • Population size: 5,700 • Category: Networked • Source: G01860 Otaki water supply Tasman Rd Bore	Southern edge of the Project crosses the Source Protection Zone marked by GWRC for Tasman Road Bore (GWRC Bore ID – R25/5235).

Other bores

86. A search of both the Horizon's and GWRC's online data portals in September 2021, identified numerous bores within the three groundwater management zones discussed above; however, most are down-gradient of the Ō2NL Project (*Figure G.11*). There are approximately 34 bores within the proposed Ō2NL Project designation and a further 104 within 250m.

87. It is unknown exactly how many of these bores provide a water supply, either unconsented or under the Permitted Activity Rules of the respective regional councils. However, few of the bores have an associated water permit which is required for any significant groundwater abstraction (*Figure G.12*).

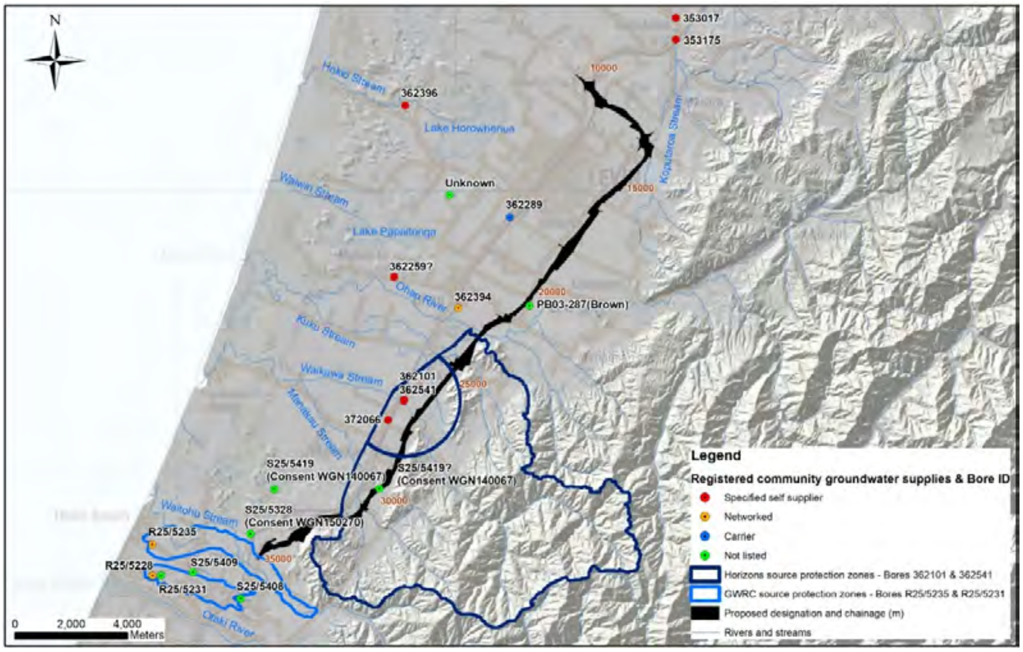

Figure G.10: Community groundwater drinking supplies and source protection zones. (Source: Horizons & GWRC online databases, September 2021)

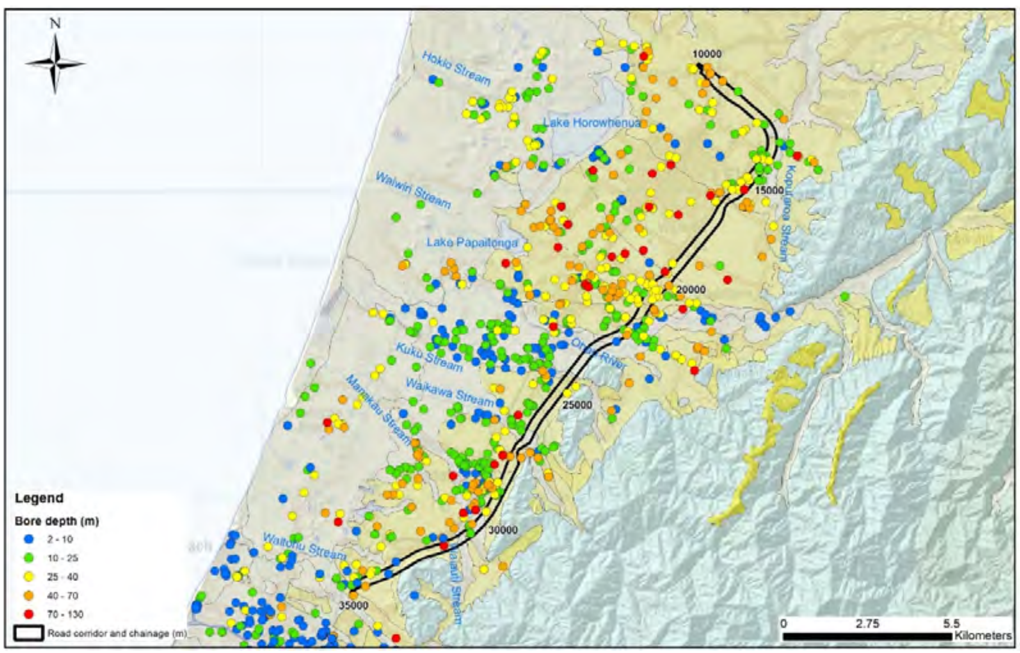

Figure G.11: Bores and their depth throughout the wider area of the Ō2NL Project. Chainages along the proposed highway are indicated. (Source: Horizons & GWRC online databases, September 2021).

88. As of September 2021, there would appear to be only one bore with an existing water permit within the proposed designation (*Figure G.12*). Most bores with water permits are a significant distance from the Ō2NL Project.

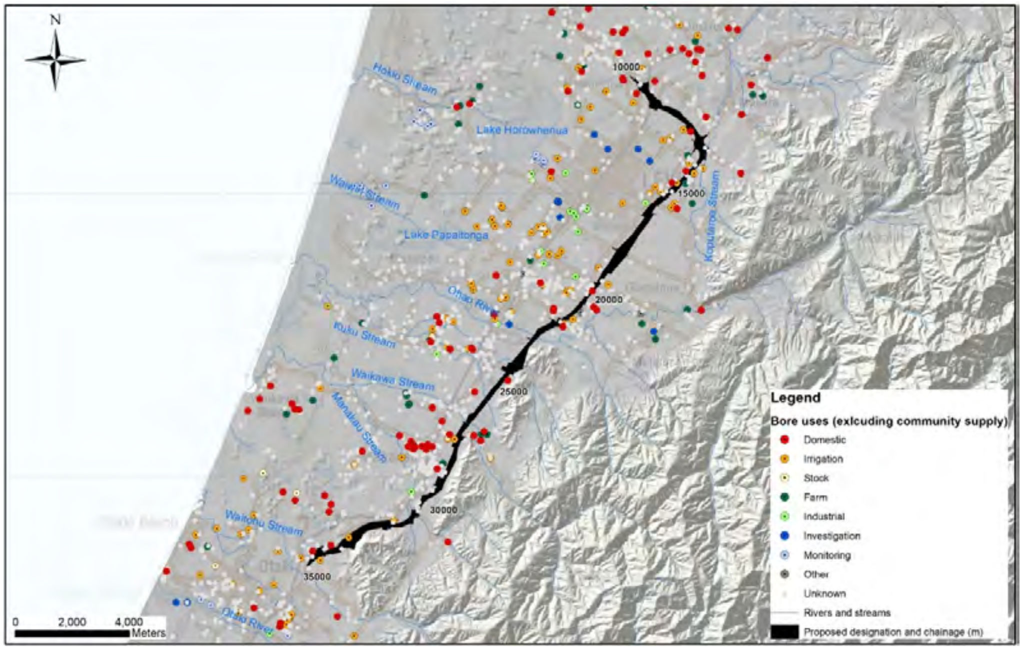

Figure G.12: Consented groundwater abstractions and monitoring bores. Chainages along the proposed highway are indicated. (Source: Horizons & GWRC online databases, September 2021).

METHODOLOGY

89. A comprehensive suite of geotechnical and hydrogeological investigations has been undertaken to support the Ō2NL Project. These investigations commenced in May 2020 and are ongoing. They include 63 boreholes, 77 test pits, 36 CPTs, 58 monitoring bores, 10 hand auger holes, eight slug tests and nine soil infiltration tests (*Appendix G.1*).

90. This information, together with that collected previously by other parties, provides an excellent understanding of the depths to groundwater, groundwater level variation over time, maximum groundwater levels, and the dominant sources of groundwater recharge beneath and adjacent to the Ō2NL Project (*Figure G.13*).

91. Despite the comprehensive and intensive nature of the groundwater investigations undertaken to support the design of the Project, there remains some small residual uncertainty. This is the result of essentially point measurements being extrapolated to the wider groundwater system which exhibits a degree of heterogeneity. This heterogeneity is caused by the range of processes that have affected the hydrogeology (ie, the media containing the groundwater) discussed earlier. This can lead to significant differences in groundwater behaviour over relatively short distances. This small residual uncertainty, however, will be reduced as further investigations

are undertaken, additional data collected, and the design of the Project refined.

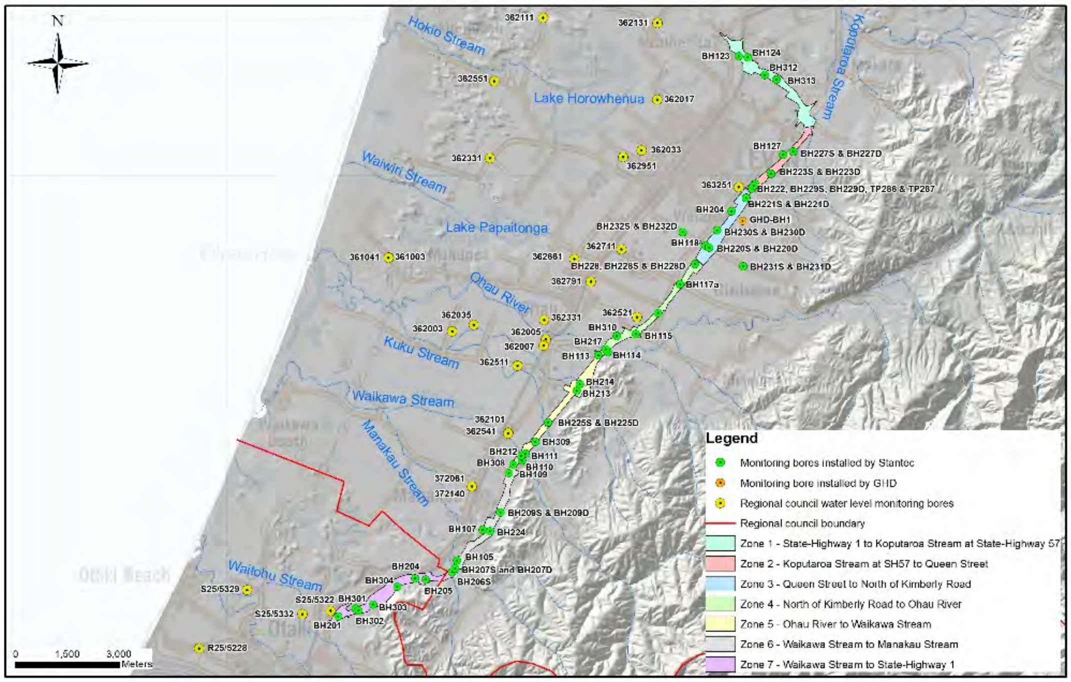

Figure G.13: Groundwater level monitoring bores used to inform the design of the Ō2NL Project. (Source: Horizons & GWRC databases, September 2021 and Project files).

92. Twelve pairs of nested monitoring bores were installed to compare the groundwater levels in both shallow and deep bores at a single location. Most bores were constructed of PN12, 32mm diameter uPVC with 0.5mm diameter slotted screens. A few were also constructed of PN12 50mm diameter uPVC. Details of the bores, test pits and CPTs are provided in *Appendix G.1*.

93. Groundwater levels were recorded from boreholes during drilling, test pits, CPT tests and the 58 monitoring bores. Manual groundwater level readings were taken from each monitoring bore at weekly to bi-monthly intervals using an electronic dip meter. Non-vented pressure transducers (compensated for changes in barometric pressure) recording water levels at 30-minute intervals were installed in 37 of the 58 monitoring bores.

Groundwater levels

Spatial patterns and trends

94. The initial static groundwater level recorded from bores listed on the regional council databases and the highest groundwater level observed from shallow

Ō2NL Project monitoring bores (<≈15m deep), test pits (<5m deep), and shallow CPT holes (<≈15m deep) between December 2020 and September 2021 are shown in *Figure G.14*.

95. *Figure G.15* shows the highest and lowest observed groundwater levels along a section described above.

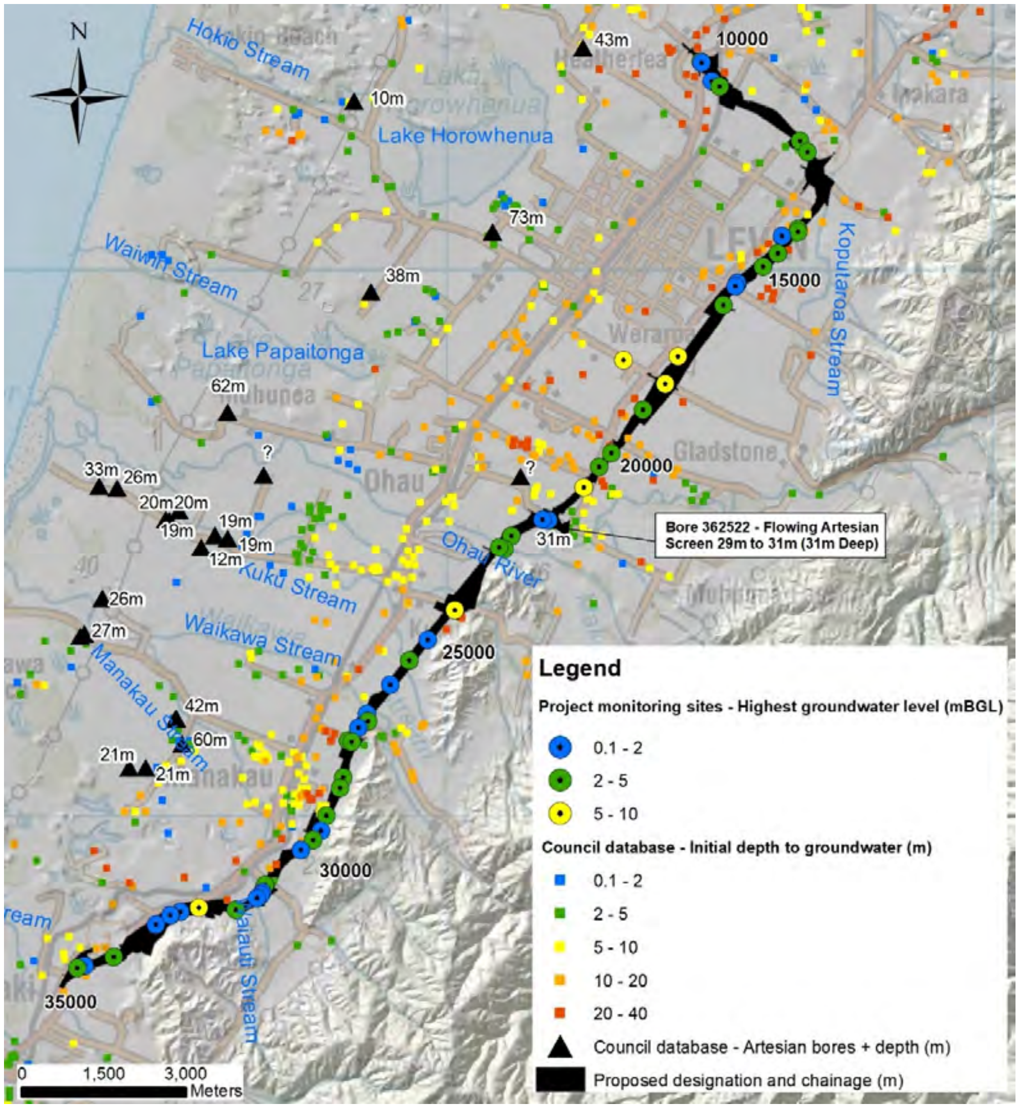

Figure G.14: Initial static groundwater level from the regional councils' bore databases and highest groundwater level measured in shallow monitoring bores, test pits and CPTs installed for the Ō2NL Project. Chainages along the proposed highway are indicated.

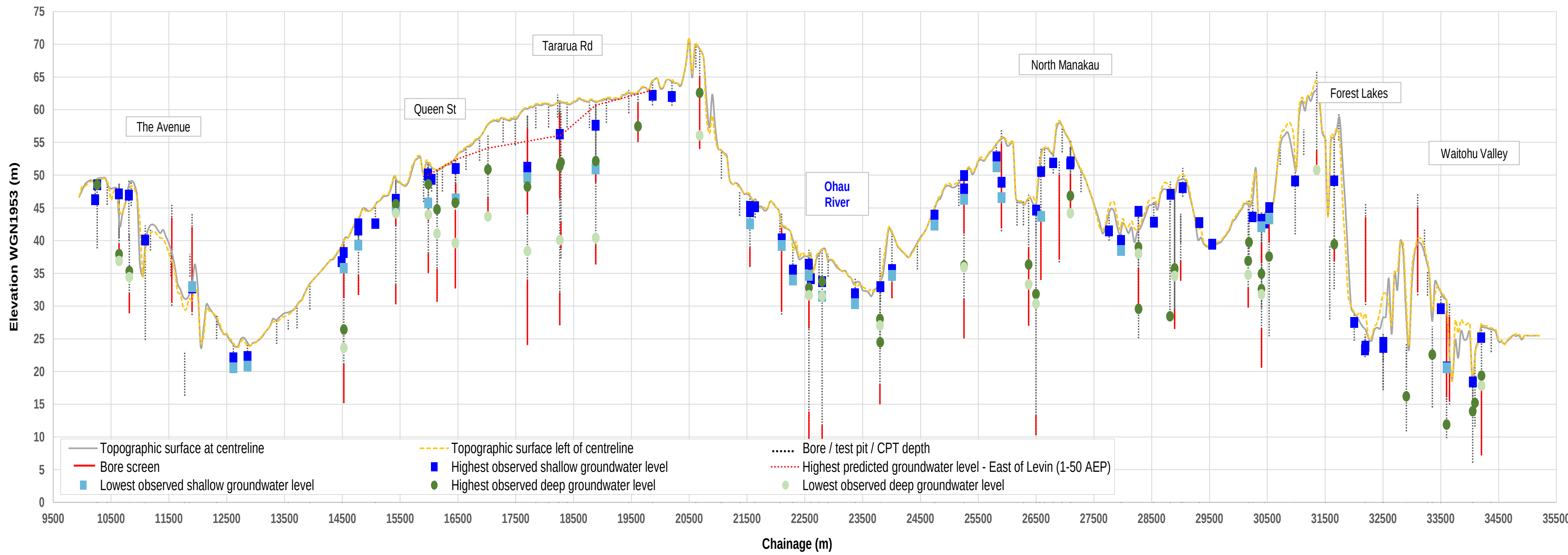

Figure G.15: Section showing the observed groundwater levels from the Project monitoring bores, test pits and CPT holes as well as the highest predicted groundwater level east of Levin.

96. Key observations are:

(a) Bores and CPTs deeper than approximately 15m generally have groundwater levels at least 15m deeper than the shallower bores and CPTs. This difference in groundwater pressures is also shown in many of the nested monitoring bores. The groundwater levels in the deeper bores are at times more than 5m lower (*Appendix G.1*). This results in a positive vertical hydraulic gradient with groundwater flowing from the surface and unconfined aquifers to deeper and more confined aquifers beneath most of the Ō2NL Project. These conditions are not unexpected given the location of the Ō2NL Project towards the Tararua Range which is the assumed principal recharge zone. The variation in groundwater levels with depth reflects the high level of hydrogeologic stratification and numerous discontinuous lower permeability layers of fine sand, silt and clay which restrict the vertical movement of groundwater *(Figure G.16*).

(b) The groundwater levels in the Ō2NL Project monitoring bores, especially those less than 15m deep, are generally higher than the initial static water levels recorded in bores listed in the regional council databases. This is most noticeable east of Levin and south of Waikawa Stream. This may be because well drillers preferentially target deeper groundwater for higher yields and better-quality water. Monitoring of the bores installed for the Ō2NL Project has also so far been restricted largely to winter conditions when higher groundwater levels would be expected. Dryer conditions with lower groundwater levels were recorded over the 2021-22 summer.

(c) The thickest unsaturated zone, 5-10m, and greatest variability in groundwater level is observed east of Levin. The high degree of variability may be at least partly caused by the lack of surface water features. This allows a greater proportion of rainfall to drain through the soil causing rapid groundwater recharge. Other contributing factors may include recharge from streams draining the Tararua Range, distance from the Ohau River, and aquifer hydraulic properties. The thicker unsaturated zone allows greater fluctuations in the groundwater level because of the greater potential storage to hold groundwater when additional water is available, from either rainfall or higher streamflows. The steeper hydraulic gradient, and generally coarser aquifer media, in this location also allow faster drainage during periods when there is no recharge. This then provides greater storage when the next recharge event occurs.

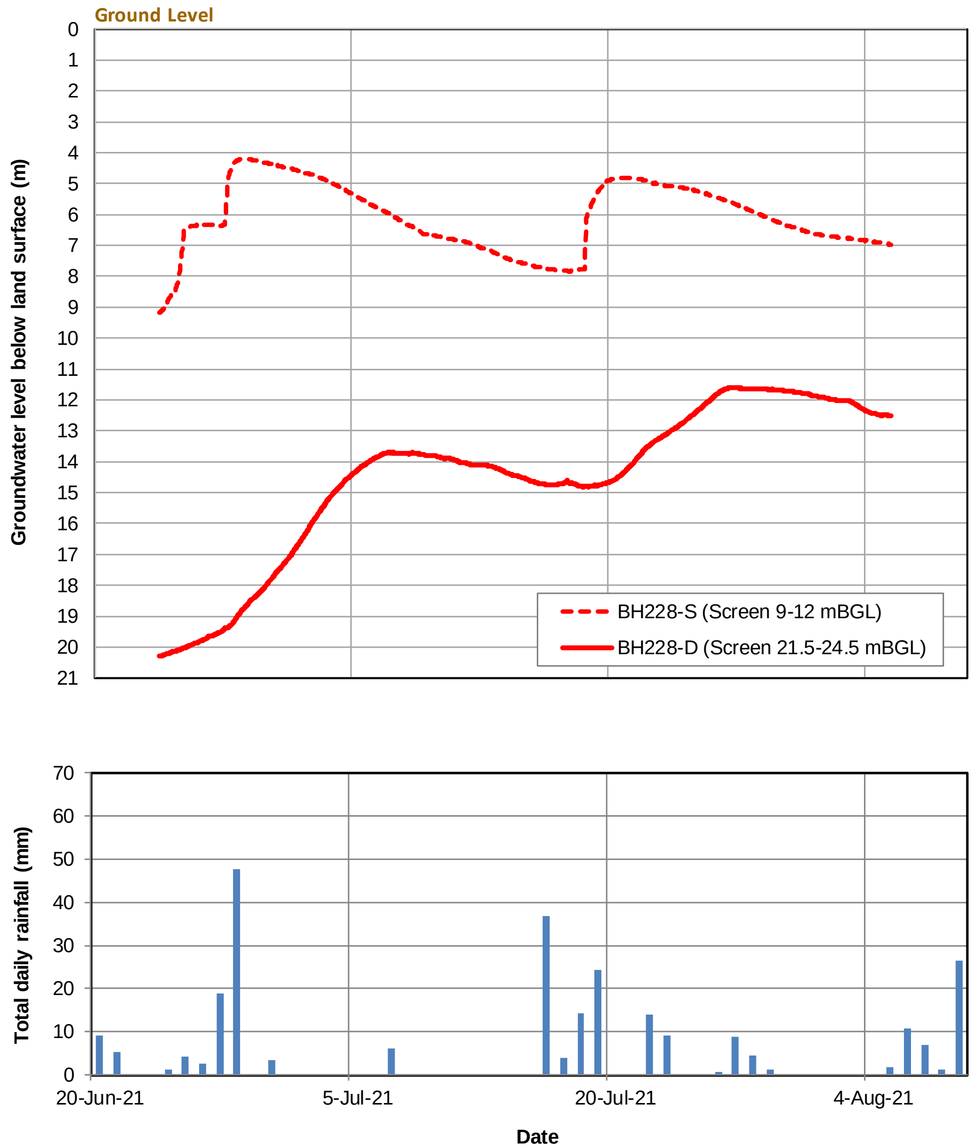

Figure G.16: Variation in groundwater levels in shallow and deep nested piezometers south of Levin.

(d) Flowing artesian groundwater is reported in the Horizons bore database in a 31m deep bore (ID 362522) screened from 29-31m adjacent to the Ō2NL Project (*Figure G.14*). This bore is located on the south-eastern edge of the Project designation and approximately 500m north of the Ohau River. The bore was drilled in 1981 and recorded an initial depth to water of 0.8m on 9/12/1981, suggesting approximately 0.8m artesian head.

The behaviour of bore 362522 appears to be unique in this area as an adjacent bore, drilled for the Project, has not exhibited artesian flow.

The unique behaviour may relate to a direct hydraulic connection between the Ohau River and the aquifer tapped by this bore. It is likely that a paleochannel of the Ohau River exists in this area that extends, from where the river leaves its greywacke confined channel, in a northwest direction towards Punahau / Lake Horowhenua. This provides a preferential flow path for water from the river. This hydraulic connection appears to operate most effectively when the water level in the Ohau River is higher during moderate or larger flood events.

No flowing artesian groundwater has been encountered to date in any of the monitoring bores established for the Project. These range in depth from 2-35m below the ground surface.

(e) The water table, ie, the top of the unconfined aquifer, follows the topography very closely. However, this relationship is not so clear within the deeper groundwater which does not appear to mimic the topography. This is likely because the deeper groundwater mimics the topographic surface that existed at the time those water-bearing units were deposited, rather than the current ground surface.

(f) *Figure G.15* shows where the water table may intercept the ground surface beneath the Ō2NL Project based on the available monitoring data. Where the groundwater intercepts the surface, there may be seepages, springs and discharge into the rivers and streams.

(g) *Figure G.15* also shows the highest predicted groundwater level east of Levin. The predictions suggest there may be only 2-4m of permanently unsaturated material beneath sections of the Ō2NL Project east of Levin.

Groundwater variation over time

97. As well as varying spatially as discussed above, the groundwater level also varies temporally in response to the balance between inflows and outflows from the groundwater system. During periods of recharge, when there is net inflow of water to the groundwater system, groundwater levels rise. When discharge from the system exceeds the recharge, groundwater levels decrease.

98. Because of this, there is a strong relationship between groundwater levels and rainfall and flow in the various rivers and streams. However, rainfall also

affects the flow in rivers and streams so these are not two independent controls (*Figure G.17* & *Figure G.18*).

99. There is a stronger correlation between groundwater levels and prolonged periods of rainfall than with the amount of rainfall during individual rainstorms (*Figure G.17*). Wetter antecedent conditions also appear to stimulate a greater response in groundwater levels, ie, there are likely to be less losses to soil moisture and other storages and therefore more water is available to recharge the groundwater.

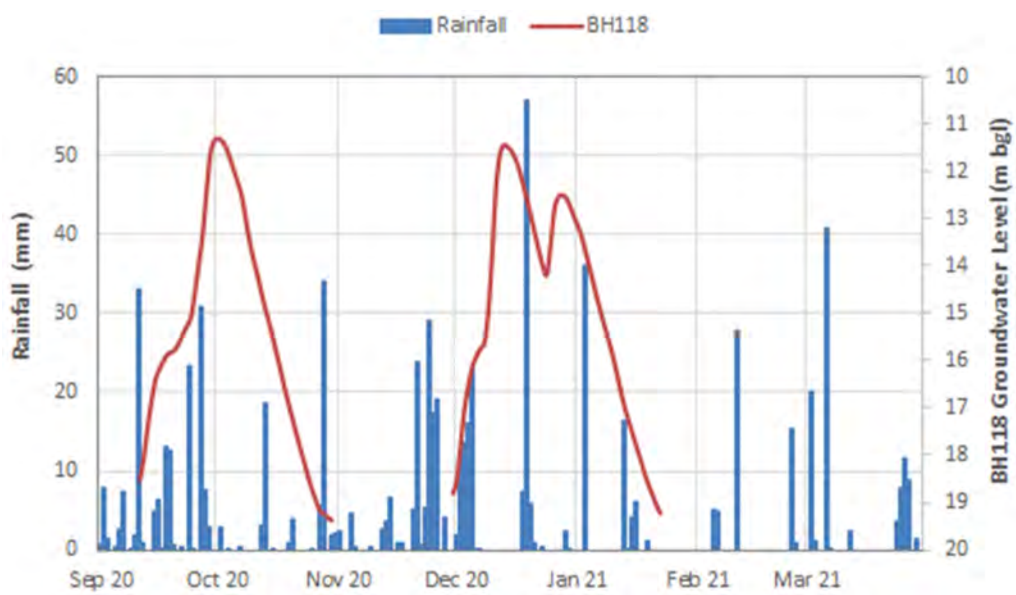

Figure G.17: Relationship between rainfall and groundwater level.

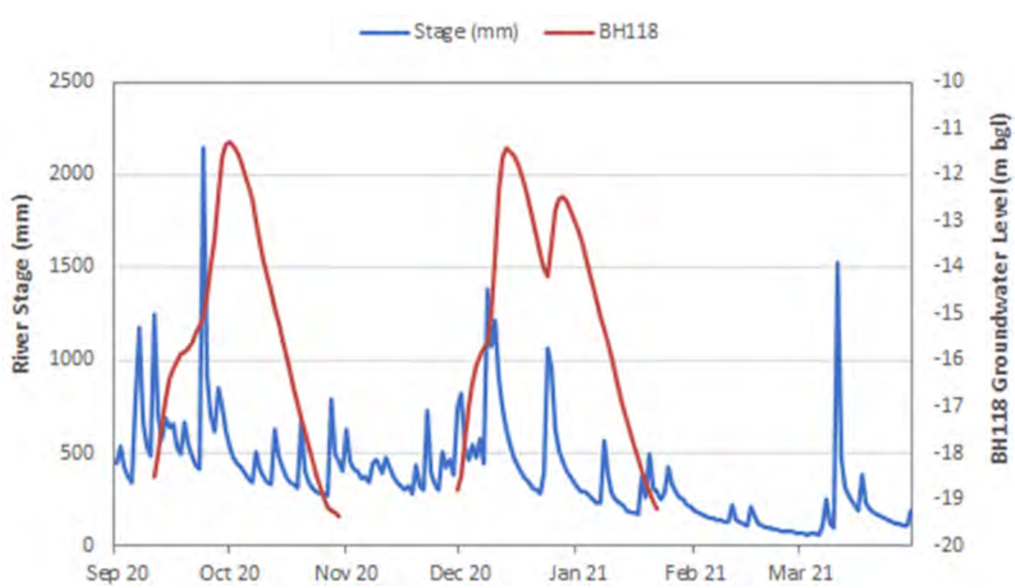

Figure G.18: Relationship between river level (ie, stage) and groundwater level.

100. Groundwater levels also appear to respond more to sustained periods of higher flows in rivers and streams, and particularly to flows above what appears to be a threshold level in the Ohau River. This is likely to result from the hydraulic conductivity of the water-bearing units, which tends to slow and lag any response to river conditions observed in the bores. It is also likely to be a function of the elevation of the hydraulic connection between the Ohau River and Bore 118 that intersects the paleochannel that now forms the water-bearing unit described earlier (*Figure G.19*).

Figure G.19: Potential hydraulic connection between a paleochannel that now forms the water-bearing unit intersected by BH118 and the contemporary channel of the Ohau River, indicated by the line of vegetation 1-2m above the baseflow water level.

101. The groundwater monitoring data indicates that:

(a) The highest groundwater level recorded by any bore was 0.3m below the ground surface. This was adjacent to Manakau Stream. In general, the highest groundwater levels ranged from 0.5m to 2m below the ground surface in areas near Queen Street (east of Levin), east of Manakau Township, and adjacent to Manakau Stream;

(b) There was no flowing artesian groundwater in any of the Ō2NL Project monitoring bores, test pits, or CPT holes.

(c) The lowest groundwater levels and the greatest groundwater level variation were observed east of Levin, from south of Queen Street to McLeavy Road;

(d) Larger groundwater water level variations were observed in bores screened at depths greater than 10-15m;

(e) The groundwater levels in bores adjacent to the Ohau River respond to changes in river flow (ie, water level) for the reason described above;

(f) Flows in Kuku, Waikawa and Manakau Streams may affect, or be affected by, the adjacent groundwater depending on the reach and the hydraulic gradient between the river and the groundwater; and

(g) There is a lag in the response of groundwater levels to rainfall recharge that ranges from hours up to ten days in some deeper bores. Some deeper bores east of Levin respond up to two days after the shallower bores at the same location. Despite the differences in lag times, the deep and shallow bores follow a very similar trend (*Figure G.16*). This indicates that at least most of groundwater beneath the piedmont plain is acting as a single interconnected and interacting system.

Groundwater level modelling

102. Despite the comprehensive investigations undertaken for the Ō2NL Project, understanding the dynamics of the groundwater system, particularly its behaviour under more extreme conditions, is constrained by the limited availability of temporal data. Groundwater level data from most bores along the potential corridor of the Ō2NL highway, despite being recorded at 30-min intervals, cover less than a 3-year period. Longer term data from other bores, generally monitoring bores used by Horizons, however, have lower temporal resolution; with only occasional readings at 1-2 month intervals.

103. Even over the relatively short period for which groundwater levels have been monitored, the bores east of Levin showed some of the largest seasonal variability along the alignment of the Ō2NL Project. Depending on bore depth and location, the static groundwater levels of these bores vary from 2.8m to more than 20m below the ground surface. Groundwater levels in some deeper bores varied by more than 9m and rose rapidly after high rainfall events during winter.

104. To inform the detailed design of the Ō2NL Project, particularly to the east of Levin where several deep cuts were initially proposed, it was necessary to quantify the inherent variability of the groundwater. Of particular interest is the highest level that groundwater, and therefore the saturated zone, might attain over the life of the Ō2NL Project, ie, 100-years.

105. Consequently, a long-term simulation of groundwater levels at five bores east of Levin (*Figure G.20*) was developed using an Eigen model,[17] coupled with a soil moisture balance model (SMB). The sole source of recharge driving the groundwater level response predicted by the Eigen model was land surface recharge (LSR) obtained from the SMB. The SMB used total daily rainfall and evapotranspiration (Penman-Monteith) from a NIWA Virtual Climate Station (VCS) at Levin. The modelling and calibration are discussed in detail in *Appendix G.1*.

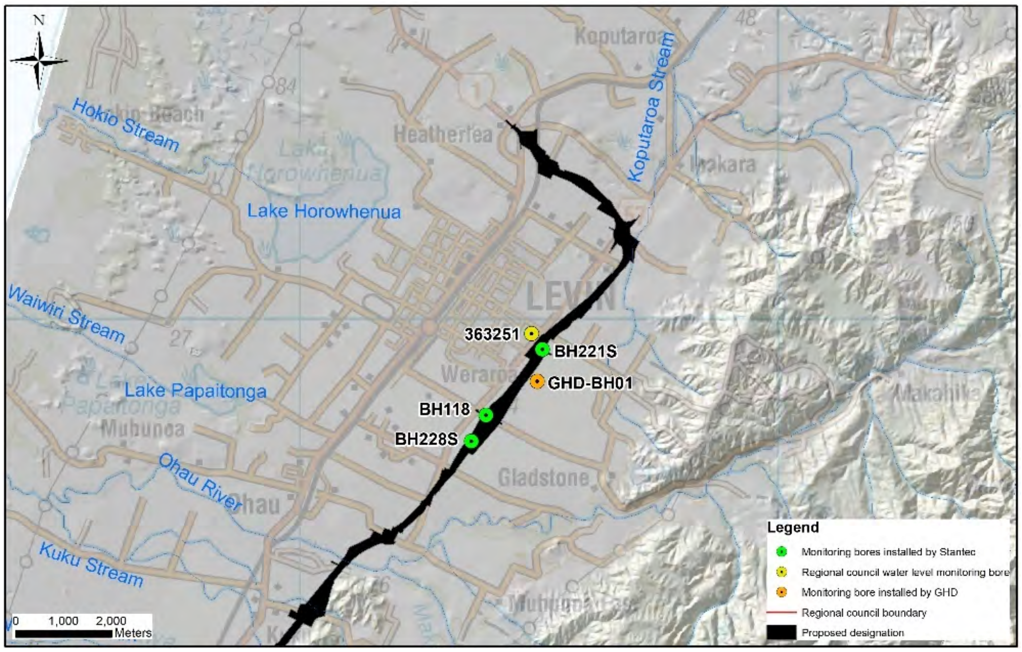

Figure G.20: Location of the five bores, east of Levin, for which Eigen models of the groundwater level were developed.

106. An example of the calibration of the Eigen model against measured groundwater levels in a bore where the Ō2NL Project would intersect Tararua Road is provided in *Figure G.21*. It is apparent that the model, following calibration, provides a good simulation of the recorded groundwater levels.

[17] Bidwell, V. (2003). Realistic forecasting of groundwater level, based on the eigenstructure of aquifer dynamics. In D. A. Post (Ed.), MODSIM 2003 International Congress on Modelling and Simulation, Townsville, 14-17 July 2003. Modelling and Simulation Society of Australia and New Zealand.

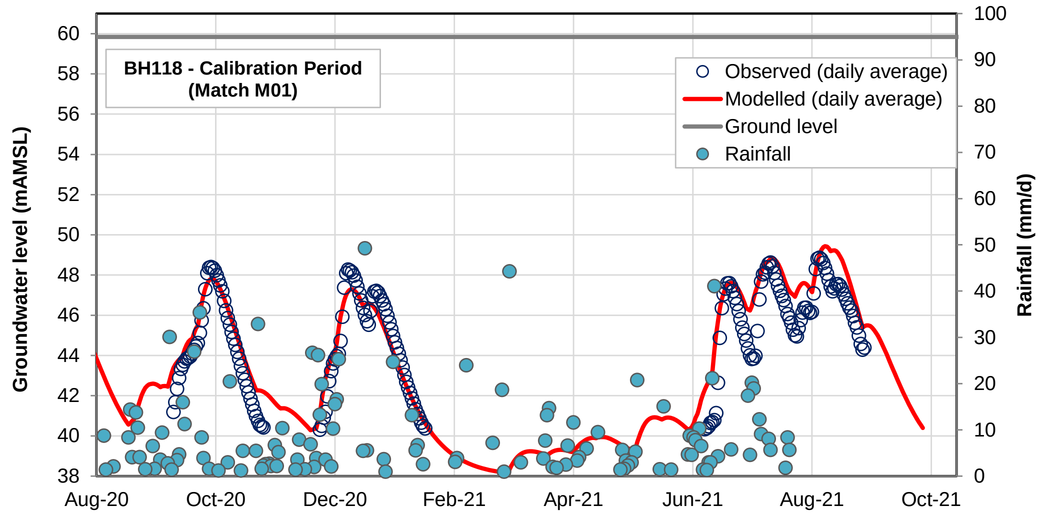

Figure G.21: Calibration of the Eigen model for a bore (BH118) near where the Ō2NL Project would intersect Tararua Road.

107. The calibrated SMB and Eigen models were used to predict the average groundwater level in the bores each day since 31 December 1971. The predictions therefore cover a period of approximately 49 years (*Figure G.22*).

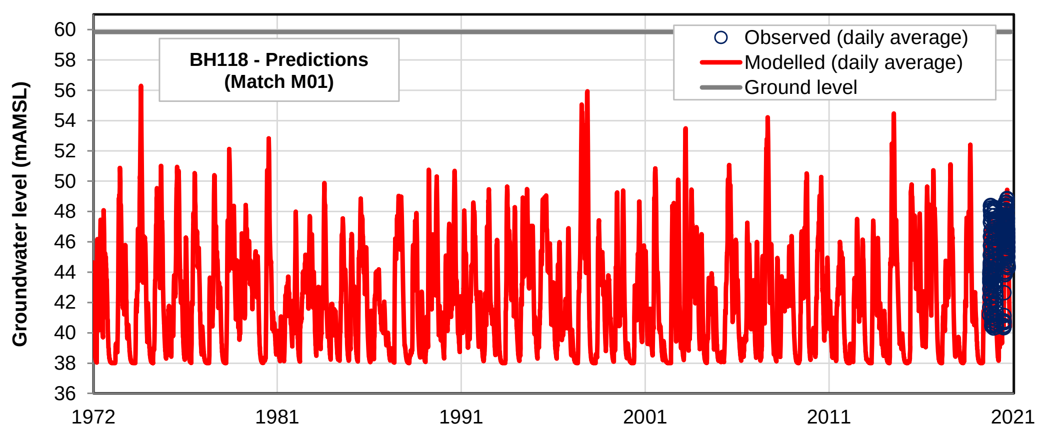

Figure G.22: Groundwater level predictions using the calibrated Eigen model for a bore (BH118) near where the Ō2NL Project would intersect Tararua Road.

108. The results of the groundwater level modelling show two periods of high groundwater levels, in 1974 and 1998. Two smaller peaks are predicted in 2008 and 2015. The peak groundwater level during these events lasted from one to three weeks and coincided with periods of flooding reported in Levin. This provides anecdotal validation of the modelling as flooding is likely to be associated with higher groundwater levels. The model predictions suggest that groundwater levels measured over the winter of 2021 were likely to have been 'average to high'.

109. In general, groundwater is deepest near Tararua Road (BH118), becoming shallower both north towards Queen Street (GHD-BH01 & BH221S) and south towards the Ohau River (BH228S).

110. Despite being synthetic data series, since the models calibrate well, the results provide a good basis for estimating a range of design groundwater levels.

111. Using the annual minima (shortest distance from the ground surface to groundwater) from the 50-years of simulated groundwater levels in four bores, which approximate a PE3 statistical distribution, the maximum groundwater levels during 2% AEP (50-year ARI) and 1% AEP (100-year ARI) design events were estimated (*Table G.3*).

112. It appears that the maximum groundwater levels simulated for the past 50-years are very close to those that might be expected during extremely wet conditions. The highest groundwater levels from the simulation are closer to the ground surface than would be expected during a 2% AEP event and are less than half a metre lower than what would be expected to occur during the 1% AEP event. Consequently, despite the relatively short groundwater levels available currently, it is possible to have confidence in the more extreme groundwater scenarios developed and how they may interact with the Project.

Table G.3: Maximum predicted groundwater levels (mBGL) in four bores during two design events.

Scenario	BH228S	BH221	GHD-BH01	BH118
Maximum simulated	0.24	0.62	4.43	2.31
2% AEP event	0.49	0.87	4.68	2.90
1% AEP event	0.00	0.52	4.21	1.79

Groundwater/surface water interaction

113. As described above, there is a strong hydraulic connection and interaction between the surface water and groundwater within the Ō2NL Project area. The nature of any interaction depends on the surface topography, the depth to groundwater, the hydrogeology, and the hydraulic gradient between the surface water and groundwater. Any interaction, however, can also be variable through both space and time.

114. Since rainfall and surface water features provide recharge of the groundwater system, *Figure G.23* shows the potential interaction of the Ō2NL Project with the groundwater capture zones for Punahau / Lake Horowhenua and Lake Papaitonga, and the Te Hakari wetland. These capture zones are based on PDP (2017 & 2019).[18 & 19]

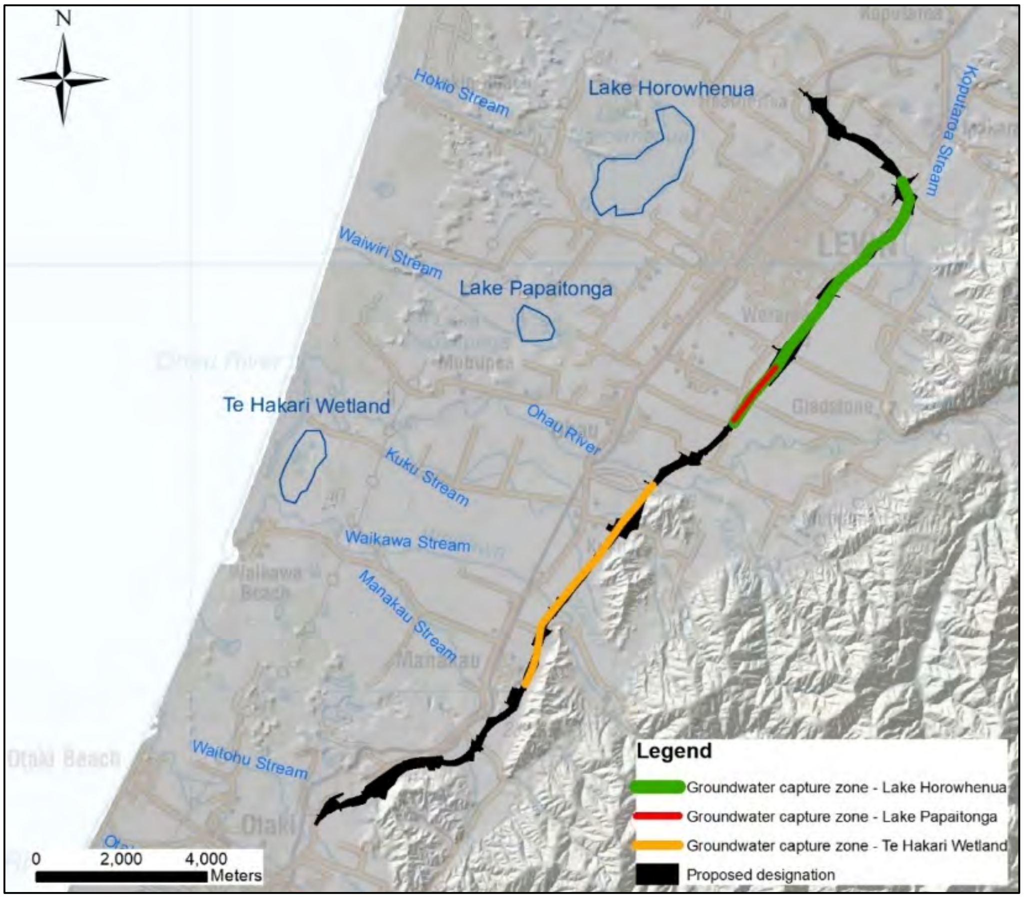

Figure G.23: Lakes and wetlands with groundwater capture zones intersecting the Project.

115. Using the groundwater levels collected to inform the Project, together with the results from the groundwater modelling, a longitudinal section was developed which shows the inferred maximum and minimum groundwater levels, relative to the existing ground surface, along the proposed Ō2NL highway (*Figure G.24*).

[18] PDP (2017). Coastal Lakes Groundwater Capture Zones Investigation. Prepared for Horizons Regional Council. August 2017. Horizons Report 2017/EXT/1549.
[19] PDP (2019). Lake Horowhenua Water Balance Assessment and Quantification of Uncertainties – 2019 Update. Prepared for Horizons Regional Council. October 2019.

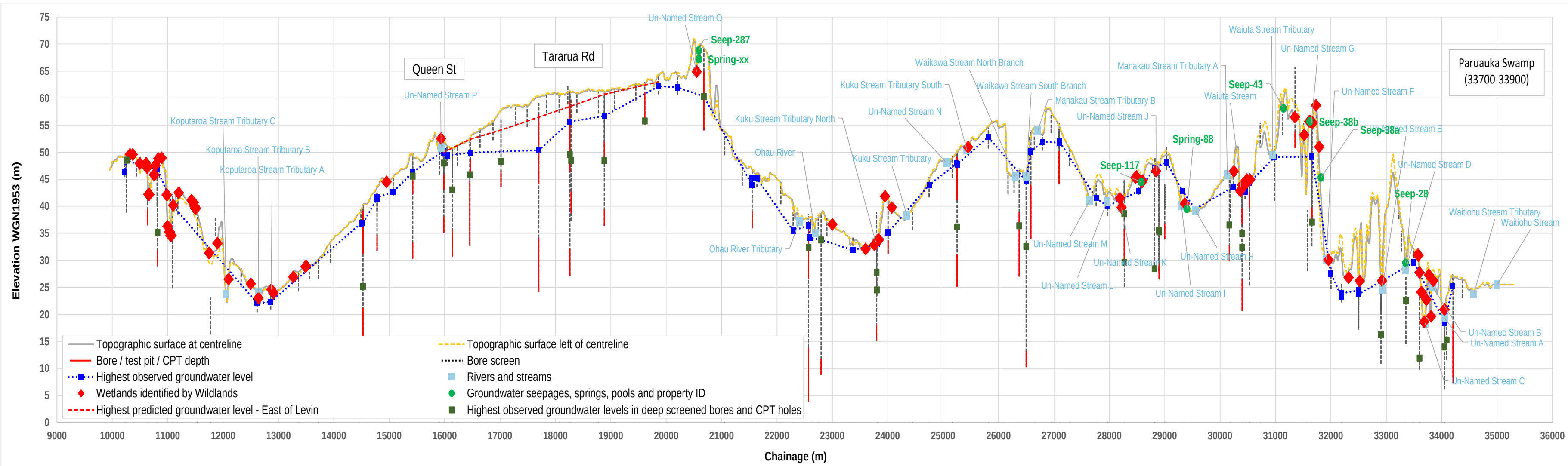

Figure G.24: **Section showing both the measured and modelled groundwater levels as well as surface rivers, streams, wetlands, springs, and groundwater seepages identified within the proposed designation.**

116. Along most of the proposed alignment, the maximum groundwater level remains below the ground surface. However, there are a few locations where maximum groundwater levels would appear to approach the ground surface and a small number where the groundwater may potentially intersect the ground surface.

117. Potential groundwater interaction with surface water features along the Ō2NL Project corridor is indicated by:

(a) The water table being close to the ground surface in topographic depressions containing streams and the Ohau River, and larger ephemeral drainage lines across the piedmont plain. This is a common characteristic of groundwater-fed streams and rivers, or where changes in groundwater levels effect the rate at which a stream or river loses or gains flow from the adjacent groundwater system;

(b) A high water table is associated with a number or springs and wetlands;

(c) The high water table north of Levin intersects the bed of several tributaries flowing into Koputaroa Stream;

(d) The water table appears slightly lower than the water level in the Ohau River suggesting that the river over the reach where it crosses the Ō2NL Project is losing flow to the groundwater system; and

(e) Further south, where Kuku, Waikawa and Manakau Streams cross the Ō2NL Project, the water table is at approximately the same elevation as the ground. It is therefore likely that these streams also lose flow to groundwater over the reach which crosses the Ō2NL Project. It is also possible that these streams may either gain or lose flow to groundwater depending on the hydraulic gradient between the streams and the groundwater. The hydraulic gradient will change in magnitude, and potentially direction, depending on conditions in both the groundwater system and the stream.

118. While the high groundwater levels coincide with some of the ‘wetlands’ identified in Technical Assessment J (Terrestrial Ecology), there are many locations where the ‘wetlands’ are significantly above the maximum groundwater levels; either recorded or predicted. It is therefore likely that only some of the ‘wetlands’ identified are supported by groundwater. The remaining wetlands are in topographic depressions and supported by

hydrological processes operating at the ground surface rather than the groundwater system. The potential sources of water supporting the wetlands, their classification, and the sensitivity of the wetlands to the effects of the Project are discussed later In this assessment in the section on 'Assessment of Effects'.

Springs and Wetlands

119. Numerous springs and wetlands have been identified, both from the field investigations and anecdotal comments provided by Ō2NL Project partners (*Figure G.25*). Most are towards the northern and southern ends of the Ō2NL Project. This is because of the relatively lower topography, higher water table, and the impeded surface drainage caused by the lower permeability soils in these areas.

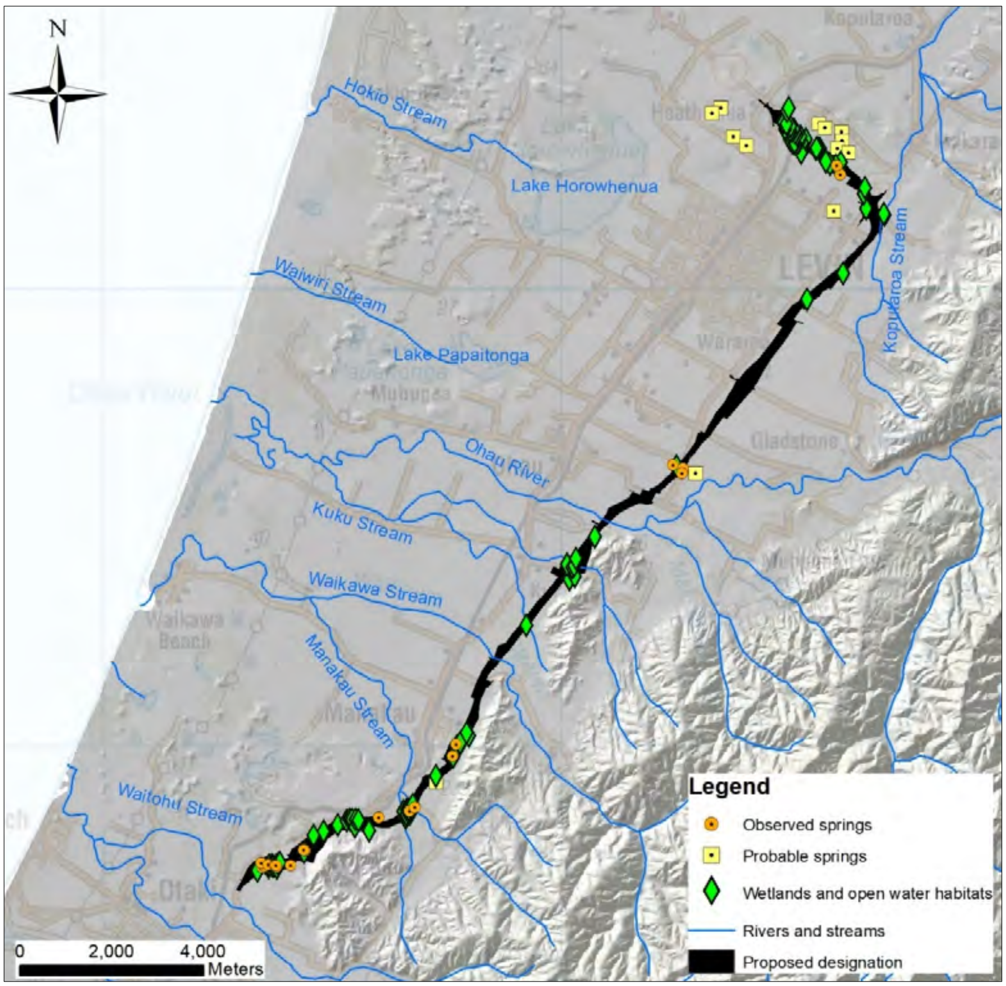

Figure G.25: Springs and wetlands within and near the Ō2NL Project corridor.

120. Springs and seepages are not confined solely to low-lying valley floors. They also occur at the base of terraces and on hillslopes where either:

(a) A water-bearing unit crops out, allowing the water to flow from the unit onto the ground surface; or

(b) Where the vertical movement of groundwater is restricted by a unit of lower permeability which forces the groundwater to move laterally.

121. The hillslope seepages are generally areas of saturated ground rather than the sources of concentrated groundwater flow. A cluster of these seepages is approximately 500m north of the Ohau River. Additional seepages occur towards the northern and southern ends of the Ō2NL Project for the reason discussed above.

Groundwater dependent ecosystems

122. Some areas of wetland, open water habitat, and forest exist within the indicative Ō2NL Project construction footprint that may be adapted to, and supported by groundwater; at least at some times during the year. This includes approximately 3.81ha of low to high ecological value wetlands (0.61ha of indigenous wetlands, 0.8ha of mixed indigenous wetlands, and 2.06ha of exotic-dominated wetlands and 0.34ha of open water habitat), as well as 3.25ha of indigenous forest. Combined, this represents about 2% of the total indicative Ō2NL Project construction footprint. Further information is provided in Technical Assessment J (Terrestrial Ecology). The vulnerability of these areas to activities associated with the Project is discussed later in the section on 'Assessment of Effects'.

123. Wetland habitats within the indicative Ō2NL Project construction footprint consist primarily of swamps on valley floors which are intermittently to permanently wet. These wetlands are locally common, generally small and degraded, grazed, and dominated by exotic herbs and grasses. There are also smaller areas of 'oxbow wetlands' associated with meandering streams, and two hillslope seepage wetlands fed by groundwater.

Summary

124. The groundwater investigations have therefore identified several potential constraints that inform the design of the Ō2NL Project. Recognising these constraints allows the Ō2NL Project to avoid, wherever practical, adverse effects on the groundwater, both its quantity and quality, while at the same time maximising a range of potential benefits to the groundwater system (ie, both quantity and quality).

ASSESSMENT OF ENVIRONMENTAL EFFECTS ON GROUNDWATER

125. As discussed above, through the partnership process several overarching principles were developed to guide the design and construction of the Ō2NL Project. To support the Ō2NL Project meet these aspirations, several hydrological and hydrogeological principles were also developed. These include:

(a) Maintaining the existing water balance ie, the input, output and storage of water;

(b) Avoiding any direct interaction with the groundwater system, where practical;

(c) Maintaining existing hydraulic connections in both surface water and groundwater;

(d) Maintaining, and where practical, enhancing the existing hydraulic connections between surface water and groundwater;

(e) Improving the quality of groundwater, where practical; and

(f) Maintaining, and where practical, improving the quality and quantity of groundwater to Punahau / Lake Horowhenua.

126. The comprehensive and detailed groundwater investigations and results summarised above, and described in detail in *Appendix G.1*, have allowed these principles to be incorporated into the design and construction of the Ō2NL Project.

Catchment-scale groundwater model

127. There is currently no robust, calibrated, high-resolution, ‘catchment-scale’, groundwater model of the area traversed by the Project. The only models that exist focus on specific issues such as the likely water balance of Punahau / Lake Horowhenua.

128. Given the extent of the Project and the small proportion of this area that will be affected (ie, the footprint is only 1.3% of the piedmont plain traversed and significantly less if the upper catchments are included), in my opinion it would be both unrealistic and impossible to develop and calibrate a groundwater model that would allow the effects of the Project to be quantified.

129. Furthermore, and as stated previously, the Project will have no effect on the water balance of the area and no measurable effect on the net recharge to

groundwater. The Project involves neither the active abstraction nor recharge of groundwater. The same rainfall-runoff processes will continue to operate throughout the wider area, except for under the immediate footprint of the proposed highway. Rainfall that would have fallen on 'pasture' and then infiltrated and percolated to groundwater will be directed into swales and treatment devices adjacent to the proposed highway. Any difference to the rate / volume of infiltration will be negligible adjacent to the highway and zero beyond the designation. Consequently, it would be impossible to develop and calibrate a catchment-scale model with the resolution necessary to detect/quantify any effect of the Project. In my opinion, there will be no catchment-scale effects to model.

130. The only situations where the Project has any potential to affect groundwater relate to mounding under and adjacent to the stormwater treatment wetlands during extreme rainfall events and the excavation of cuttings below the water table. Both of these situations are examined in detail in *Appendices G.1.G & I*. These analyses show that any actual and potential effects can be considered, in my opinion, '*less than minor'*.

131. In summary, given the scale of any potential effects of the Project, the development of a catchment-scale model is not warranted. No catchment-scale groundwater model would be able to detect the *'less than minor'* affects that might eventuate from the Project.

Avoiding adverse environmental effects

132. The avoidance of adverse effects of the Ō2NL Project on groundwater has been an iterative process. The alignment proposed has been designed to avoid, and where this has not been possible, minimise any adverse effects on groundwater. At the same time, opportunities have been sought to enhance groundwater where practical.

Indicative alignment

133. The development of a potential design for the Ō2NL highway has been an iterative process involving the wider Project team, partners, and stakeholders. While the design is likely to change to some extent prior to construction, the indicative design is presented in *Figure G.26*.

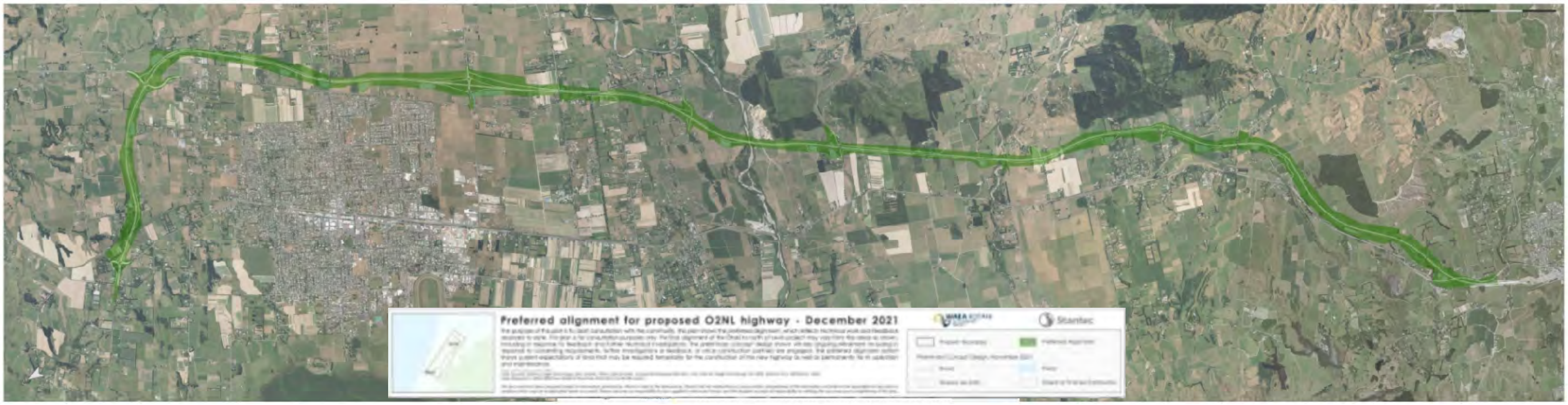

Figure G.26: Lateral alignment of the proposed Ō2NL Highway.

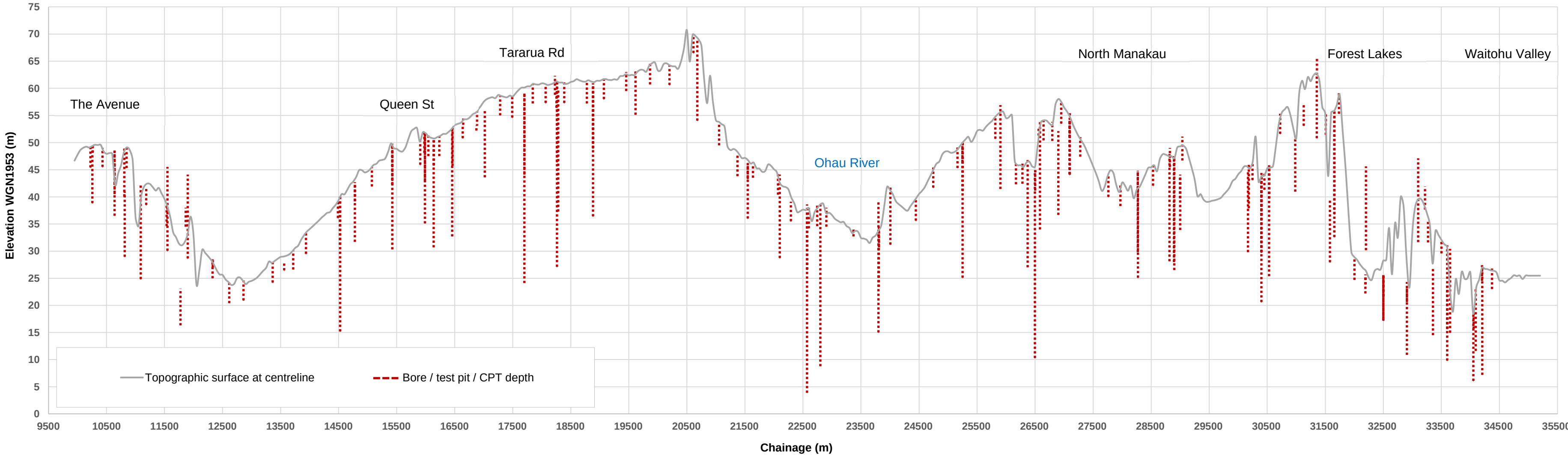

Figure G.27: Location and depth of various intrusive investigations along the existing terrain of the proposed Ō2NL Highway.

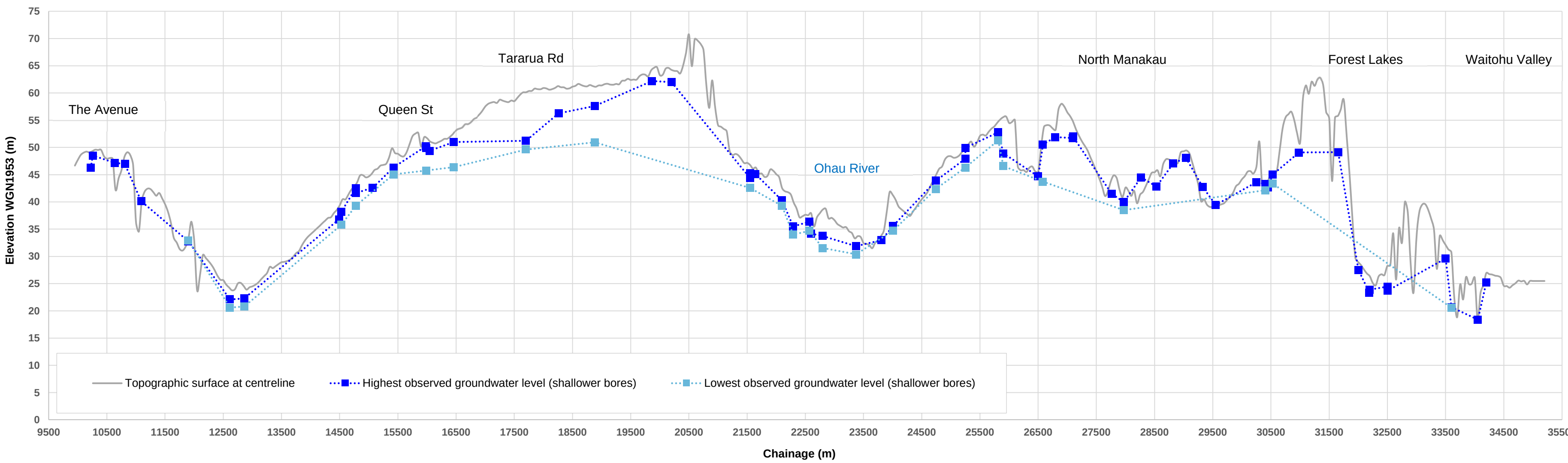

Figure G.28: Highest and lowest groundwater levels recorded along the existing terrain of the proposed Ō2NL Highway.

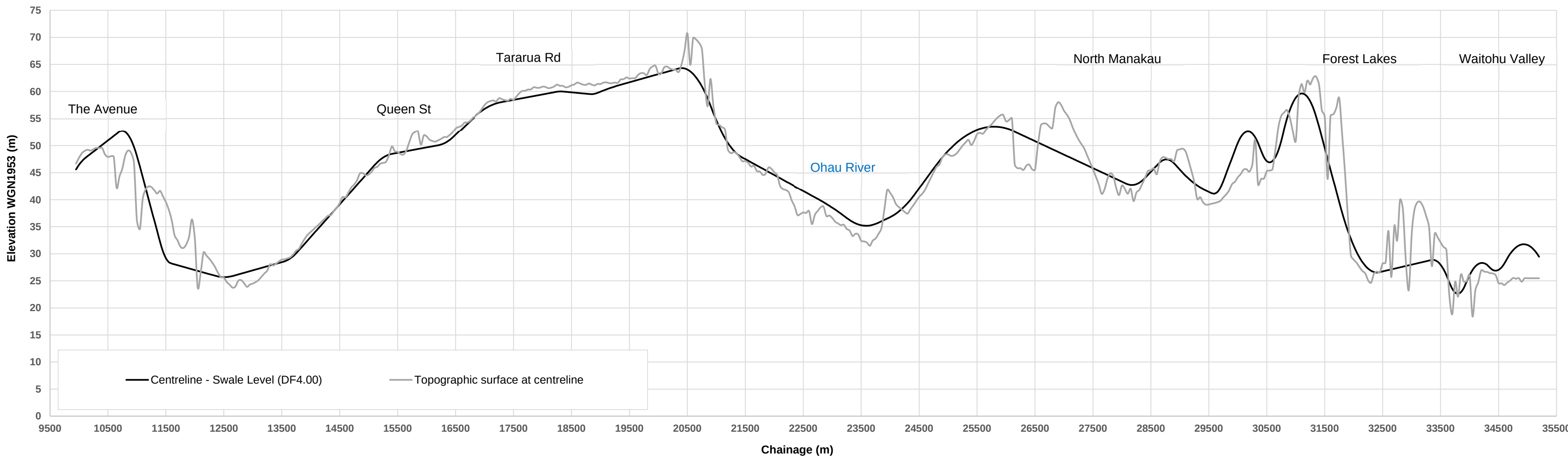

Figure G.29: Comparison of existing and proposed elevation along the existing terrain of the proposed Ō2NL Highway.

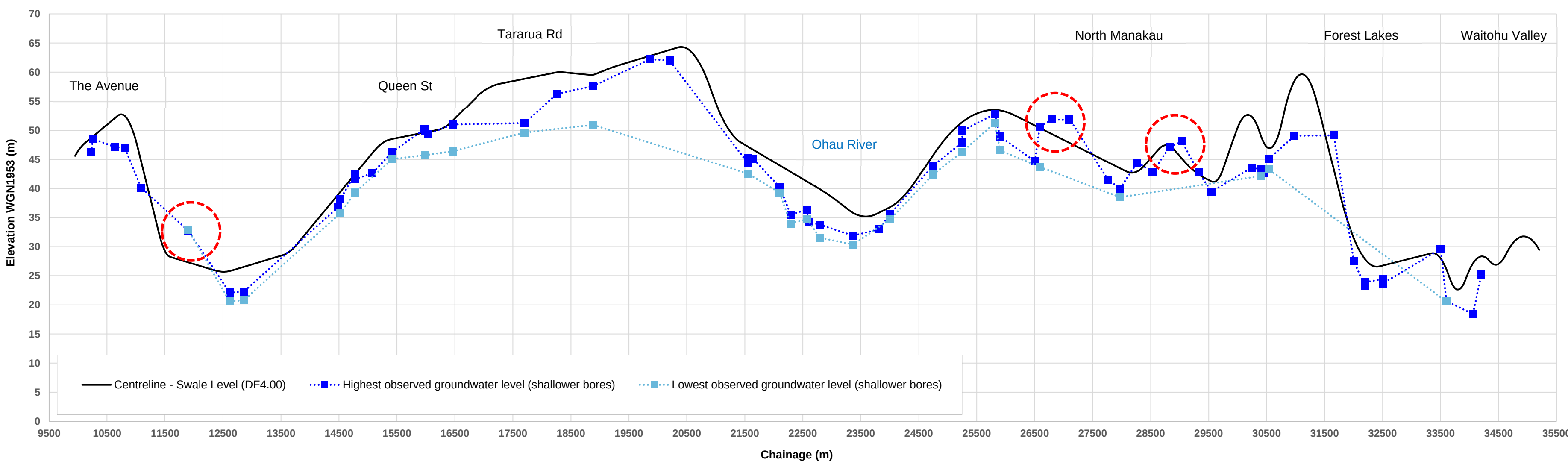

Figure G.30: Highest and lowest observed groundwater levels relative to the vertical alignment along the proposed Ō2NL Highway.

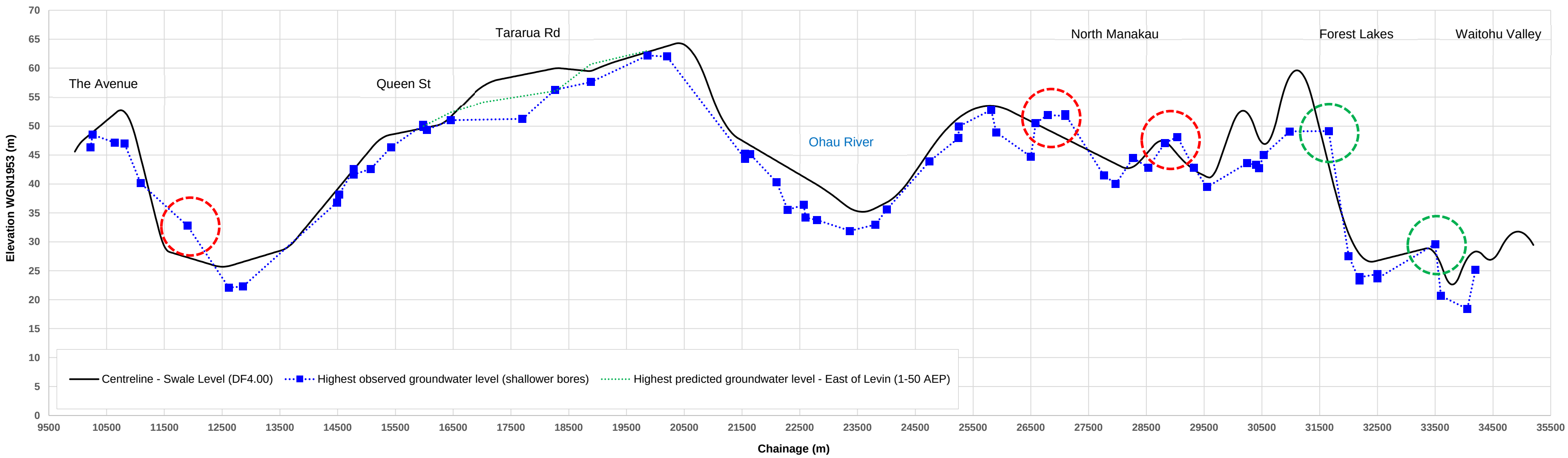

Figure G.31: Highest observed and predicted groundwater levels relative to the vertical alignment along the proposed Ō2NL Highway.

134. A range of intensive groundwater investigations have been undertaken along the proposed alignment to inform the design, particularly the vertical alignment, and allow the potential effects of the Project on the groundwater system to be quantified (*Figure G.27*).

135. The maximum and minimum groundwater levels observed or recorded in the various bores and excavations are shown in *Figure G.28*. Although the periods over which groundwater conditions have been monitored are relatively short, these groundwater levels have been used to inform the design of the proposed highway.

136. The vertical alignment of the proposed highway, relative to the existing terrain, is shown in *Figure G.29*. There are several characteristics of this alignment which have implications for any potential interaction of the Project with the groundwater system. These include:

(a) The proposed vertical alignment generally follows the existing topography, although in a slightly more subdued manner;

(b) The proposed alignment tends to lower high points but does not reduce the elevations of low points and topographic depressions; and

(c) The alignment fills some of the topographic depressions, raising the ground surface relative to the current level of the groundwater.

137. The net effect of these changes is that the vertical alignment of the proposed highway will be similar to the existing topography but slightly more smoothed, generating more gradual changes in slope.

138. As a consequence of this proposed vertical alignment, there are three areas where the Ō2NL Highway may intersect the 'estimated' maximum groundwater level. These areas are in the vicinity of chainages:

- 11,000-12,000;
- 26,500-27,500; and
- 29,000 ('red' circles on *Figure G.30*).

139. There are two other very small areas towards the south of the proposed alignment, near to Forest Lakes Road and ~2km further south, where the highway appears to be below the maximum level of the groundwater ('green' circles on *Figure G.31*). These, however, are considered to be the result of interpolation of the vertical alignment of both the proposed highway and the

maximum groundwater levels. It is considered unlikely that the groundwater will actually intersect the ground surface in these areas.

140. These few small areas where there is a potential for the proposed road to intersect the groundwater do not meet the overall aspiration of avoiding any interaction with the groundwater. This is the result of balancing cost, efficiency and effectiveness of the final design, constructability, risk, and a wide range of potential environmental effects. However, when considering the 24km length of the Project, in my opinion these small effects relating to groundwater can be considered '*less than minor*'.

141. Furthermore, these few small areas must be placed in the context of the uncertainty that is always present in groundwater investigations, even extensive and intensive investigations as undertaken to support the development of this Project.

142. In my opinion, these few small areas must also be considered in the context of the following:

(a) Despite the detailed groundwater investigations that have been undertaken, the information available is still basically 'point measurements' which have been extrapolated to infer likely conditions on the proposed alignment. Consequently, there may be differences between what has been inferred and what may be found once construction begins. To accommodate this residual uncertainty, the assessment has been 'conservative' ie, worst case or highest potential groundwater levels have been considered.

(b) Throughout the Project area there are multiple water-bearing units at different depths. In the areas where the proposed alignment appears to intersect groundwater, this is most likely to be isolated and localised 'perched' water-bearing units which are not connected to the deeper or 'regional groundwater'. This means that any effects of the proposed highway will be 'localised' and so can be managed during construction relatively easily by providing a hydraulic connection to adjacent surface water or groundwater. This is discussed in more detail later in this assessment and in *Appendix G.1.G*.

(c) While groundwater (a saturated zone) has been identified in a particular bore, there is currently little information on the rate of flow. However, given the generally flat terrain, the absence of large rivers (except for the Ohau), and nature of some of the material in the area, flow is likely to be slow and involve relatively small volumes of water. This is particularly the case in water-bearing units near the ground surface, which are those that may potentially be affected by the Project.

(d) Just because the road 'may' intersect groundwater is not in itself problematic, at least from engineering and groundwater perspectives. So long as the hydraulic connections are maintained, and the quality and quantity of water is not diminished (and will be enhanced as a result of the Project) the interaction of the highway with the groundwater will not have any adverse effects. Consequently, while any potential intersection of the alignment with the groundwater will need to be considered during detailed design and construction, any effects on the environment will be localised and, in my opinion, '*less than minor*'.

(e) The area between Chainage 11,000 and 12,000, north of Levin, is likely in Ōtaki Sandstone which has very low permeability and does not form a preferential flow path for groundwater.[20] The gradient is also very flat so any groundwater will be of low volume and have low rates of flow. This area is also on the 'interfluve' between the Punahau / Lake Horowhenua and Manawatū catchments. The flow in this area is likely to be to the north rather than towards the lake.

(f) The other two areas are well south of Lake Papaitonga and therefore, should there be any extremely small effect from the Project, it will have no effect on the lakes. The groundwater in this area is likely to parallel the surface streams and have a strong hydraulic connection with these streams. Consequently, as long as the hydraulic connections are maintained, and the quality and quantity of water is not diminished (and will be enhanced as a result of the Project) the interaction of the highway with the groundwater should not have any adverse effects.

Maintaining the water balance

143. The Ō2NL Project will have no effect on the water balance of the area. There will be no changes to the rainfall or the evapotranspiration. Any potential reduction to the soil moisture storage, and hence rainfall recharge to

[20] McLarin, W.; Bekesi, G.; Brown, L.; McConchie, J.A. 1999: Nitrate contamination of the unconfined aquifer, Manakau, Horowhenua, New Zealand. Journal of Hydrology (NZ) 38(2): 137-148.

groundwater, will only occur beneath the immediate footprint of the proposed highway.

144. The total area of the proposed designation is 5.76km^2 while the area of the footprint of the indicative highway is 0.82km^2. The area of the piedmont / coastal plain traversed by proposed Ō2NL highway is approximately 65km^2, with the total catchment area draining across the plain being significantly larger. The Ō2NL Project will therefore affect only a very small percentage of the piedmont / coastal plain traversed by the Ō2NL highway, ie, the designation and indicative footprint will represent 9% and 1.3% respectively of the piedmont plain.

145. Any rainfall that would have infiltrated the ground surface beneath the footprint of the Ō2NL highway will be 'diverted' to roadside swales, wetland treatment devices, and soakage basins immediately adjacent to the highway. Any runoff that would have infiltrated the ground surface, and potentially some additional rainfall, will infiltrate the area beneath, and adjacent to, these devices. This will maintain, and potentially enhance to a small degree, the existing water balance of the area.

146. Given the storage and attenuation of runoff provided by these devices, it is likely that the soil moisture adjacent to the Ō2NL highway may be slightly higher than under current conditions, particularly following larger rainfall events. This will act to both increase land surface recharge to groundwater and mitigate some of the existing flood hazard to the area and down-gradient. There may also be a small amount of mounding of the height of the water table immediately adjacent to the treatment devices. While this discussed in more detail later (and in *Appendix G.1.I*), this slight increase in the saturated zone will be of short duration and of very limited lateral extent. As a result, it will have no effects outside the immediate vicinity of the treatment device.

147. Since there will be no change to the existing water balance, the Ō2NL Project will have, in my opinion, a *'less than minor'* effect on groundwater.

Avoiding any direct interaction with groundwater

148. The detailed monitoring and modelling of groundwater conditions has allowed the position of the water table, under a range of design events, to be estimated along the length of the proposed highway.

149. Using the 'maximum likely groundwater level', it has been possible to design the Ō2NL Project to generally avoid, and where this has not been possible minimise, any direct interaction with the groundwater system. This has been achieved by constructing the highway at grade and above the maximum height of the water table, wherever practical. The few small areas where avoiding any potential interaction with groundwater has not been possible have been described and discussed previously.

Maintaining existing hydraulic connections

150. The development of the stormwater management system, discussed in the 'Stormwater Management Design Report',[21] will ensure that as far as practical any surface hydraulic connections will be maintained past the proposed highway. Where this is not practical, any diversion or deviation from the existing flow paths will be kept as short as possible to minimise any potential adverse effects. Any runoff from the highway will be retained within its existing catchment, ie, there will be no inter-basin transfers.

151. The construction of the Ō2NL Project above the maximum elevation of the water table will mean that any existing groundwater flow paths beneath the proposed highway will not be affected. Groundwater will be able to continue to flow past the highway.

152. There will also be no change to the hydraulic gradient of the groundwater since groundwater levels both upstream and downstream of the highway will be unchanged.

153. Since there will be no change to the existing hydraulic connections, the Ō2NL Project will have no adverse effect on existing groundwater supported wetlands and forests. The justification for this conclusion is discussed in more detail later.

Maintaining existing links between surface water and groundwater

154. As mentioned, the only significant potential effect of the Ō2NL Project on the linkages between surface water and groundwater will occur under the immediate footprint of the proposed highway. The pavement of the highway will 'seal' the existing ground surface, preventing the infiltration and percolation of any excess rainfall.

[21] Stormwater management and design report. Appendix to the Design and Construction Report.

155. However, the runoff from the pavement will be ‘diverted’ into swales and wetland treatment devices constructed immediately adjacent to the highway. Therefore, any runoff that would have infiltrated the ground surface, and potentially some additional rainfall, will infiltrate the area beneath and adjacent to these devices. This will maintain, and potentially enhance, the existing hydraulic connection between surface water and groundwater.

156. It is likely that the increased water in these treatment devices, compared to the existing situation, will facilitate the greater infiltration and percolation of surface water into the groundwater system. This will result in a small, but likely unquantifiable, increase in potential groundwater recharge, particularly during larger rainfall events. The potential effect of this increased infiltration and saturation on localised mounding of the groundwater is considered below. The increased infiltration and percolation of groundwater will, however, reduce the amount of surface runoff. This will reduce the existing flood hazard both in the vicinity of the Ō2NL Project and further down-gradient.

157. Since there will be no change to the existing hydraulic connections between surface water and groundwater, the Ō2NL Project will have no adverse effect on existing groundwater supported wetlands and forests. The reasons for this are summarised below and discussed in detail in *Appendix G.1.F* to this Technical Assessment.

Wetlands

158. A series of criteria were developed to identify any proposed cutting, culvert, underpass, or site for ground improvement where drawdown effects from dewatering may occur (*Table G.4*). The geological and hydrogeological characteristics at each site were assessed using information provided in Stantec 2021(a&b).[22&23]

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[22] Stantec (2021a). Geotechnical Factual Report. SH1 Ōtaki to North Levin. Prepared for Waka Kotahi. New Zealand Transport Agency. September 2021.
[23] Stantec (2021b). SH1 Ōtaki to North Levin. Geotechnical Interpretation Report. Prepared for Waka Kotahi. NZ Transport Agency.

Table G.4: Criteria used to identify drawdown effects on neighbouring wetlands, bores, and structures.

Step	Criterion	No	Yes
1	Will dewatering for excavation be deeper than the lowest seasonal GWL (which is higher than the lowest ever predicted GWL)?	Further assessment not required	Further assessment required (Go to Step 2)
2	Will the excavation be in fine-grained (silt/clay) material, and are neighbouring bores, wetlands, structures > 50 m away, or will drawdown at the excavation is small (<1m) and neighbouring bores, wetlands, and structures <50m away?	Further assessment required (Go to Step 3)	Further assessment not required
3	Using 1D analytical model (discussed in *Appendix G.1.H*) will there be drawdown at neighbouring wetlands, bores, or structures?	Further assessment not required	Further assessment required (Go to Step 4)
4	Assess where dewatering is required along culvert alignment. Is the drawdown at a neighbouring: • Bore >20% of available drawdown? • Wetland >5 cm, and the wetland dependent on groundwater? • Structure >0.5m?	Further assessment not required	Further assessment required

159. A total of 69 sites were assessed initially; however, it was considered that only 13 needed further assessment (ie, at Step 2). Of these, two sites, both proposed new culverts (culverts 4 & 11) in existing water courses, required the analytical modelling specified for Step 3.

160. A hydrological assessment of these wetlands and the potential effect of the Ō2NL Project on these are discussed in detailed in *Appendix G.1.F* to this Technical Assessment.

161. Wetlands within and adjacent to the Project designation consist primarily of swamps / bogs on valley floors. These can be intermittently to permanently wet. These wetlands are locally common and in general they are small and degraded, grazed, and dominated by exotic herbs and grasses. There are also small areas of wetland located in oxbows (ie, cut-off meanders) associated with rivers and streams, and some hillslope seepage wetlands fed by groundwater. In addition, there are some areas of remnant forest over areas where the shallow groundwater may at times get close (≲5m) to the ground surface.

162. Any open-water habitats were omitted from the assessment.

163. While most of the assessed wetlands and forest remnants are within the indicative Project Construction Footprint, including a 20m buffer, some are outside of the Project designation.

164. The hydrological assessment was based on field observations of the wetland ecology (see Technical Assessment J (Terrestrial Ecology)) and a mixture of field observations and a desktop assessment. No invasive work (drilling, test pits, cone penetration tests) was undertaken to determine the precise groundwater characteristics (ie, groundwater levels, perched versus regional water table) beneath the wetlands. Rather, groundwater conditions have been inferred from the nearest site investigation data. Consequently, an indication of the confidence that can be placed in the groundwater assessment is also provided. The various hydrological criteria used in this assessment are described in *Table G.5.*

Table G.5: Criteria used when assessing the source of water supporting a wetland.

Groundwater/Surface Water	Water source	Code	Description
Groundwater	Regional Water Table	GW-RWT	Valley floor seepages Base of terrace seepages Adjacent to surface water bodies High groundwater (≲5m deep) in adjacent shallow monitoring bores (≲10m deep).
	Perched (above regional water table)	GW-P	Hillslope seepages Presence of low permeability material Low groundwater (≳5m deep) in adjacent deep monitoring bores (≳10m deep).
Surface water	Stream	SW-S	Generally permanent flow of water
	Overland flow	SW-OF	Ephemeral flow paths
	Ponded rainfall	SW-PR	Rainfall ponded in area with no connection to streams or flow paths

165. *Appendix G.1.F* contains the summary of the hydrological regimes and assessments of the 69 wetlands and selected forest remnants. Examples of the results of the hydrological assessment are provided in *Figure G.32*. All those wetlands where the Project may have an adverse effect are highlighted.

166. Ten of these wetlands and forest remnants were assessed to be connected to perched groundwater and 56 to the regional water table. In addition, 62 of

the wetlands and forest remnants are considered to be connected to surface water flows. Fifty-six of these features are likely fed by a combination of groundwater and surface water. This information was used to provide site-specific assessments of where the Ō2NL Project, through its effect on groundwater, may have an effect on the wetlands and forest remnants.

167. There were seven wetlands that are connected to groundwater and within a zone where the Project has the potential to reduce groundwater levels. These sites are located around road cuts from CH11,350-11,650, CH20,500-20,800, and CH31,650-31,950 (*Table G.6*).

Table G.6: Summary of wetlands and forest remnants that could potentially be affected by a lowering of groundwater levels.

Wetland or forest remnant	Chainage or location	Cause for drawdown	Water source	Proportion of groundwater to total inflow	Expected effects
67 (A)	11,350-11,650	Cutting below groundwater table	GW-RWT(H)+SW-OF(L)	High	Significant reduction in groundwater inflows
58 (B)	20,500-20,800		GW-RWT(M)+GW-P(L)+SW-OF(H)	Low	Minor reduction in groundwater inflows
18	31,650-31,950		GW-RWT(L)+SW-PR(M)	Moderate	Significant reduction in groundwater inflows
19			GW-RWT(L)+SW-S(L)+SW-PR(M)	Moderate	Significant reduction in groundwater inflows
70 (E)			GW-RWT(M)+GW-P(H)	High	No groundwater inflows
71			GW-RWT(L)+GW-P(L)	High	No groundwater inflows
72			GW-P(M)+SW-PR(M)	High	No groundwater inflows
12	Culvert 4	Temporary dewatering	GW-RWT(L)+SW-S(L)	Moderate	Temporary minor reduction in groundwater inflows
13	Culvert 11		GW-RWT(M)+SW-OF(H)	Low	Temporary minor reduction in groundwater inflows

Figure G.32: **Example of the summary of the assessment of the hydrology of wetlands and forest remnants.**

Vegetation Overview						Topography	Geology (Qmap)	Potential Surface Water / Groundwater Sources	Groundwater (GW)				Surface Water (SW)		Vegetation Risk Assessment	
									Regional Water Table (RWT)		Perched (P)					
Site Object Identifier DF4.0	DF4.0 Outside Footprint (OF) & 20m Outside Designation (OD) Buffer Inside Designation (ID)	Chainage (m)	Vegetation ID Name	Vegetation Name	Wetland or Forest	Valley Floor Base of Terrace Hillslope Elevated Gentle Slope Base of Hill Narrow Channel Oxbow Depression		GW-RWT GW-P SW-xxx Assumes direct rainfall as a source for all sites *Confidence High(H), Medium (M), Low(L)*	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Regional Water Table	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Perched GW	Maximum 1-10 Year Flood Depths (m)	Within Surface Water Drainage Feature	Potential Reduction in GW Inputs	Potential Rise in GW Inputs
													None	Yes (Not Shown on Topo50) Yes (Topo50) None		
													<0.1			
									< 1	High	< 1	High	0.1 - 0.5		High	High
									1 – 2	Moderate	1 – 2	Moderate	0.5 - 1		Moderate	Moderate
									2 – 5	Low	2 – 5	Low	1 - 3		Low	Low
									> 5	None	> 5	None	> 3		None	None
0	OF-ID	12825	EWG1	Floating sweet grass grassland	Wetland	Oxbow	Q5b	GW-RWT(M)+SW-OF(H)	1 – 2	Moderate	Unknown	Unknown	0.5 - 1	Yes (Topo50)	None	None
7	OF-ID&OD	12075	EWG7	Creeping bent grassland	Wetland	Narrow Channel	Q5b	GW-RWT(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	None	None
2	OF-OD	25750	ITF1	Tawa forest	Forest	Gentle Slope	Q2a	SW-OF(M)	> 5	None	Unknown	Unknown	<0.1	No	None	None
83	OF-OD	31150 - 31250	ITF2	Tawa-kohekohe forest	Forest	Hillslope	Q2a	SW-OF(M)	> 5	None	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
4	OF-OD	31050	ITF2	Tawa-kohekohe forest	Forest	Elevated	Q5b	GW-P(L)+SW-PR(L)	> 5	None	< 1	High	<0.1	No	None	None
5	OF-ID&OD	23725	ITT07	Tawa-tÄirtoki treeland	Forest	Valley Floor	Q1a	GW-RWT(M)+SW-OF(H)	1 – 2	Moderate	Unknown	Unknown	0.5 - 1	Yes (Topo50)	None	None
95	OF-ID&OD	28225	MWSe2	Isolepis prolifera-floating sweet grass sedgeland	Wetland	Gentle slope	Q2a	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
8	OF-ID&OF-OD	13350 - 13550	MWG1d	Mixed wetland species grassland	Wetland	Narrow Channel	Q5b	GW-RWT(L)+SW-S(H)	2 – 5	Low	Unknown	Unknown	0.5 - 1	Yes (Topo50)	None	None
9	OF-ID&OF-OD	13000	EWG1d	Exotic wetland species grassland	Wetland	Oxbow	Q1a	GW-RWT(L)+SW-OF(H)	2 – 5	Low	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
56	OF-ID	33925	EWF1	Crack willow forest	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-S(M)+SW-OF(M)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
11	OF-ID	15875	EWG3	Blue sweetgrass-creeping buttercup grassland	Wetland	Gentle Slope	Q5b	GW-RWT(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
13	OF-ID	31575	EWG4	Mercer grass-water pepper grassland	Wetland	Valley Floor	Q5b	GW-RWT(L)+SW-S(L)	1 – 2	Moderate	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	Moderate	None
12	OF-ID	33375	EWG5	Yorkshire fog-creeping buttercup grassland	Wetland	Base of Terrace	Q5b	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	Low	None
14	OF-ID	28525	EWG6	Yorkshire fog-creeping buttercup-Mercer grass grassland	Wetland	Valley Floor	Q2a	GW-RWT(M)+SW-S(M)	2 – 5	Low	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
58	OF-ID&OF-OD	20550	MWG3	Yorkshire fog-Isolepis prolifera grassland	Wetland	Valley Floor, Base of Terrace, Hillslope	Q5b	GW-RWT(M)+GW-P(L)+SW-OF(H)	< 1	High	< 1	High	0.5 - 1	Yes (Not Shown on Topo50)	Low	None
16	OF-ID	23850	MWH1	Water celery-kikuyu-Isolepis	Wetland	Oxbow	Q1a	GW-RWT(L)+SW-PR(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	None	None

Vegetation Overview						Topography	Geology (Qmap)	Potential Surface Water / Groundwater Sources	Groundwater (GW)				Surface Water (SW)		Vegetation Risk Assessment	
									Regional Water Table (RWT)		Perched (P)					
Site Object Identifier DF4.0	DF4.0 Outside Footprint (OF) & 20m Outside Designation (OD) Buffer Inside Designation (ID)	Chainage (m)	Vegetation ID Name	Vegetation Name	Wetland or Forest	Valley Floor Base of Terrace Hillslope Elevated Gentle Slope Base of Hill Narrow Channel Oxbow Depression		GW-RWT GW-P SW-xxx Assumes direct rainfall as a source for all sites Confidence *High(H), Medium (M), Low(L)*	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Regional Water Table	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Perched GW	Maximum 1-10 Year Flood Depths (m)	Within Surface Water Drainage Feature	Potential Reduction in GW Inputs	Potential Rise in GW Inputs
													None			
													<0.1	Yes (Not Shown on Topo50) Yes (Topo50) None		
									< 1	High	< 1	High	0.1 - 0.5		High	High
									1 – 2	Moderate	1 – 2	Moderate	0.5 - 1		Moderate	Moderate
									2 – 5	Low	2 – 5	Low	1 - 3		Low	Low
									> 5	None	> 5	None	> 3		None	None
				prolifera herbfield												
60	OF-ID	10900 - 10950	EWH2	Creeping buttercup-water pepper herbfield	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
98	OF-ID	33750 - 33950	EWH3	Water celery herbfield	Wetland	Valley Floor, Base of Terrace, Hillslope	Q5b	GW-RWT(H)+SW-S(H)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
15	OF-ID	10950	EWH3	Water celery herbfield	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
61	OF-ID	10875	EWH3	Water celery herbfield	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
21	OF-ID	10650	EWH3	Water celery herbfield	Wetland	Gentle Slope	Q5b	GW-RWT(M)+SW-OF(M)	Moderate	1 – 2	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
6	OF-ID	33675	EWH5	Water pepper herbfield	Wetland	Valley Floor	Q5b	GW-RWT(M)+SW-OFH)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	None	None
23	OF-ID	14975	EWH5	Water pepper herbfield	Wetland	Narrow Channel	Q5b	GW-RWT(M)+SW-OF(H)	1 – 2	Moderate	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
18	OF-ID	31700	EWH6	Water pepper-creeping buttercup-Yorkshire fog herbfield	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(L)+SW-PR(M)	1 – 2	Moderate	Unknown	Unknown	None	None	Moderate	None
19	OF-ID	31625	EWH6	Water pepper-creeping buttercup-Yorkshire fog herbfield	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(L)+SW-S(L)+SW-PR(M)	1 – 2	Moderate	Unknown	Unknown	<0.1	Yes (Not Shown on Topo50)	Moderate	None
20	OF-ID	34100	EWH8	Broad-leaved fleabane/Yorkshire fog herbfield	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-S(L)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
96	OF-ID	30400	EWRs1	Soft rush rushland	Wetland	Valley Floor	Q3a	GW-RWT(H)+SW-PR(L)+SW-OF(M)	< 1	High	Unknown	Unknown	<0.1	None	None	None
22	OF-ID	33800 - 33950	EWRs3	Soft rush-Yorkshire fog rushland	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(H)+SW-S(M)+SW-OF(M)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
29	OF-ID	31950	ITF2	Tawa-kohekohe forest	Forest	Elevated	Q5b	GW-P(M)	> 5	None	1 – 2	Moderate	None	None	None	None
27	OF-ID	33800	MWFn1	Kiokio-Spike sedge-Yorkshire fog fernland	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-OF(M)	< 1	High	Unknown	Unknown	<0.1	None	None	None

Vegetation Overview						Topography	Geology (Qmap)	Potential Surface Water / Groundwater Sources	Groundwater (GW)				Surface Water (SW)		Vegetation Risk Assessment	
									Regional Water Table (RWT)		Perched (P)					
Site Object Identifier DF4.0	DF4.0 Outside Footprint (OF) & 20m Outside Designation (OD) Buffer Inside Designation (ID)	Chainage (m)	Vegetation ID Name	Vegetation Name	Wetland or Forest	Valley Floor Base of Terrace Hillslope Elevated Gentle Slope Base of Hill Narrow Channel Oxbow Depression		GW-RWT GW-P SW-xxx Assumes direct rainfall as a source for all sites Confidence *High(H), Medium (M), Low(L)*	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Regional Water Table	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Perched GW	Maximum 1-10 Year Flood Depths (m)	Within Surface Water Drainage Feature	Potential Reduction in GW Inputs	Potential Rise in GW Inputs
													None <0.1	Yes (Not Shown on Topo50) Yes (Topo50) None		
									< 1	High	< 1	High	0.1 - 0.5		High	High
									1 – 2	Moderate	1 – 2	Moderate	0.5 - 1		Moderate	Moderate
									2 – 5	Low	2 – 5	Low	1 - 3		Low	Low
									> 5	None	> 5	None	> 3		None	None
66	OF-ID	11500	IWSe1-SPG	Isolepis prolifera sedgeland	Wetland	Hillslope	Q2a	GW-RWT(H)+SW-OF(L)	< 1	High	Unknown	Unknown	<0.1	None	None	None
67	OF-ID	11425 - 11525	IWSe1-SPG	Isolepis prolifera sedgeland	Wetland	Valley Floor	Q2a	GW-RWT(H)+SW-OF(L)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	High	None
68	OF-ID	11425	IWSe1-SPG	Isolepis prolifera sedgeland	Wetland	Hillslope	Q2a	GW-RWT(H)+SW-PR(L)	< 1	High	Unknown	Unknown	<0.1	None	None	None
89	OF-OD	23025	EWG9	Mercer grass-open water grassland	Wetland	Base of Hill	Q1a	GW-RWT(L)	2 – 5	Low	Unknown	Unknown	<0.1	None	None	None
62	OF-ID	28450	EWG8	Soft rush/Yorkshire fog-creeping buttercup grassland	Wetland	Depression	Q2a	GW-P(L)	2 – 5	Low	< 1	High	None	None	None	None
69	OF-ID	31600 - 31750	MTF6d	Karaka-mÄ□hoe-kawakawa forest and scrub	Forest	Valley Floor	Q5b	GW-RWT(L)+SW-S(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
93	OF-OD	16400 - 16500	MTF6	Karaka-mÄ□hoe-kawakawa forest and scrub	Forest	Gentle Slope	Q2a	SW-OF(M)	1 – 2	Moderate	Unknown	Unknown	0.1 - 0.5	None	None	None
70	OF-ID	31650	MWSe1-SPG	Isolepis prolifera-soft rush sedgeland	Wetland	Hillslope	Q2a	GW-RWT(M)+GW-P(H)	1 – 2	Moderate	< 1	High	None	None	High	None
71	OF-ID	31750	MWSe1-SPGd	Isolepis prolifera-soft rush sedgeland	Wetland	Hillslope	Q5b	GW-RWT(L)+GW-P(L)	1 – 2	Moderate	< 1	High	None	None	High	None
72	OF-ID	31825	EWH10d	Soft rush/creeping buttercup-Yorkshire fog-mercer grass herbfieldÂ	Wetland	Hillslope	Q5b	GW-P(M)+SW-PR(M)	2 – 5	Low	< 1	High	<0.1	None	High	None
92	OF-ID	28475	EWH10	Soft rush/creeping buttercup-Yorkshire fog-mercer grass herbfieldÂ	Wetland	Valley Floor	Q2a	GW-RWT(L)+SW-PR(L)	2 – 5	Low	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
88	OF-ID	30450	EWRs1	Soft rush rushland	Wetland	Base of terrace	Q1a	GW-RWT(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
85	OF-ID&OD	24100	EWRs1d	Soft rush rushland	Wetland	Gentle Slope	Q2a	SW-OF(M)	> 5	None	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None

168. The potential reduction of groundwater flow was assessed as ‘Low’ for wetlands 12 and 58; ‘Moderate’ for wetlands 13, 18, and 19; and ‘High’ for wetlands 67, 70, 71, and 72. All these potentially affected wetlands are mapped in the Ecology plans in Volume III – Drawings. The potential effects of the Project on those wetlands identified as being ‘at risk’ is discussed in detail in Technical Assessment J (Terrestrial Ecology).

169. Taking a conservative approach, wetlands where the reduction in groundwater was assessed as ‘Moderate’ or ‘High’ are assumed to be lost and will need to be addressed by offsetting (seven wetlands in total comprising a combined area of 0.33 hectare). The extent of the loss for each individual wetland, and the measures by which the residual impacts will be addressed, are discussed in *Table J.3* of Technical Assessment J (Terrestrial Ecology).

170. In my opinion, any effects of the Project overall on the groundwater affecting wetlands and forest remnants will be ‘*less than minor’*. This is despite effects at a few (ie, seven) specific locations being more than minor.

Effect of potential road cuts

171. As discussed, the current conceptual design of the Project involves several cuttings with the potential to extend below the depth of the maximum assumed groundwater level. These sites are located around road cuts from CH11,350-11,650, CH20,500-20,800, and CH31,650-31,950 (*Table G.7*).

Table G.7: Summary of where ‘cuts’ associated with the Project may intersect the highest predicted groundwater levels.

Site	Chainage defining maximum cut length (m)	Highest predicted GWL (m)	Wetlands	Potential water source(s)	Potential effect on neighbouring bores
A	11350–11650	3.5	64 68	Regional groundwater, overland flow, ponded rainfall	Very unlikely
B	20450–20800	2.0	54, 58	Regional groundwater and overland flow	Very unlikely
C	26600–27250	5.0	None	No wetlands nearby	Unlikely
D	28950–29200	3.0	None	No wetlands nearby	Very unlikely
E	31750–31850	1.5	13, 18, 19, 69-72	Regional and perched groundwater, surface water and overland flow	Very unlikely
F	33400–33600	3.0	16, 20, 22, 25, 26, 27, 48, 56, 59	Regional and perched groundwater, surface water, overland flow	Very unlikely

172. A detailed analysis of the potential effects of road cuts on groundwater, and consequential effects on wetlands and bores, is provided in *Appendix G.1.G*. The conservative assumption that the invert of the swales within these cuts will be 1.25m below the centreline of the proposed highway has been adopted in these analyses.

173. However, it must be recognised that the current design is to inform consenting, and to provide an envelope of potential effects within which the final design and construction must fit. Consequently, the potential vertical (and horizontal) alignments are only conceptual at this stage. The carriageway shown in some of these cuttings could be repositioned higher to reduce the potential for the Project to interact with any groundwater. However, the current configuration has been informed by a range of factors, including geometrics and the need to get a better cut/fill balance.

174. As discussed above, it has been conservatively assumed in Technical Assessment J (Terrestrial Ecology), that any wetland adversely affected by the Project will be 'lost'. In reality, it is more likely that the wetland will be diminished rather than lost. This loss will be compensated through offsets.

175. The 'maximum assessed' groundwater level in bores close to the proposed cuttings fluctuated by >4m during monitoring. Any settlement caused by expected drawdown of the groundwater (assessed conservatively) will have already occurred during these seasonal fluctuations. Consequently, there is no risk that the proposed road cuttings will result in ground settlement.

176. Negative vertical hydraulic gradients have also been identified during monitoring. Conceptually, this indicates that downwards seepage is occurring at its maximum rate. Therefore, it is unlikely that any pressure reduction in surficial layers (affected by the cut) will be transmitted to deeper levels of the aquifer.

177. Finally, road-side swales will recharge the groundwater, maintaining a relatively unchanged hydraulic gradient towards any wetland or stream.

178. The conceptualisation of the groundwater provided in the vicinity of these cuttings, and therefore the potential effects of the Project, must also be considered within the context of the uncertainty discussed previously. Key aspects of the Project are that the water balance will be unaffected and that the hydraulic connections (surface and subsurface) and groundwater flow paths will be maintained. At certain locations, these hydraulic connections

may be moved slightly (only 10s of metres) to accommodate the drainage necessary for the Project.

179. Furthermore, while road cuts may reduce groundwater levels at these seven wetlands, wetlands can be formed from either discharges of groundwater or be acting as recharge pathways to groundwater. Where the latter is true, reducing groundwater levels will not affect the water balance at the wetland.

180. Despite the conceptual nature of the possible highway design at this stage, the effect of potential cuttings on existing bores is considered in *Appendix G.1.G*.

181. At Site A identified in *Table G.7*, the nearest bore (ID 353066) is 270m to the north and beyond an ephemeral tributary to Koputaroa Stream. Consequently, this cut, should it eventuate, would have no effect on the yield or efficiency of this bore.

182. At Site B identified in *Table G.7*, an un-named private bore was located during site investigations 170m to the south-east of the potential cut. The bore depth and screen interval are unknown, as is the groundwater level; however, the bore is used for domestic supply. Given the possible invert of the cut will be at a slightly higher elevation than the ground level at the bore, any drawdown effects as a result of the cut are considered very unlikely.

183. At Site C identified in *Table G.7*, the nearest bore (ID 372111) is 110m west of the potential cut, at a similar elevation (1–2m lower), screened from 40.4–49.3mbgl, and with an initial depth to groundwater of 30.6m when drilled. Given the relatively deep bore and groundwater level, and the cut being in low permeability sediment, any effect on the reliability of water supply is considered unlikely. The next closest bore (ID 372006) is 10m deep, 250m east of the potential cut, and had a depth to groundwater of 3m when drilled. Although this bore is shallow and moderately close to the cut, it is unlikely that any drawdown from the cut will reach this bore because the low permeability of material reduces the radius of influence significantly. Using Sichardt's formula for steady-state, planar flow, and assuming a drawdown of 5m at the cut and a hydraulic conductivity of 1m/d (considered conservatively high), the predicted radius of influence is only 26m. Hence, even if the drawdown is larger than predicted, it is considered unlikely that this will have any effect on the reliability of supply from this bore. The greater distance of any other bores from the potential cut means that any drawdown effects are considered extremely unlikely.

184. At Site D identified in *Table G.7*, the nearest bore (ID 372007) is 120m away and 35.8m deep. The bore had an initial depth to static water level of 17m when drilled. Given the large available drawdown from this bore and the relatively small amount of drawdown that may occur, any effects on the reliability of supply are considered unlikely. Any other bores are more than 420m away and so any effects on the reliability of supply are considered unlikely.

185. There are no bores in the vicinity of Sites E & F identified in *Table G.7* so any potential effects on groundwater yield and bore efficiency did not need to be considered.

186. The issue of the depth of any cuts will be considered by the design team and more critically by the team awarded the contract to design and construct the final Project. Any effects of these cuts, however, will not exceed those indicated in *Appendix G.1.G*.

Temporary dewatering

187. Two sites within the conceptual design may potentially be affected temporarily by dewatering required for culvert construction (*Table G.6*). A detailed analysis of the potential effects of temporary dewatering is provided in *Appendix G.1.H*.

188. The modelling indicates that dewatering to install Culvert 4 would potentially lower the groundwater below the seasonal lowest level in two wetlands, one of which is expected to have a high dependence on groundwater.

189. Dewatering to install Culvert 11 is unlikely to reach depths that would result in a more than minor drop of the seasonal lowest groundwater level beneath the wetland. Consequently, any effects of dewatering can, in my opinion, be considered '*less than minor*'.

190. The temporary dewatering will have no effect on any bores or structures in the vicinity.

191. Any temporary adverse effects of dewatering can be either avoided or mitigated through management and discharge of any water abstracted.

Potential groundwater mounding

192. Fundamental to the design of the Project, and particularly the treatment of runoff from the proposed highway, are various stormwater management and

treatment devices. These work by providing storage and attenuation, encouraging infiltration to ground, and conveying any excess runoff to existing watercourses. The proposed stormwater management regime for the Project is described in the Stormwater Management Design Report.[24]

193. Increasing infiltration to ground has the potential to cause mounding of the groundwater beneath the treatment device. Any mounding will be of generally short duration, immediately following any rainfall event. The risk from mounding on causing locally-high water tables and potentially exacerbating flooding depends on specific site conditions and the magnitude, duration, and intensity of rainfall.

194. A detailed assessment of any potential risk from groundwater mounding, under and adjacent to stormwater treatment devices, is provided in *Appendix G.1.I*.

195. The area where mounding is considered to have potentially the greatest effect is east of Levin, from approximately 500m north of Queen Street to approximately 500m south of Tararua Road (chainages 15400-18900). Five treatment facilities (shown on the Stormwater Drawings in Volume III - Drawings) are proposed in this area to capture, treat, and then discharge to ground all stormwater from the Project within the Punahau / Lake Horowhenua catchment. Across the remainder of the Project, excess stormwater will be discharged into surface water and so any risk from mounding will be negligible.

196. The five treatment facilities are located approximately 450m to 700m apart. Except during extreme events (ie, very high rainfall and/or high groundwater levels) there will be no discharges to surface water from these facilities.

197. The treatment facilities range from 50-150m in width and 150-300 in length. Each facility consists of a treatment train including a sediment forebay, constructed wetland, and overflow basin. The base of the sediment forebay and overflow basin are expected to be constructed between 1.0-1.5m below existing ground level. The maximum water depth in the sediment forebay, constructed wetland, and overflow basin will be 1-1.5m. This means that the maximum water level will be approximately equal to natural ground level.

198. Stormwater will be discharged initially into the unlined sediment forebay to allow fine sediment and sand to drop out of suspension before flow is

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[24] Stormwater management and design report. Appendix to the Design and Construction Report.

discharged into the constructed wetland. The constructed wetland will be lined with silt / clay or geo-material to reduce soakage to ground and help maintain at least 0.25m depth of water. Any residual stormwater will be discharged into the overflow basin. The current system is designed so that discharges into the overflow basin will occur during rainfall events that exceed a 2-year ARI (50% AEP). The constructed wetland makes up approximately 50% of the total area, the overflow basin 35%, and sediment forebay 15%.

199. The highest infiltration rates are required in the sediment forebay and overflow basin. It is therefore expected that the surficial, naturally occurring, silt and clay material will be removed and replaced with higher permeability coarse sand and gravel.

200. The sediment forebay, and to a lesser extent the overflow basin, may clog with fine sediment in the stormwater runoff over time. This would result in a reduction of hydraulic conductivity. This will be managed by periodic cleaning to maintain sufficient hydraulic conductivity and seepage rates to meet the design specifications.

201. The modelling of the potential for groundwater mounding considered the design rainfall, geology, hydrogeology, and infiltration rates as described in in *Appendix G.1.I*.

202. Groundwater mounding predictions beneath and adjacent to the five stormwater soakage facilities were undertaken using Function W_6 from Hunt (2012).[25] This transient analytical model predicts the groundwater level rise in an unconfined aquifer where specific yield is used instead of storativity, and leakage from any overlying confining layer is ignored. These assumptions are considered appropriate for the conditions east of Levin. The model assumes the aquifer is homogeneous, isotropic (K_v=K_h), and of infinite lateral extent. The groundwater model inputs are aquifer transmissivity, specific yield, groundwater recharge rate, and time from the start of the recharge (recharge duration). The derivation of these parameters is described in *Appendix G.1.I*.

[25] Hunt (2012). Groundwater Analysis Using Function.xls. Bruce Hunt. Civil Engineering Department University of Canterbury. E-mail: bruce.hunt@kinect.co.nz. Last Update: 14 January 2012.

203. It should be noted that the modelling considered the effect of the proposed treatment device on mounding relative to that predicted under the existing environment, ie, it determined the effect of the Project.

204. Groundwater mounding was predicted separately for three potential design scenarios:

(a) *Beneath the Constructed Wetland*: Mounding after 365 days of continuous seepage based on a groundwater recharge rate of approximately 0.001m/d. The value was calculated assuming a conservative (high) specific discharge through the base of the constructed wetlands of 0.002m/d, minus the existing land surface recharge from rainfall (approximately 0.001m/d).

(b) *Beneath the Sediment Forebay and Overflow Basin (Average Conditions):* Mounding after 365 days continuous seepage. A conservative approach was taken by multiplying the mean annual rainfall of 1.1m/yr, by the total catchment area for each facility to give a total annual volume. The assessment is conservative because it assumes all rainfall-runoff is discharged to the facilities and there are no evaporative losses. The total annual volume for each facility was divided by 365 days to give an average daily volume which was then applied to the sediment forebay area.

(c) *Beneath the Overflow Basin (1% AEP event):* This involved calculating the maximum recharge rate and time required to discharge all the runoff from a 1% AEP rainfall event into the ground from the overflow basin plus small part (5%) area of the sediment forebay. The recharge rate was limited to ensure that the water table did not rise higher than the existing ground level. This is the highest design water level for the soakage facilities. This is the worst-case scenario for maximum stormwater discharges to ground and groundwater mounding. During the 1% AEP event, it is assumed that most of the stormwater will be diverted to and discharged into ground from the overflow basin.

205. The results of the groundwater mounding predictions are contained in *Appendix G.1.I*. However, they are summarised for each case below:

(a) The groundwater mounding predictions show little or no effects beneath the constructed wetlands. This is expected as these areas will be lined and infiltration rates to groundwater will be low.

(b) Directly beneath the sediment forebay and overflow basin, groundwater mounding predictions range from 7-60cm based on the annual rainfall runoff. These predictions are considered conservative since it is assumed that 100% of the mean annual rainfall runoff is discharged to the facility. It is likely that the actual mounding experienced may be in the order of 50% less than that indicated above.

(c) The limited unsaturated zone thickness at Facility 6, and its location north of Queen Street East on lower permeability Q5b sands, greatly reduced the groundwater recharge rate and increased the time required to discharge runoff from the 1% AEP event to ground. The maximum groundwater recharge rate was 0.7m/d after 9 days. This is not unexpected given the effects of a high-water table limiting infiltration. The second facility north of Queen Street East, Facility 5, had an even lower groundwater recharge rate of 0.3m/d and consequently a longer time to discharge all the water of 16 days.

206. In contrast, Facility 8 south of Queen Street East is located on more permeable Q2a/Q3a gravels, has a larger unsaturated zone, and it is predicted that the runoff from a 1% AEP event could be discharged into groundwater within 0.8-days, at a rate of up to 6.6m/d.

207. As described in detail in *Appendix G.1.I*, the potential effects of mounding are of limited extent and of short duration. Greater effects are only likely during the extreme design event modelled (ie, 1% AEP rainfall increase to allow for the predicted effects of climate change). Even then, the effect of the stormwater treatment facilities will be localised and of short duration. For larger events, it is also likely that the entire ground would be saturated and overland flow will occur. The proposed works will not exacerbate the existing situation. Any effects of mounding are likely to be negligible relative to the other effects of such a large event on the environment.

208. In my opinion therefore, any potential effects of mounding can be considered *'less than minor'*.

Existing groundwater users

209. Stormwater from the highway will be collected by the network of swales, retention basins, and wetlands where all runoff will be treated prior to disposal either to ground or existing waterways. Consequently, the Ō2NL

Project will have no effects on existing groundwater users, wetlands, and streams outside of the corridor.

210. The effects of seven cuts proposed in the current conceptual design on existing bores was discussed above and are described in detail in *Appendix G.1.G*. It was concluded that any effects of the Project on these bores can be considered *'less than minor'*.

211. Where there are some extremely small, localised effects caused by temporary dewatering, these effects have been shown to be localised and will be of short duration.

212. The closest 'community bore' to the Project is the Manakau Water Scheme, also known as the Glenmorgan Water Supply Scheme. This scheme supplies potable water to potentially 47 households, based on discussions with landowners. In many cases, this water is supplemented from other sources eg, rainfall.

213. This bore lies just outside and to the north of the proposed Project alignment. Given the location and depth of this bore, it should not be affected by the Project. Access will be provided for the pipeline from the bore to demand area under the proposed highway.

Positive environmental effects

214. The comprehensive groundwater investigations have allowed the design and construction of the Ō2NL Project to avoid, and where this is not practical mitigate, any adverse effects on the groundwater system.

215. The Ō2NL Project may also have some potential positive benefits relating to the hydrology, and the groundwater hydrology in the area. For example:

(a) The management of stormwater runoff from the new highway will involve storage, attenuation, and treatment for all events up to the design event (ie, the 1% AEP rainfall increased to allow for the predicted effects of climate change). Given the surface area of the highway, this will 'remove' a volume of runoff from the flood peak, even though the total runoff volume will remain approximately the same. The storage and attenuation of road runoff will consequently reduce the flood peak further downstream, mitigating and moderating both the existing and future flood hazards. Because of this management of stormwater runoff, additional water will infiltrate and percolate to the groundwater.

(b) Any rainfall that would have infiltrated the ground surface beneath the footprint of the highway will be 'diverted' to swales and wetland treatment devices immediately adjacent to the highway. Any runoff that would have infiltrated the ground surface, and potentially some additional rainfall, will infiltrate the area beneath and adjacent to these devices. This will maintain the existing water balance.

(c) Given the storage and attenuation provided by these devices, it is likely that the soil moisture and groundwater recharge will be higher than under current conditions. This will act to both increase groundwater recharge and mitigate some of the existing flood hazard to the area and down-gradient.

(d) It is likely that the increased water in these treatment devices compared to the existing situation will facilitate greater infiltration and percolation of surface water to groundwater. This will result is a small increase in potential groundwater recharge, particularly during larger rainfall events. The risk of this to groundwater mounding and potentially increased flooding has been shown to be negligible. The increased infiltration and percolation of groundwater, however, will reduce the amount of surface runoff.

(e) As discussed, the design and construction of the Ō2NL Project will see a small, probably not quantifiable, increase in both the volume and quality of rainfall/runoff entering the groundwater.

Improving water quality

216. Under the existing environment, most of the land use within the Ō2NL Project corridor is used for pastoral farming. There are few controls on the use of fertilisers and other chemicals on this land. Animal husbandry also affects both nutrients and other contaminants (eg, faecal coliforms) entering the groundwater.

217. While the area of the Ō2NL Project represents a very small percentage of the wider piedmont / coastal plain (ie, the indicative footprint is only 1.3%), the change in land use throughout the designation (ie, 9% of the piedmont/coastal plain) has the potential to reduce the existing contaminants from entering the groundwater.

218. While runoff from the O2NL highway may also contain a range of potential contaminants, treatment of these will be provided by specially designed and constructed wetlands. The effectiveness of these on water quality and treatment is discussed in Technical Assessment H (Water Quality).

219. Once the Ō2NL Project is complete, nutrient (nitrogen and phosphorus) and pathogen (bacteria, virus, protozoa) loading to groundwater will decrease where agricultural land use is replaced by the road and associated infrastructure.

220. Therefore, it is likely that the nutrient and pathogen contaminant load to the groundwater, and groundwater-fed surface water bodies such as Punahau / Lake Horowhenua, will decrease slightly because of the Ō2NL Project.[26 & 27]

221. Additional detail on the design, construction and effectiveness of these stormwater treatment wetlands is provided in the Stormwater Management Design Report[28] and in Technical Assessment H (Water Quality).

222. Consequently, the Ō2NL Project is likely to result in a small improvement in the quality of both surface runoff and groundwater.

Enhancing groundwater to Punahau / Lake Horowhenua and Lake Papaitonga

223. As described above, the design and construction of the Ō2NL Project will result in a small, but probably not quantifiable, increase in both the volume and quality of rainfall / runoff entering the groundwater.

224. Because of the hydraulic gradient and existing flow paths some of this additional, higher quality, groundwater will make its way into Punahau / Lake Horowhenua and Lake Papaitonga. Over time, this may result in both a reduction in contaminant loading and increased dilution of contaminants in these lakes.

225. The Ō2NL Project may therefore result in a small improvement in the water quality of the lakes and the groundwater from any springs down-gradient of the Ō2NL Project.

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[26] Gyopari (2005). Horowhenua Lakes Assessment of Groundwater – Surface Water Interaction. Prepared for Horizons Regional Council.
[27] White, P., Zarour, H., Meilhac, C., and Green, S. (2010). Horowhenua water resources: water budget and groundwater surface water interaction. GNS Science Consultancy Report. 2010/22.
[28] Stormwater management and design report. Appendix to the Design and Construction Report.

226. Any increase in groundwater recharge may also see a small, and probably unquantifiable, increase in spring flow. This increase may be in both the rate and continuity of discharge.

Construction phase effects

227. Potential contamination of the groundwater during construction of the Ō2NL Project will be avoided by ensuring that all runoff from the construction and adjacent areas is diverted away from any excavations. All runoff will be treated by a comprehensive system of erosion and sediment control measures outlined in the Construction and Environmental Monitoring Plan ("**CEMP**"). Most of the sediment and any pathogens in the runoff will be removed as it passes through the soil and unsaturated zone. The residual risk of groundwater contamination from bulk earthworks on existing groundwater users, groundwater dependent ecosystems, lakes and streams can therefore be considered '*less than minor*'.

228. Standard methods and measures, to be outlined in the CEMP, will avoid the risk of spillage of hazardous chemicals. I consider that the risk to groundwater can be avoided, or managed, so that any potential adverse effects are negligible.

229. All existing monitoring bores located within the construction footprint will be decommissioned and it is not intended to replace them. These bores will be decommissioned in accordance with the New Zealand Environmental Standard for Drilling of Soil and Rock (NZS 4411:2001) to remove any direct pathways for contaminants to potentially enter groundwater.

230. Since most of the Ō2NL Highway will be constructed at grade and above the maximum groundwater level, discussed in the DCR,[29] little dewatering is likely to be required. However, it is possible that some minor short-term dewatering may be required for ground improvement and to allow the installation of a small number of box culverts where the highway passes over drainage lines that are close to the water table.

231. Any dewatering will be of short duration, likely no more than a maximum of 1-2 months, and be of limited extent. The extent of dewatering will be solely to allow installation of the culverts and so any effects will be limited to the immediate vicinity of the works. Furthermore, since the culverts will be installed sequentially and not all at once, any effects of dewatering will be

[29] Design and Construction Report (Appendix Three to Volume II).

extremely localised and have negligible effect on the wider groundwater system.

232. In addition, the need for dewatering will be reduced by installing affected culverts during late summer when groundwater levels are low and the need to lower groundwater levels reduced.

233. Modelling has shown that any effects of dewatering will be '*less than minor'* (*Appendix G.1.H*).

Managing inherent and residual uncertainty

234. Despite the comprehensive groundwater investigations undertaken to support the design and construction of the Ō2NL Project, there will always be some residual uncertainty because of the heterogeneity of the hydrogeology and groundwater system.

235. To manage this uncertainty, and to monitor for any unforeseen effects on the groundwater system, a Groundwater Monitoring Plan is proposed as a component of the CEMP.

236. The Groundwater Monitoring Plan will outline how baseline conditions will be established and the monitoring necessary to confirm that the Ō2NL Project has:

    (a) No significant adverse effects to the hydrological conditions of wetlands and groundwater supported habitats; and

    (b) No significant adverse effects on either the quantity or quality of groundwater abstracted by existing owners of water supply bores.

237. The Groundwater Monitoring Plan will define the means of measuring these outcomes through monitoring and reporting in accordance with any relevant consent conditions. This will allow any potentially adverse effects to be identified early, and then mitigated and remedied if necessary.

MATERIAL SUPPLY SITES

238. The current earthworks design of the Ō2NL Project relies on a significant amount of additional fill, >1.5Mm³, above that anticipated to be won through cut activities. Design constraints, notably grade separating local roads from the highway, topography, and geological conditions cause this unfavourable cut / fill material balance.

239. To resolve this issue, 36 locations were investigated through a desktop study, for their potential to supply bulk fill earth material. A screening exercise identified four locations where more detailed analysis should be undertaken (*Table G.8*). Selection was on the basis of their proximity to Project, geotechnical conditions, and performance against a range of environmental, cultural, and economic criteria, including potential legacy outcomes.

Table G.*8*: Results of the preliminary assessment of four potential material supply sites from hydrological and hydrogeological perspectives.

Site Name	Material	Comment
Koputaroa site	Sand	No effect on surface water features or water balance. The water table may be relatively deep given the distance from and elevation above the stream and the location of the site near the interfluve between the Punahau / Lake Horowhenua and Koputaroa catchments. A significant distance above any contemporary stream or floodplain and therefore no effect on any existing hazard.
Waikawa Site A (or Waikawa South)	Alluvium (within corridor)	No effect on surface water features or water balance. The water table may be relatively deep given the distance from and elevation above the stream. Likely above the contemporary floodplain and therefore no effect on any existing hazard.
Waikawa Sites B1- 4 (or Waikawa North)	Alluvium (within corridor)	No effect on surface water features or water balance. The water table may be relatively deep given the distance from and elevation above the stream. Likely above the contemporary floodplain and therefore no effect on any existing hazard.
Ohau site	Alluvium	No effect on surface water features or water balance. The water table may be relatively deep given the distance from and elevation above the stream. Likely well above the contemporary floodplain and a significant distance from the Ōhau River. Therefore, no effect on any existing hazard. Will need to avoid any interaction with potential paleochannels and overland flow paths. Should an extreme event occur could provide some additional flood storage.

240. When assessing the various sites from hydrological and hydrogeological perspectives, the following criteria were adopted:

(a) The relationship of the site to any surface water bodies or features;

(b) The effect of any proposed works on the existing water balance and hydrological processes;

(c) The relationship of the site to any paleochannels and overland flow paths;

(d) The potential interaction of the site with the floodplain and potential flood storage;

(e) The likely depth to groundwater;

(f) The current geomorphic form of the site; and

(g) The form and function of the site following any potential works.

241. The northern-most potential material supply site is in the upper reaches of Koputaroa Stream (*Figure G.33*). Material, most likely weakly-cemented sand of marine origin, would be excavated from the remnants of a marine terrace, extending the width of the adjacent box valley.

Figure G.33: Location of the potential material supply site in the upper Koputaroa catchment and the inferred groundwater flow direction (blue arrow).

242. Given the location of the potential excavation, there would be no effect on surface water features or the existing water balance, except for increasing the width of the base of the adjacent box valley. Since the material would be excavated from the interfluve (ie, drainage divide) between two small streams, the water table is likely to be relatively deep, no higher than the floor of the box valley. Although in the Koputaroa catchment, the site is close to the interfluve with the adjacent Punahau / Lake Horowhenua catchment. The site is a significant distance above any contemporary stream or floodplain and therefore excavation of material will have no effect on any existing flood hazard.

243. Because of the existing presence of small box valleys throughout this area, any 'borrow pit' could be constructed to blend into the existing environment, ie, it would be 'just another depression' within the generally undulating landscape.

244. The site south of Waikawa Stream lies on the floodplain, slightly above the contemporary bed of the stream (*Figure G.34*). It is likely that the stratigraphy of the site includes various layers of alluvium, with material ranging from gravels to sand and silt depending on the position of the channel when this material was deposited. Because of its proximity to the greywacke hill country, the material is likely to be coarser than found further towards the coast.

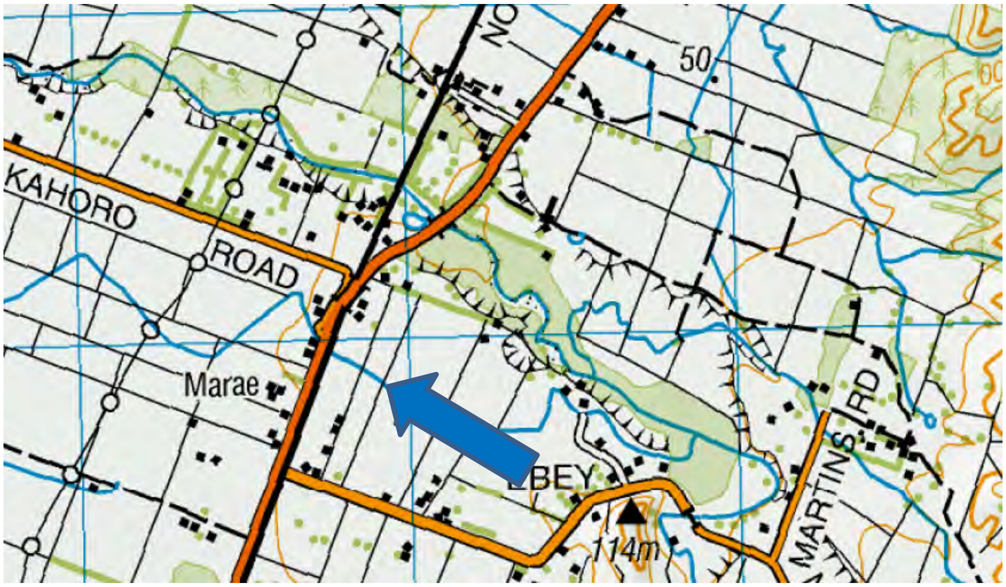

Figure G.34: Location of the site, south of Waikawa Stream, and the inferred groundwater flow direction (blue arrow).

245. Since the location is close to the interfluve between two stream catchments, it is likely that the groundwater is relatively deep. The only bore in the area (BH308) was drilled in February 2022 and therefore limited data relating to the groundwater level and its variability are available currently. At the time the bore was drilled, being towards the end of summer when the water table is likely to be depressed, the static water level was 6.46m below ground level. Assuming seasonal variation in the depth to the static water level of ~1.5m, approximately 5m of material could therefore be excavated at this site before interacting with the water table and groundwater.

246. It is likely that the groundwater flow direction is east-west beneath the site, and essentially parallel to Waikawa Stream (*Figure G.34*).

247. The surface topography in this area contains a network of small paleochannels formed by Waikawa Stream. It would be essential that the drainage provided by these during larger storm events is considered in the design and construction of any ‘borrow pit’. The continuity of any surface hydraulic connections would also need to be considered. None of these ‘requirements’, however, are seen problematic and simple solutions can be found prior to any excavation.

248. The formation of the ‘borrow pit’ could provide some additional flood storage, although the effect of this on the existing flood hazard would depend on the volume of the pit and the magnitude of the flood event. The effect of any pit would be greatest during smaller and more frequent events.

249. While the borrow pit would provide some additional flood storage for overbank flows from Waikawa Stream, the effect of this on the existing flood hazard, while positive, would likely be small.

250. Given the presence of paleochannels, any ‘borrow pit’ could be constructed to blend into the existing environment, ie, it would be ‘just another depression’ within the generally undulating landscape.

251. It is recommended that, prior to the finalisation of design, construction, and rehabilitation plans, piezometers be installed in the immediate vicinity of the proposed borrow pit. This would allow the depth to groundwater and seasonal groundwater dynamics to be defined more accurately. The resulting bore logs would also allow the characteristics of the material beneath the site to be assessed more accurately.

252. This information would also be critical to the design and effectiveness of any rehabilitation of the site, particularly if the desire is to create a ‘legacy’ by constructing a wetland and associated habitat.

253. The site on the north side of Waikawa Stream lies on an aggradational surface above the contemporary floodplain of the stream (*Figure G.35*). It is therefore likely that the stratigraphy of the site includes various layers of alluvium, with material ranging from gravels to sand and silt; depending on the source of the material and the mechanism by which it was deposited. Because of the proximity of this site to the greywacke hill country, the material is likely to be coarser than found further towards the coast; however, the lack of a large river or stream in this area (at least under present

conditions) may indicate that the material is finer than that discussed previously for the site on the south side of the stream.

Figure G.35: Location of potential material supply site north of Waikawa Stream, and the inferred groundwater flow direction (blue arrow).

254. Given the relatively elevated position of this site, and it being close to the interfluve between Waikawa and Kuku Streams, it is likely that the groundwater is relatively deep. The closest bore in the area (BH111) was drilled towards the end of winter in 2020 (*Figure G.36*). Although this is a short period of record, the data confirm that the groundwater is relatively deep, at least 11m below the ground surface. It would also appear that the seasonal variation in the depth to groundwater is at least 2m. Although limited, this data indicates that a considerable depth of material (ie, ~10m) could be excavated before any potential interaction with the groundwater.

255. It is likely that the groundwater flow direction is south-east-north-west beneath the site, and essentially normal to the topographic contours.

256. The surface topography in this area contains a network of small paleochannels and drainage lines. It would be essential that the drainage provided by these during larger storm events is considered in the design and construction of any 'borrow pit'. The continuity of any surface hydraulic connections and their importance would need to be considered.

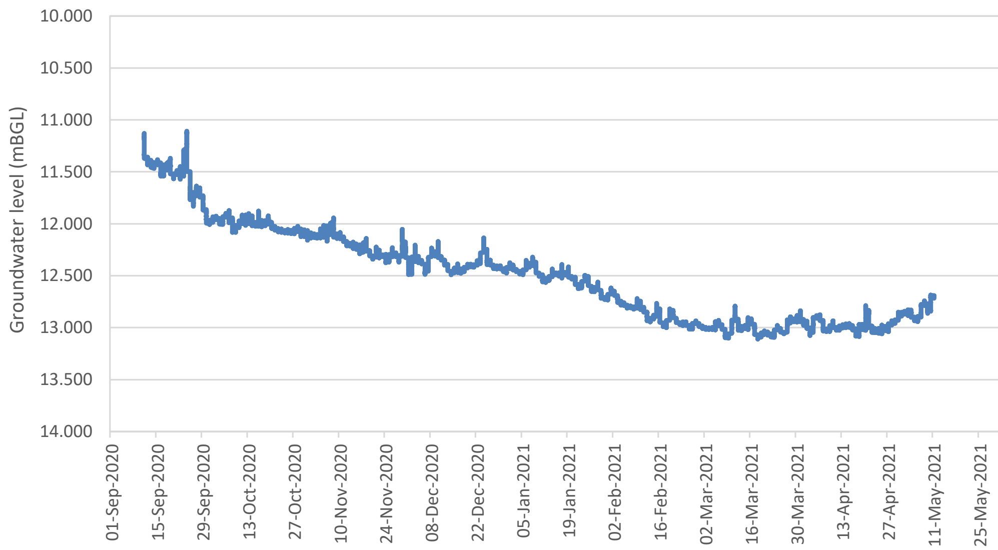

Figure G.36: Depth to groundwater in BH111.

257. The formation of the 'borrow pit' could provide some additional flood storage for the paleochannels, although the effect of this on the existing flood hazard would depend on the volume of the pit and the magnitude of the flood event. The effect of any pit would be greatest during smaller and more frequent events.

258. The borrow pit is unlikely to provide any additional flood storage for overbank flows from either the Kuku or Waikawa Streams because of the elevation of the site.

259. Given the presence of paleochannels, any 'borrow pit' could be constructed to blend into the existing environment, ie, it would be 'just another depression' within the generally undulating landscape.

260. It is recommended that, should this site be considered further, piezometers be installed in the immediate vicinity of the proposed borrow pit. This would allow the depth to groundwater and seasonal groundwater dynamics to be defined more accurately. This would also allow the characteristics of the material beneath the site to be assessed more accurately.

261. The final potential material supply site is located just north of the Ohau River. Critically, this site would meet bulk fill material shortages for the northern section of the Project, in advance of the Ohau River bridge being opened.

262. This site lies on the floodplain, but above the currently active channel, of the Ohau River (*Figure G.37*). Although the site is close to the river, it is separated by some distance, a berm, and scrubby vegetation. This means

that the site is buffered from the river and fluvial processes under the current environment, except during larger flood events that overflow the channel. It should be noted, however, that the Ohau River is a highly dynamic environment, and the position of the active channel has varied significantly, both laterally and vertically, over time. The characteristics and behaviour of the Ohau River can also be affected naturally by catastrophic events such as extreme rainstorms, ex-tropical cyclones, and earthquakes which can trigger wide-scale slope failures and the input of large volumes of sediment and debris to the river.

Figure G.37: Conceptual layout for a potential borrow pit adjacent to the Ohau River.

263. Meanders within the Ohau River also migrate downstream over time. While channel management in the past has tended to stabilise the banks and river alignment, the goals of river management and channel control can change. These practices can have a significant effect on the stability and 'predictability' of the river and fluvial processes.

264. The surface topography in this area contains a network of paleo and overflow channels, cut-off and abandoned meanders, and incipient drainage lines. The drainage lines potentially active during a 10-year ARI (10% AEP) event are shown in *Figure G.38*. These features are all characteristic of an active floodplain. Consequently, any borrow pit or subsequent open-water pond and wetland could be constructed and rehabilitated to blend into the existing environment and over time would become part of the 'natural landscape'.

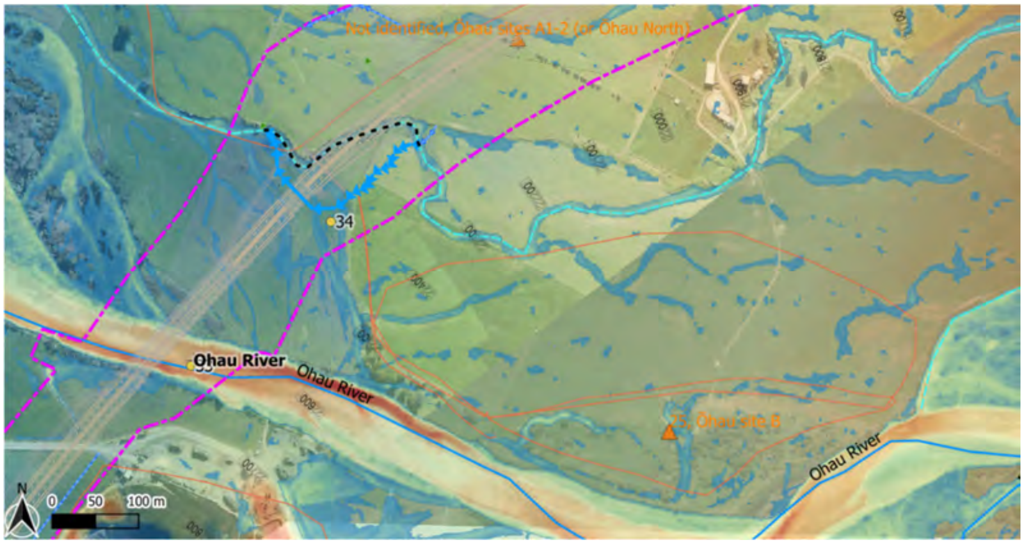

Figure G.38: **Existing potential overland flow paths in the wider vicinity of the proposed borrow pit adjacent to the Ohau River.**

265. Although there is no direct interaction of the Ohau River with the site, except during larger floods or extreme events as described above, the groundwater beneath the site is likely to have a hydraulic connection to the river. This is because the stratigraphy of the site includes various layers of alluvium, with material ranging from gravels to sand and silt depending on the position of the active channel when the material was deposited. However, the material at this site is likely to be relatively coarse because of its proximity to the Ohau River and the greywacke hill country.

266. Given the proximity to the Ohau River, and the generally coarse alluvium associated with the river at this location, groundwater flow is likely to be both rapid and parallel to the current course of the river. Groundwater flow is therefore likely to be east-west beneath the site (*Figure G.39*). Because of the proximity of this site to the Ohau River, both vertically and horizontally, the groundwater is also likely to be relatively shallow and highly responsive to flow conditions in the Ohau River.

267. The closest bore in the area (BH114) was drilled towards the end of winter in 2020 (*Figure G.40*). Although this is a relatively short period of record from which to establish longer term trends, the data confirm that the groundwater is relatively shallow, no deeper than 4m below the ground surface. The level of the groundwater is both sensitive and highly responsive to flow in the Ohau River. This results in a highly dynamic groundwater system with rises of at least 2m common in response to floods passing down the Ohau River.

Figure G.39: **Location of the potential material supply site just north of the Ohau River, and the inferred groundwater flow direction (blue arrow).**

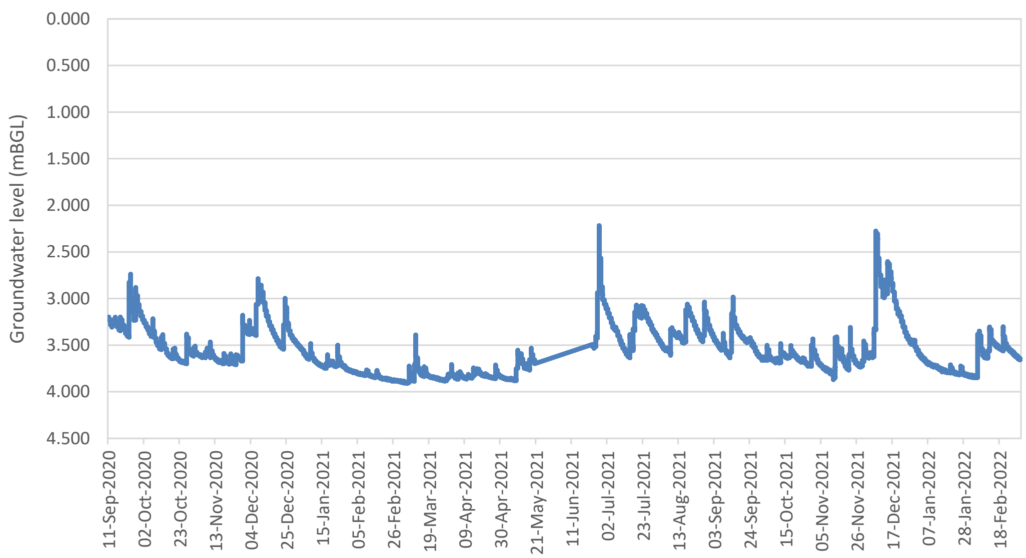

Figure G.40: **Depth to groundwater in BH114, and its response to flow in the Ohau River.**

268. The likely shallow depth to groundwater would restrict the amount of material that could be excavated without interacting with the groundwater system. However, should this site be subsequently developed into an open-water pond and wetland, the shallow depth to groundwater, hydraulic connection to the Ohau River, and highly dynamic groundwater system, would all be positive characteristics.

269. As discussed, there is no direct interaction between the Ohau River and the site of the proposed borrow pit under the current environment, except during relatively infrequent flood events that exceed the channel capacity, or catastrophic events that result in a large volume of sediment and debris entering the system. This situation will not change following construction of the borrow pit. The proposed works will also not affect the natural migration of meanders down the Ohau River.

270. During larger flood events, when water overflows the channel onto the adjacent banks, flow across the floodplain is generally shallow and of low velocity, with low bed shear stress. Therefore, floods tend to deposit sediment rather than erode material on the floodplain. Overbank flows are further slowed, and any potential erosion mitigated, by vegetation. Larger vegetation adjacent to the banks is particularly effective at retaining flow within the channel and slowing any overbank flow. This further mitigates any risk of erosion.

271. It is important to recognise that during larger flood events, the maximum velocity and bed shear stress is within the active channel and not on the adjacent floodplain. Consequently, floods tend to ‘enhance’ the existing channel. There may be some erosion on the outside of meanders where they are not protected and formed in alluvium, however, any erosion of the wider floodplain should be negligible. Floodplains tend to be areas of deposition rather than erosion.

272. The potential for rivers to avulse (change their position suddenly and dramatically) is generally related to rising bed levels and not larger flow events. The proposed works will have no effect on the level of the bed of the Ohau River, which will continue to respond to natural processes in the upper catchment and be managed by Horizons. Consequently, the works will have no effect on the risk of the Ohau River changing position.

273. The formation of the ‘borrow pit’ could provide some additional flood storage for the Ohau River, although the effect of this on the existing flood hazard would be relatively small and depend on the volume of the pit and the magnitude of the flood event. The effect of any pit would be greatest during smaller and more frequent events. To optimise the potential for flood storage this aspect of the borrow pit would need to be considered during the design process.

274. The formation of the borrow pit will therefore have no significant effect on the existing flood hazard or fluvial processes. It will also not increase the risk of the Ohau River changing its path or potentially eroding the floodplain adjacent to the existing channel.

275. Since the proposed borrow pit has the potential to intersect and interact with the groundwater, the site could be rehabilitated as an open-water pond and wetland. Essentially the borrow pit would form a ‘pond’ within the alluvial deposits of the floodplain. For most of the time, the hydrological processes would be supported by the inflow and outflow of groundwater. These processes will be similar to those operating at Winstone’s Ōtaki and Ashford Park quarries on the floodplain on the north bank of the Ōtaki River.

276. While the water level in the open-water pond and wetland will respond to fluctuating water levels in the Ohau River, there will be no direct interaction with the river most of the time.

277. During larger flood events, when water flows over the floodplain adjacent to the river, the depression in which the open-water pond and wetland would be formed will fill with water. As mentioned, this will provide a small amount of flood mitigation. The planting of the wetland, and that associated with the rehabilitation of the site, will mitigate any risk of erosion.

278. If it is decided to improve and increase the surface connection between the wetland and the river, to optimise environmental outcomes, this would involve the construction of engineered weirs at the upstream and downstream ends of the pond and wetland. These weirs would control flow into the wetland, both the amount and timing. The weirs would also mitigate any risk of erosion and ensure that flow across the floodplain occurs in a more predictable manner than at present.

279. Consequently, neither the construction of the borrow pit nor the formation of a wetland as part of the rehabilitation of the site will increase the existing flood hazard or the risk of the active channel of the Ohau River shifting and potentially affecting adjacent landowners or existing land use.

CONCLUSION AND RECOMMENDATIONS

280. Despite the relatively large scale of the Ō2NL Project, its actual and potential effects on the hydrogeology and groundwater of the area will be small and generally positive. There are several reasons for this:

(a) The magnitude of any potential effects is small relative to the size and existing dynamics of the receiving environment. For example, the potential Ō2NL Project footprint represents only 1.3% of piedmont / coastal plain it traverses, and a significantly smaller percentage of the total catchment area;

(b) The area has already been subject to significant land cover and land use change. Any changes caused by the Ō2NL Project will be extremely small relative to those that have occurred in the past;

(c) The design and construction of the Ō2NL Project will:

(i) Not alter the existing water balance of the area;

(ii) Avoid any direct interaction with the groundwater system;

(iii) Maintain existing hydraulic connections in both surface water and groundwater;

(iv) Maintain the existing hydraulic connections between surface water and groundwater;

(v) Improve the quality of groundwater; and

(vi) Maintain the quality and quantity of groundwater entering Punahau / Lake Horowhenua.

(d) Any actual and potential adverse effects of the Ō2NL Project will be avoided, and where necessary mitigated, through the design process and subsequent construction. A comprehensive CEMP, including a Groundwater Monitoring Plan, will be developed to monitor compliance with all relevant consent conditions.

(e) The proposed management and treatment of stormwater is likely to result in a slight increase in groundwater recharge and a small improvement in water quality. The treatment of any runoff and groundwater recharge will represent an improvement over many of the permitted land use activities which occur currently throughout the area.

281. In my professional opinion, any potential adverse effects of the Ō2NL Project on the groundwater system can be largely avoided because of the improved understanding now available. Despite the inherent uncertainty of groundwater systems, any effects of the Ō2NL Project will, in my opinion, be *‘less than minor’* and potentially positive. This is despite effects at a few

specific locations being potentially more than minor. These effects, however, will be offset by the various rehabilitation and offsetting measures that have been proposed.

282. It is possible that the Ō2NL Project may result in a slight increase in groundwater recharge and groundwater quality. This may have benefits to Punahau / Lake Horowhenua and Lake Papaitonga and potentially several springs throughout the area.

Dr John (Jack) McConchie

18 October 2022

APPENDIX G.1

Stantec (2022): Ōtaki to North Levin Highway – Hydrogeology and Groundwater Investigations. Report prepared for Waka Kotahi NZ Transport Agency, May 2022.

Ōtaki to North Levin Highway – Hydrogeology and Groundwater Investigation

PREPARED FOR Waka Kotahi | May 2022

We design with community in mind

Stantec

Revision Schedule

Rev No.	Date	Description	Signature or Typed Name (documentation on file)			
			Prepared by	Checked by	Reviewed by	Approved by
01	28/10/2021	Draft for review	James Dommisse	Hisham Zarour	Hisham Zarour	
02	02/06/2022	Draft for review	Mark Scaife	Vanessa Dally	Vanessa Dally	
03	07/07/2022	Final for client use	James Dommisse	Vanessa Dally	Hisham Zarour	Jon England

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Executive Summary

The Ōtaki to North Levin (Ō2NL) Project involves the construction, operation, use, and maintenance of a 24 km four-lane highway from Ōtaki to north of Levin.

This report provides a discussion of the hydrogeological setting and analysis of groundwater information collected along the length of the Project based on data collected as part of a series of geotechnical investigations by Stantec between May 2020 and November 2021. The site investigations were undertaken to gain a better understanding of the groundwater system beneath and adjacent to the proposed highway and avoid or mitigate any adverse potential impacts on groundwater. This report is an appendix to Technical Assessment G Hydrogeology & Groundwater.

The site investigations included 63 boreholes, 77 test pits, 36 Cone Penetration Test (CPT) holes, 57 monitoring bores, 10 hand auger holes, eight slug tests and nine soil infiltration tests.

Beneath the road alignment, the investigation data shows the water table closely mirroring the surface topography, ranging from ground level to 20 m below ground level (bgl). Springs and wetlands occur where the water table intersects the topographic surface, commonly at the base of terraces, although in some locations there are seepages on the sides of valleys and small hills. These valley and hill slope seepages may be perched or partially disconnected from the underlying, and deeper regional water table. Springs and wetlands are mostly found at the northern and southern ends of the Project whether the topography is much more undulating. The deepest groundwater levels generally occur east of Levin where there were few wetlands and no springs identified.

Groundwater levels beneath the Project (where data was available from nested monitoring bores) show a slight too relatively steep downward vertical hydraulic gradient as would be expected given the Projects location in a groundwater recharge zone near the Tararua ranges. As such, groundwater levels in more shallow bores (5 m – 15 mbgl), test pits and CPT holes were higher (0.25m - 10m) than in deeper bores at the same location. Groundwater levels in deep and shallow monitoring bores show very similar seasonal trends and responses to recharge events, suggesting that groundwater is acting as one large interconnected system.

Across an area east and just south of Levin Township, Eigen modelling was undertaken to predict groundwater levels collected during this investigation at daily intervals back to 1971. The purpose of this work was to predict the highest groundwater levels to assist with road design.

An assessment of wetland and forest fragment water sources, indicated that the majority of these features were connected to groundwater. Water source information was used to feed into site specific assessments of effects where road cuttings, temporary dewatering, or infiltration facilities were expected to effect groundwater levels. Assessments indicated that, while minor, there are some wetlands that will have temporary or permanent reductions in groundwater inflows.

1.0 INTRODUCTION

The proposed Ōtaki to North Levin (Ō2NL) highway (the Project) consists of a 300 m wide corridor and 24 km long 4-lane highway from north of Ōtaki to north of Levin (Figure 1). The Project will become the new State Highway 1 (SH1), replacing the existing SH1 and State Highway 57 along Arapaepae Road.

Between May 2020 and November 2021, Stantec undertook a series of geotechnical investigations reported in Stantec (2021a) and Stantec (2021b), which included the collection of groundwater data. This report provides a discussion and analysis of this information to assess groundwater conditions beneath and adjacent to the Project.

This report is an appendix to Technical Assessment G Hydrogeology & Groundwater. The technical assessment provides a discussion of the potential environment effects and core design principals of the Project. Management of potential effects during and post construction is to be covered off in the Groundwater Management Plan (GMP). The GMP will be a sub plan of the Construction Environmental Management Plan, which will be developed to monitor compliance with all relevant consent conditions.

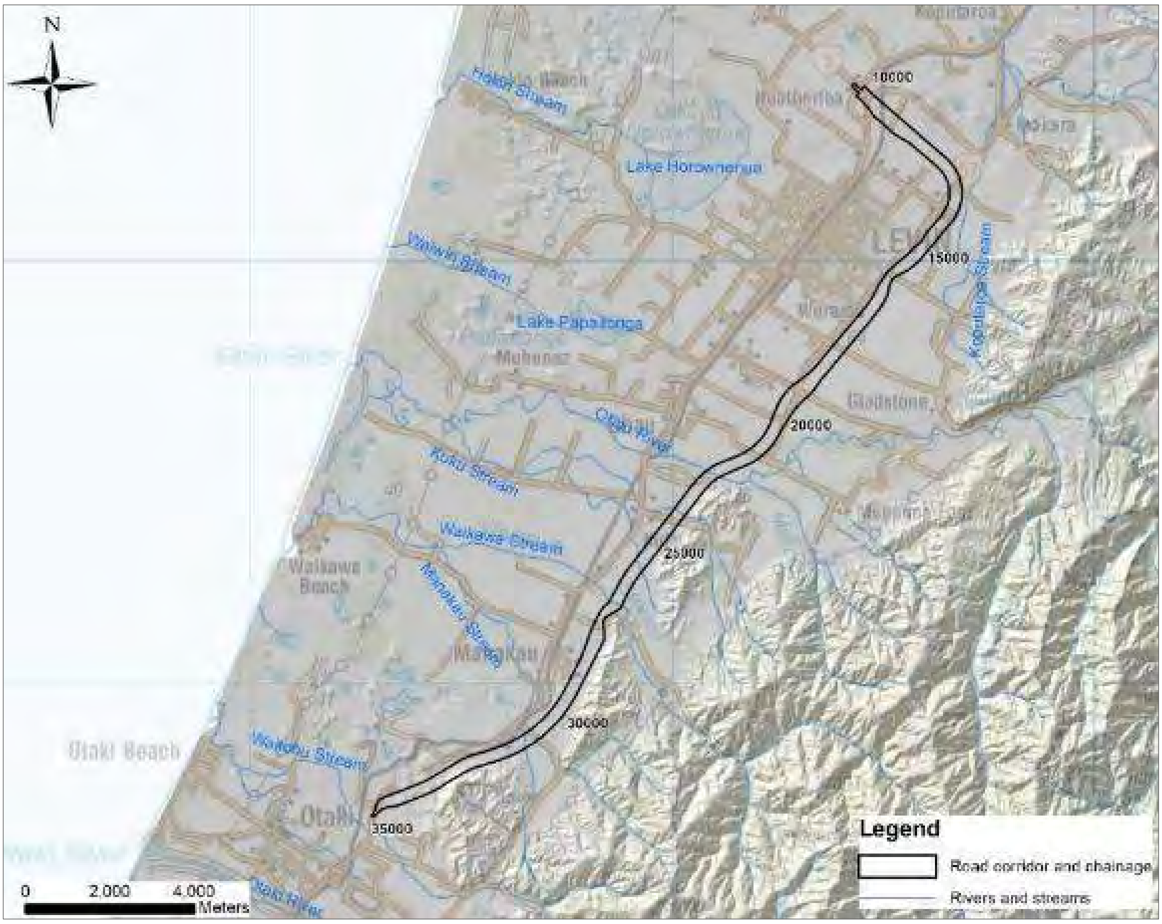


Figure 1 Location map showing the road corridor and main features in the area.

2.0 HYDROGEOLOGICAL SETTING

2.1 GEOLOGY

The geological setting is characterised by Last Glacial alluvium extending across the plains and dune sand deposits near the coast with greywacke basement outcrops forming the Taurarua Ranges in the east. Holocene (recent) age alluvial gravel deposits underlie the Ohau River and there are patches of Holocene swamp deposits adjacent to and possibly underneath Lake Horowhenua. Rivers are generally incised into late Pleistocene sediments, with lakes present within the interdune hollows and near the Poroutawhao Basement High. Figure 2 shows the QMap (Heron, 2014), simplified 1:250,000 geological map for the general Project area. The main geological units are described in Table 1 Geological units underlying the Project area.. More detailed information on the geology beneath the Project is provided in the Geotechnical Interpretation Report (Stantec, 2021b).

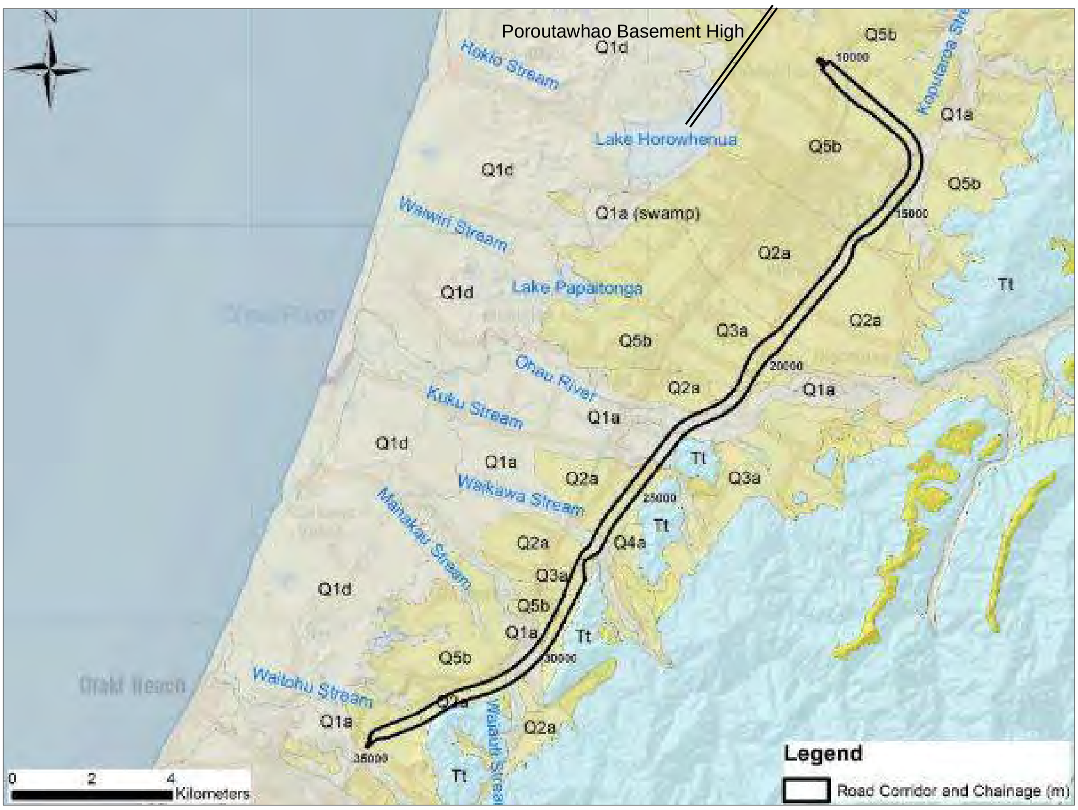


Figure 2 Simplified 1:250,000 geological map and road corridor.

Table 1 Geological units underlying the Project area.

Unit Map Label	Age and Depositional Environment	Description
Q1a	Holocene river deposits	Alluvial gravel, sand, silt, mud and clay with local peat, includes modern riverbeds.
Q2a	Late Pleistocene river deposits	Poorly to moderately sorted gravel with minor sand or silt underlying terraces; includes minor fan gravel.
Q2f	Late Pleistocene fan deposits	Poorly sorted steep fan gravel deposits
Q3a	Late Pleistocene river deposits	Weathered; poorly sorted to moderately sorted gravel underlying loess-covered; commonly eroded aggregational surfaces.
Q5b	Late Pleistocene shoreline deposits	Beach deposits consisting of marine gravel with sand; commonly underlying loess and fan deposits.
Q6a	Mid Pleistocene alluvium	Weathered; poorly sorted to moderately sorted gravel underlying loess-covered; commonly eroded aggregational surfaces.
Tt	Basement rock (greywacke)	Alternating sandstone, mudstone, poorly bedded, conglomerate, basalt, chert.

2.2 GROUNDWATER MANAGEMENT ZONES

Approximately 70% of the Project is located within the Horowhenua Groundwater Management Zone (HGMZ) administered by Horizons Regional Council (Horizons), with the northern part crossing into the Manawatu Groundwater Management Zone (MGMZ) (also administered by Horizons) (Figure 3)). The southern end of the Project is located within the Ōtaki Groundwater Management Zone (OGMZ) administered by Greater Wellington Regional Council (GWRC) (Figure 3).

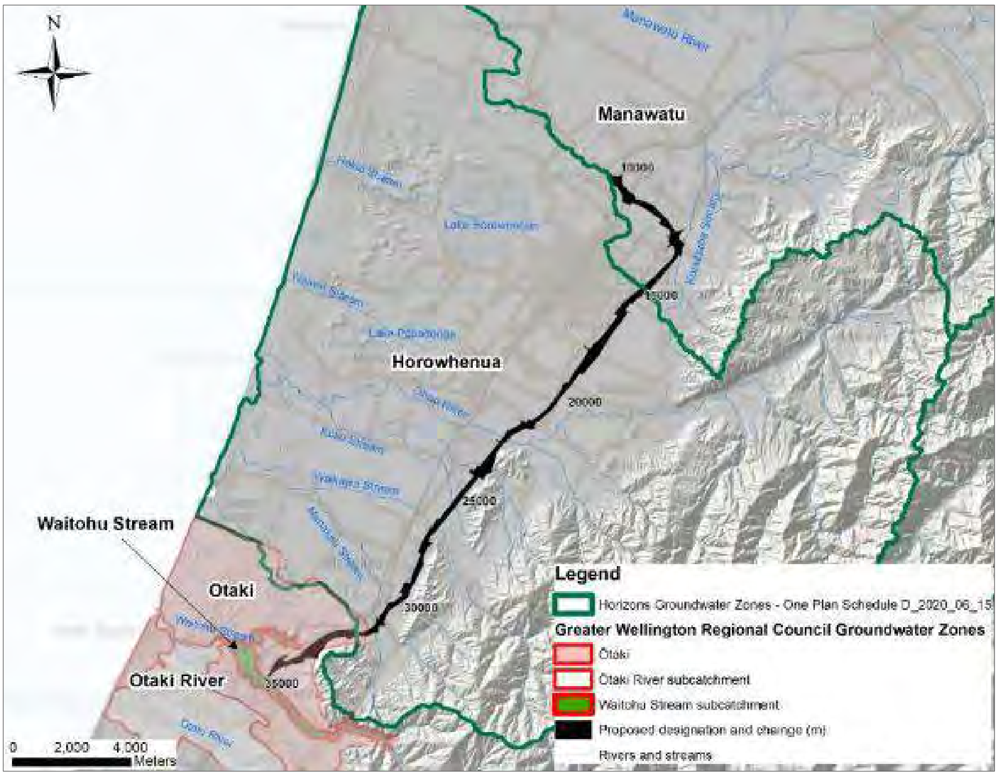


Figure 3 Regional council groundwater management zones (Source: Horizons and GWRC)

2.2.1 Horowhenua Groundwater Management Zone

The HGMZ covers 388 km^2 and extends from the Tararua Range foothills to the coast. Groundwater occurs within a multi-layered, unconfined and semi-confined (leaky) aquifer system. Unconfined aquifers are often underlain by silt and clay. There are up to four semi-confined sand/gravel aquifers, which become progressively more confined with depth. Unconfined aquifers are present across the entire HGMZ, ranging in thickness from 5 m to 40 m, with the water table from approximately ground level to 30 m below ground level (bgl). The aquifer system (unconfined and semi-confined) extends from 15 m to greater than 300 m bgl and is underlain by low permeability Tararua Range greywacke basement.

White *et al.* (2010) divided the HGMZ down further into nine sub-zones, four of which (Koputaroa East, Lake Horowhenua, Ohau and Waikawa) cross the Project (Figure 2-3). The HGMZ boundary defined by White *et al.* extends slightly further north compared to the more recent groundwater zone boundary marked in Horizons One Plan (Figure 3).

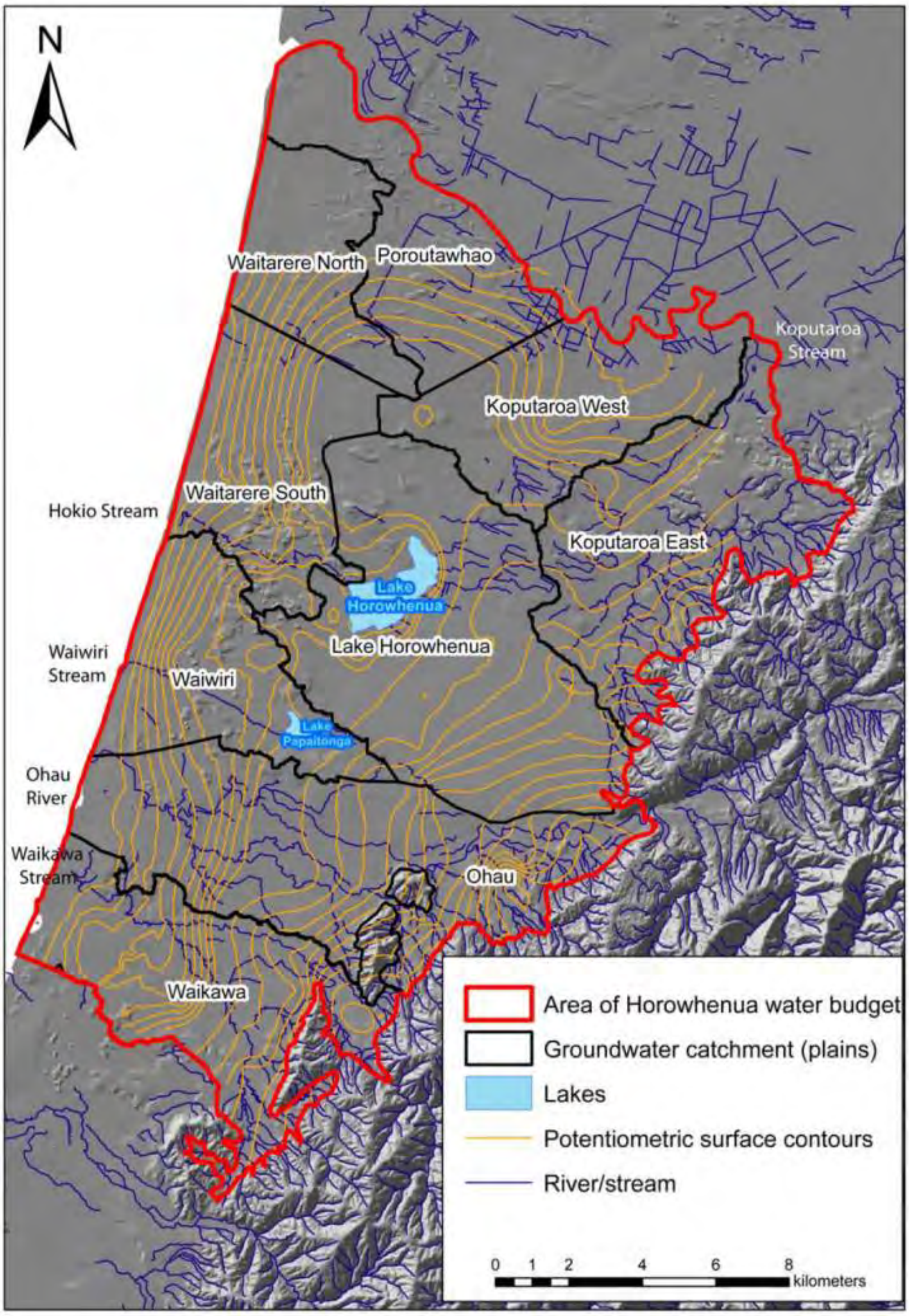


Figure 4 Groundwater sub-zones within the HGMZ (Source: White *et al.*, 2010)

2.2.1.1 Groundwater Balance

The two principal recharge sources to the groundwater system are rainfall infiltration through the land surface, and surface water leakage through the bed of the Ohau River. Smaller surface water drainage systems sourced at the foothills of the Tararua Ranges may provide some additional groundwater recharge. East of Levin, high soil infiltration rates result in most of the rainfall (minus evapotranspiration) being stored in the soil or recharging groundwater. Groundwater inflows from deeper aquifers and adjacent greywacke bedrock to the east are probably minor sources of groundwater in comparison (Gyopari, 2005).

The principal discharge components of the groundwater system are groundwater outflows to the sea, and leakage into rivers, lakes and streams (baseflow).

2.2.1.2 Horizontal Groundwater Flow Directions

Groundwater flow across the Project area is in a general east-west direction, from the Tararua Ranges to the coast, where it discharges directly into the Tasman Sea and indirectly through hydraulically connected surface water bodies such as Lake Horowhenua and various spring fed streams (Figure 5).

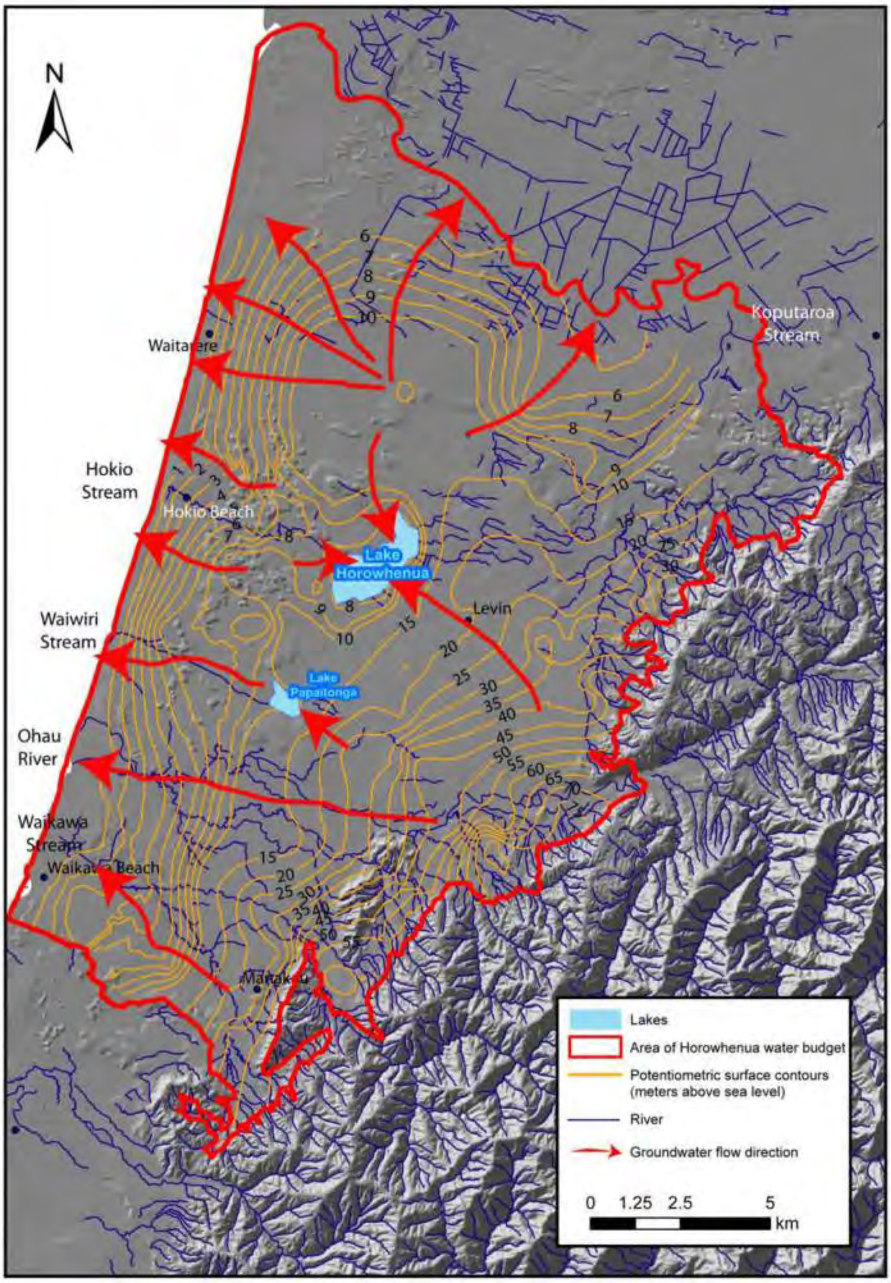


Figure 5 Groundwater flow direction in the HGMZ (Source: White *et al.*, 2010)

Near the Tararua Ranges, groundwater flows downward from the surface into deeper semi-confined sand and gravel aquifers. Near the coast and Lake Horowhenua, the vertical hydraulic gradient reverses with upward flow from the semi-confined aquifers into the shallow overlying unconfined aquifers and hydraulically connected surface water bodies.

2.2.1.3 Groundwater Levels

Groundwater levels within the HGMZ show a typical seasonal pattern of highs in late winter/spring, and lows in late summer. This pattern is typical of rainfall recharged groundwater as shown in Appendix B. Groundwater levels in bores range from artesian (above ground level) to approximately 40 m bgl depending on the bore screen depth and location. Typically, groundwater levels are deeper near the Tararua ranges and shallower near the coast. Seasonal variation ranges from approximately 1–15 m bgl, with larger seasonal variations east of Levin.

2.2.1.4 Surface Water Drainage

The HGMZ has limited natural surface water drainage features. This is noticeable between the Ohau River and Koputaroa Stream where Zarour (2008) described the area as having very high permeability material that is susceptible to direct rainfall recharge and little or no surface water run-off.

2.2.1.5 Groundwater/Surface Water Interaction

The main surface water bodies are Ohau River, Lake Horowhenua and Lake Papaitonga. Relatively small streams and lakes include Waikawa, Kuku and Koputaroa streams.

Lake Horowhenua

Lake Horowhenua is a major groundwater discharge point in the HGMZ. Groundwater moves through the more permeable gravel and sand, hitting a greywacke basement high forcing flow upwards into the base of the lake (Figure 6). The lake is also fed by multiple spring fed streams, the main one being Arawhata Stream (largest), Managaroa Stream and Patiki Stream. Queen Street Drain also feeds the lake but it is largely fed by urban stormwater. The most recent water balance undertaken by PDP (2019) estimated that 36–63% of the total lake inflow comes from direct seepage of groundwater through its bed and shoreline. This estimate excludes the groundwater flow component from spring fed streams flowing into the lake. Therefore, the total groundwater input is greater. The lake's groundwater capture zone extends from north Levin to Lake Papaitonga in the south, to the Tararua ranges in the east (PDP, 2019).

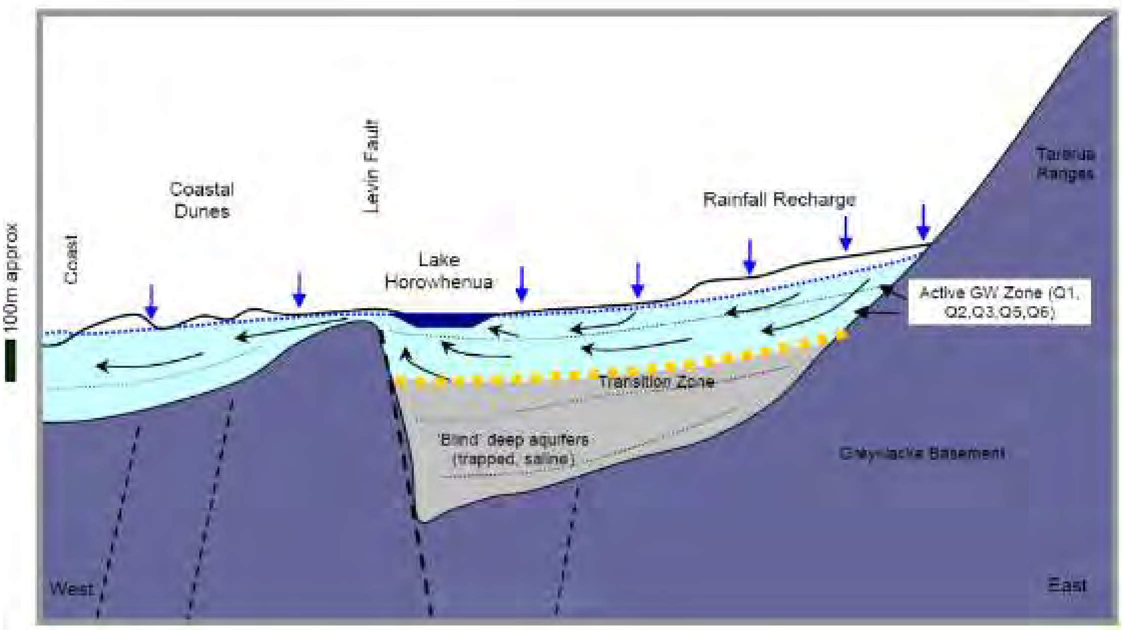


Figure 6 Conceptual hydrogeological cross-section for Horowhenua Lakes (source: Gyopari 2005)

Lake Papaitonga

Lake Papaitonga is the other major lake in in the area. Lake inflow appears to be dominated by groundwater in the form of springs emanating from a series of deeply entrenched gullies in the sandstone terrace on the eastern side of the lake (Gyopari, 2005). Springs may also occur at the base and sides of gullies. Flow in these springs has not been quantified. The lake's groundwater capture zone crosses the Project just south of Levin (PDP, 2017) ().

Ohau River

Seepage loss from the Ohau River is the main source of surface water recharge to the groundwater system (Zarour, 2008). The Ohau River is regarded as an important source of recharge to the younger glacial gravels, in particular, the Q2 and Q3 formations (Gyopari, 2005).

Springs

Figure 7 shows springs within the HGMZ. Most are located half-way between the ranges and the coast, within or adjacent to surface water drainage features or along the eastern edges of Lake Horowhenua and Lake Papaitonga. The rest are mainly clustered around Koputaroa Stream.

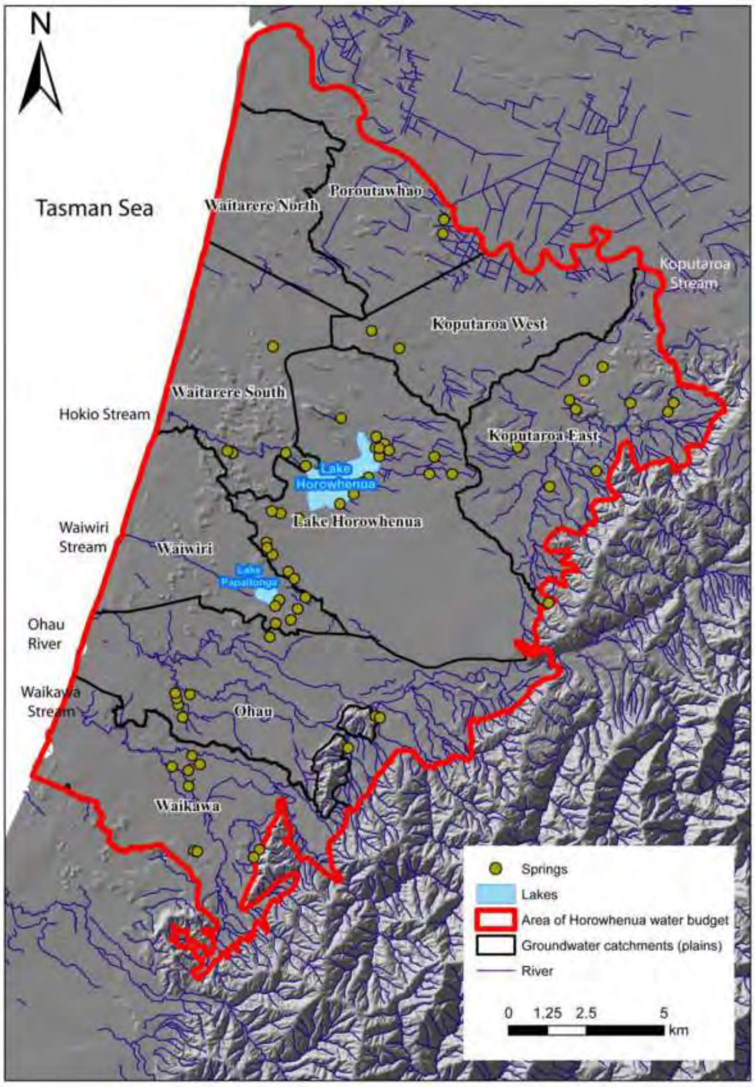


Figure 7 Springs in the HGMZ (Source: White *et al.*, 2010).

2.2.1.6 Existing Bores and Consented Groundwater Takes

As of 2022, there were 986 bores in the HGMZ, with a maximum depth of 277.3 m and a median of approximately 20 m. Bores in this area are generally low yielding <5 L/s (Zarour, 2008).

As of 2021 there were 46 permitted groundwater abstractions within the HGMZ. Consented takes range from 20 - 4098 m³/day and were mainly used for irrigation/water supply (73%), industrial supply (15%) and farm supply (12%). Non-consented shallow groundwater takes are extensively used for private drinking and stock water supply.

As of 2021 consented groundwater use was approximately 5 – 10% of the available allocation limit of 27,000,000 m³/yr in the Horizons One Plan. However, concerns about poor water quality in lakes, streams and rivers in the HGMZ have led to a revision in the amount of groundwater available in certain parts of the zone.

Groundwater Quality

The groundwater is generally high in Nitrate-Nitrogen and shallow groundwater is prone to microbiological contamination from intensive land uses such as dairy, sheep / beef and horticultural market gardens. The average Nitrate-Nitrogen concentration in groundwater is 10.3 mg/L[1] compared to the New Zealand drinking water Maximum Acceptable Value of 11.3 mg/L. The groundwater is also relatively high in iron and manganese with average total concentrations of 4.5 mg/l and 0.3 mg/L, respectively. In comparison the New Zealand drinking water Guideline Values is 0.2 mg/L for iron and 0.04 mg/L (laundry) / 0.1 mg/L (taste) for manganese, respectively.

2.2.2 Manawatu Groundwater Management Zone

A relatively small area of the Project north of Levin extends into the southern edge of the MGMZ. A natural groundwater flow divide (groundwater high, which can change due to recharge) separates it from the HGMZ. The MGMZ hosts much more bores and is extensively used for municipal, industrial, agricultural and domestic water supply. Groundwater flows through a sequence of Quaternary sediments towards the coast, with vertical movement limited by interbedded silts and clays. Preferential flow occurs through moderate-high yielding gravel and sand lenses. Beneath and adjacent to the Project, the MGMZ is characterised by shallow groundwater, springs, wetlands and the Koputaroa Stream.

2.2.3 Ōtaki Groundwater Management Zone

The OGMZ includes three main aquifers: (1) an unconfined aquifer to 10 m bgl, (2) a semi-confined aquifer at 10–20 m bgl, and (3) a semi-confined aquifer at >20 m bgl.

The unconfined aquifer consists of river gravels, sand and silt overlain by up to four metres of sand, silt and clay deposited during Ōtaki River flood events. Adjacent to the Ōtaki River, constant reworking of alluvial sediments has resulted in an unconfined, high-yielding aquifer, hydraulically connected to the Ōtaki River. Piezometric contours show that groundwater within the unconfined aquifer flows in a northwest direction towards the coast. The unconfined aquifer is predominantly recharged by surface water losses from the Ōtaki River and land surface recharge from rainfall (Mzila et al 2015).

The largest surface water features include Ōtaki River and Waitohu Stream, which are approximately 2.3 km, and 600 m south of the Project, respectively. Both surface water bodies show significant interaction with the unconfined aquifer, losing water downstream of their emergence from the Tararua foothills and gaining appreciable baseflow in their lower reaches near the coast (Mzila et al 2015).

[1] From Horizons bore water quality database (May 2021), 25 km radial search from centre of the Project.

2.3 EXISTING GROUNDWATER USERS

2.3.1 Community Supply

From a desktop study in September 2021, a total of 19 registered and unregistered community drinking water supply bores were identified within and near the Project (Figure 8). A search of the Horizons Online GIS data base included all groundwater community supplies in the HGMZ and MGMZ north to the Manawatu River and 2 km upgradient of the Project. For the GWRC area in the southern part of the Project, the search included all groundwater community supplies within the Ōtaki, Ōtaki River sub catchment (south to the Ōtaki River) and Waitohu Stream groundwater management zones. The GWRC data was sourced online from NRP - Schedule M2 - Drinking Groundwater Protection Areas (GWRC Open Data). Table 2-2 lists the three bores that have a source protection zone crossing the Project. All three bores are currently registered drinking water suppliers (see ESR, 2021).

Table 2. also includes one expired consented groundwater take for community supply in the Horizons region near Manakau that occurs within the proposed designation. The groundwater take is not on the ESR (2001) list of registered drinking water supplies, but the expired GWRC consent WGN140067 for community water supply occurs at the same location as the Glenmorgan community groundwater supply scheme. The Glenmorgan scheme provides water to 47 properties.

Table 2: Community drinking water suppliers potentially affected by the Project.

Owner / Regional Council	Groundwater Take Consent	ESR (2001) Information	Description
Unknown / Horizons	None identified	• Population served: Tatum Park Holiday Conference Centre • Population size: Less 25 people • Category: Self supplied • Source: G01860 Tatum Park Bore 1 • Source: G01476 Tatum Park Bore 2	Crosses source protection zone 2 marked by Horizons for Tatum Park 1 Bore (Horizons Bore ID – 362101) and Tatum Park 2 Bore (Horizons Bore ID – 362541). Both bores located approximately 700 m west of the Project. Source Protection Zone 2 is the area where microbiological contamination to the water supply might potentially occur.
Les & Christine / Horizons	GWRC consent WGN140067	None. Not listed as a registered supply	Glenmorgan water supply scheme. Identified as a community supply to 47 households based on discussions with landowners.
Kapiti District Council / GWRC	None identified	• Population served: Ōtaki Township • Population size: 5,700 • Category: Networked • Source: G01860 Ōtaki water supply Tasman Rd Bore	Southern edge of the Project crosses the source protection zone marked by GWRC for Tasman Road Bore (GWRC Bore ID – R25/5235).

2.3.2 Private Bores

Figures to 8-10 provide information on existing bore depths, uses and consented takes. General observations include:

1. Within the Project designation, 34 bores were identified. This included bores listed on regional council databases, private bores not listed on council databases and identified as part of this investigation, plus community supply bores. A further 104 bores are located within 250 m of the designation.
2. One consented groundwater take within the Project designation labelled S25/5419? (WGN140067) in Figure 11. However, there is no regional council bore listed at this site. The site of the consent does however, match the location of a bore not listed on any regional council data base and supplies water to the Glenmorgan water supply scheme (Table 3).
3. Domestic and irrigation are the main recorded groundwater uses.
4. The median bore depth is 22 m with 80% of the bores less than 40 m deep.
5. Very few bores east of Levin.
6. Very few bores with consent to take and use groundwater. Those that do are mainly for irrigation and stock supply.

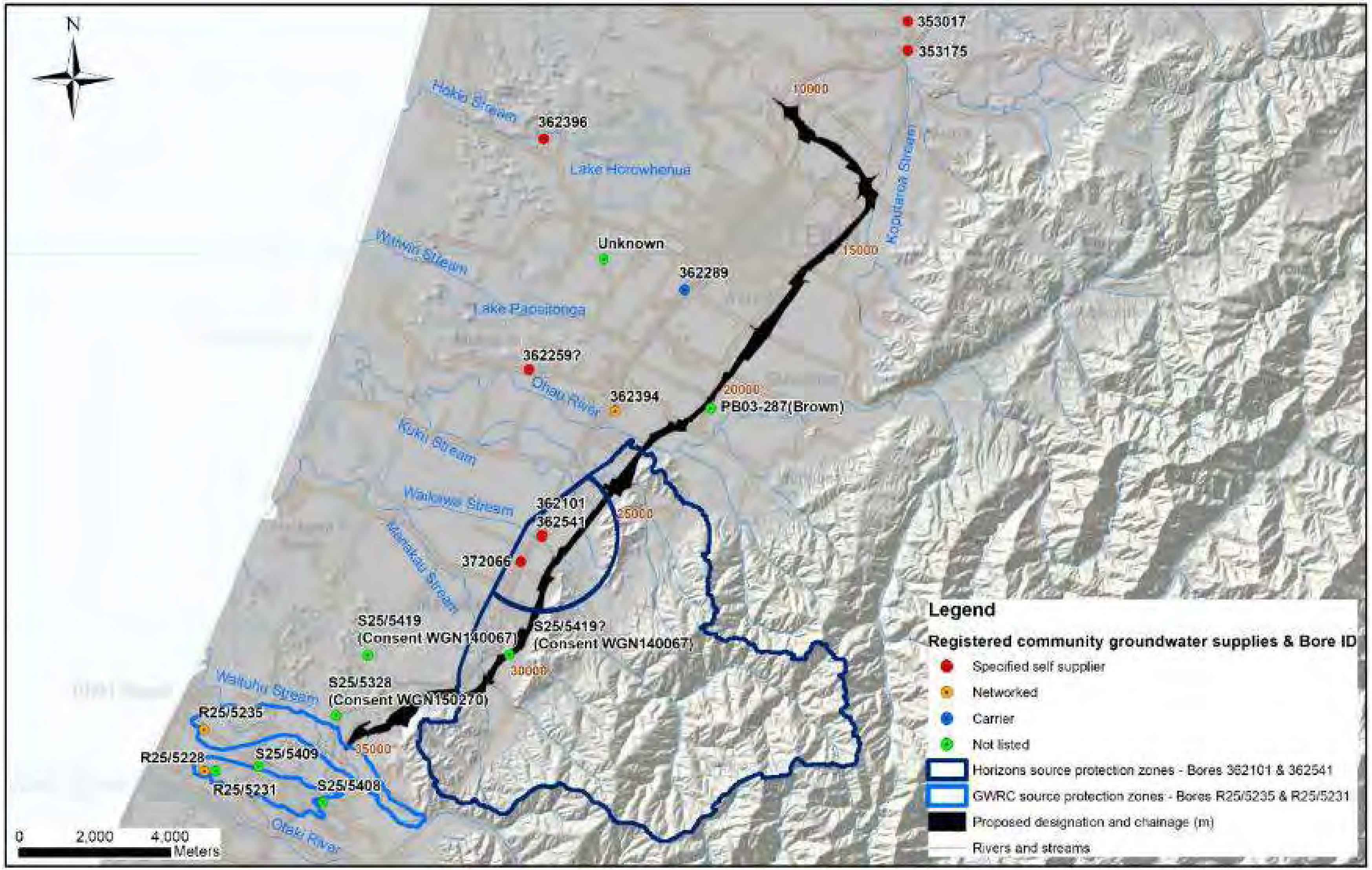


Figure 8 Community drinking water supplies and groundwater source protection zones marked by Horizons and GWRC as of September 2021

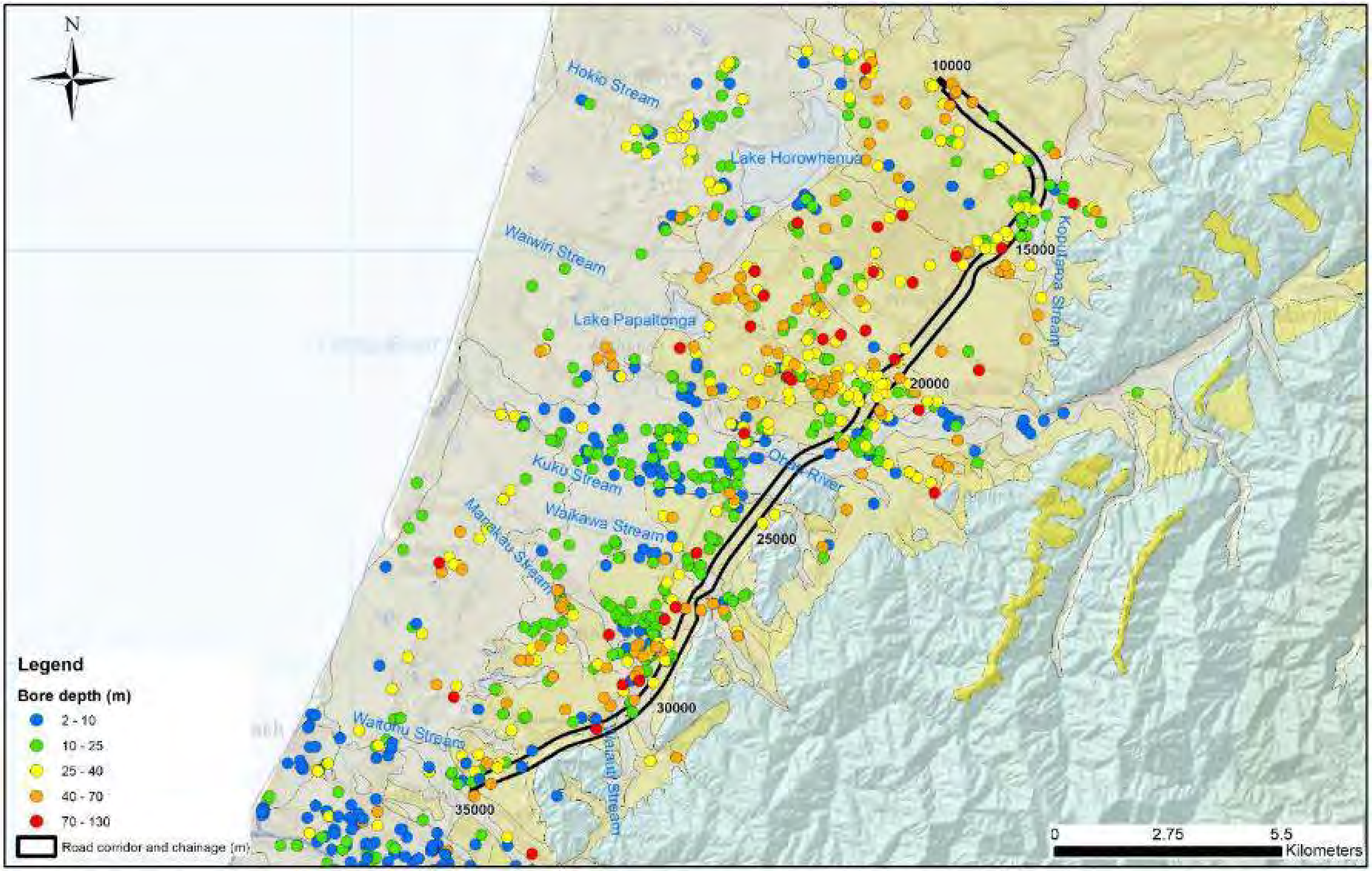


Figure 9 Bores with recorded depths as of June 2020 (bore data sourced from Horizons 'Bore Database' and GWRC online GIS):

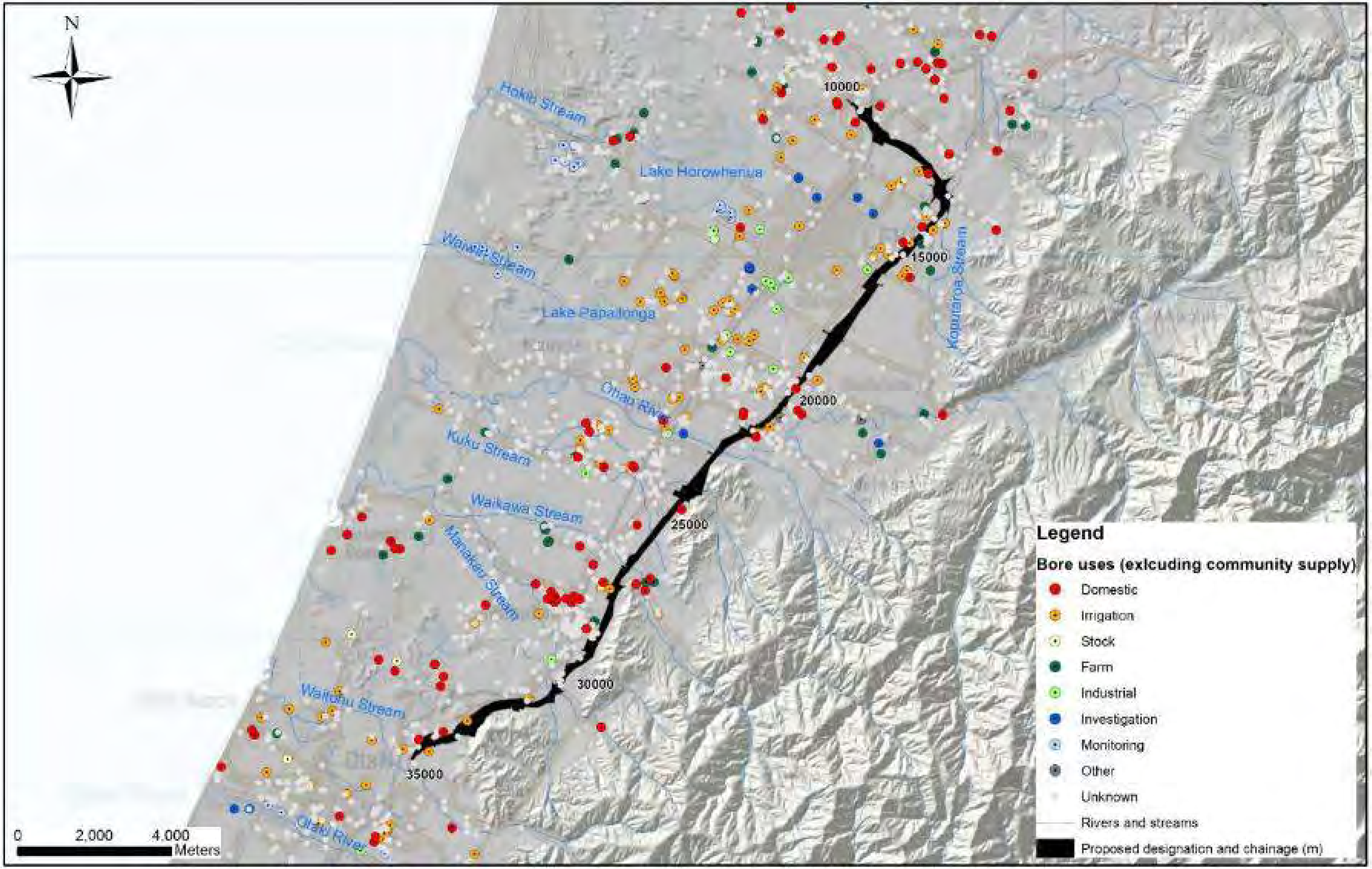


Figure 10 Bore uses excluding community supply as of May 2021 (bore data sourced from Horizons 'Bore Database' and GWRC online GIS)

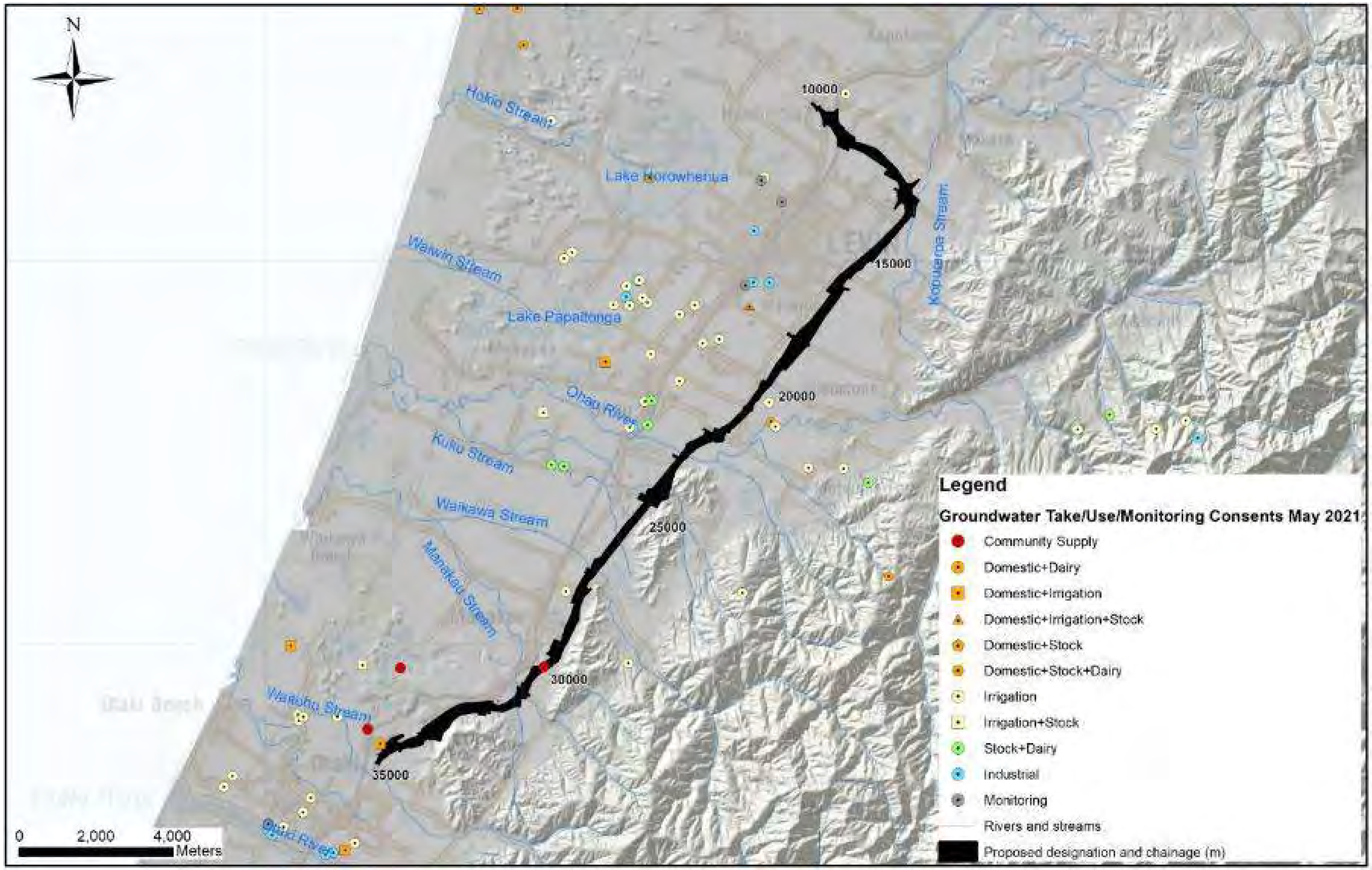


Figure 11 Consented groundwater take /use and groundwater monitoring consents as of May 2021

3.0 GROUNDWATER BENEATH THE PROJECT

3.1 PROJECT SPECIFIC DATA COLLECTION

Stantec undertook geotechnical investigations for the Project between May 2020 and November 2021 (Stantec 2021a, and Stantec 2021b). This work included:

1. 86 test pits
2. 63 boreholes
3. 57 monitoring bores
4. 36 Cone Penetration Test (CPT) holes
5. 10 hand auger holes
6. 9 soil infiltration tests
7. 8 slug tests

This information provided a greater understanding of depth to groundwater, groundwater level variations with time, maximum high groundwater levels, hydraulic properties, and dominant sources of groundwater recharge beneath and immediately adjacent to the Project. Figure 3-1 shows the location of monitoring bores installed by Griffths Drilling and supervised by Stantec, a monitoring bore installation supervised by GHD, and regional council long-term groundwater level monitoring bores. In addition, the Project designation is broken down in seven geomorphic zones, which approximate those defined in the Ō2NL Geotechnical Interpretive Report (Stantec, 2021b).

Twelve pairs of nested monitoring bores were installed to compare groundwater levels at shallow and deep levels in the groundwater system. Most bores were constructed of PN12, 32 mm diameter uPVC with 0.5 mm diameter slotted screens. A few were also constructed of PN12, 50 mm diameter uPVC. Monitoring bore, test pit and CPT details are provided in Appendix A.

Groundwater levels were measured in boreholes during drilling, test pits, 58 monitoring bores and from CPT test data. Manual groundwater level readings were taken from each monitoring bore at weekly to bi-monthly intervals using an electric dip meter. Non-vented pressure transducers recording water levels at 30-minute intervals were installed in 37 of the 57 monitoring bores. The data was compensated for barometric pressure using air pressure barometric pressure transducers located at locations along the length of the Project.

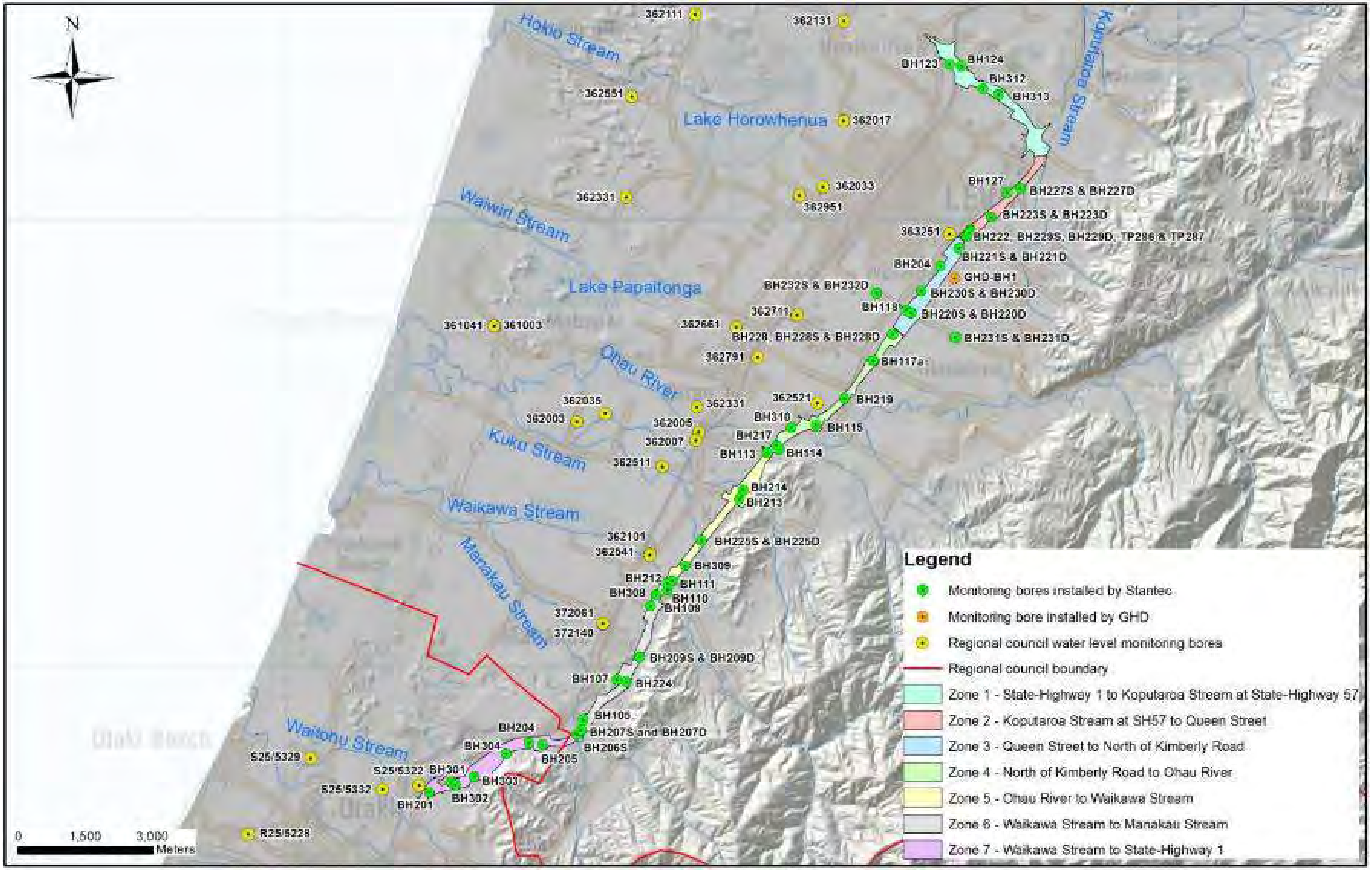

N
Hokio Stream
Lake Horowhenua
Koputaroa Stream
Waiwiri Stream
Lake Papaitonga
Ohau River
Kuku Stream
Waikawa Stream
Manakau Stream
Waitohu Stream
Legend
Monitoring bores installed by Stantec
Monitoring bore installed by GHD
Regional council water level monitoring bores
Regional council boundary
Zone 1 - State-Highway 1 to Koputaroa Stream at State-Highway 57
Zone 2 - Koputaroa Stream at SH57 to Queen Street
Zone 3 - Queen Street to North of Kimberly Road
Zone 4 - North of Kimberly Road to Ohau River
Zone 5 - Ohau River to Waikawa Stream
Zone 6 - Waikawa Stream to Manakau Stream
Zone 7 - Waikawa Stream to State-Highway 1
0 1,500 3,000 Meters

Figure 12 Groundwater monitoring bores

3.2 GROUNDWATER LEVELS

3.2.1 Observations and Trends

Figure 13 shows the initial depth to groundwater recorded on the regional council databases versus the highest groundwater level observed from shallow Project monitoring bores (≲ 15 m deep), test pits (<5 m deep), and shallow CPT holes (≲ 15 m deep) between December 2020 and September 2021. The purpose of Figure 13 is to show how the highest groundwater levels measured during this investigation compare against the knowledge of groundwater in the area prior to undertaking these investigations. Figure 14 represents a cross-section showing the highest and lowest observed groundwater levels along a transect through the shallow monitoring sites described above. For comparison, Figure 14 also shows groundwater levels in deeper Project monitoring bores and CPT holes (≳ 15 m depth). Key observations are:

1. Monitoring bore and CPT holes deeper than 15 m generally have groundwater levels as much as 15 m deeper than shallower bores and CPT holes. This is also clearly shown in many of the nested monitoring bores where groundwater levels in the deeper bores are at times more than 5 m deeper (see Appendix C). The result is a downward vertical gradient with groundwater flow from the unconfined to the deeper more confined aquifers beneath most of the Project. These conditions are expected given the Projects location in a groundwater recharge area near the base of the Taraura ranges. The variation in groundwater levels with depth probably reflects a high level of stratification and numerous discontinuous lower permeability layers of fine sand, silt and clay, which restrict the vertical movement of groundwater and produce relatively large vertical hydraulic gradients.
2. Largest unsaturated zone of 5–10 m and greatest groundwater level variability observed east of Levin. The high groundwater level variability may be partly due to deeper water levels and lack of groundwater drainage features, as well as a significant proportion of the rainfall draining through the soil allowing for rapid groundwater recharge. Other contributing factors may include recharge from streams draining the Tararua ranges, distance from the Ohau River and aquifer hydraulic properties (relatively low storativity hydraulic conductivity).
3. Generally, there is higher groundwater levels at the Project monitoring sites compared with the static water levels recorded for bores on the regional council databases. This is most noticeable east of Levin and south of Waikawa Stream. Causes may include well drillers preferentially targeting deeper groundwater for higher yields and better-quality water, and longer-term monitoring from the Project capturing higher groundwater levels over winter.
4. One 31 m deep bore (ID 362522) screened from 29-31 m deep is described as flowing artesian in the Horizons bore database. This bore is located on the south-eastern edge of the Project designation and approximately 500 m north of the Ohau River. The bore was drilled in 1981 and recorded an initial depth to water of 0.8m on 9/12/1981, suggesting approximately 0.8m artesian head above ground level. However, no flowing artesian groundwater was encountered to date from the Project monitoring bores which ranged in depth from 2 m to 35 m below land surface.
5. The water table is a subdued replica of the land surface and in general ranges between 0.5 m above ground level to between 10–15 m bgl.
6. The cross section (Figure 3-3) shows where the water table is likely to intercept the land surface along the Project length, resulting in groundwater seepages, springs and potential groundwater flow into streams.
7. Figure 3-3 shows the observed groundwater levels from the Project monitoring bores, test pits, and CPT holes as well as the highest predicted and interpolated groundwater levels east of Levin. The predictions suggest there is generally at least 2–4 m of permanently dry (unsaturated) sediment beneath sections of the Project east of Levin. Further details provided in Section 3.2.3.

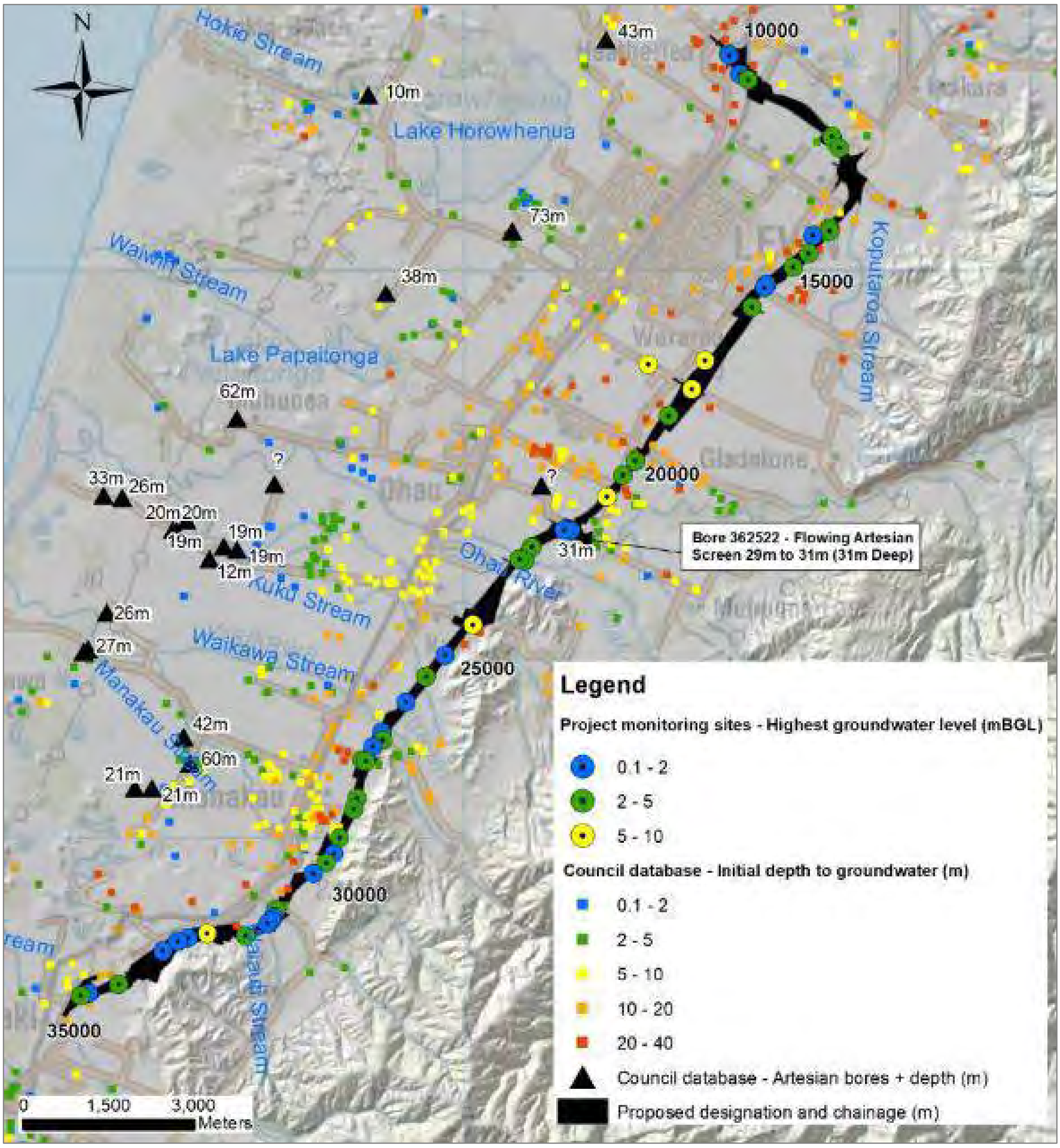


Figure 13 Depth to groundwater from the Horizons and GWRC bore database and highest groundwater level measured from shallow Project monitoring bores, test pits and CPTs.

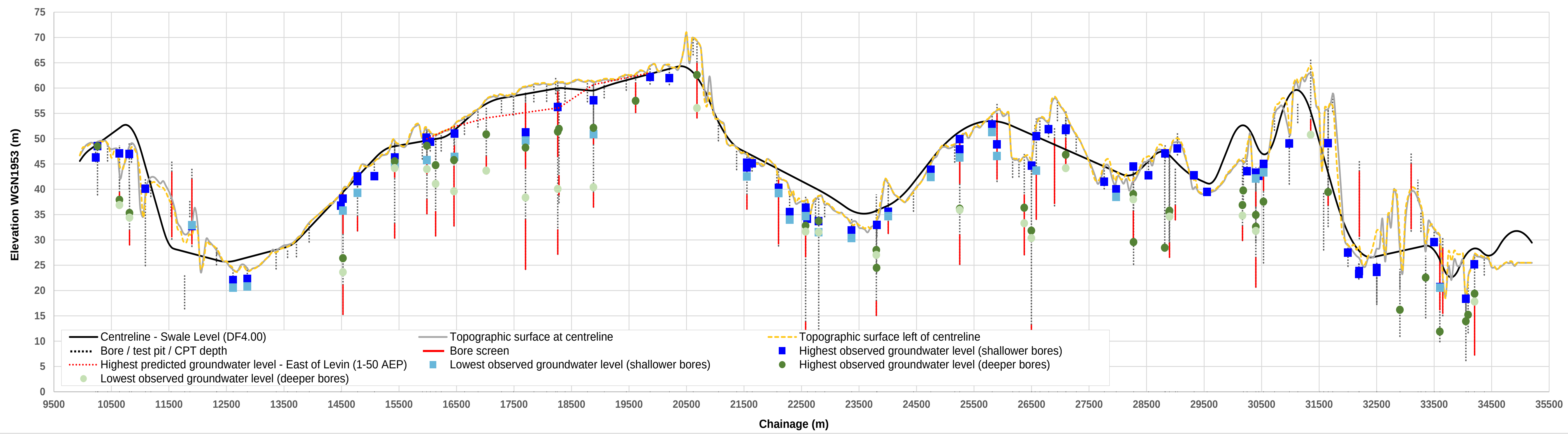


Figure 142 D section showing DF4.0 vertical alignment 1.25 m below centreline (swale invert), observed groundwater levels from Project monitoring bores, test pits, and CPT's and the highest predicted groundwater levels east of Levin (red dashed line).

3.2.2 Variations with Time

Groundwater level hydrographs for the monitored bores within the Project area are presented in Appendix B. The monitoring data has been broken into roughly the same seven geomorphic zones defined in the Ō2NL Geotechnical Interpretive Report (Stantec, 2021b). These zones are shown in Figure 12 and were based on geological features, boundaries and lithology.

The total daily rainfall and the monthly accumulative residual rainfall (1959 to February 2022) from Levin (at climate station Levin Aws) is also plotted to better understand the effects of land surface recharge. A summary of the groundwater level variations by geomorphic zone in order from north to south is provided in Table 3-1. Key observations over the period of monitoring (September 2020 to March 2022) are:

1. Highest groundwater levels of 0 m to 0.3 m below ground level recorded in shallow bores screened less than 15 m deep located in zones 2, 5 and 6. These highest groundwater levels occurred along Waihou Road (east of Levin), adjacent to Kuku Stream south branch tributary and east of Manakau Township.
2. Lowest groundwater levels and the highest groundwater level variation is to the east of Levin from south of Queen Street to McLeavy Road.
3. Generally larger groundwater water level variations are observed in bores screened deeper than 15 m.
4. Bores adjacent to Ohau River, Kuku Stream, Waikawa Stream and Manakau Stream all show potential water level responses to changes in river / stream flow. In addition, there may be periods of time when flow changes in these surface water bodies are affected by adjacent groundwater.
5. The time lag response to rainfall recharge ranges from hours to ten days in some deeper bores (screened > 15 m bgl). Some deeper bores east of Levin show a lag time of up to two days behind the shallower bores. The lag time is probably the result of restricted vertical downward flow of groundwater as reflected by the relatively large vertical hydraulic gradients in some locations. Despite various time lag differences, the deep and shallow bores follow a very similar trend, suggesting that groundwater is acting as one large interconnected system together with the associated surface waterways.

Table 3: Observed groundwater level variations from individual monitoring bores within and adjacent to the proposed designation.

Geomorphic Zone (Stantec, (2021b)	Groundwater Zone – Sub Zone (Figure 2-2 & Figure 2-3)	Geology (summary from Stantec 2021b)	Monitoring bores	Bores screened < 15 m deep		Bores screened > 15 m deep		Recharge sources
				Water depth below ground level (m)	Water level variation (m)	Water depth below ground level (m)	Water level variation (m)	
1 (SH1 to Koputaroa Stream at SH57)	MGMZ – Koputaroa East	Shoreline beach and dune sand deposits (Q5b) overlain by loess (Q5b) and alluvial sediment near existing and historical waterways.	4	6 – > 12	0.5	Not measured	Not measured	Rainfall
2 (Koputaroa Stream at SH57 to Queen Street)	HGMZ – Koputaroa East / Lake Horowhenua	Shoreline beach and dune sand deposits (Q5b) overlain by loess (Q5b) and silty clay and clayey sandy gravel near Koputaroa Stream (Q1a).	10	0 – 6	2 – 3	3 – 17	3 – 4	Rainfall Koputaroa Stream (?)
3 (Queen Street to North of Kimberly Road)	HGMZ – Lake Horowhenua	Shoreline beach and dune sand deposits (Q5b) near Queen Street and alluvium gravel with minor sand or silt (Q2a/Q3a) south to Kimberly Road.	8	1.5 – 15	4 – > 8	7 – > 20	5 – > 12	Rainfall Ohau River (?)
4 (North of Kimberly Road to Ohau River)	HGMZ – Lake Horowhenua	Silt / Clay, silty gravel alluvium (Q2a/Q3a), and shoreline beach and dune sand deposits (Q5b) overlain by loess (Q5b), and silty clayey gravel alluvium near the Ohau River (Q1a).	8	1.5 – > 10	1 – > 7	5 – > 20	2 – > 11	Rainfall Ohau River

Geomorphic Zone (Stantec, (2021b)	Groundwater Zone – Sub Zone (Figure 2-2 & Figure 2-3)	Geology (summary from Stantec 2021b)	Monitoring bores	Bores screened < 15 m deep		Bores screened > 15 m deep		Recharge sources
				Water depth below ground level (m)	Water level variation (m)	Water depth below ground level (m)	Water level variation (m)	
5 (Ohau River to Waikawa Stream)	HGMZ – Ohau	Silt / Clay, silty gravel alluvium (Q2a/Q3a), overlain by loess (Q5b), and silty clayey gravel alluvium near the Ohau River and Waikawa Stream (Q1a).	9	0.2 – 13	1 – 5	11 – 14	2	Rainfall Ohau River Kuku Stream (?) Waikawa Stream (?)
6 (Waikawa Stream to Manakau Stream)	HGMZ – Waikawa	Shoreline beach and dune sand deposits (Q5b), alluvium silt / clay and silty gravel (Q2a/Q3a & Q6a), overlain by loess (Q5b) and silty clayey gravel alluvium (Q1a) near Manakau and Waikawa Streams.	10	0.3 – 10	2 – 7	7 – >19	2 – >3	Rainfall Manakau Stream Waikawa Stream (?)
7 (Manakau Stream to SH1)	OGMZ	Shoreline beach and dune sand deposits (Q5b), alluvium silt / clay and silty gravel (Q2a/Q3a & Q6a), overlain by loess (Q5b).	7	6 – 12	>1	8 – 19	1.5 – >3	Rainfall Manakau Stream

3.2.3 Predictions East of Levin

Groundwater Eigen models were constructed to predict the maximum groundwater levels at five bores east and southeast of Levin to assist with predicting potential impacts from the Project. The bore locations are shown in Figure 15.

3.2.3.1 Model Description

The selected approach was an Eigen model (Bidwell, 2003) coupled with a soil moisture balance (SMB) model. The sole source of water driving the groundwater level response predicted by the Eigen model was land surface recharge (LSR) from rainfall, which was output from the SMB model. The SMB model used total daily rainfall and evapotranspiration (penman monteith) from a NIWA Virtual Climate Station (VCS) at Levin to get a long-term un-broken record of evapotranspiration. The SMB and Eigen models were coupled and calibrated together. The resultants predications were an average groundwater level every single day from the end of monitoring back to 31 December 1971. The predictions therefore cover a period of approximately 50 years.

Four bores were selected for modelling from Queen Street south to Kimberley Road. These bores were BH221A (screen, 4 m –7 m), GHD-BH01 (screen, 9.5 m - 12.5 m), BH118 (screen 17 m – 21 m) and BH228S (screen, 9 m – 12 m). A shallower bore, BH230S (screened from 2 m – 15 m) exists close to BH118, however there was insufficient data available for model calibration at the time of undertaking this analysis.

3.2.3.2 Calibration

The SMB and Eigen models were calibrated simultaneously to observed daily average groundwater levels. Daily average levels were less than 20 cm lower than the highest observed groundwater levels; therefore, daily stress periods were considered appropriate. Table 4 shows the SMB and Eigen model parameters varied during calibration, parameter constraints and justification. Modelled versus observed groundwater levels are shown in Appendix D.

Table 4: Model parameters, constraints and basis for constraints

Model	Calibration parameters	Parameter constraints	Basis for constraints
Eigen	Lowest groundwater level (m)	None	Based on best fit.
	Vadose zone travel time (day)	≥ 1	Daily model stress period.
	Aquifer storage coefficient (dimensionless)	0.0001 – 0.3	Typical values for semi-confined and unconfined aquifers.
	Aquifer dynamic time response (T/SL^2) where T = Transmissivity (m^2/d), S = Storage coefficient, L = Length of aquifer (m) in horizontal direction of groundwater flow	> 0 – Infinity	Must be greater than 0.
SMB	Profile available water for a rooting depth of 0.5 m to 0.7 m (mm)	90 –200	Fundamental soils layer. Highest scaled to 0.7 m maximum rooting depth as most land in pasture.
	Evapotranspiration reduction factor (dimensionless)	8 – 13	For depletion factor[2] 0.4 – 0.6.
	Crop coefficient for grazed pasture (dimensionless)	0.75 – 1.05	Allen *et al.* (1998) Table 12.
	Maximum land surface recharge in one day (mm)	86	Highest daily rainfall. SMB assumes no rainfall run-off.

[2] Fraction of profile available water depleted from the root zone before moisture stress (reduction in evapotranspiration) occurs.

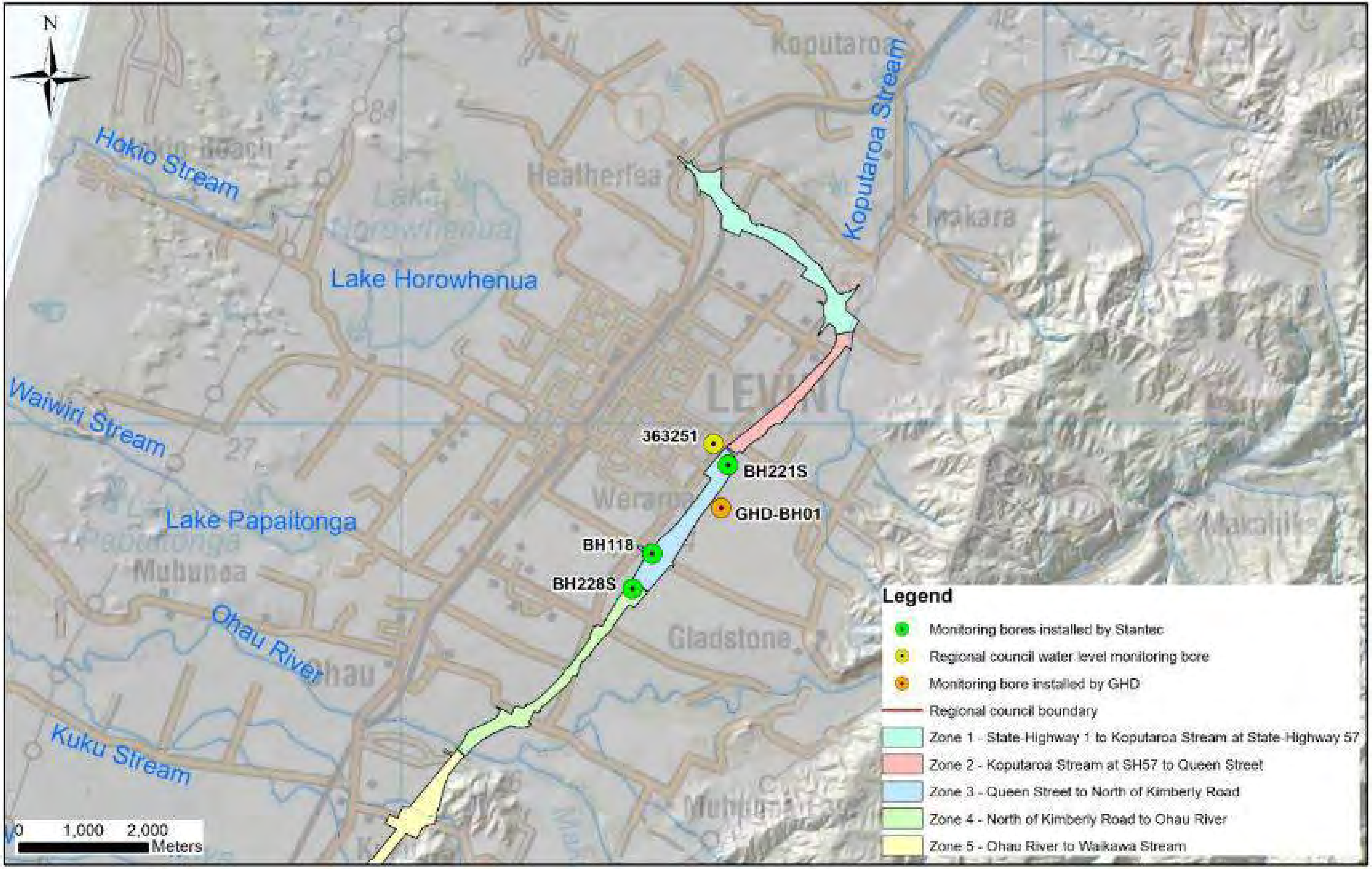


Figure 15 Monitoring bores used for Eigen model groundwater level predictions

In addition to the calibration parameters listed in Table 4, aquifer length in the direction of groundwater flow (L) was assumed to be approximately 14,000 m based on distance from Tararua Ranges (no flow boundary) to the coast (constant head boundary). The prediction location (x) was based on the bore's distance from the Tararua Ranges (upgradient boundary). Values for both L and x were fixed in the model. Calibration was non-unique with similar fits to the observed data providing different predictive results. As a result, two calibrations were undertaken to assess the potential range of predicted groundwater levels.

3.2.3.3 Predictive Modelling Results

The hydrographs presented in Appendix C show three main high groundwater level events occurring in 1974, 1998 and 2015. The peak groundwater level during these events lasted for one to three weeks. The model predictions, of which the results are presented in Appendix D, suggest that groundwater levels over winter 2021 were average to high.

The hydrographs in Appendix C also show that the model does well to predict groundwater levels over a longer period of time (Horizons monitoring bore 363251 located about 500 m down-gradient of the Project east of Levin). Figure 16 shows the predicted groundwater levels in each bore, and each calibration as the percentage of time below the highest groundwater level (lowest depth to groundwater).

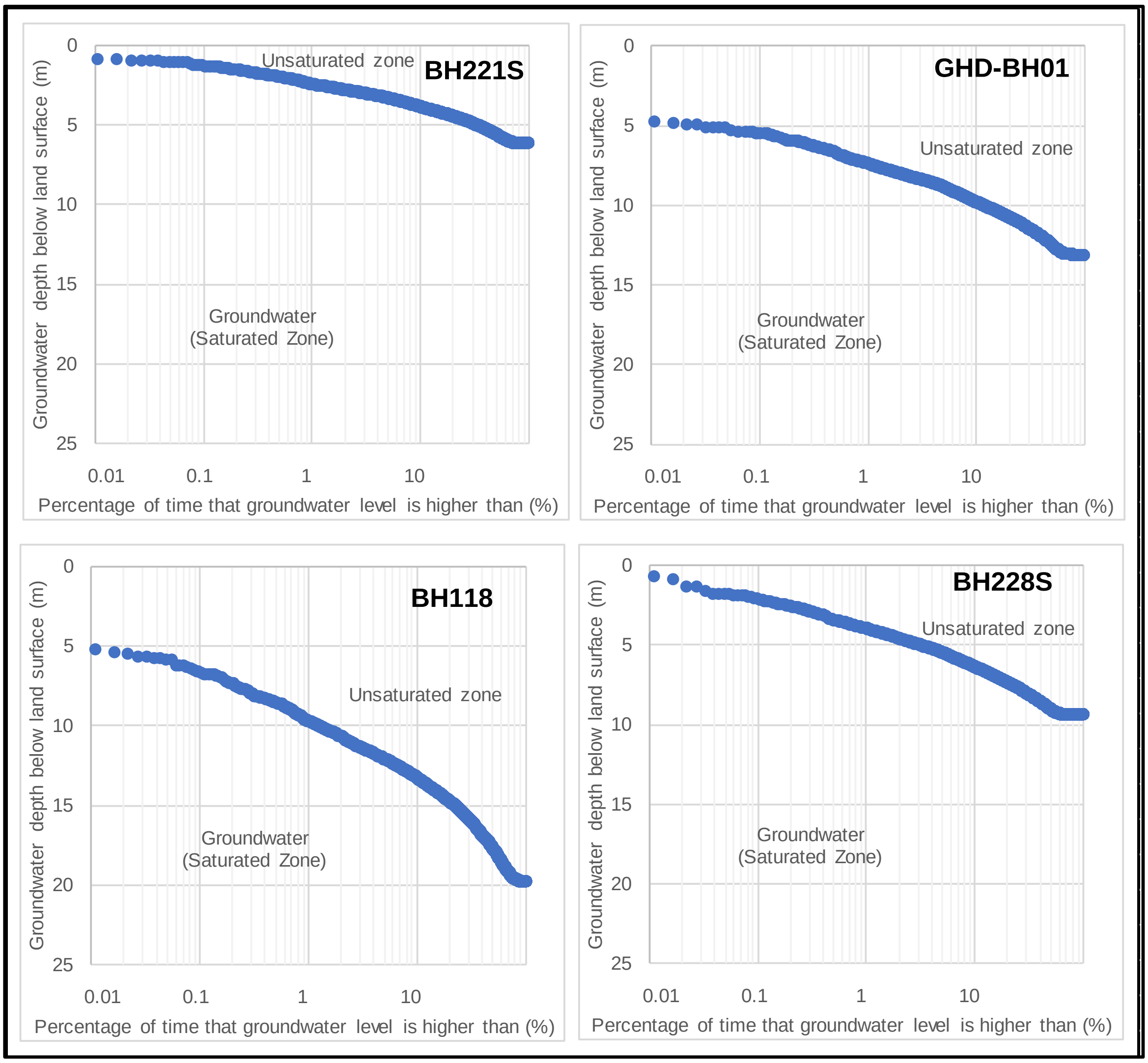


Figure 16 Groundwater level predictions east of Levin.

Figure 16 shows the highest groundwater levels occur for relatively short periods of time. For example, water levels in BH118 were predicted to be lower than 5 m bgl for 99.7% of the time between 1971 and 2021. The graphs also show that in general, depth to groundwater is lowest near BH118 at Tararua Road, becoming shallower north towards Queen Street and south towards the Ohau River (for location see Figure 16).

3.3 Groundwater / Surface Water Interaction

Figure 17 shows the where the groundwater capture zone for Lake Horowhenua, Lake Papaitonga and Te Hakari wetland intersect the Project alignment. The intersection points are based on capture zones provided in PDP (2017) and PDP (2019).

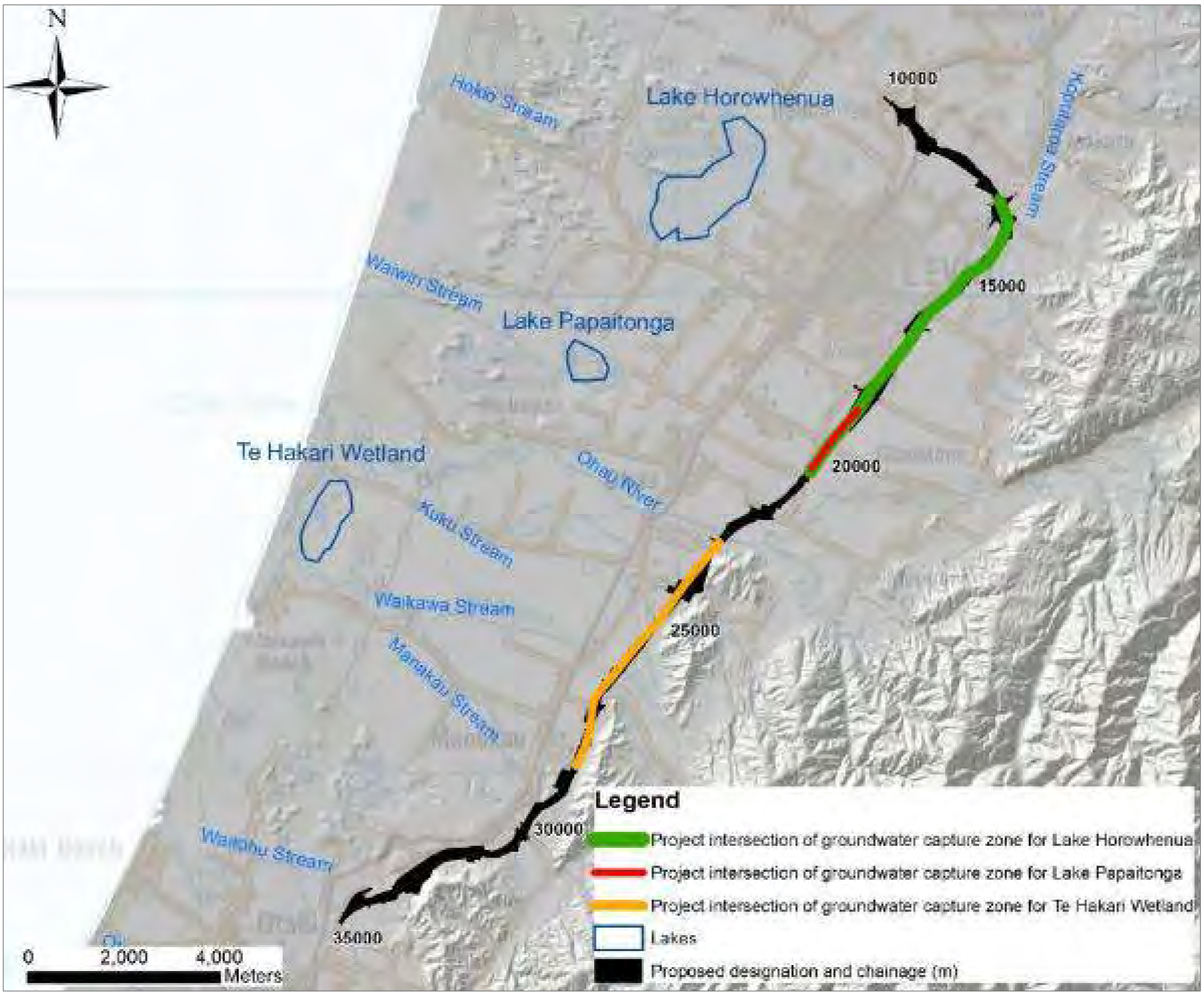


Figure 17 Lakes and wetlands with groundwater capture zones intersecting the Project (intersection points drawn from capture zones shown in PDP (2017) and PDP (2019).

Figure 14 presented previously in this section, shows a cross-section with the highest observed groundwater levels from monitoring sites (bores, test pits, CPTs) roughly 15 m deep or less, the highest predicted groundwater levels east of Levin (Section 3.2.3) as well as rivers, streams, wetlands, springs and groundwater seepages identified by Stantec within the proposed designation. Potential groundwater interaction with surface water beneath the Project alignment is indicated by:

1. The water table is often close to ground level at topographic low points with stream beds as potential discharge points for groundwater.
2. A high water table is generally associated with a larger number or springs and wetlands.
3. The high water table north of Levin intersects the stream bed of tributaries flowing into Koputaroa Stream. White *et al.* (2010) suggests that groundwater flow is towards Koputaroa Stream in this area.
4. The water table appears slightly lower than the surface water level in the Ohau River suggesting river losses to groundwater where it crosses the Project. This is in general agreement with White *et al.* (2010) who described the Ohau River as losing flow to groundwater in this section.
5. Further South where Waikawa and Manukau streams cross the Project, the water table is roughly at ground level. Section 3.4.3 of White *et al.* (2010), describes these two streams as generally losing flow to groundwater in the sections where they cross the Project (though Horizons, 2009 cited in White et al. 2010) suggested there was no net loss/gain of water in Waikawa Stream over an area that includes the

Project). White et al. 2010 provides no information on the connection between groundwater and Kuku Stream where it intersects the Project.

3.4 GROUNDWATER SEEPAGES

Figures 18-20 show the location of groundwater seepages identified on site by Stantec (March 2021 to August 2021) during the Project investigation. No flowing springs were observed though that does not preclude their existence or may be a result of the time of the field investigations. Most groundwater seepages were observed in the northern and southern ends of the Project in depressions, at the base of terraces and on the sides of hills. Some common features of the northern and southern ends of the project are a higher water table, lower permeability soil and areas of impeded drainage. A description and classification of the seepages identified by Stantec is provided in Appendix E.

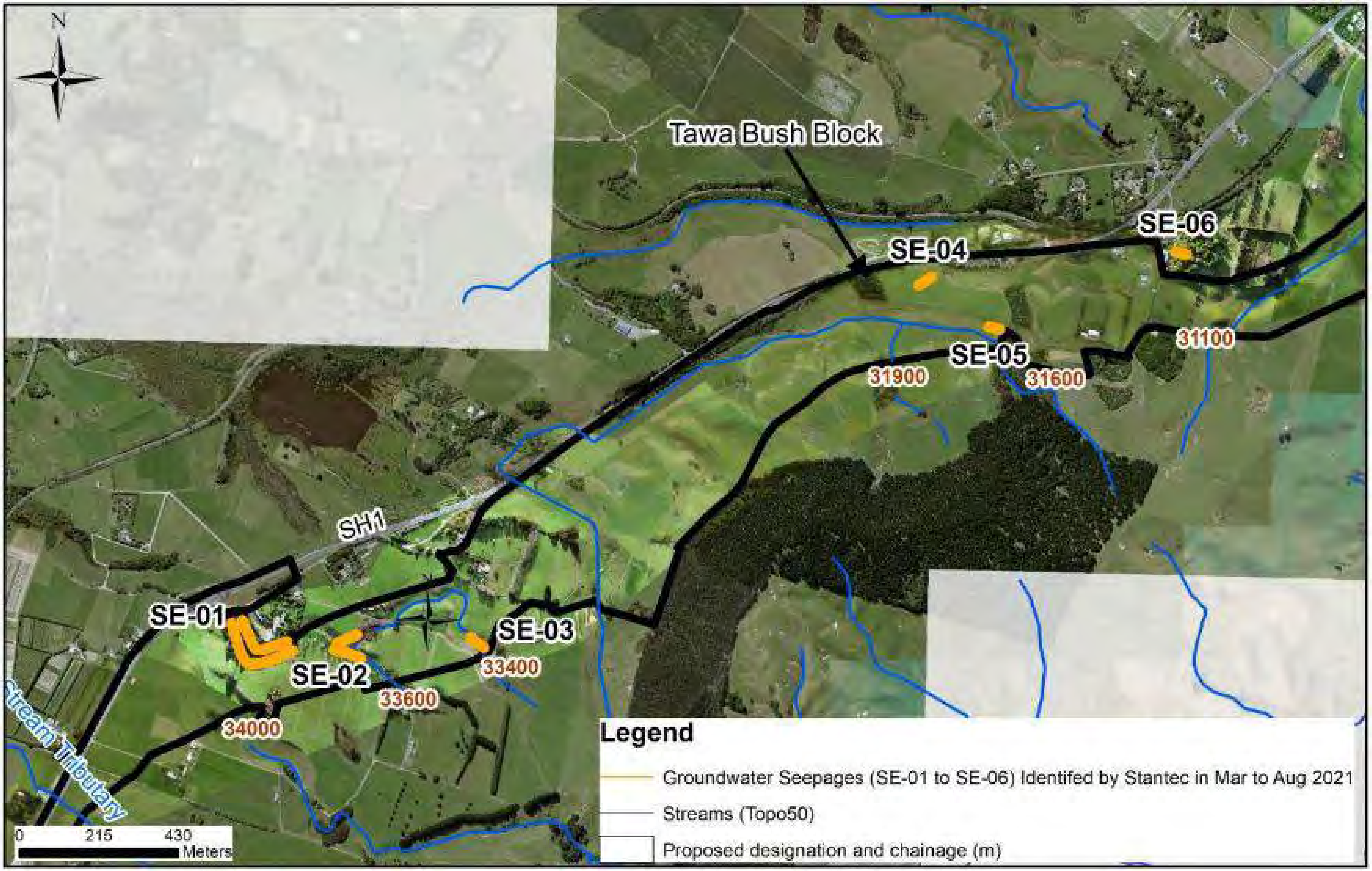

N
Tawa Bush Block
SE-04
SE-06
SE-05
31100
31900
31600
SH1
SE-01
SE-02
SE-03
33400
33600
34000
Stream Tributary
0
215
430
Meters
Legend
Groundwater Seepages (SE-01 to SE-06) Identifed by Stantec in Mar to Aug 2021
Streams (Topo50)
Proposed designation and chainage (m)

Figure 18 Groundwater seepages (SE-01 to SE-06) observed by Stantec – March to August 2021.

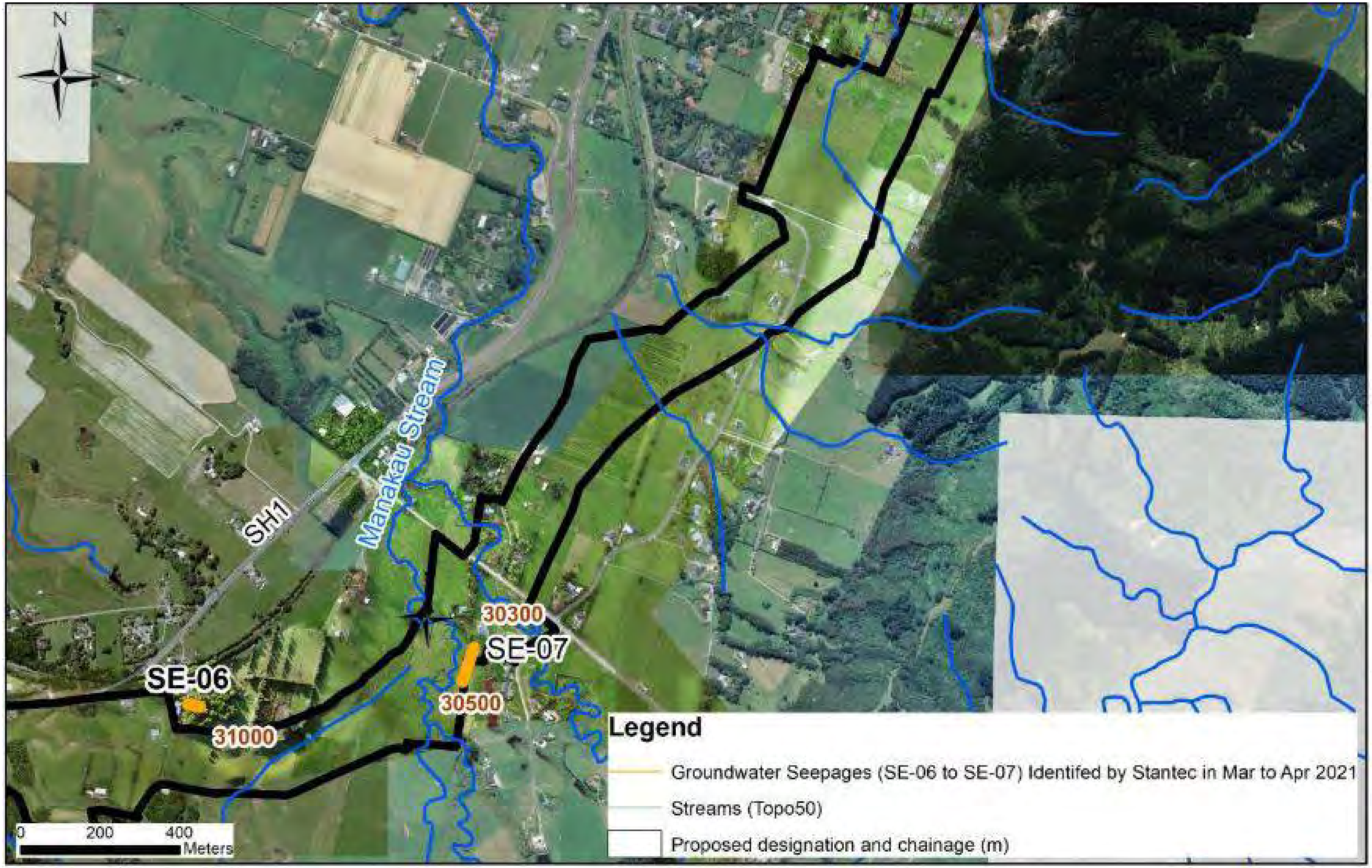


Figure 19 Groundwater seepage (SE-06 and SE-07) observed by Stantec – March to April 2021:

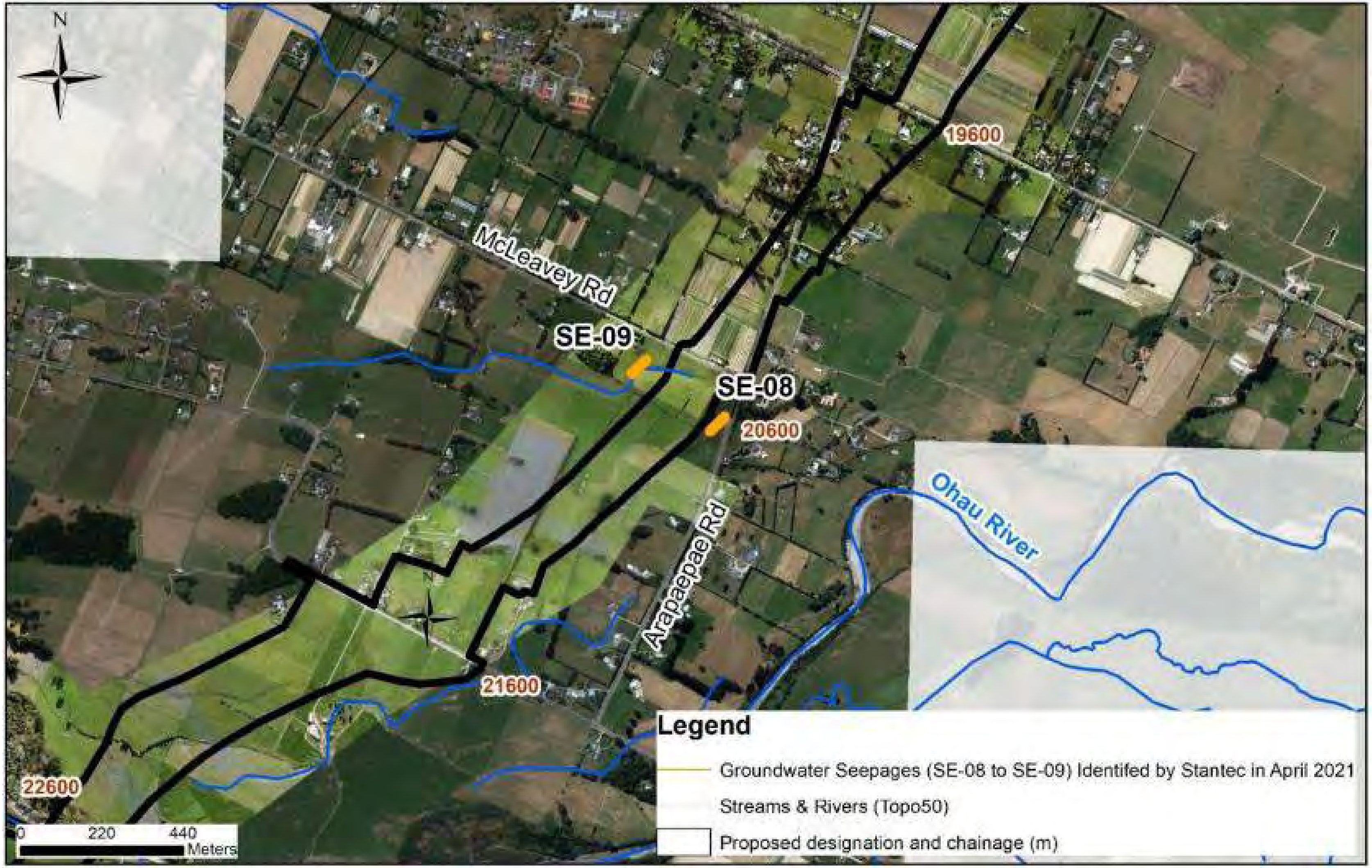


Figure 20 Groundwater seepages (SE-08 and SE-09) observed by Stantec – April 2021.

4.0 WETLAND AND FOREST HYDROLOGY

4.1 METHODODOLOGY FOR ASSESSMENT

Wetland habitats within the Project designation consist primarily of swamps on valley floors, which are intermittently to permanently wet. These wetlands are locally common, but small and degraded, grazed and dominated by exotic herbs and grasses. There are also smaller areas of oxbow wetlands associated with meandering streams and some hillslope seepage wetlands fed by groundwater. In addition, some areas of forest occur over areas where the shallow groundwater (water table) may at times get close ($\lessapprox$ 5 m) below ground level.

Appendix F contains a tabulated summary of the hydrological regime of wetland and selected forest fragments. The selected forest fragments assessed for this investigation were selected by Wildlands (Technical Assessment J - Terrestrial Ecology) and include those most likely to be dependent on groundwater. Open water habitats were omitted from the assessment. The assessment included some wetland and selected forest fragments outside the DF4.0 Project Footprint and 20 m buffer; however, most assessed wetland and selected forest fragments occurred inside the Project designation.

The assessment was based on field observations of the wetland ecology, and a mixture of field observations and a desktop assessment of the hydrology. However, no invasive work (e.g., drilling, test pits or CPT's) was undertaken to determine the groundwater characteristics (i.e., groundwater levels and perched versus regional water table) beneath the wetlands, hence groundwater conditions had to be inferred from the nearest site investigation data. Monitoring bores constructed for this investigation, groundwater seepages identified during the investigation, and in some cases groundwater level data from bores listed on regional council databases provided useful information to predict the potential interactions with groundwater.

Table 4-1 summarises the criteria used to classify wetland and selected forest fragments into water source(s) categories, based on inputs from groundwater and surface water data. The distinction between streams as largely permanent flowing water bodies and overland ephemeral flow paths is based on work undertaken for the Hydrology and Flooding evidence (Technical Assessment F), which included mapping surface water features into one of these two categories.

Table 5: Wetland and selected forest fragments – criteria for surface and groundwater water sources

Groundwater / Surface Water	Water Source(s) Category	Code	Description
Groundwater	Regional Water Table	GW-RWT	Valley floor seepages. Base of terrace seepages. Adjacent to surface water bodies (streams and rivers). High groundwater ($\lessapprox$ 5 m deep) in adjacent shallow monitoring bores ($\lessapprox$ 10 m deep).
	Perched (above regional water table)	GW-P	Hillslope seepages. Presence of low permeability geological material. Deep groundwater ($\gtrapprox$ 5 m deep) in adjacent deep monitoring bores ($\gtrapprox$ 10 m deep).
Surface Water	Stream	SW-S	Generally permanent flow of water.

Groundwater / Surface Water	Water Source(s) Category	Code	Description
	Overland flow	SW-OF	Ephemeral flow paths. Duration of flow may vary widely from less than one day to months. 1-10 year flood depth used in the analysis.
	Ponded rainfall	SW-PR	Rainfall ponded in a defined area with no connection to streams or ephemeral flow paths.

Appendix F also lists the confidence levels in assigning water sources to a wetland or forest fragment based on the criteria provided in Table 4-1. Where there was locally available groundwater level data and site observations of nearby seepages, the site was given a high confidence level (H). For sites some distance from the Project with no local groundwater level information, the sites were generally given a low confidence (L). Sites somewhere in the middle with some local information were listed with a medium confidence level (M).

The wetland and selected forest fragments were assessed to determine their hydrological regime, including an assessment of the potential connection to groundwater (regional water table and perched) and surface water (ephemeral / permanent streams, overland flow and ponded rainfall). This information was used to inform site specific assessments of groundwater levels beneath wetland or forest fragments that were near:

- cuts that are expected to intercept the groundwater table
- temporary dewatering for culverts, underpasses, or foundation treatments
- stormwater soakage facilities

A summary of cutting, temporary dewatering or the installation of soakage facilities that may have potential effects on groundwater below wetlands or forest fragments is presented in Table 4 2. For more detail on the individual assessments including the methodologies please refer to Appendix G, Appendix H, and Appendix I.

4.2 RESULTS

Along the alignment, 69 wetland and forest fragments were classified regarding their likely water source/s including the confidence level of each assessment, this information can be found in Appendix F. The distribution of wetland and forest fragments and varying water source/s as assessed are provided in Figures 21-26. Of the locations, and at varying confidence levels, 10 were assessed to be in connection with perched groundwater and 56 in connection with the regional water table. Additionally, 62 wetland and forest fragments were found to be in connection with surface water flows, of which, 56 were feed by a combination of groundwater and surface water. This information was feed forward into site-specific assessments where changes to groundwater where expected.

In total, there were seven wetland sites assessed to be 1) connected to the groundwater and 2) within the zone of influence of road cuts that are expected to intercept and permanently reduce surrounding groundwater levels. These sites are located around road cuts from CH11,350-11,650, CH20,500-20,800, and CH31,650-31,950 and summarized in Table 6. While cutting will reduce groundwater levels at these seven wetlands, it is important to understand that wetlands can be formed due to discharges of groundwater or be acting as recharge pathways to groundwater and, where the latter is true, reducing groundwater levels will not affect the water balance at the wetland. A more detailed assessment of these potentially effected cutting sites is contained within Appendix G.

Two sites were assessed to be effected by temporary dewatering for culvert construction. As groundwater levels are only expected to be lowered temporarily and the effects are of a magnitude that can be readily mitigated by directing dewatering discharges, the actual effects of temporary dewatering are expected to be less than minor. A summary of wetlands effected by temporarily dewatering is contained in Table 6. The detailed assessment of these potentially effected sensitive sites is presented in Appendix H.

The mounding assessment at infiltration facilities indicated no effects on wetland or forest fragment blocks. The detailed assessment for mounding effects is presented in Appendix I.

Table 6: Summary of wetlands and forest fragments assessed to be effected by lowering groundwater levels.

Wetland or forest fragment ID	Chainage or location	Cause for drawdown	Wetland or Forest fragment water source	Estimate of groundwater inflows vs total inflows	Expected effects to groundwater below wetland or forest fragment	For further information refer to
67	11,350-11,650	Cutting below groundwater table	GW-RWT(H)+SW-OF(L)	High	Significant reduction in groundwater inflows	Appendix G
58	20,500-20,800		GW-RWT(M)+GW-P(L)+SW-OF(H)	Low	Minor reduction in groundwater inflows	
18	31,650-31,950		GW-RWT(L)+SW-PR(M)	Moderate	Significant reduction in groundwater inflows	
19			GW-RWT(L)+SW-S(L)+SW-PR(M)	Moderate	Significant reduction in groundwater inflows	
70			GW-RWT(M)+GW-P(H)	High	No groundwater inflows	
71			GW-RWT(L)+GW-P(L)	High	No groundwater inflows	
72			GW-P(M)+SW-PR(M)	High	No groundwater inflows	
12	Culvert 4	Temporary Dewatering	GW-RWT(L)+SW-S(L)	Moderate	Temporary minor reduction in groundwater inflows	Appendix H
13	Culvert 11		GW-RWT(M)+SW-OF(H)	Low	Temporary minor reduction in groundwater inflows	


Legend
Stream
Ephemeral flowpath
DF4_Filtered_Wetlands
GW-P
GW-P+SW-OF+SW-PR
GW-P+SW-PR
GW-RWT
GW-RWT+GW-P
GW-RWT+GW-P+SW-OF
GW-RWT+SW-OF
GW-RWT+SW-PR
GW-RWT+SW-PR+SW-OF
GW-RWT+SW-S
GW-RWT+SW-S+SW-OF
GW-RWT+SW-S+SW-PR
None
SW-OF
SW-OF+SW-PR
<all other values>
O2NL_DF4_Bridges_20220429
O2NL_DF4_Earthworks_20220429
10000
10500
11000
12000
12500
13000
13500
14000
N
0
0.25
0.5
1
Kilometers

Figure 21 Wildlands Wetlands categorized by water source. Wetland Identifiers are in green, DF4.0 chainage in pink.


Legend
Stream
Ephemeral flowpath
DF4_Filtered_Wetlands
GW-P
GW-P+SW-OF+SW-PR
GW-P+SW-PR
GW-RWT
GW-RWT+GW-P
GW-RWT+GW-P+SW-OF
GW-RWT+SW-OF
GW-RWT+SW-PR
GW-RWT+SW-PR+SW-OF
GW-RWT+SW-S
GW-RWT+SW-S+SW-OF
GW-RWT+SW-S+SW-PR
None
SW-OF
SW-OF+SW-PR
<all other values>
O2NL_DF4_Bridges_20220429
O2NL_DF4_Earthworks_20220420
17000
17500
18000
N
0 0.25 0.5 1
Kilometers

Figure 22 Wildlands Wetlands categorized by water source. Wetland Identifiers are in green, DF4.0 chainage in pink.


Legend
Stream
Ephemeral flowpath
DF4_Filtered_Wetlands
GW-P
GW-P+SW-OF+SW-PR
GW-P+SW-PR
GW-RWT
GW-RWT+GW-P
GW-RWT+GW-P+SW-OF
GW-RWT+SW-OF
GW-RWT+SW-PR
GW-RWT+SW-PR+SW-OF
GW-RWT+SW-S
GW-RWT+SW-S+SW-OF
GW-RWT+SW-S+SW-PR
None
SW-OF
SW-OF+SW-PR
<all other values>
O2NL_DF4_Bridges_20220429
O2NL_DF4_Earthworks_20220429
18000
18500
19000
19500
20000
20500
21000
21500
22000
N
0
0.25
0.5
1
Kilometers

Figure 23 Wildlands Wetlands categorized by water source. Wetland Identifiers are in green, DF4.0 chainage in pink.


Legend
Stream
Ephemeral flowpath
DF4_Filtered_Wetlands
GW-P
GW-P+SW-OF+SW-PR
GW-P+SW-PR
GW-RWT
GW-RWT+GW-P
GW-RWT+GW-P+SW-OF
GW-RWT+SW-OF
GW-RWT+SW-PR
GW-RWT+SW-PR+SW-OF
GW-RWT+SW-S
GW-RWT+SW-S+SW-OF
GW-RWT+SW-S+SW-PR
None
SW-OF
SW-OF+SW-PR
<all other values>
O2NL_DF4_Bridges_20220429
O2NL_DF4_Earthworks_20220429
22000
22500
23000
23500
24000
24500
25000
25500
26000
N
0
0.25
0.5
1
Kilometers

Figure 24 Wildlands Wetlands categorized by water source. Wetland Identifiers are in green, DF4.0 chainage in pink.


Legend
Stream
Ephemeral flowpath
DF4_Filtered_Wetlands
GW-P
GW-P+SW-OF+SW-PR
GW-P+SW-PR
GW-RWT
GW-RWT+GW-P
GW-RWT+GW-P+SW-OF
GW-RWT+SW-OF
GW-RWT+SW-PR
GW-RWT+SW-PR+SW-OF
GW-RWT+SW-S
GW-RWT+SW-S+SW-OF
GW-RWT+SW-S+SW-PR
None
SW-OF
SW-OF+SW-PR
<all other values>
O2NL_DF4_Bridges_20220429
O2NL_DF4_Earthworks_20220429
28000
26500
27000
27500
28000
28500
29000
29500
N
0 0.25 0.5 1
Kilometers

Figure 25 Wildlands Wetlands categorized by water source. Wetland Identifiers are in green, DF4.0 chainage in pink.

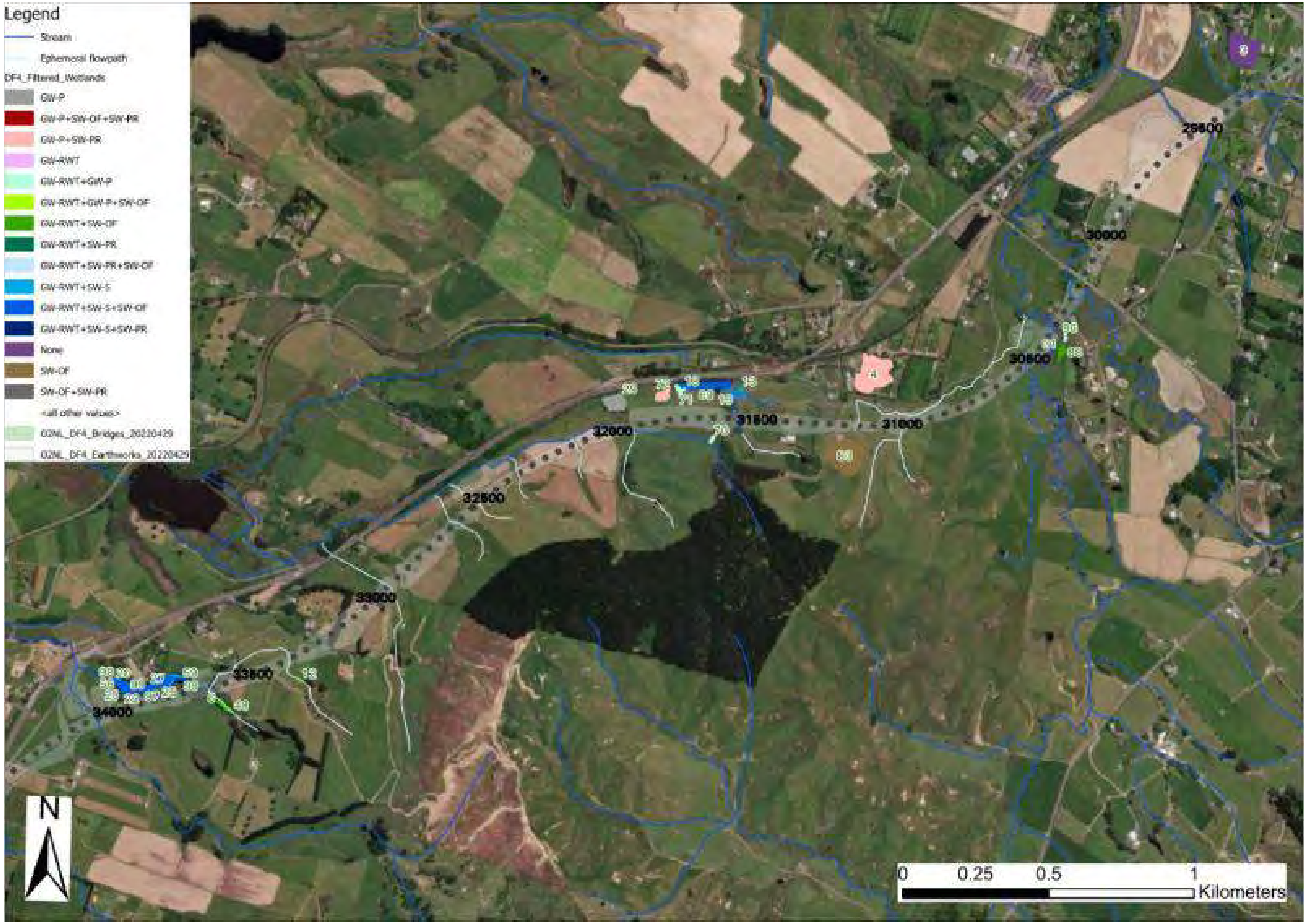

Legend
Stream
Ephemeral flowpath
DF4_Filtered_Wetlands
GW-P
GW-P+SW-OF+SW-PR
GW-P+SW-PR
GW-RWT
GW-RWT+GW-P
GW-RWT+GW-P+SW-OF
GW-RWT+SW-OF
GW-RWT+SW-PR
GW-RWT+SW-PR+SW-OF
GW-RWT+SW-S
GW-RWT+SW-S+SW-OF
GW-RWT+SW-S+SW-PR
None
SW-OF
SW-OF+SW-PR
<all other values>
O2NL_DF4_Bridges_20220429
O2NL_DF4_Earthworks_20220429
29500
30000
30500
31000
31500
32000
32500
33000
33500
34000
N
0
0.25
0.5
1
Kilometers

Figure 26 Wildlands Wetlands categorized by water source. Wetland Identifiers are in green, DF4.0 chainage in pink.

5.0 REFERENCES

Allen, RG; Pereira, LS; Raes, D & Smith, M (1998). Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Drainage and Irrigation Paper 56. ISBN 92-5-104219-5. http://www.fao.org/docrep/X0490E/X0490E00.htm

Bidwell, V. (2003). Realistic forecasting of groundwater level, based on the eigen structure of aquifer dynamics. In D. A. Post (Ed.), MODSIM 2003 International Congress on Modelling and Simulation, Townsville, 14-17 July 2003. Modelling and Simulation Society of Australia and New Zealand.

Earl, A.P. (1998). Springs database manual. Field procedures and database management. Environment Canterbury technical report. U98/8.

ESR (2021). Drinking-water Register for New Zealand. Retrieved August 29, 2021, from https://www.esr.cri.nz/our-services/consultancy/water-quality-and-sanitation/register-of-suppliers/

Heron, D.W. (custodian) (2014). Geological Map of New Zealand 1:250 000. GNS Science Geological Map 1. Lower Hutt, New Zealand. GNS Science.

Mzila, D., Hughes, B., & Gyopari, M. (2015). Kapiti Coast groundwater resource investigation. Proposed framework for conjunctive water management. Greater Wellington Regional Council, Publication No. GW/ESCI-T-14/103, Wellington.

PDP (2017). Coastal Lakes Groundwater Capture Zones Investigation. Prepared for Horizons Regional Council. August 2017. Horizons Report 2017/EXT/1549

PDP (2019). Lake Horowhenua Water Balance Assessment and Quantification of Uncertainties – 2019 Update. Prepared for Horizons Regional Council. October 2019.

Gyopari (2005). Horowhenua Lakes Assessment of Groundwater – Surface Water Interaction. Prepared for: Horizons Regional Council.

Stantec (2021a). Geotechnical Factual Report. SH1 Ōtaki to North Levin. Prepared for Waka Kotahi. New Zealand Transport Agency. September 2021.

Stantec (2021b). SH1 Ōtaki to North Levin. Geotechnical Interpretation Report. Prepared for Waka Kotahi. NZ Transport Agency.

Toews, M.W. (2017). Groundwater protection zones for community drinking water supply wells in the Wellington Region. Lower Hutt (NZ): GNS Science. 33p. (GNS Science consultancy report; 2017/190).

Zarour, H. (2008). Groundwater resources in the Manawatu–Wanganui Region: technical report to support policy development. 2008/EXT/948. Horizons Regional Council, Palmerston North.

White, P., Zarour, H., Meilhac, C., & Green, S. (2010). Horowhenua water resources: water budget and groundwater surface water interaction. GNS Science Consultancy Report. 2010/22.

Appendices

We design with community in mind

Appendix A INVESTIGATION MONITORING BORE, TEST PIT AND CPT DETAILS

A.1 MONITORING BORES

Bore ID	Coordinates (NZTM2000)		Top of Casing (Collar) Elevation - WGN1953 (m)	Bore Depth Below Ground Level (m)	Screen Interval Below Ground Level (m)	PVC Bore Casing Diameter (mm)
	Easting (m)	Northing (m)				
BH105	1786669	5488840	44.6	15	12 - 15	32
BH107	1787424	5489737	44.0	12	7 - 10	32
BH109	1788181	5491386	54.2	10	4 - 10	32
BH110	1788558	5491742	54.0	20	10 - 20	32
BH111	1788658	5491952	47.2	20	8 - 20	32
BH113	1790779	5494807	38.5	30	27 - 30	50
BH114	1791051	5494892	38.6	12	1.5 - 12	32
BH115	1791864	5495424	46.7	10	7 - 10	32
BH117a	1793150	5496868	63.1	8	2 - 8	32
BH118	1793889	5497983	59.8	21	17 - 21	32
BH123	1794849	5503484	48.6	12	9 - 12	32
BH124	1795115	5503451	41.0	12	9 - 12	32
BH127	1796142	5500626	42.7	11	8 - 11	32
BH201	1783226	5487222	27.2	20	9 - 20	32
BH204	1785462	5488325	55.8	19	16 - 19	32
BH205	1785763	5488290	65.8	15	12 - 15	32
BH206	1786527	5488508	45.7	6	3 - 6	32
BH207S	1786623	5488611	43.6	7	4 - 7	32
BH207D	1786623	5488611	43.6	23	17 - 23	32
BH209S	1787930	5490236	44.8	3.5	2.5 - 3.5	32
BH209D	1787930	5490236	44.8	15	9 - 15	32
BH212	1788537	5491883	44.8	34.5	31.5 - 34.5	50
BH213	1790149	5493776	41.7	10.5	8.0 - 10.5	32
BH214	1790241	5493966	39.0	24	21 - 24	32
BH217	1790994	5494975	37.9	34	24 - 34	50
BH219	1792506	5496025	69.0	15	4 - 15	32
BH220S	1793993	5497925	61.4	15	2 - 15	32
BH220D	1793993	5497925	61.4	34.3	29.3 - 34.3	32
BH221D	1795072	5499379	52.7	20	8 - 20	32
BH221S	1795065	5499371	52.7	7	4 - 7	32
BH222	1795235	5499643	50.7	20	15 - 20	32
BH223S	1795792	5500072	49.8	7.5	4.5 - 7.5	32
BH223D	1795792	5500072	49.8	19.5	16.5 - 19.5	32
BH224	1787627	5489692	47.5	21	18 - 21	32
BH225S	1789314	5492853	50.1	5.7	1 - 5.7	32
BH225D	1789314	5492853	50.1	25	10 - 25	32
BH227S	1796430	5500716	40.2	9	1 - 9	32
BH227D	1796430	5500716	40.2	25	19 - 25	32
BH228S	1793588	5497454	60.9	12	9 - 12	32
BH228D	1793588	5497454	60.9	24.5	21.5 - 24.5	32

Appendix A Investigation Monitoring Bore, Test Pit and CPT Details

Bore ID	Coordinates (NZTM2000)		Top of Casing (Collar) Elevation - WGN1953 (m)	Bore Depth Below Ground Level (m)	Screen Interval Below Ground Level (m)	PVC Bore Casing Diameter (mm)
	Easting (m)	Northing (m)				
BH229S	1795316	5499777	51.6	8.7	5.7 - 8.7	32
BH229D	1795316	5499777	51.6	16.6	13.6 - 16.6	32
BH230S	1794227	5498428	58.6	15	2 - 15	32
BH230D	1794227	5498428	58.6	35	30 - 35	32
BH231S	1794981	5497381	75.3	15	2 - 15	32
BH231D	1794981	5497381	75.3	34.4	29.4 - 34.4	32
BH301	1783727	5487446	30.4	15.45	2 - 15	32
BH302	1783817	5487389	31.1	15.45	2 - 15	32
BH303	1784238	5487567	47.1	15.45	2 - 15	32
BH304	1784944	5488081	45.6	15.45	2 - 15	32
BH308	1788302	5491629	52.5	15.45	2 - 15	32
BH309	1788945	5492288	56.9	15.45	2 - 15	32
BH310	1791314	5495367	44.1	15.45	2 - 15	32
BH312	1795605	5502937	45.5	15.45	2 - 15	32
BH313	1795947	5502806	44.1	15.45	2 - 15	32
GHD-BH1	1794644	5498982	56.1	12.5	9.5 - 12.5	50
TP286	1795324	5499776	52.0	3.9	Unknown	50
TP287	1795283	5499722	51.3	3.8	Unknown	50

A.2 TEST PITS

Test Pit ID	Coordinates (NZTM2000)		Ground Elevation - WGN1953 (m)	Depth Below Ground Level (m)
	Easting (m)	Northing (m)		
TP201	1783094	5487116	26.8	3.8
TP202	1783368	5487267	19.3	3.6
TP204	1784104	5487522	35.4	3.8
TP205	1784166	5487514	41.9	4.3
TP206	1784395	5487729	24.3	3.7
TP207	1784679	5488017	25.7	4
TP208	1784941	5488193	25.7	3.5
TP208-S	1784937	5488195	25.5	1.65
TP209	1785124	5488254	28.7	4
TP210	1785383	5488319	59.3	4
TP211	1785610	5488326	55.4	4
TP212	1785990	5488337	57	3.9
TP213	1786393	5488375	55.3	3.7
TP214	1786592	5488566	44.3	3
TP216	1787326	5489385	44.6	2.8
TP217	1787554	5489567	51.1	4.4
TP218	1787693	5489737	49	3.5
TP219	1787796	5490012	45.7	3.7
TP220	1788047	5490516	42.3	4
TP221	1788105	5490714	44	4
TP223	1788190	5491191	51	3.6
TP224	1788278	5491507	57.3	3.8
TP225	1788685	5492038	46.1	3.7
TP226	1788732	5492142	46.2	3.9
TP227	1788966	5492410	54.8	4.1
TP229	1789386	5492908	49.3	4
TP230	1789651	5493231	45.4	3.7
TP231	1789834	5493468	39.5	3.9
TP234	1790779	5494684	38	3.5
TP235	1790868	5494815	38.4	3.6
TP235B	1790872	5494841	37.6	2.5
TP236	1790958	5494927	38.2	4
TP237	1791178	5495138	39.1	3.6
TP238	1791355	5495268	44.2	3.8
TP239	1791990	5495559	47.6	3.8
TP240	1792242	5495753	53.5	4
TP241	1792549	5496070	70	3.5
TP242	1792786	5496408	64.3	3.7

Appendix A Investigation Monitoring Bore, Test Pit and CPT Details

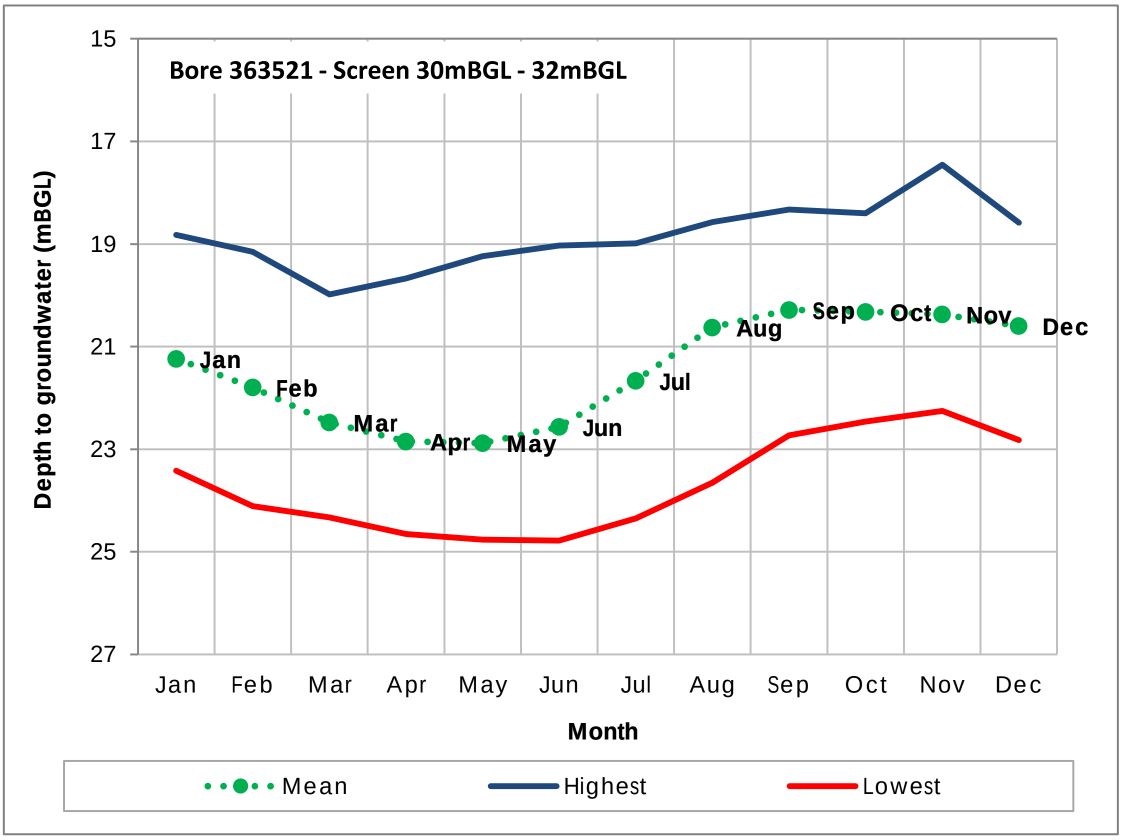
Test Pit ID	Coordinates (NZTM2000)		Ground Elevation - WGN1953 (m)	Depth Below Ground Level (m)
	Easting (m)	Northing (m)		
TP243	1793008	5496661	64.5	3.8
TP244	1793252	5496993	63	3.5
TP245	1793478	5497304	61.8	3.8
TP246	1793645	5497545	61.1	3.9
TP247	1793899	5497840	61.2	3.9
TP248	1793900	5498013	59.9	3.5
TP249	1794090	5497895	62.3	3.5
TP250	1794108	5498082	60.8	3.5
TP251	1794235	5498266	60.7	3.5
TP252	1794458	5498540	58.5	3.9
TP253	1794583	5498707	58.5	3.5
TP254	1794827	5499033	55.8	3.6
TP255	1794954	5499232	54.5	3.7
TP256	1795151	5499587	51.2	3.7
TP257	1795378	5499822	50.2	4.3
TP259	1796058	5500314	45.5	3.6
TP261	1796432	5500762	39.4	3.3
TP263	1796781	5501186	33.5	4
TP264	1796860	5501389	30.1	3.5
TP264B-S	1796781	5501467	31.1	1.6
TP266	1796820	5501738	28	3.8
TP266B-S	1796960	5501551	27.9	1.5
TP269	1796603	5502179	24.6	3.7
TP270	1796462	5502379	24.2	3.8
TP271	1796284	5502606	28.5	3.5
TP271-S	1796290	5502605	28.5	1.5
TP273	1795874	5502816	38	3.5
TP274	1795605	5503006	38.5	3.9
TP275	1795281	5503137	41.7	3.2
TP276	1795027	5503350	49.2	3.9
TP279	1794799	5503697	49	3.5
TP280	1794645	5503835	49.2	3.8
TP280-S	1794673	5503808	49.6	1.5
TP285	1788454	5491758	54.2	3.8
TP286	1795324	5499776	52	3.9
TP287	1795283	5499722	51.3	3.8
TP288-S	1787919	5490187	43.7	1.5
TP290	1788386	5491622	53.8	3.5
TP291	1786665	5488753	46.4	3.3

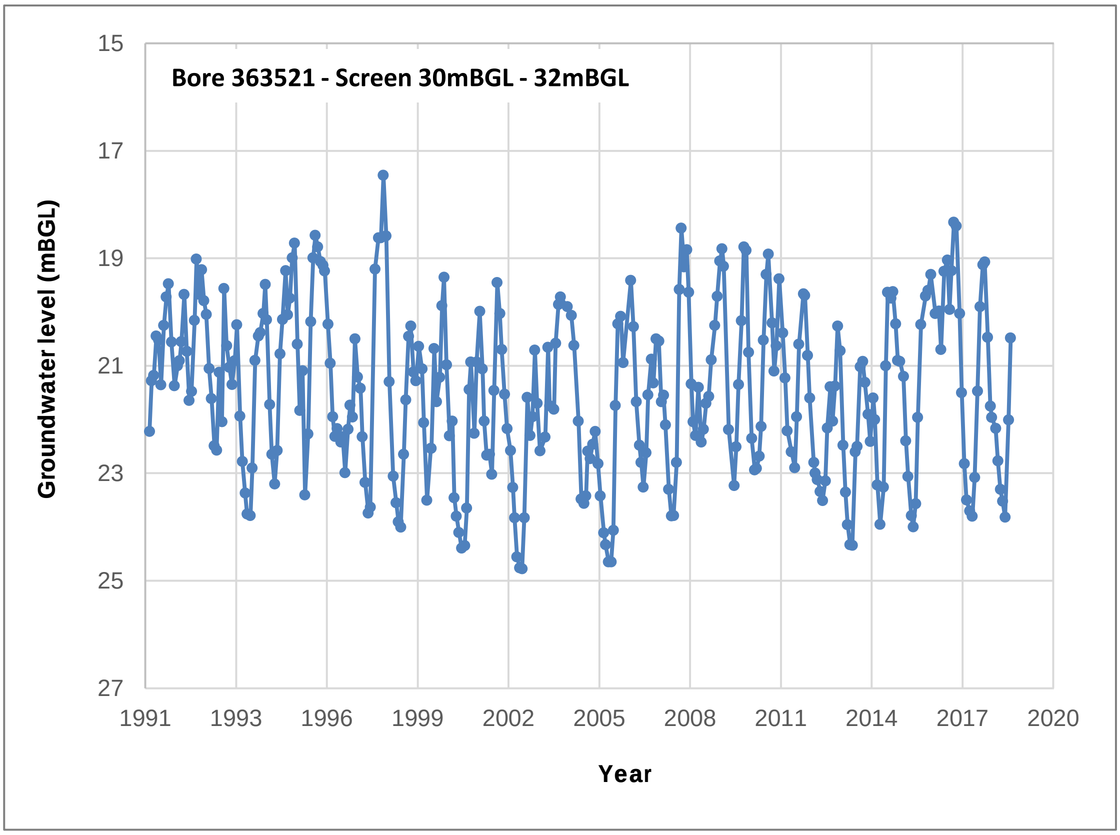
A.3 CPT HOLES

CPT ID	Corresponding Borehole	Coordinates (NZTM2000)		Ground Elevation - WGN1953 (m)	Depth Below Ground Level (m)
		Easting (m)	Northing (m)		
CPT101	BH101	1783340	5487235	23.1	11.5
CPT102	BH102	1783898	5487431	31.6	2.13
CPT103	BH107	1787420	5489739	44.1	4.38
CPT104	BH109	1788187	5491383	54.3	3.24
CPT105	BH115	1791854	5495431	46.7	3.42
CPT107	BH127	1796137	5500635	42.6	3.44
CPT108	BH123	1794849	5503479	48.7	8.22
CPT201	BH201-P	1783229	5487224	27.4	2.88
CPT202	N/A	1783373	5487266	19.5	13.41
CPT203	N/A	1783789	5487448	23.6	13.78
CPT204	N/A	1784031	5487486	26.9	12.38
CPT205	N/A	1784388	5487723	23.6	12.73
CPT207	N/A	1784675	5488019	25.3	8.12
CPT208	BH204	1785463	5488329	55.8	23.22
CPT209	N/A	1785529	5488394	39.3	11.35
CPT210	N/A	1786139	5488297	51.1	10.15
CPT211	BH206	1786527	5488503	45.8	20.42
CPT212	BH207	1786626	5488601	44.4	14.66
CPT213	BH208	1786744	5488784	46.2	8.31
CPT214	BH106	1787628	5489692	47.5	19.53
CPT215	N/A	1787677	5489753	48.1	19.99
CPT216	BH209	1787931	5490236	42	16.91
CPT217	BH210	1788252	5491359	55.4	1.7
CPT218	BH211	1788510	5491822	52.8	1.53
CPT219	BH212	1788534	5491878	44.9	0.41
CPT219A	BH212	1788534	5491878	45	3.85
CPT220	N/A	1790185	5493961	34.6	4.02
CPT221	BH214	1790235	5493969	34.3	10.89
CPT222	BH215	1790463	5494328	34.3	1.5
CPT224	BH218	1791750	5495438	45.8	2.28
CPT225	BH222	1795231	5499641	50.8	5.01
CPT228	N/A	1795845	5502955	23.1	6.78
CPT230	N/A	1795172	5503173	42.3	17.45
CPT231	N/A	1794994	5503374	49.3	9.23
CPT233	N/A	1794668	5503811	49.5	10.66
CPT234	BH225	1789315	5492855	50	3.59

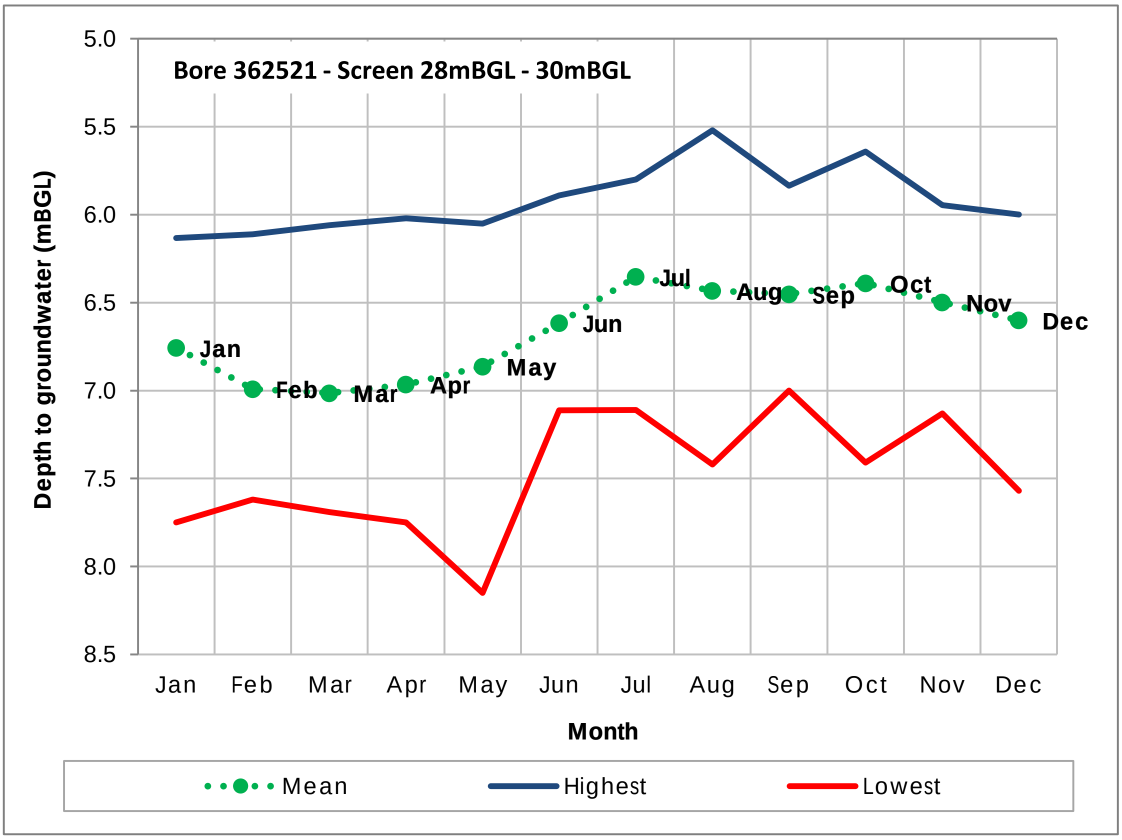
Appendix B GROUNDWATER LEVEL VARIATIONS AND MONTHLY STATISTICS FROM HORIZONS MONITORING BORES WITHIN THE HGMZ

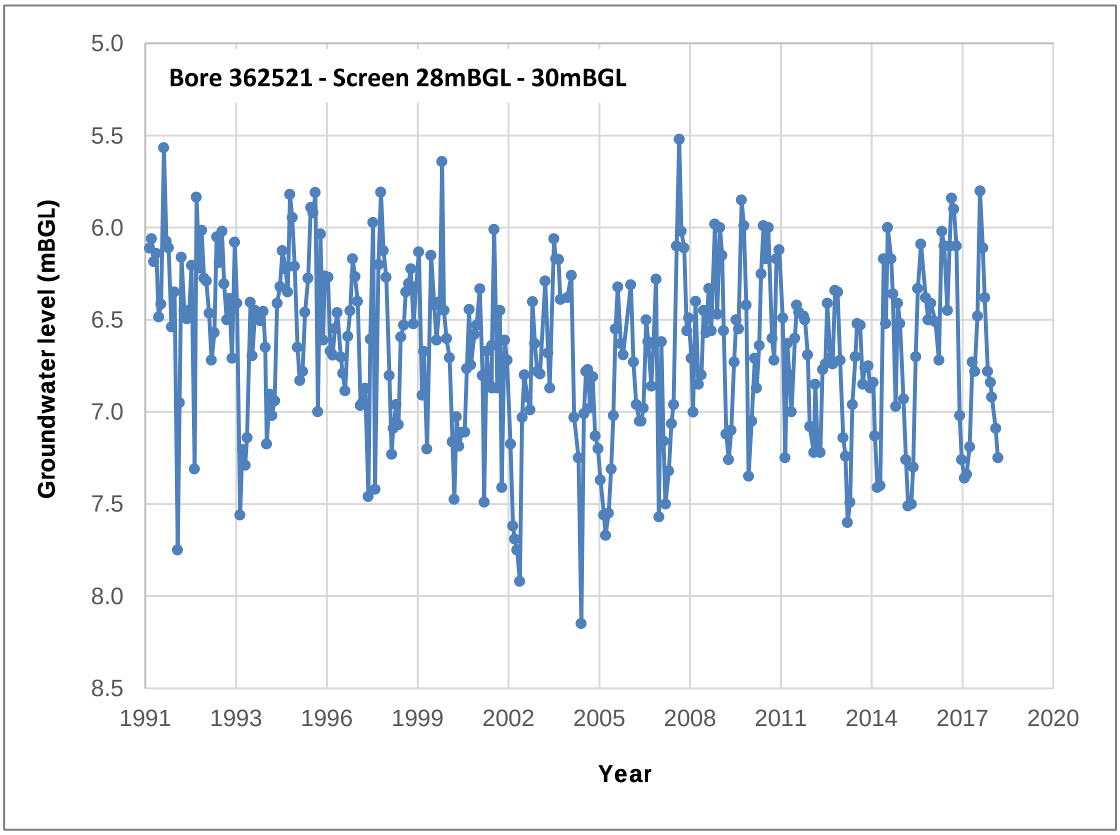
Appendix B Groundwater Level Variations and Monthly Statistics from Horizons Monitoring Bores within the HGMZ



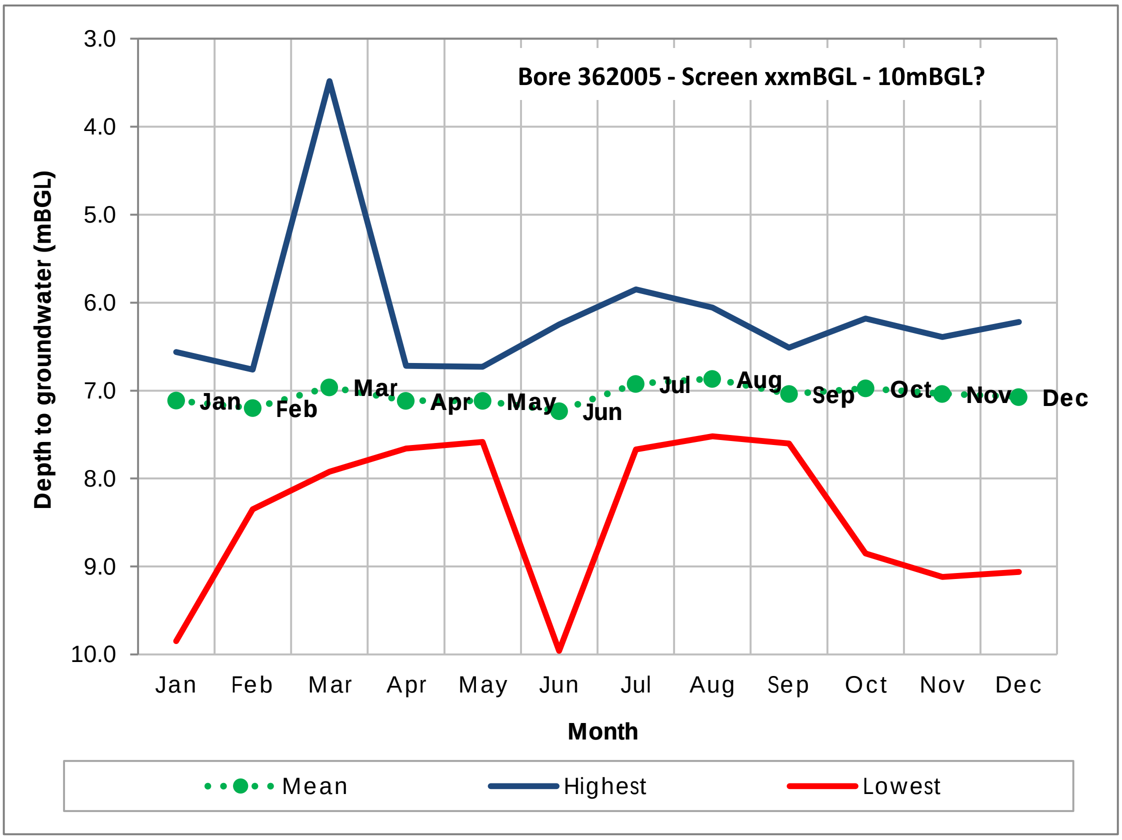


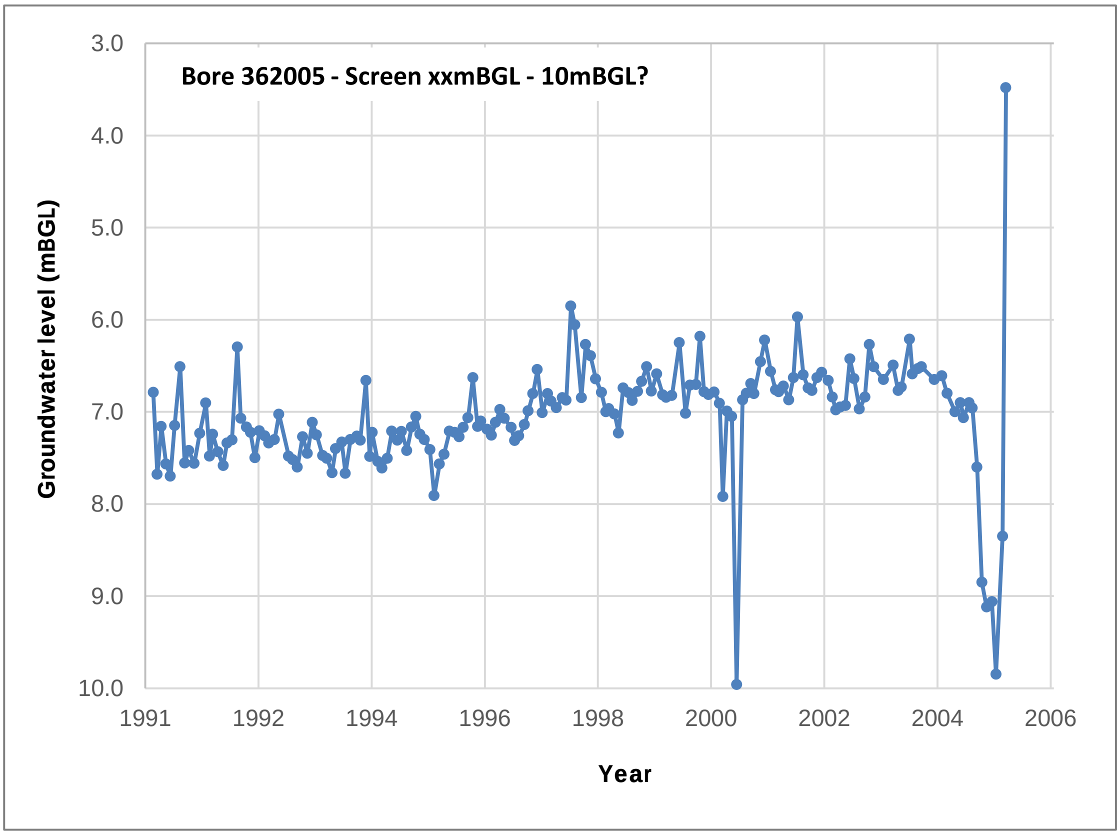
Appendix B Groundwater Level Variations and Monthly Statistics from Horizons Monitoring Bores within the HGMZ



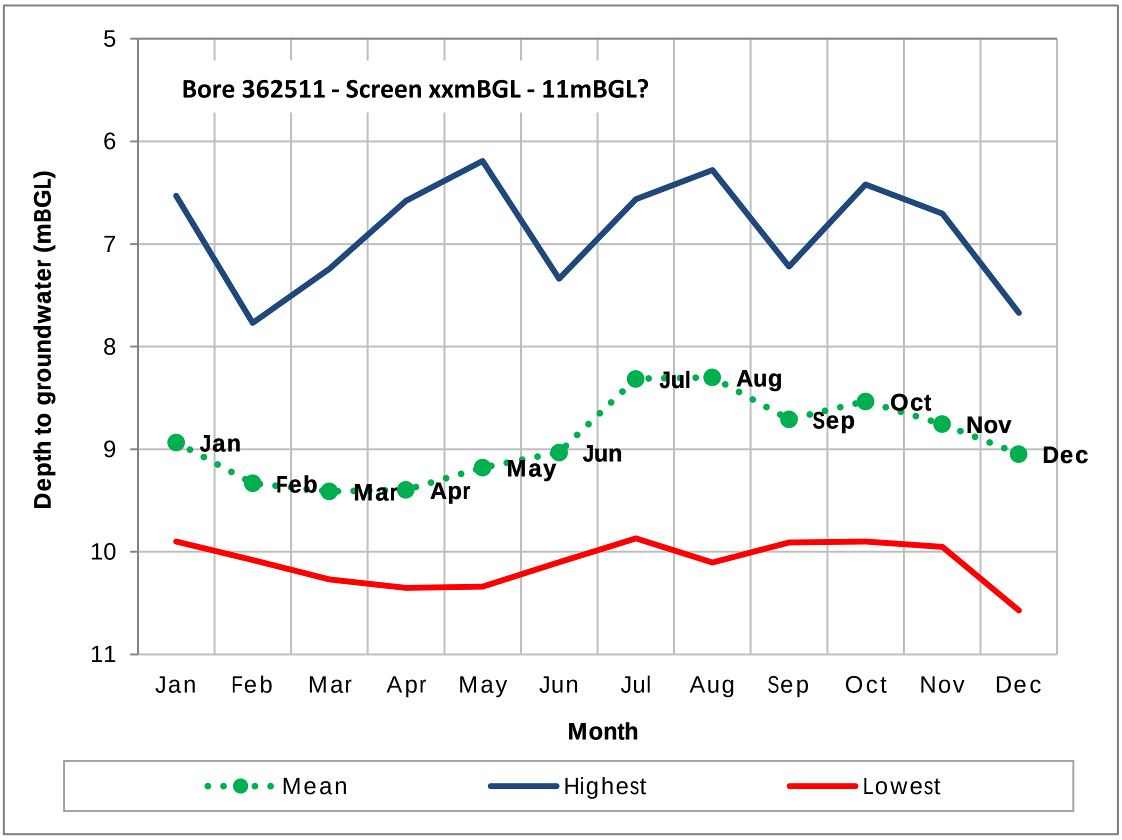


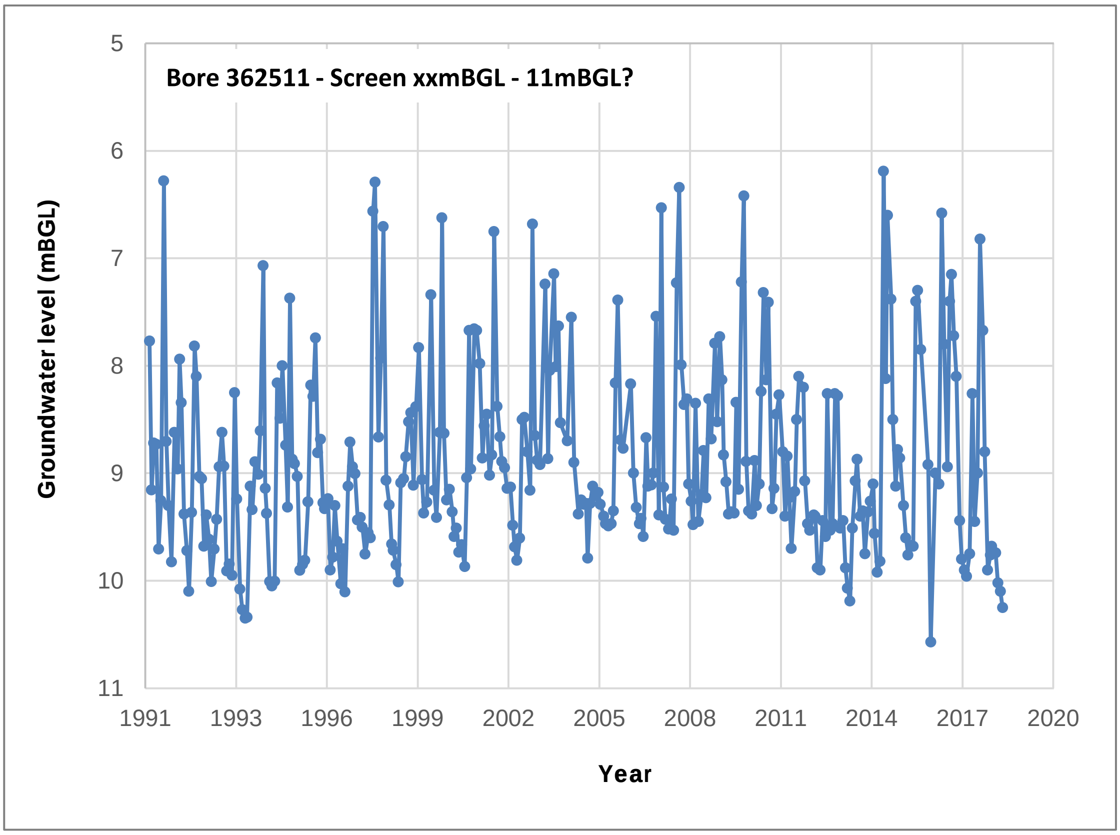
Appendix B Groundwater Level Variations and Monthly Statistics from Horizons Monitoring Bores within the HGMZ



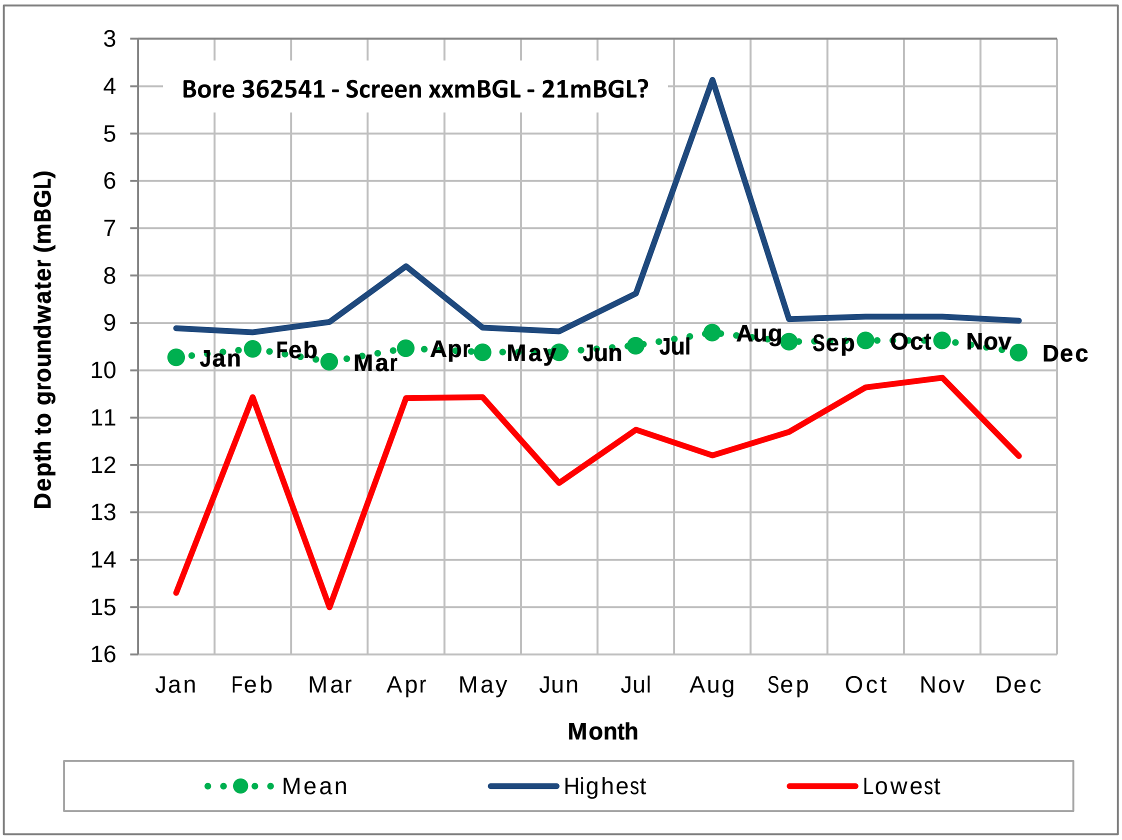


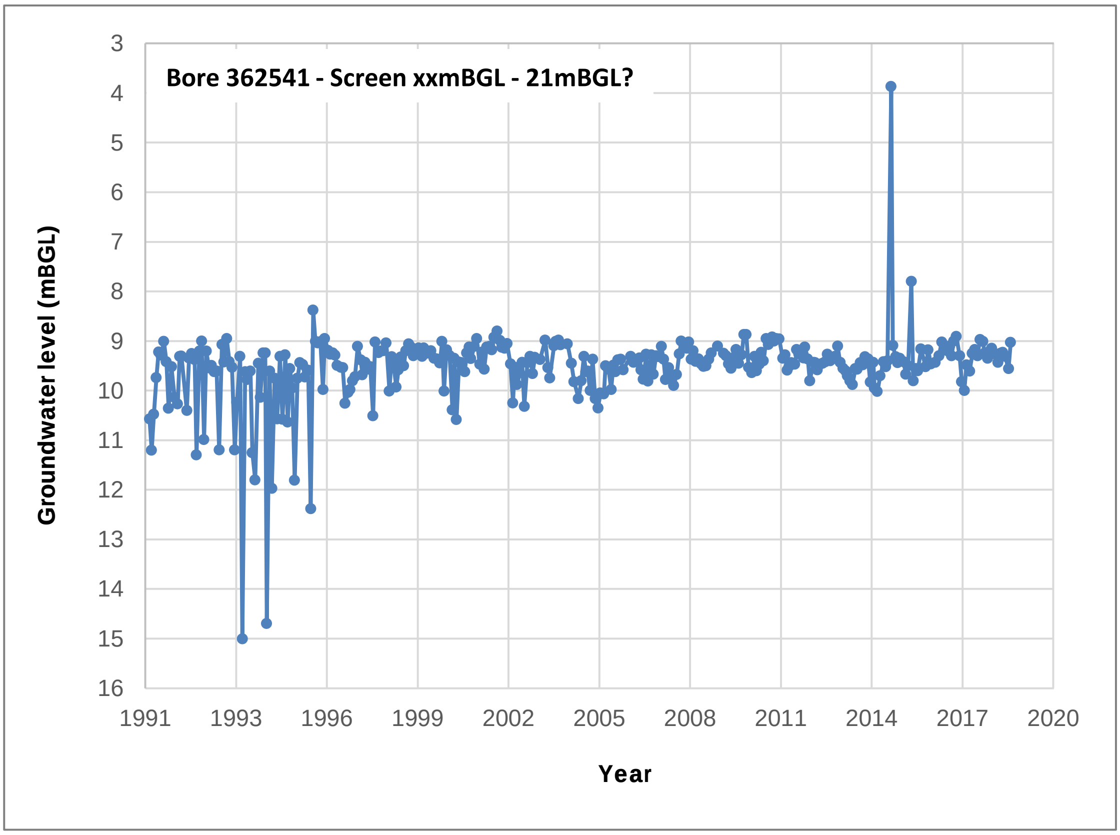
Appendix B Groundwater Level Variations and Monthly Statistics from Horizons Monitoring Bores within the HGMZ



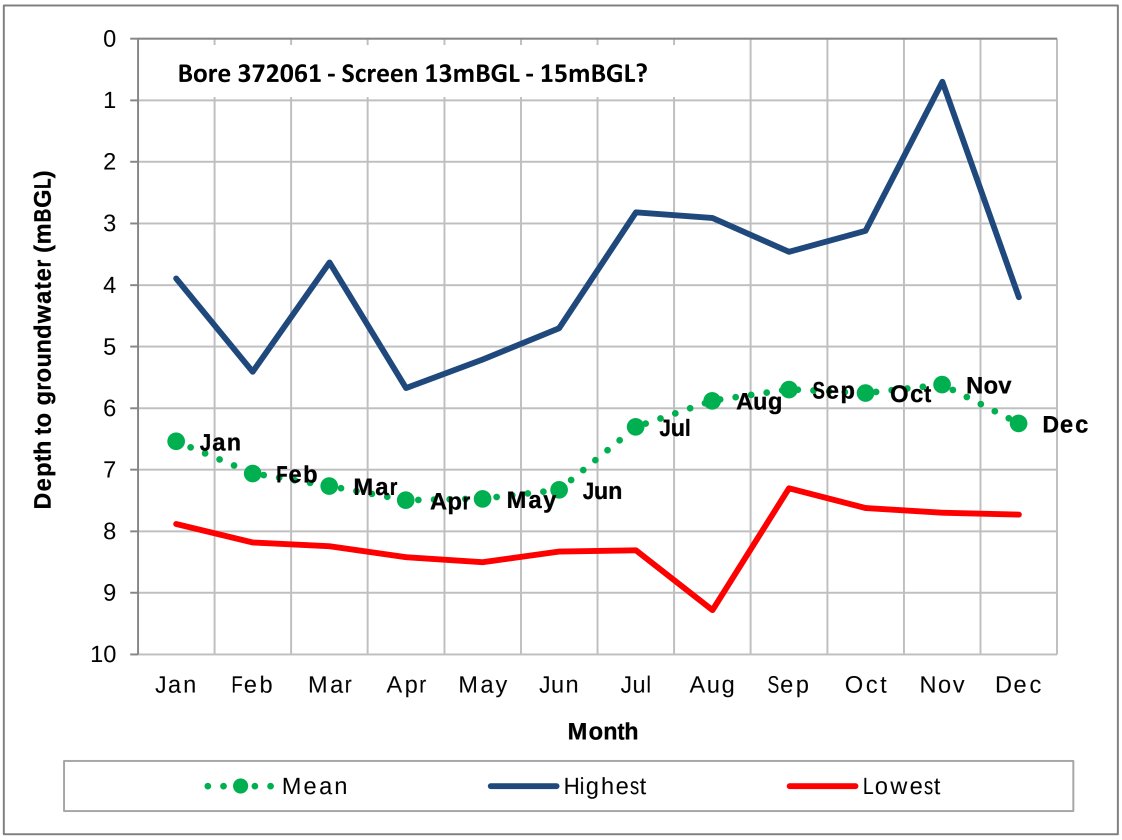


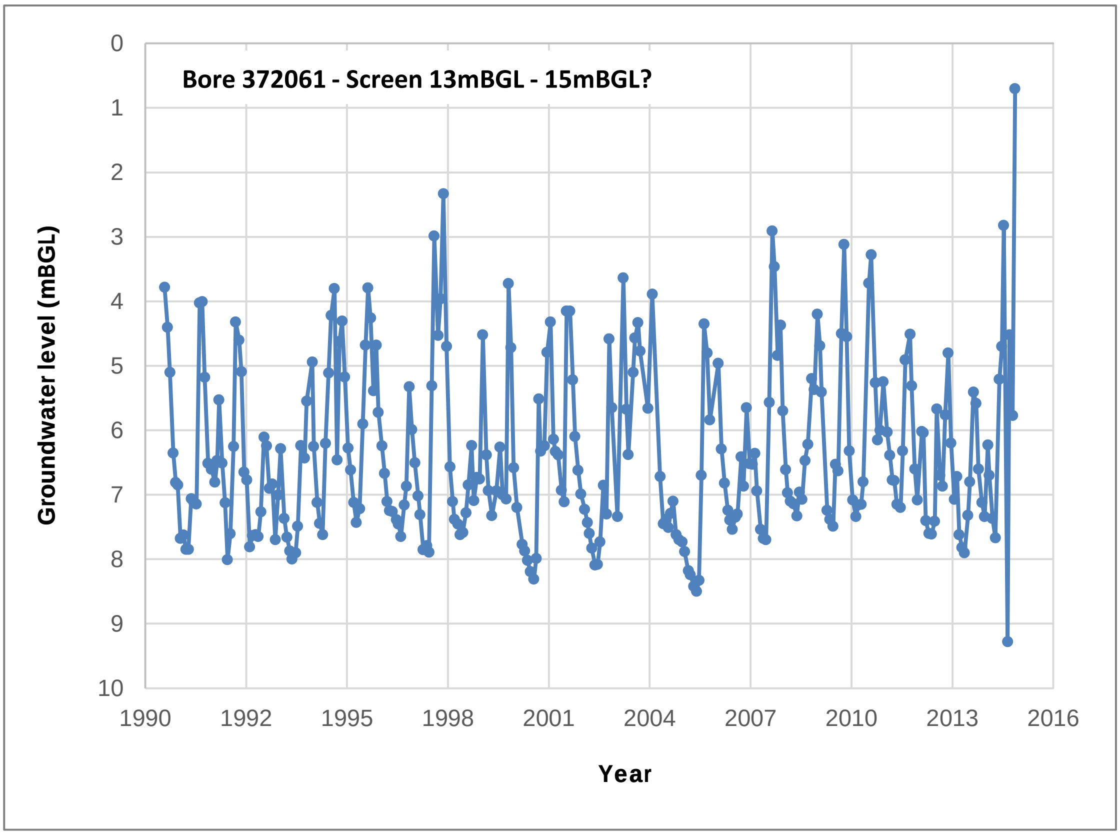
Appendix B Groundwater Level Variations and Monthly Statistics from Horizons Monitoring Bores within the HGMZ





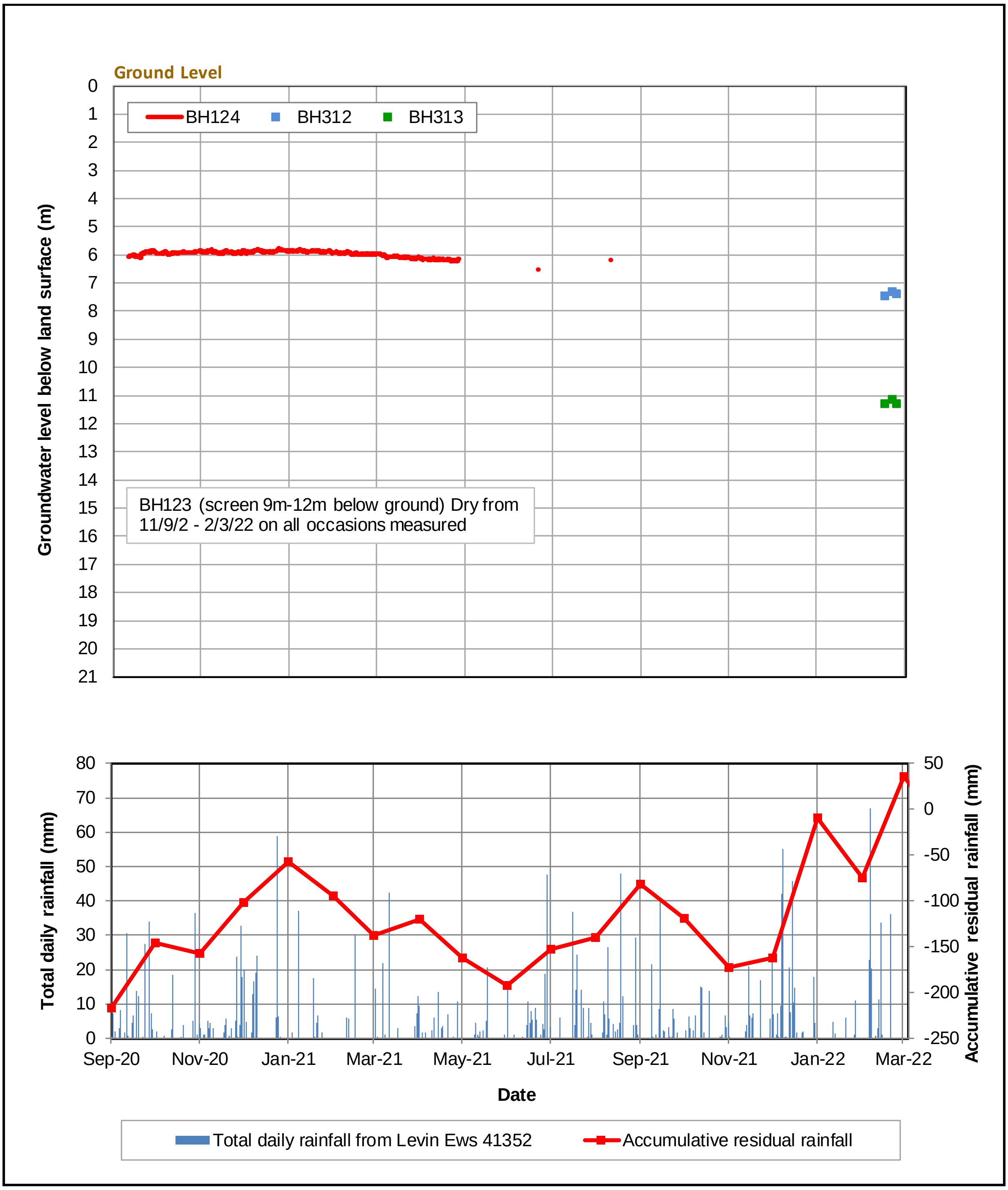
Appendix B Groundwater Level Variations and Monthly Statistics from Horizons Monitoring Bores within the HGMZ



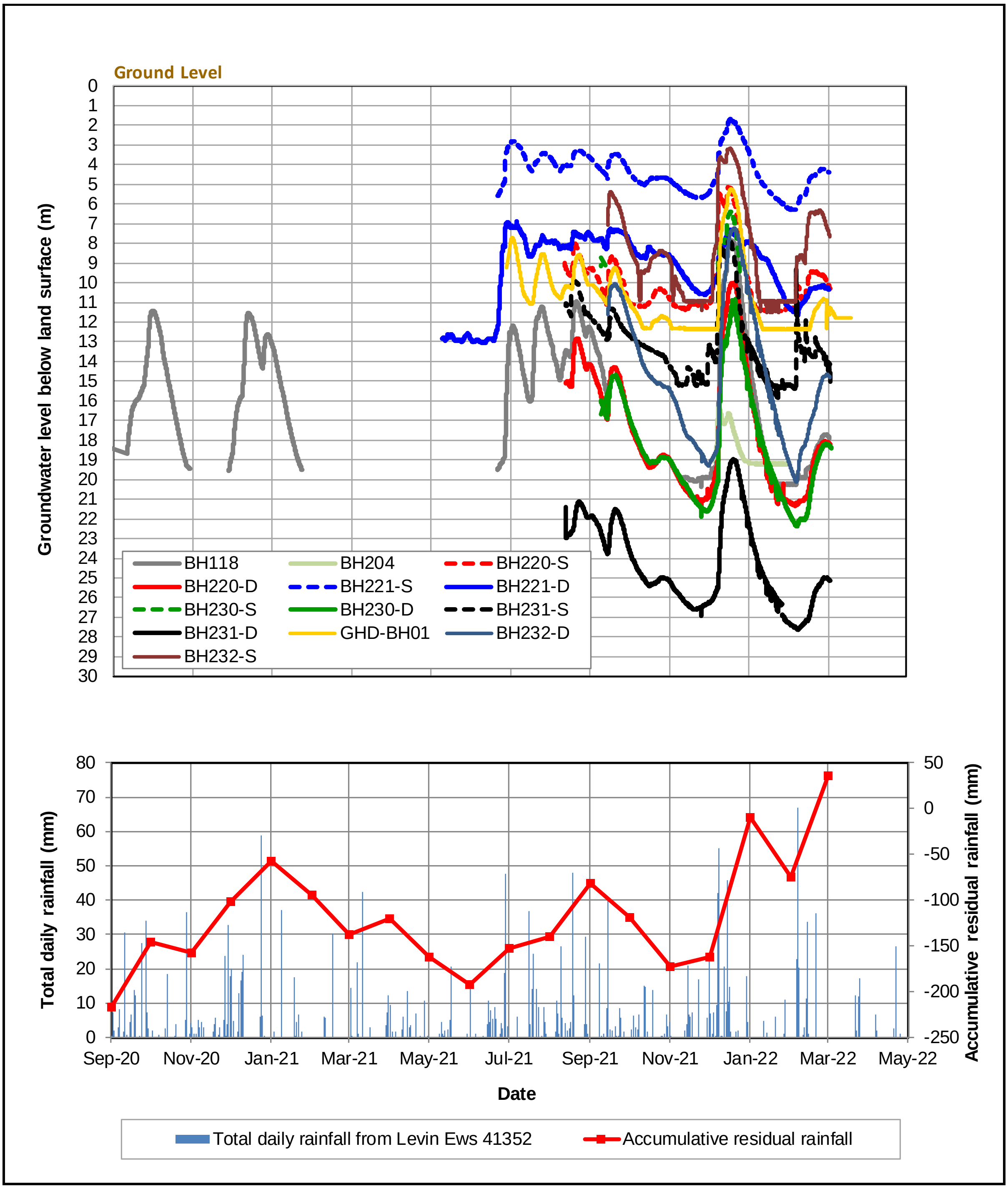


Appendix C GROUNDWATER LEVEL VARIATIONS BENEATH THE PROJECT

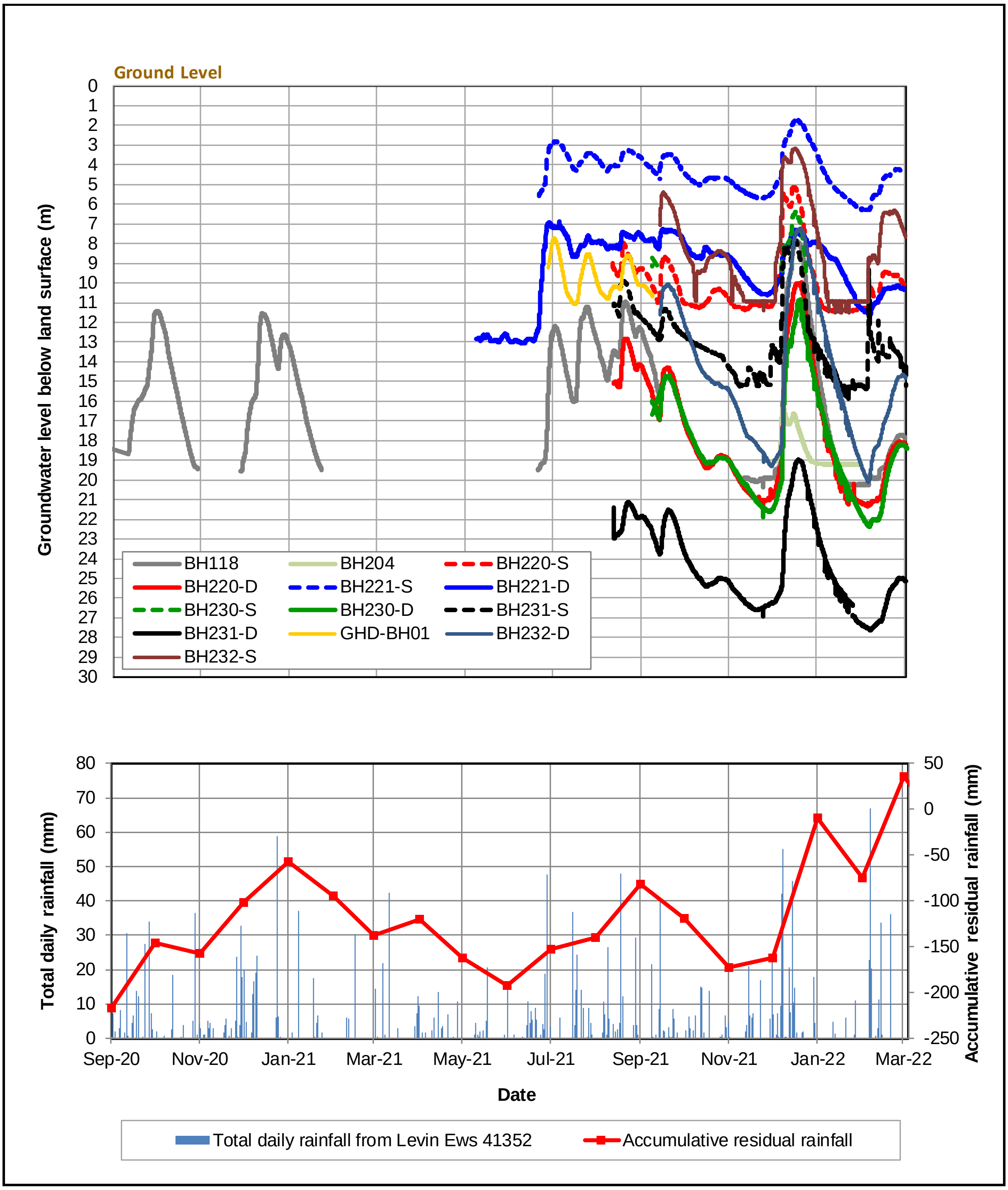
C.1 ZONE 1 – SH1 TO KOPUTARORA STREAM AT SH57



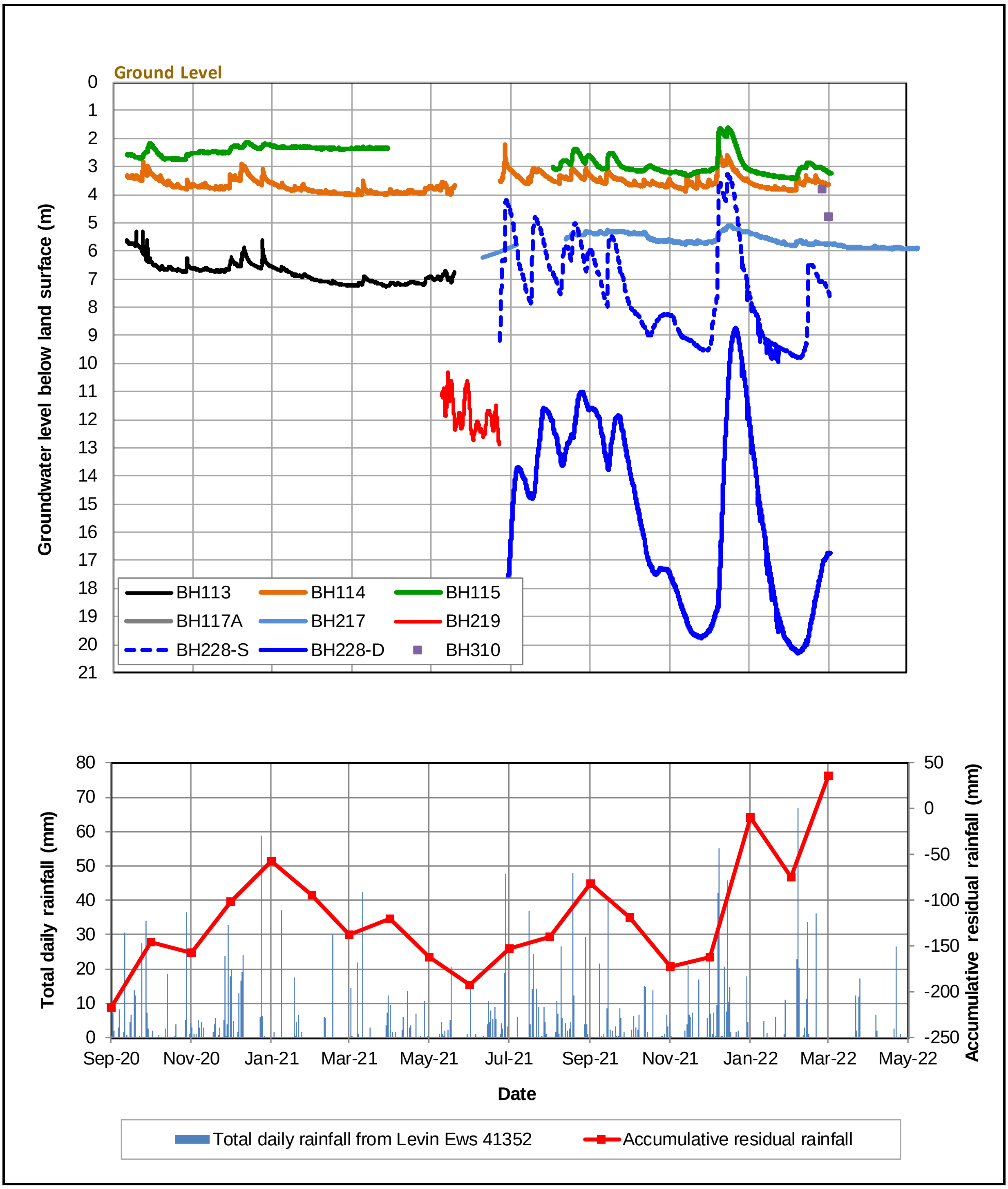
C.2 ZONE 2 – KOPUTAROA STREAM AT SH57 TO QUEEN STREET



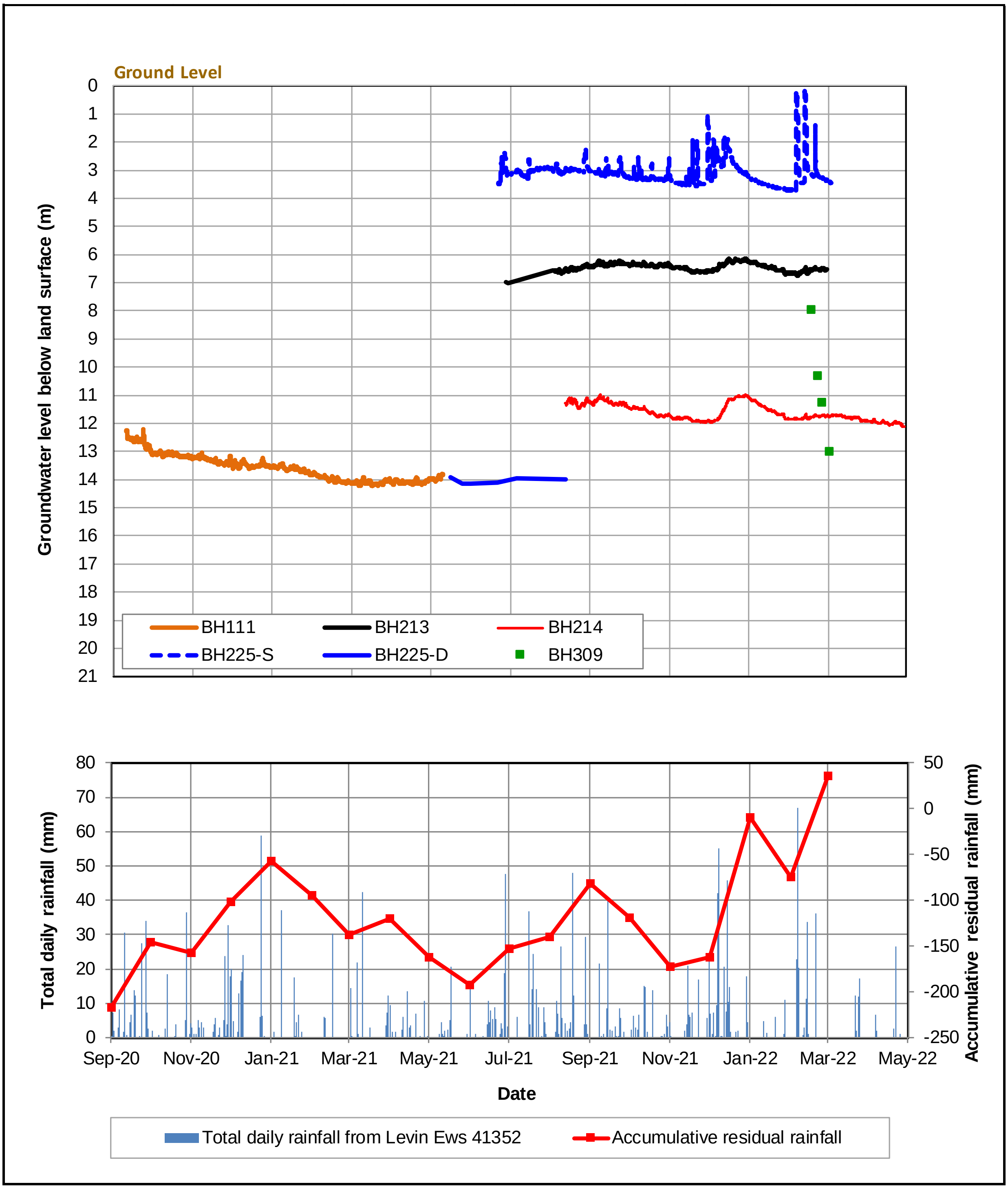
C.3 ZONE 3 – QUEEN STREET TO NORTH OF KIMBERLY ROAD



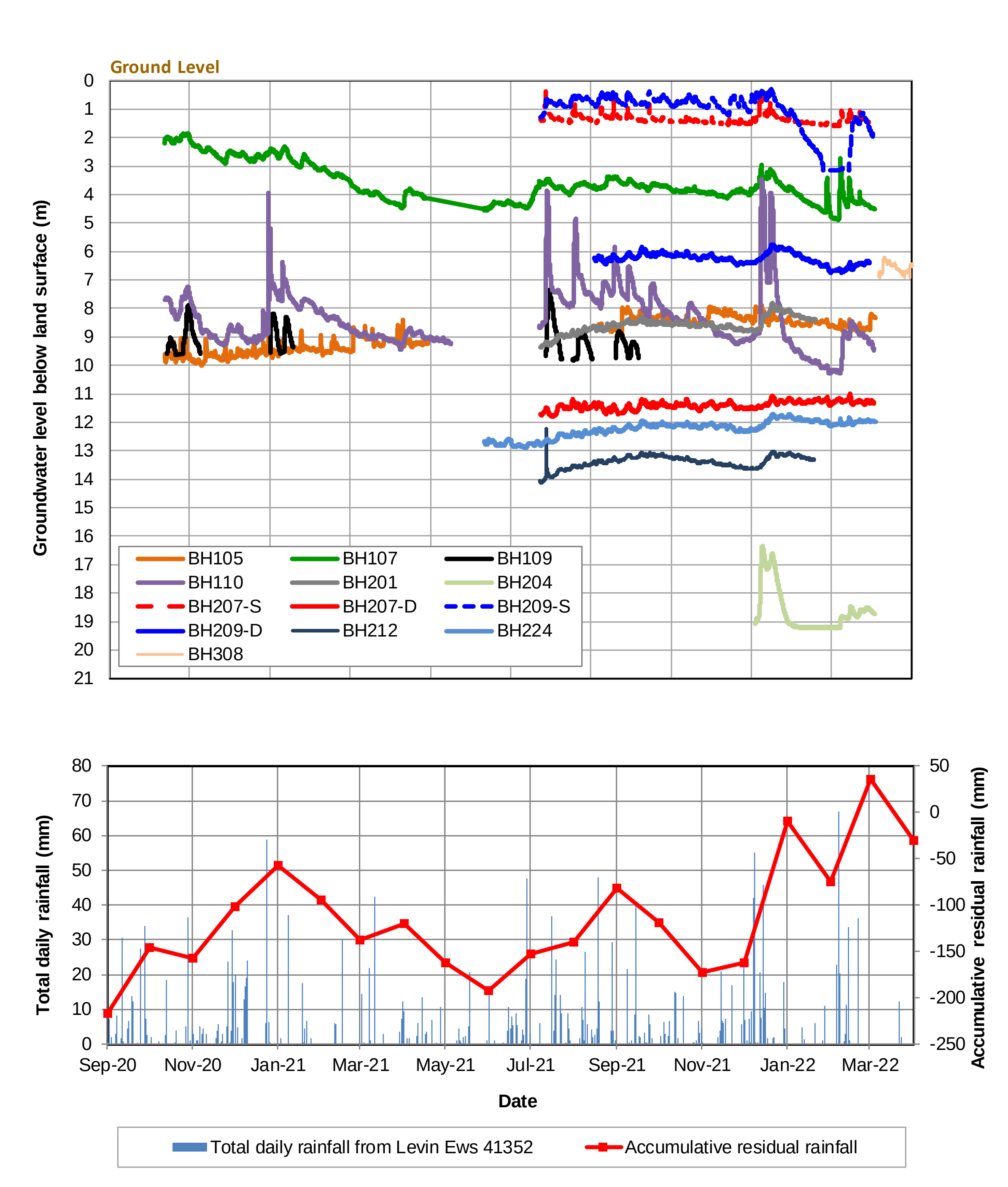
C.4 ZONE 4 – NORTH OF KIMBERLY ROAD TO OHAU RIVER



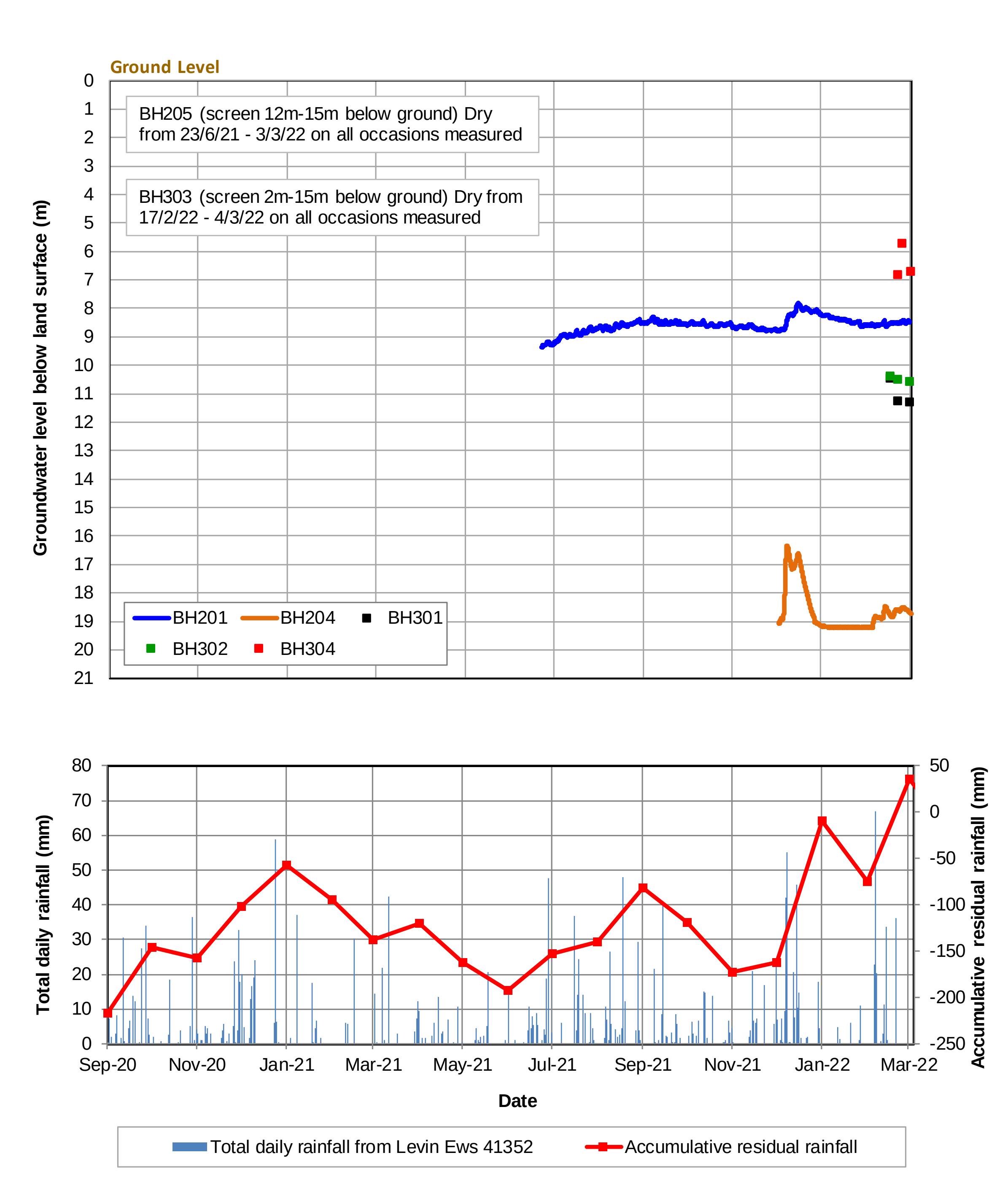
C.5 ZONE 5 – OHAU RIVER TO WAIKAWA STREAM



C.6 ZONE 6 – WAIKAWA STREAM TO MANAKAU STREAM



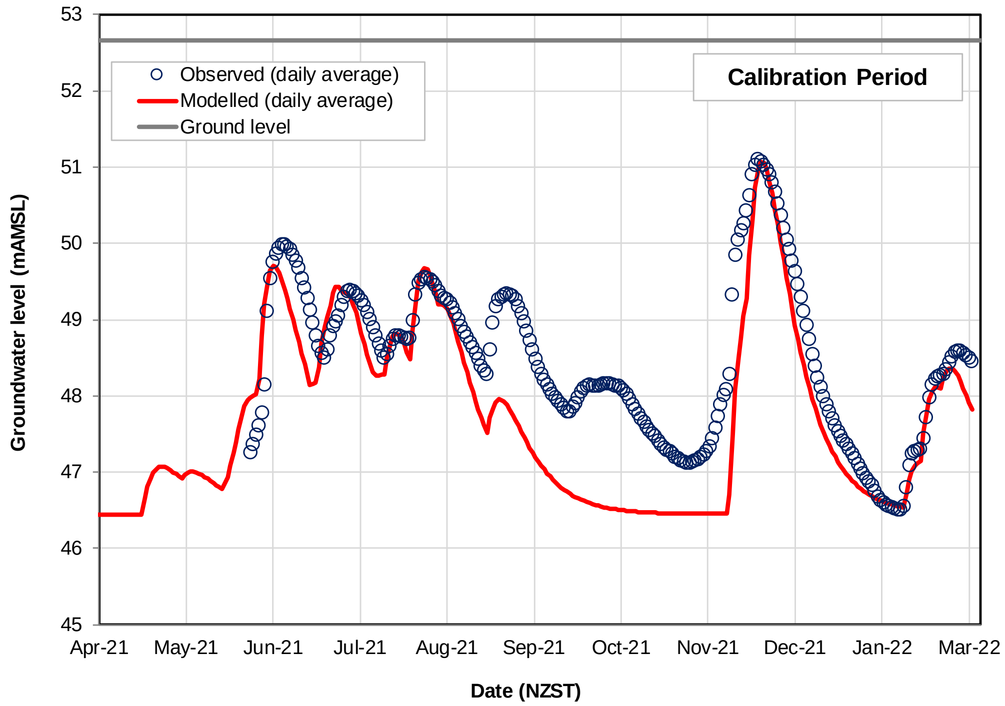
C.7 ZONE 7 – MANAKAU STREAM TO SH1

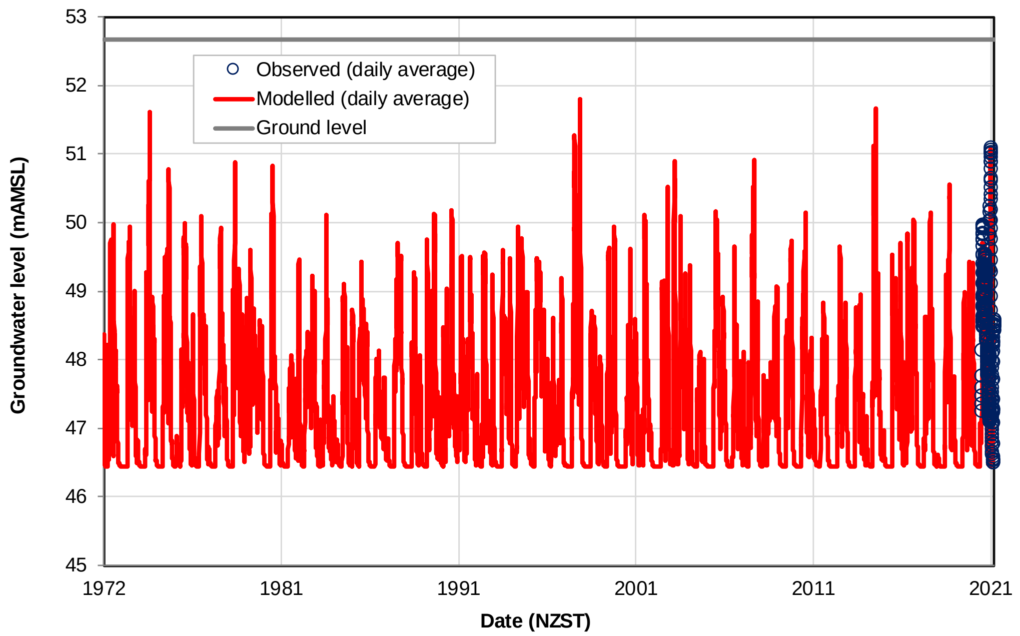


Appendix D MODEL CALIBRATIONS AND PREDICTIONS EAST OF LEVIN

C.8 BH221S

BH221S - Match 10 (M10)

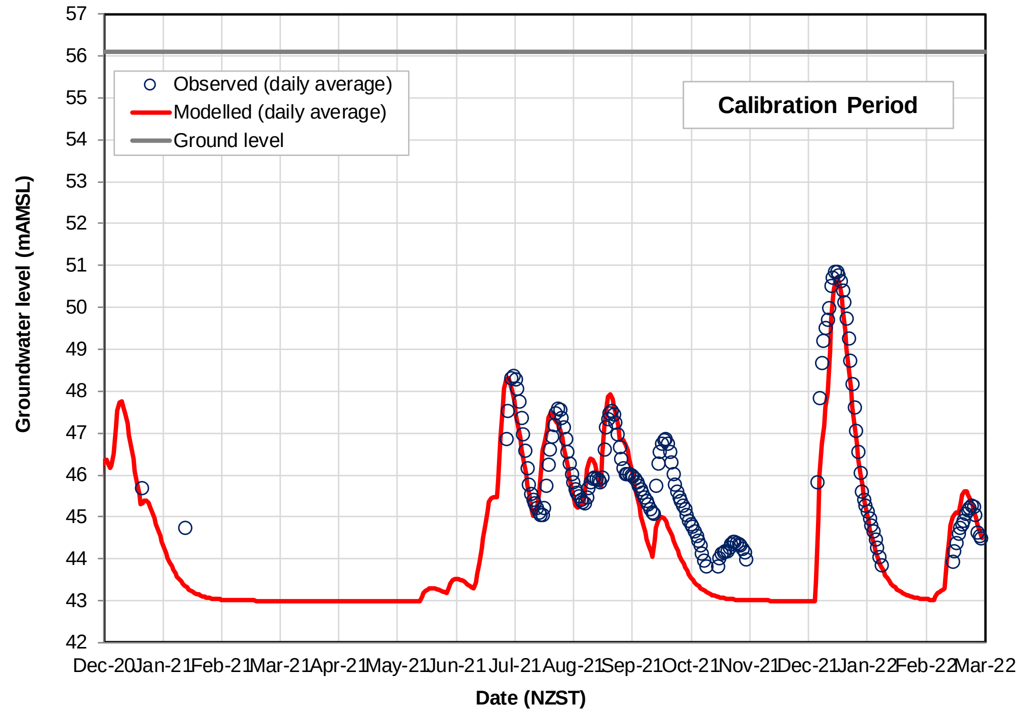


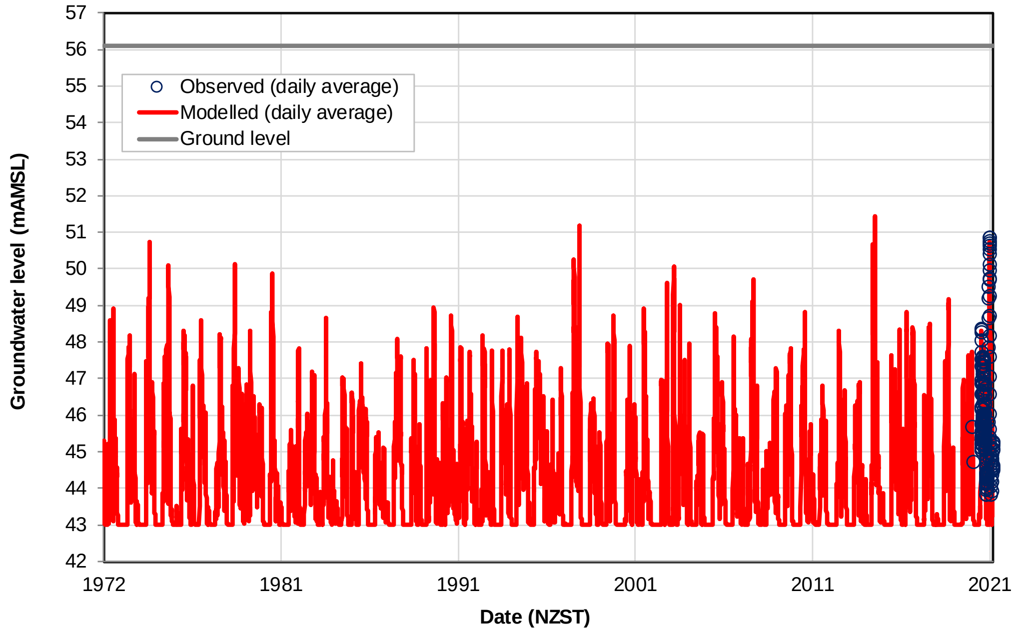


Lowest water level (mAMSL)	Aquifer storage (-)	Vadose zone travel time (d)	Aquifer mean residence time (d)	Aquifer length (m)	Prediction location (m)	Aquifer transmissivity (m^2/d)	Profile available water (mm)	Evapo transpiration reduction factor (-)	Crop coefficient (-)	Max rainfall recharge in a day (mm)
d	S	t_v	t_{res}	L	x	T	PAW	r	C	D_T
46.45	**0.008**	**11.0**	**5**	**14,000**	**2,300**	**4,756**	**90**	**13.0**	**0.75**	**86**

C.9 GHD-BH01

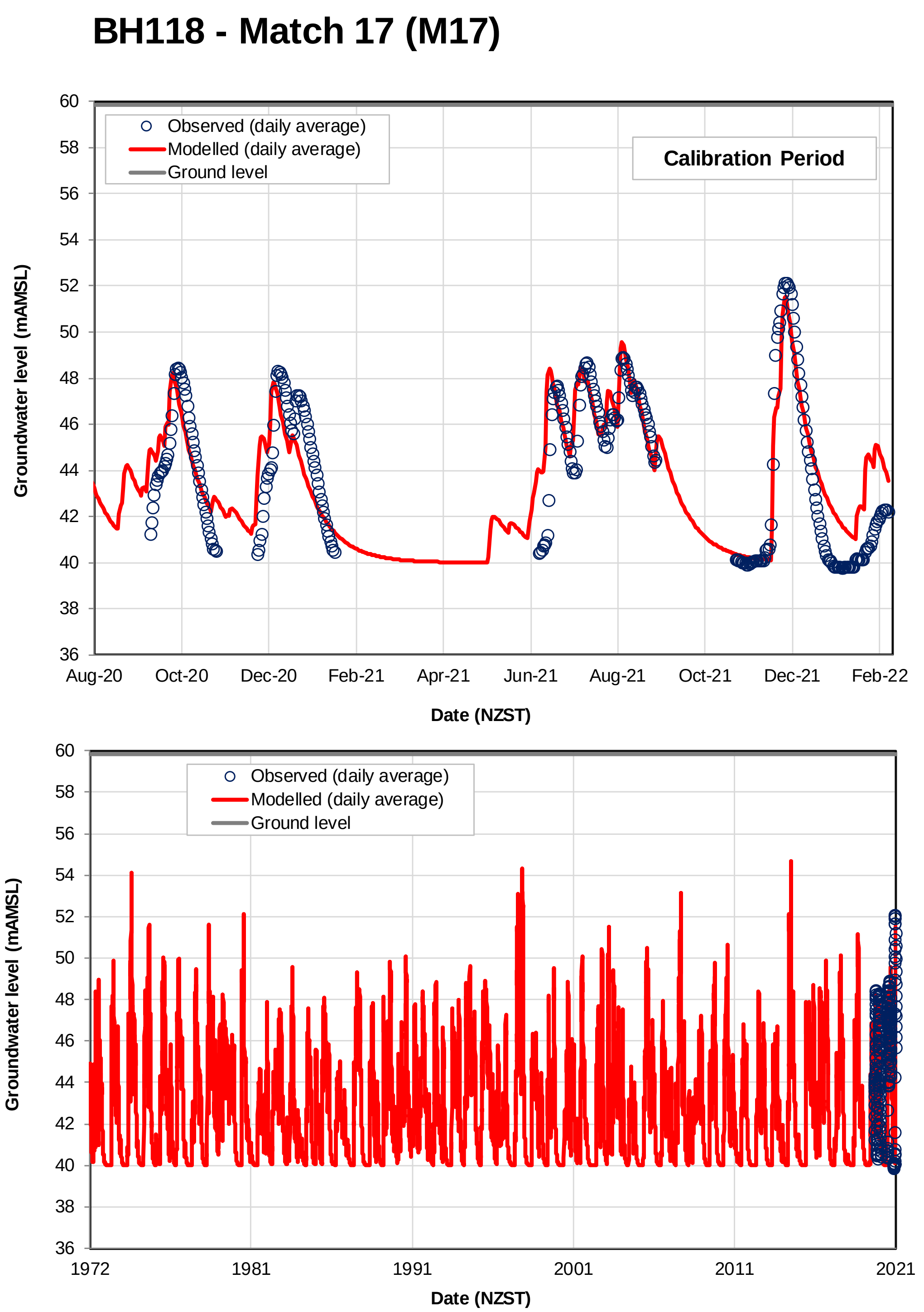
GHD-BH01 - Match 06 (M06)





Lowest water level (mAMSL)	Aquifer storage (-)	Vadose zone travel time (d)	Aquifer mean residence time (d)	Aquifer length (m)	Prediction location (m)	Aquifer transmissivity (m^2/d)	Profile available water (mm)	Evapo transpiration reduction factor (-)	Crop coefficient (-)	Max rainfall recharge in a day (mm)
d	S	t_v	t_{res}	L	x	T	PAW	r	C	D_T
43.00	**0.007**	**7.0**	**5**	**14,500**	**2,500**	**3,650**	**110**	**10.0**	**0.75**	**86**

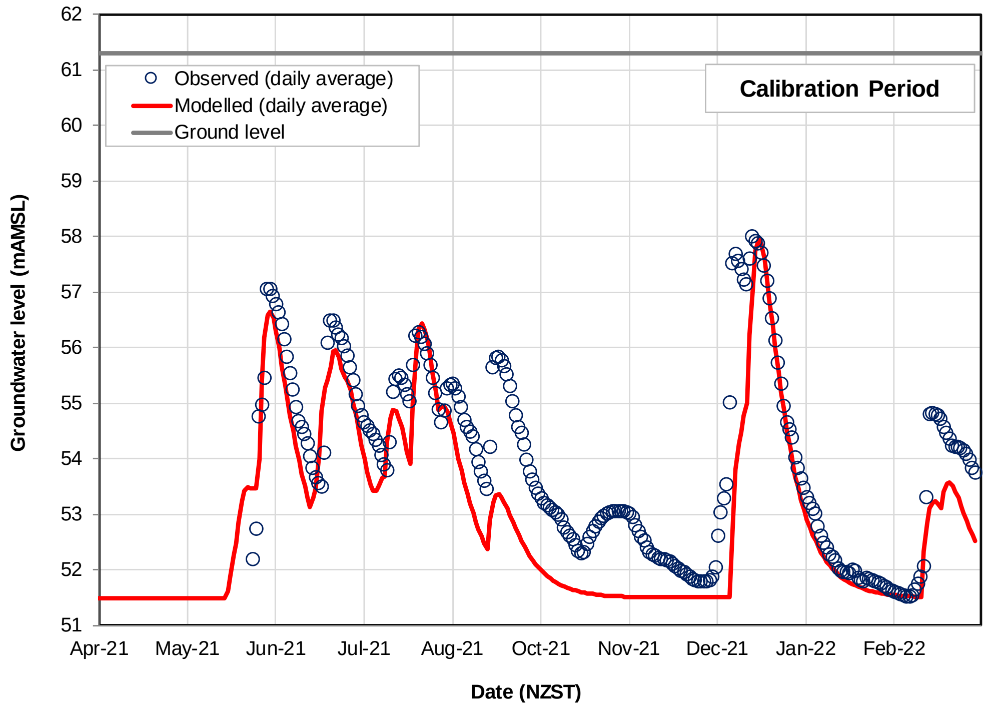
C.10 BH118

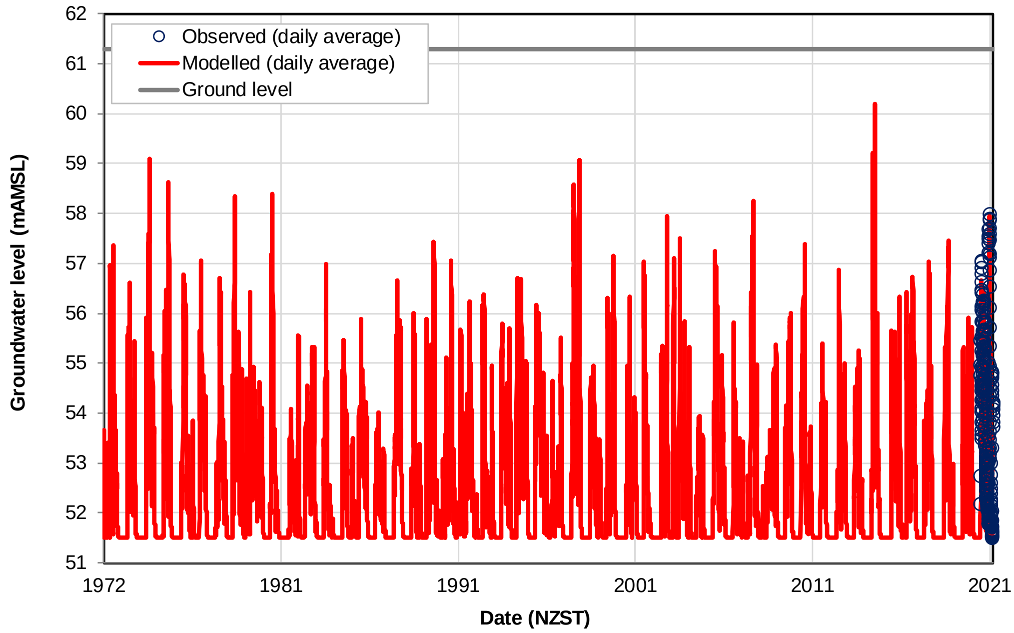


Lowest water level (mAMSL)	Aquifer storage (-)	Vadose zone travel time (d)	Aquifer mean residence time (d)	Aquifer length (m)	Prediction location (m)	Aquifer transmissivity (m²/d)	Profile available water (mm)	Evapo transpiration reduction factor (-)	Crop coefficient (-)	Max rainfall recharge in a day (mm)
d	S	t_v	t_{res}	L	x	T	PAW	r	C	D_T
40.00	**0.012**	**1.0**	**20**	**14,000**	**3,000**	**1,547**	**90**	**8.0**	**0.75**	**86**

C.11 BH228S

BH228S - Match 06 (M06)

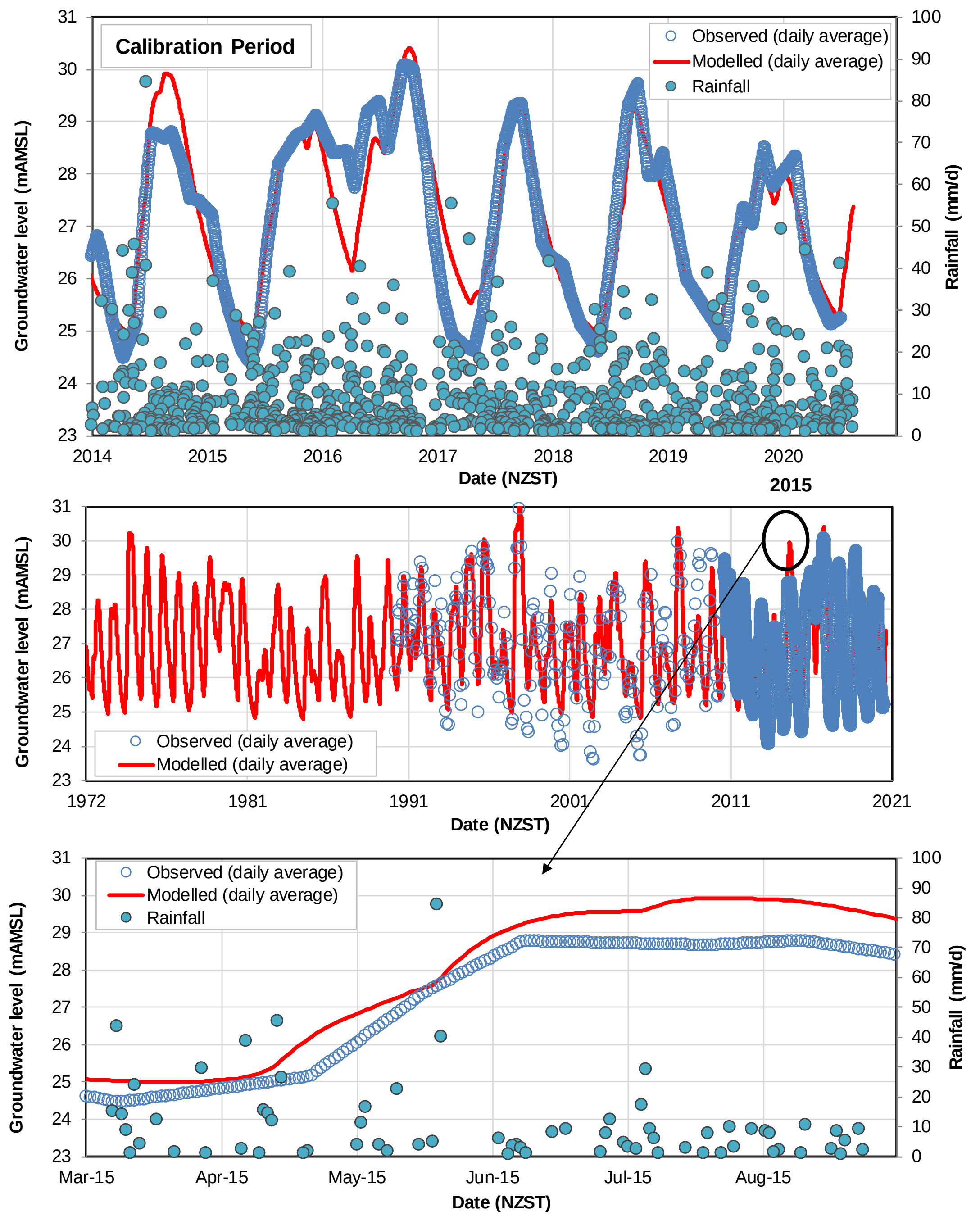




Lowest water level (mAMSL)	Aquifer storage (-)	Vadose zone travel time (d)	Aquifer mean residence time (d)	Aquifer length (m)	Prediction location (m)	Aquifer transmissivity (m^2/d)	Profile available water (mm)	Evapo transpiration reduction factor (-)	Crop coefficient (-)	Max rainfall recharge in a day (mm)
d	S	t_v	t_{res}	L	x	T	PAW	r	C	D_T
51.50	**0.004**	**9.0**	**3**	**14,000**	**3,500**	**3,383**	**110**	**10.0**	**0.90**	**86**

C.12 363251 (HORIZONS MONITORING BORE)

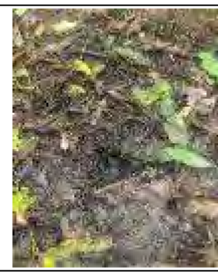
363251 - Match 01 (M01)



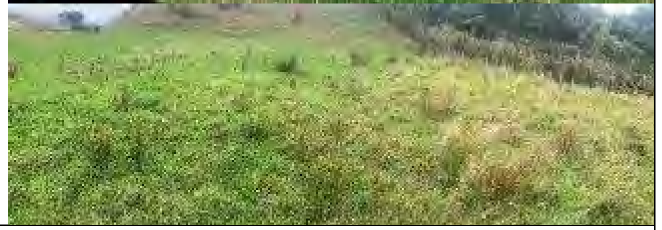
Lowest water level (mAMSL)	Aquifer storage (-)	Vadose zone travel time (d)	Aquifer mean residence time (d)	Aquifer length (m)	Prediction location (m)	Aquifer transmissivity (m2/d)	Profile available water (mm)	Evapo transpiration reduction factor (-)	Crop coefficient (-)	Max rainfall recharge in a day (mm)
d	S	tv	tres	L	x	T	PAW	r	C	DT
24.58	**0.048**	**23.1**	**88**	**14,000**	**2,800**	**1,431**	**120**	**10.0**	**0.90**	**86**

Appendix E GROUNDWATER SEEPAGES

Appendix E Groundwater Seepages

Seepage (SE) ID	Property ID	Chainage (m)	Classification (Earl, 1998)					Dimensions			Centre of Seepage(s)		Date : Description	Photos
			Type	Morphology	QMap	Flow Variability	Flow Rate (L/s)	Width (m)	Length (m)	Depth (m)	Easting (NZTM2000)	Northing (NZTM2000)		
SE-01	19	33800 - 33950	Depression	Linear channel	Q5b	Permanent	Seep	n/a	250	n/a	1783479	5487377	27/5/2021: Seepage from terrace starting approximately 1 m up from flowing surface water in bottom of channel. Water table in channel at similar level to surface water.	
SE-02	21	33650 - 33700	Depression	Linear channel	Q5b	Permanent	Seep	n/a	200	n/a	1783726	5487392	23/3/2021: Seepage from terrace starting approximately 0.5 m up from ponded surface water and boggy ground in bottom of channel. Water table in channel at similar level to surface water.	
SE-03	28	33400	Depression	Seepage	Q5b	Intermittent	Seep	5	10	n/a	1784087	5487399	23/3/2021: Seepage near the base of the terrace at the head of an incised channel. Observed at the end of summer after period of extended dry weather. Probably groundwater fed. May be a very small flow (< 1 L/s) in	No photo
SE-04	38	31850	Depression	Seepage	Q5b	Intermittent ?	Seep	30	20	0.5	1785299	5488382	13/8/2021: Seepage. Damp ground and time of visit.	
SE-05	38	31650	Depression	Seepage	Q2f	Intermittent ?	Seep	1 - 2	20	0.5	1785488	5488257	13/8/2021: Seepage at top of ridge line.	
SE-06	43	31100	Depression	Seepage	Q5b	Permanent	Seep	0.5 – 0.75	> 2	0.25	1786000	5488457	19/4/2021: Seepage in bush block. Possibly small flow (<1 L/s) during winter or after heavy rainfall.	 

Appendix E Groundwater Seepages

Seepage (SE) ID	Property ID	Chainage (m)	Classification (Earl, 1998)					Dimensions			Centre of Seepage(s)		Date : Description	Photos
			Type	Morphology	QMap	Flow Variability	Flow Rate (L/s)	Width (m)	Length (m)	Depth (m)	Easting (NZTM2000)	Northing (NZTM2000)		
SE-07	47 & 52	30350 - 30500	Depression	Seepage	Q1a * Q31	Permanent	Seep	25	125	n/a	1786687	5488556	24/3/2021: Seepage from side and base of terrace. Wet ground at base of terrace probably caused by high water table.	
SE-08	287	20600	Depression	Seepage	Q2a	Permanent	Seep	75	56	n/a	1792634	5496000	19/4/2021: Seepage from side and base of terrace. Wet ground at base of terrace probably caused by high water table.	 
SE-09	287	20600	Depression	Seepage	Q5b	Intermittent	Seep	10	5	0.25	1792436	5496149	19/4/2021: Seepage from side of terrace.	No photo

Earl, A.P. (1998). Springs database manual. Field procedures and database management. Environment Canterbury technical report. U98/8.

Heron, D.W. (custodian) (2014). Geological Map of New Zealand 1:250 000. GNS Science Geological Map 1. Lower Hutt, New Zealand. GNS Science.

Appendix F WETLAND AND SELECTED FOREST HYDROLOGY

Appendix F Wetland and Selected Forest Hydrology

Vegetation Overview						Topography	Geology (Qmap)	Potential Surface Water / Groundwater Sources	Groundwater (GW)				Surface Water (SW)		Vegetation Risk Assessment	
									Regional Water Table (RWT)		Perched (P)					
Site Object Identifier DF4.0	DF4.0 Outside Footprint (OF) & 20m Outside Designation (OD) Buffer Inside Designation (ID)	Chainage (m)	Vegetation ID Name	Vegetation Name	Wetland or Forest	Valley Floor Base of Terrace Hillslope Elevated Gentle Slope Base of Hill Narrow Channel Oxbow Depression		GW-RWT GW-P SW-xxx Assumes direct rainfall as a source for all sites *Confidence High(H), Medium (M), Low(L)*	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Regional Water Table	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Perched GW	Maximum 1-10 Year Flood Depths (m) None <0.1	Within Surface Water Drainage Feature Yes (Not Shown on Topo50) Yes (Topo50) None	Potential Reduction in GW Inputs	Potential Rise in GW Inputs
									< 1	High	< 1	High	0.1 - 0.5		High	High
									1 – 2	Moderate	1 – 2	Moderate	0.5 - 1		Moderate	Moderate
									2 – 5	Low	2 – 5	Low	1 - 3		Low	Low
									> 5	None	> 5	None	> 3		None	None
0	OF-ID	12825	EWG1	Floating sweet grass grassland	Wetland	Oxbow	Q5b	GW-RWT(M)+SW-OF(H)	1 – 2	Moderate	Unknown	Unknown	0.5 - 1	Yes (Topo50)	None	None
7	OF-ID&OD	12075	EWG7	Creeping bent grassland	Wetland	Narrow Channel	Q5b	GW-RWT(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	None	None
2	OF-OD	25750	ITF1	Tawa forest	Forest	Gentle Slope	Q2a	SW-OF(M)	> 5	None	Unknown	Unknown	<0.1	No	None	None
83	OF-OD	31150 - 31250	ITF2	Tawa-kohekohe forest	Forest	Hillslope	Q2a	SW-OF(M)	> 5	None	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
4	OF-OD	31050	ITF2	Tawa-kohekohe forest	Forest	Elevated	Q5b	GW-P(L)+SW-PR(L)	> 5	None	< 1	High	<0.1	No	None	None
5	OF-ID&OD	23725	ITT07	Tawa-tÄ«toki treeland	Forest	Valley Floor	Q1a	GW-RWT(M)+SW-OF(H)	1 – 2	Moderate	Unknown	Unknown	0.5 - 1	Yes (Topo50)	None	None
95	OF-ID&OD	28225	MWSe2	Isolepis prolifera-floating sweet grass sedgeland	Wetland	Gentle slope	Q2a	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
8	OF-ID&OF-OD	13350 - 13550	MWG1d	Mixed wetland species grassland	Wetland	Narrow Channel	Q5b	GW-RWT(L)+SW-S(H)	2 – 5	Low	Unknown	Unknown	0.5 - 1	Yes (Topo50)	None	None
9	OF-ID&OF-OD	13000	EWG1d	Exotic wetland species grassland	Wetland	Oxbow	Q1a	GW-RWT(L)+SW-OF(H)	2 – 5	Low	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
56	OF-ID	33925	EWF1	Crack willow forest	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-S(M)+SW-OF(M)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
11	OF-ID	15875	EWG3	Blue sweetgrass-creeping buttercup grassland	Wetland	Gentle Slope	Q5b	GW-RWT(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
13	OF-ID	31575	EWG4	Mercer grass-water pepper grassland	Wetland	Valley Floor	Q5b	GW-RWT(L)+SW-S(L)	1 – 2	Moderate	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	Moderate	None
12	OF-ID	33375	EWG5	Yorkshire fog-creeping buttercup grassland	Wetland	Base of Terrace	Q5b	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	Low	None
14	OF-ID	28525	EWG6	Yorkshire fog-creeping buttercup-Mercer grass grassland	Wetland	Valley Floor	Q2a	GW-RWT(M)+SW-S(M)	2 – 5	Low	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
58	OF-ID&OF-OD	20550	MWG3	Yorkshire fog-Isolepis prolifera grassland	Wetland	Valley Floor, Base of Terrace, Hillslope	Q5b	GW-RWT(M)+GW-P(L)+SW-OF(H)	< 1	High	< 1	High	0.5 - 1	Yes (Not Shown on Topo50)	Low	None
16	OF-ID	23850	MWH1	Water celery-kikuyu-Isolepis	Wetland	Oxbow	Q1a	GW-RWT(L)+SW-PR(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	None	None

Appendix F Wetland and Selected Forest Hydrology

Vegetation Overview						Topography	Geology (Qmap)	Potential Surface Water / Groundwater Sources	Groundwater (GW)				Surface Water (SW)		Vegetation Risk Assessment	
									Regional Water Table (RWT)		Perched (P)					
Site Object Identifier DF4.0	DF4.0 Outside Footprint (OF) & 20m Outside Designation (OD) Buffer Inside Designation (ID)	Chainage (m)	Vegetation ID Name	Vegetation Name	Wetland or Forest	Valley Floor Base of Terrace Hillslope Elevated Gentle Slope Base of Hill Narrow Channel Oxbow Depression		GW-RWT GW-P SW-xxx Assumes direct rainfall as a source for all sites *Confidence High(H), Medium (M), Low(L)*	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Regional Water Table	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Perched GW	Maximum 1-10 Year Flood Depths (m)	Within Surface Water Drainage Feature	Potential Reduction in GW Inputs	Potential Rise in GW Inputs
													None	Yes (Not Shown on Topo50) Yes (Topo50) None		
													<0.1			
									< 1	High	< 1	High	0.1 - 0.5		High	High
									1 – 2	Moderate	1 – 2	Moderate	0.5 - 1		Moderate	Moderate
									2 – 5	Low	2 – 5	Low	1 - 3		Low	Low
									> 5	None	> 5	None	> 3		None	None
				prolifera herbfield												
60	OF-ID	10900 - 10950	EWH2	Creeping buttercup-water pepper herbfield	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
98	OF-ID	33750 - 33950	EWH3	Water celery herbfield	Wetland	Valley Floor, Base of Terrace, Hillslope	Q5b	GW-RWT(H)+SW-S(H)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
15	OF-ID	10950	EWH3	Water celery herbfield	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
61	OF-ID	10875	EWH3	Water celery herbfield	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
21	OF-ID	10650	EWH3	Water celery herbfield	Wetland	Gentle Slope	Q5b	GW-RWT(M)+SW-OF(M)	Moderate	1 – 2	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
6	OF-ID	33675	EWH5	Water pepper herbfield	Wetland	Valley Floor	Q5b	GW-RWT(M)+SW-OFH)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	None	None
23	OF-ID	14975	EWH5	Water pepper herbfield	Wetland	Narrow Channel	Q5b	GW-RWT(M)+SW-OF(H)	1 – 2	Moderate	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
18	OF-ID	31700	EWH6	Water pepper-creeping buttercup-Yorkshire fog herbfield	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(L)+SW-PR(M)	1 – 2	Moderate	Unknown	Unknown	None	None	**Moderate**	None
19	OF-ID	31625	EWH6	Water pepper-creeping buttercup-Yorkshire fog herbfield	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(L)+SW-S(L)+SW-PR(M)	1 – 2	Moderate	Unknown	Unknown	<0.1	Yes (Not Shown on Topo50)	**Moderate**	None
20	OF-ID	34100	EWH8	Broad-leaved fleabane/Yorkshire fog herbfield	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-S(L)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
96	OF-ID	30400	EWRs1	Soft rush rushland	Wetland	Valley Floor	Q3a	GW-RWT(H)+SW-PR(L)+SW-OF(M)	< 1	High	Unknown	Unknown	<0.1	None	None	None
22	OF-ID	33800 - 33950	EWRs3	Soft rush-Yorkshire fog rushland	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(H)+SW-S(M)+SW-OF(M)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
29	OF-ID	31950	ITF2	Tawa-kohekohe forest	Forest	Elevated	Q5b	GW-P(M)	> 5	None	1 – 2	Moderate	None	None	None	None
27	OF-ID	33800	MWFn1	Kiokio-Spike sedge-Yorkshire fog fernland	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-OF(M)	< 1	High	Unknown	Unknown	<0.1	None	None	None

Vegetation Overview						Topography	Geology (Qmap)	Potential Surface Water / Groundwater Sources	Groundwater (GW)				Surface Water (SW)		Vegetation Risk Assessment	
									Regional Water Table (RWT)		Perched (P)					
Site Object Identifier DF4.0	DF4.0 Outside Footprint (OF) & 20m Outside Designation (OD) Buffer Inside Designation (ID)	Chainage (m)	Vegetation ID Name	Vegetation Name	Wetland or Forest	Valley Floor Base of Terrace Hillslope Elevated Gentle Slope Base of Hill Narrow Channel Oxbow Depression		GW-RWT GW-P SW-xxx Assumes direct rainfall as a source for all sites *Confidence High(H), Medium (M), Low(L)*	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Regional Water Table	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Perched GW	Maximum 1-10 Year Flood Depths (m)	Within Surface Water Drainage Feature	Potential Reduction in GW Inputs	Potential Rise in GW Inputs
													None	Yes (Not Shown on Topo50) Yes (Topo50) None		
													<0.1			
									< 1	High	< 1	High	0.1 - 0.5		High	High
									1 – 2	Moderate	1 – 2	Moderate	0.5 - 1		Moderate	Moderate
									2 – 5	Low	2 – 5	Low	1 - 3		Low	Low
									> 5	None	> 5	None	> 3		None	None
31	OF-ID	30450	IWSe1	Isolepis prolifera sedgeland on the flats	Wetland	Base of terrace	Q1a	GW-RWT(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
32	OF-ID	23775	IWSe1	Isolepis prolifera sedgeland on the flats	Wetland	Oxbow	Q1a	GW-RWT(L)+SW-OF(H)	1 – 2	Moderate	Unknown	Unknown	0.5 - 1	Yes (Topo50)	None	None
59	OF-ID	33750	IWSe3	Rautahi sedgeland	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-S(L)+SW-PR(L)	< 1	High	Unknown	Unknown	<0.1	Yes (Not Shown on Topo50)	None	None
99	OF-ID	33925	IWSe4	Isolepis prolifera-Juncus planifolius sedgeland	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-S(M)+SW-OF(M)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
97	OF-ID	33825	IWSe5	Kiokio-spike sedge-kÄ□pÅ«ngÄ□wh Ä□ sedgeland	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-OF(L)	< 1	High	Unknown	Unknown	<0.1	None	None	None
36	OF-ID	16450 - 16550	MTF3	False acacia-tÄ«toki-cherry forest	Forest	Gentle Slope	Q2a	SW-PR(L)+SW-OF(H)	1 – 2	Moderate	Unknown	Unknown	0.1 - 0.5	None	None	None
25	OF-ID	33775 - 33950	MWG2	Yorkshire fog-spike sedge grassland	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-S(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
38	OF-ID	23850	MWSe2	Isolepis prolifera-floating sweet grass sedgeland	Wetland	Oxbow	Q1a	GW-RWT(L)+SW-PR(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	None	None
49	OF-ID	28175	MWG1d	Mixed wetland species grassland	Wetland	Depression	Q2a	GW-RWT(M)+SW-PR(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
50	OF-ID	25450	MWG1d	Mixed wetland species grassland	Wetland	Gentle slope	Q2a	GW-RWT(L)+SW-OF(H)	1 – 2	Moderate	Unknown	Unknown	<0.1	Yes (Topo50)	None	None
51	OF-ID	25500	MWG1d	Mixed wetland species grassland	Wetland	Gentle slope	Q2a	GW-RWT(L)+SW-PR(M)	2 – 5	Low	Unknown	Unknown	<0.1	Yes (Not Shown on Topo50)	None	None
52	OF-ID	13450	MWG1d	Mixed wetland species grassland	Wetland	Oxbow	Q1a	GW-RWT(L)+SW-OF(H)	2 – 5	Low	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
53	OF-ID	13475	MWG1d	Mixed wetland species grassland	Wetland	Gentle Slope	Q1a	GW-RWT(L)+SW-OF(H)	2 – 5	Low	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
3	OF-OD	29200	ITF1	Tawa forest	Forest	Hillslope	Q5b	None(M)	> 5	None	Unknown	Unknown	None	No	None	None
55	OF-OD	20650	ITF1	Tawa forest	Forest	Elevated	Q5b	GW-P(L)+GW-RWT(L)	2 – 5	Low	Unknown	Unknown	<0.1	No	None	None
64	OF-ID & OF-OD	11550	IWSe1-SPG	Isolepis prolifera sedgeland	Wetland	Hillslope	Q2a	GW-RWT(H)+SW-OF(L)	< 1	High	Unknown	Unknown	<0.1	None	None	None
65	OF-ID	11525	IWSe1-SPG	Isolepis prolifera sedgeland	Wetland	Hillslope	Q2a	GW-RWT(H)+SW-OF(L)	< 1	High	Unknown	Unknown	<0.1	None	None	None

Vegetation Overview						Topography	Geology (Qmap)	Potential Surface Water / Groundwater Sources	Groundwater (GW)				Surface Water (SW)		Vegetation Risk Assessment	
									Regional Water Table (RWT)		Perched (P)		Maximum 1-10 Year Flood Depths (m)	Within Surface Water Drainage Feature		
Site Object Identifier DF4.0	DF4.0 Outside Footprint (OF) & 20m Outside Designation (OD) Buffer Inside Designation (ID)	Chainage (m)	Vegetation ID Name	Vegetation Name	Wetland or Forest	Valley Floor Base of Terrace Hillslope Elevated Gentle Slope Base of Hill Narrow Channel Oxbow Depression		GW-RWT GW-P SW-xxx Assumes direct rainfall as a source for all sites *Confidence High(H), Medium (M), Low(L)*	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Regional Water Table	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Perched GW	None <0.1	Yes (Not Shown on Topo50) Yes (Topo50) None	Potential Reductio n in GW Inputs	Potential Rise in GW Inputs
									< 1	High	< 1	High	0.1 - 0.5		High	High
									1 – 2	Moderate	1 – 2	Moderate	0.5 - 1		Moderate	Moderate
									2 – 5	Low	2 – 5	Low	1 - 3		Low	Low
									> 5	None	> 5	None	> 3		None	None
66	OF-ID	11500	IWSe1-SPG	Isolepis prolifera sedgeland	Wetland	Hillslope	Q2a	GW-RWT(H)+SW-OF(L)	< 1	High	Unknown	Unknown	<0.1	None	None	None
67	OF-ID	11425 - 11525	IWSe1-SPG	Isolepis prolifera sedgeland	Wetland	Valley Floor	Q2a	GW-RWT(H)+SW-OF(L)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	High	None
68	OF-ID	11425	IWSe1-SPG	Isolepis prolifera sedgeland	Wetland	Hillslope	Q2a	GW-RWT(H)+SW-PR(L)	< 1	High	Unknown	Unknown	<0.1	None	None	None
89	OF-OD	23025	EWG9	Mercer grass-open water grassland	Wetland	Base of Hill	Q1a	GW-RWT(L)	2 – 5	Low	Unknown	Unknown	<0.1	None	None	None
62	OF-ID	28450	EWG8	Soft rush/Yorkshire fog-creeping buttercup grassland	Wetland	Depression	Q2a	GW-P(L)	2 – 5	Low	< 1	High	None	None	None	None
69	OF-ID	31600 - 31750	MTF6d	Karaka-mÄ□hoe-kawakawa forest and scrub	Forest	Valley Floor	Q5b	GW-RWT(L)+SW-S(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Not Shown on Topo50)	None	None
93	OF-OD	16400 - 16500	MTF6	Karaka-mÄ□hoe-kawakawa forest and scrub	Forest	Gentle Slope	Q2a	SW-OF(M)	1 – 2	Moderate	Unknown	Unknown	0.1 - 0.5	None	None	None
70	OF-ID	31650	MWSe1-SPG	Isolepis prolifera-soft rush sedgeland	Wetland	Hillslope	Q2a	GW-RWT(M)+GW-P(H)	1 – 2	Moderate	< 1	High	None	None	High	None
71	OF-ID	31750	MWSe1-SPGd	Isolepis prolifera-soft rush sedgeland	Wetland	Hillslope	Q5b	GW-RWT(L)+GW-P(L)	1 – 2	Moderate	< 1	High	None	None	High	None
72	OF-ID	31825	EWH10d	Soft rush/creeping buttercup-Yorkshire fog-mercer grass herbfieldÂ	Wetland	Hillslope	Q5b	GW-P(M)+SW-PR(M)	2 – 5	Low	< 1	High	<0.1	None	High	None
92	OF-ID	28475	EWH10	Soft rush/creeping buttercup-Yorkshire fog-mercer grass herbfieldÂ	Wetland	Valley Floor	Q2a	GW-RWT(L)+SW-PR(L)	2 – 5	Low	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
88	OF-ID	30450	EWRs1	Soft rush rushland	Wetland	Base of terrace	Q1a	GW-RWT(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
85	OF-ID&OD	24100	EWRs1d	Soft rush rushland	Wetland	Gentle Slope	Q2a	SW-OF(M)	> 5	None	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None

Appendix F Wetland and Selected Forest Hydrology

Vegetation Overview						Topography	Geology (Qmap)	Potential Surface Water / Groundwater Sources	Groundwater (GW)				Surface Water (SW)		Vegetation Risk Assessment	
									Regional Water Table (RWT)		Perched (P)		Maximum 1-10 Year Flood Depths (m)	Within Surface Water Drainage Feature	Potential Reduction in GW Inputs	Potential Rise in GW Inputs
Site Object Identifier DF4.0	DF4.0 Outside Footprint (OF) & 20m Outside Designation (OD) Buffer Inside Designation (ID)	Chainage (m)	Vegetation ID Name	Vegetation Name	Wetland or Forest	Valley Floor Base of Terrace Hillslope Elevated Gentle Slope Base of Hill Narrow Channel Oxbow Depression		GW-RWT GW-P SW-xxx Assumes direct rainfall as a source for all sites *Confidence High(H), Medium (M), Low(L)*	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Regional Water Table	Highest Predicted GW Level Below Natural Topographic Surface Anywhere Beneath Site (m)	Site Connectivity to Perched GW	None <0.1	Yes (Not Shown on Topo50) Yes (Topo50) None		
									< 1	High	< 1	High	0.1 - 0.5		High	High
									1 – 2	Moderate	1 – 2	Moderate	0.5 - 1		Moderate	Moderate
									2 – 5	Low	2 – 5	Low	1 - 3		Low	Low
									> 5	None	> 5	None	> 3		None	None
86	OF-OD	24000	EWRs1d	Soft rush rushland	Wetland	Gentle Slope	Q2a	SW-OF(M)	> 5	None	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
87	OF-ID&OF-OD	11925	IWSe1-SPGd	Isolepis prolifera sedgeland	Wetland	Hillslope & Valley Floor	Q5b	GW-RWT(M)-SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Not Shown on Topo50)	None	None
76	OF-ID	11775	IWSe1-SPGd	Isolepis prolifera sedgeland	Wetland	Valley Floor	Q5b	GW-RWT(M)-SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	None	None
74	OF-ID	23675	EWH9	Exotic dominant wetland	Wetland	Valley Floor	Q1a	GW-RWT(M)+SW-OF(H)	< 1	High	Unknown	Unknown	1 - 3	Yes (Topo50)	None	None
77	OF-ID	11200 - 11225	EWH9d	Exotic dominant wetland	Wetland	Valley Floor	Q5b	GW-RWT(L)-SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	None	None
48	OF-ID	33675	EWH1	Creeping buttercup herbfield	Wetland	Valley Floor	Q5b	GW-RWT(H)+SW-OF(H)	< 1	High	Unknown	Unknown	0.1 - 0.5	Yes (Topo50)	None	None
78	OF-OD	11100 - 11200	EWH1d	Creeping buttercup herbfield	Wetland	Valley Floor	Q5b	GW-RWT(L)+SW-OF(H)	< 1	High	Unknown	Unknown	0.5 - 1	Yes (Topo50)	None	None
91	OF-ID	10300 - 10450	EWH1d	Creeping buttercup herbfield	Wetland	Gentle Slope & Depression	Q5b	GW-P(L)+SW-OF(L)+SW-PR(L)	2 – 5	Low	< 1	High	1 - 3	Yes (Not Shown on Topo50)	None	None
79	OF-ID	10350	EWH1d	Creeping buttercup herbfield	Wetland	Gentle Slope	Q5b	GW-P(L)+SW-OF(L)+SW-PR(L)	2 – 5	Low	< 1	High	<0.1	None	None	None

Appendix G POTENTIAL ALLIGNMENT CUTS BELOW GROUNDWATER

Stantec

ŌTAKI TO NORTH LEVIN HIGHWAY
Potential Alignment Cuts Below Groundwater

07 July 2022

Prepared for:
Waka Kotahi NZ Transport Agency

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Project Number: 310203848

Revision	Description	Author	Date	Quality Check	Date	Independent Review	Date
A	Draft for client review	Mark Scaife	06/04/22	James Dommisse	30/05/22		
1	Final for client use	Mark Scaife	07/07/22	Vanessa Dally	07/07/22		

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1 Scope of Assessment

At some sites along the new Ōtaki to North Levin alignment, the highest Groundwater Level (GWL) as assessed from borehole monitoring, test pits, Cone Penetration Tests (CPT's), and surface expressions (groundwater seepages and wetlands) may be intercepted at some road cuttings. Where groundwater is above the base of the alignment, groundwater seepages / discharges from batters may occur, potentially resulting in localised lowering of GWL's.

Simplified cross-sections showing groundwater levels, topography and nearby surface water features were produced at sites where groundwater might intercept the swale inverts adjacent to vertical alignment Design Freeze 4.0 (DF4.0) (Figure 2-1). The methodology and results are discussed below.

2 Methodology

Figure 2-1 shows a 2D section of the alignment. The vertical alignment (black line), represents the swale invert, assumed to be 1.25 m below the centreline elevation of DF4.0. The lowest and highest groundwater levels (relative to ground level) measured from all site investigation boreholes, test pits and Cone Penetration Tests (CPT's) are also shown. The groundwater levels are split in those taken from shallow and deeper test zones to show, for example, the effect of bore screen depth on groundwater levels.

Table 1 summarises sites where alignment cuts (swale invert) may intersect the highest GWL. At each site, cross section(s) were taken parallel and / or perpendicular to the alignment to assess effects on surface water, wetlands outside the DF4.0 footprint (plus 20 m buffer) and private bores identified from the investigation and from the Horizons and Greater Wellington Regional Council's GIS databases.

Table 1: Summary of where alignment cuts may intersect the highest GWL.

Site	Cut Length Below Highest GWL Chainages (m)	Highest GWL Above Swale Invert at Each Site (m)	Nearby Wetlands – Wildlands ID	Potential Water Source(s) to Wetlands	Potential Effect on Reliability of Supply From Neighbouring Bores
A	11350 – 11650	3.5	64 - 68	Regional groundwater, overland flow, ponded rainfall	Very unlikely
B	20450 – 20800	2.0	54, 58	Regional groundwater and overland flow	Very unlikely
C	26600 – 27250	5.0	None	No wetlands nearby	Unlikely
D	28950 – 29200	3.0	None	No wetlands nearby	Very unlikely
E	31750 – 31850	1.5	13, 18, 19, 69 - 72	Regional and perched groundwater, surface water and overland flow	Very unlikely
F	33400 – 33600	3.0	16, 20, 22, 25, 26, 27, 48, 56, 59	Regional and perched groundwater, surface water, overland flow	Very unlikely

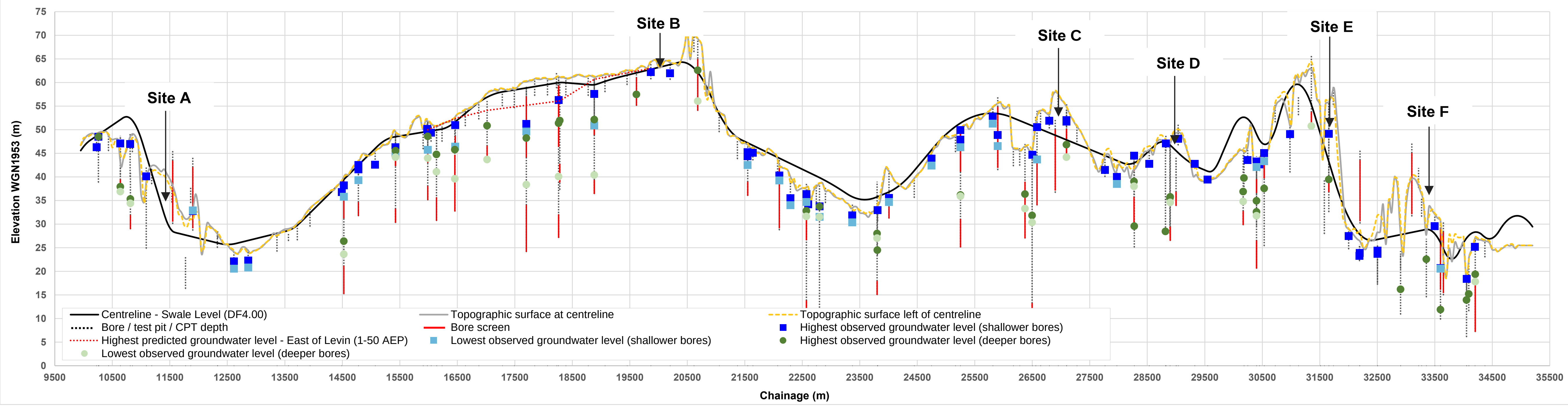

Figure 2-1: 2D section showing DF4.0 vertical alignment 1.25 m below centreline (swale invert), observed groundwater levels from Project monitoring bores, test pits, and CPT's and the highest predicted groundwater levels east of Levin (red dashed line).

3 Groundwater Conceptualisations

For the sites listed below, chainage numbers refer to the length of alignment cut that is potentially below the highest groundwater level.

3.1 Site A (CH 11350 – 11650)

The cut (swale invert) through this area is approximately 10 m deep into Q5 beach deposits. It consists of sand and a thin, approximately 1 m thick layer of clayey silt at approximately 9.0 metres below ground level (mbgl), overlying more sand. Site investigation BH312 is screened between 2 and 15 mbgl and provides an estimate of the highest GWL the cut will encounter (Figure 3 1). The green dashed line represents an interpretation of the highest GWL recorded; however, the short duration of monitoring (7-days) within BH312 means that the highest GWL may be higher than shown at the bore. No groundwater seepages (seeps) or evidence of seeps have been observed coming from hill slopes at a similar level to the clayey silt logged at 9 mbgl meaning that the presence of perched groundwater is unlikely, though this does not preclude its occurrence. As such, the GWL plotted in Figure 3 1 is probably more representative of the regional groundwater table.

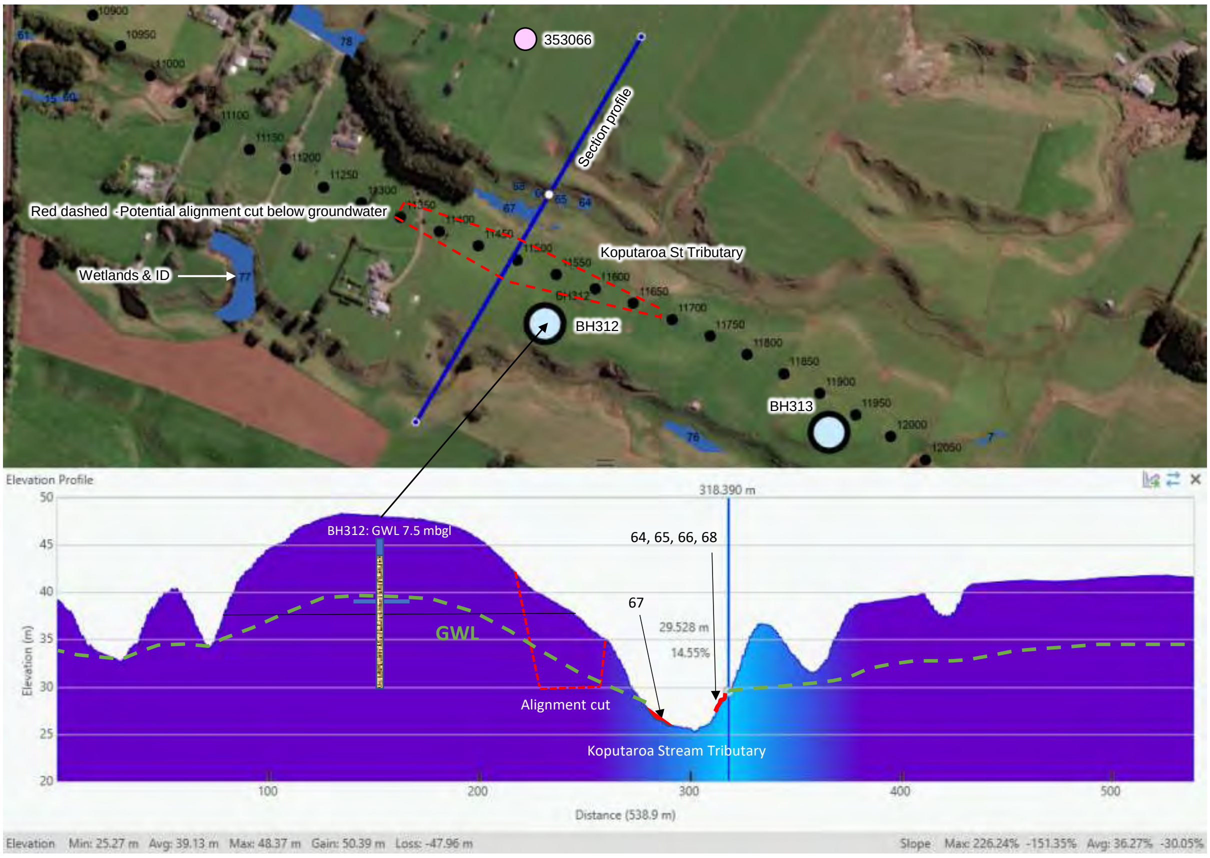

Figure 3-1: Site A - Cross-section and aerial plan showing interpreted GWL, alignment cut, wetlands, investigation boreholes, and Horizons bores (shown pink)

Construction is likely to intercept the regional groundwater table lowering nearby levels and potentially effecting wetland ID67, a hillside seep. The seeps on the opposite side of the gully, 64, 65, 66, and 68 are isolated from direct groundwater flow from the direction of the cut by a gully, the base which is 4 m below swale depth. However, these sites may be affected by the depressurising of the opposite bank.

Information on the hillside seeps is limited; however, groundwater through flow is probably low due to the dominantly fine grained (low permeability) nature of the sediments in this area. As such, construction should expect minimal groundwater discharges from batters, though saturated ground conditions may occur at subgrade level. This is likely to make compaction issues during foundation preparation.

Groundwater at the alignment cut may also intercept or be close to the bed of the adjacent Koputaroa Stream tributary which is described as a permanent flowing stream (not ephemeral). Any interception of groundwater by the alignment cut could be diverted into the adjacent tributary to offset or potentially enhance stream flows.

The nearest bore is ID 353066, listed on Horizons GIS database. The bore is located 270 m north, and on the opposite side of the alignment relative to Koputaroa Stream Tributary. As such, a groundwater level drop and reduction in reliability of supply is considered unlikely.

3.2 Site B (CH 20450 – 20800)

The maximum cut (down to swale invert) through this area is approximately 7 m deep and occurs into Q5 beach deposits, consisting of interbedded sand and silty clay. BH219 is screened between 4 and 15 mbgl and provides an estimate of the highest GWL expected relative to the cut. The green dashed line indicates the highest GWL based on nine months GWL monitoring in this bore (Figure 3 2). This is believed to be the regional groundwater table and not a perched aquifer. However, hillslope seeps were identified during the investigation adjacent to the cut. These were observed as very low flow rate seepages rather than springs, which indicates that hill slope sediments are of low permeability. The hillslope seepages may reflect localised perched groundwater.

The alignment will intercept the highest regional GWL within the cut by approximately 2 m, with some drawdown expected within the immediate vicinity of the cut. During periods of low rainfall, the GWL will be lower, and potentially at or slightly below the alignment. The GWL below and adjacent to the nearest wetland ID54 and 58 (Te Waiaruhe Swamp) are unlikely to significantly drop as the swale base (61.8 mRL) is significantly above the swamp (approximately 58 mRL).

Construction should expect some groundwater discharge from batters and saturated conditions at subgrade level. This is likely to make compaction issues during foundation preparation. Any groundwater discharges from the batters could be directed towards the Te Waiaruhe Swamp in order to maintain the hydrological regime to the wetlands in this area.

An Un-Named private bore identified during the investigation occurs approximately 170 m from the south-east of the alignment cut. The bore depth and screen interval are unknown, neither is the groundwater level; however, the bore is used for domestic supply. Given the invert of the cut (swale) will be at a slightly higher elevation than ground level at the private bore, any drawdown effects as a result of the cut, and subsequent impacts on reliability of supply are considered very unlikely

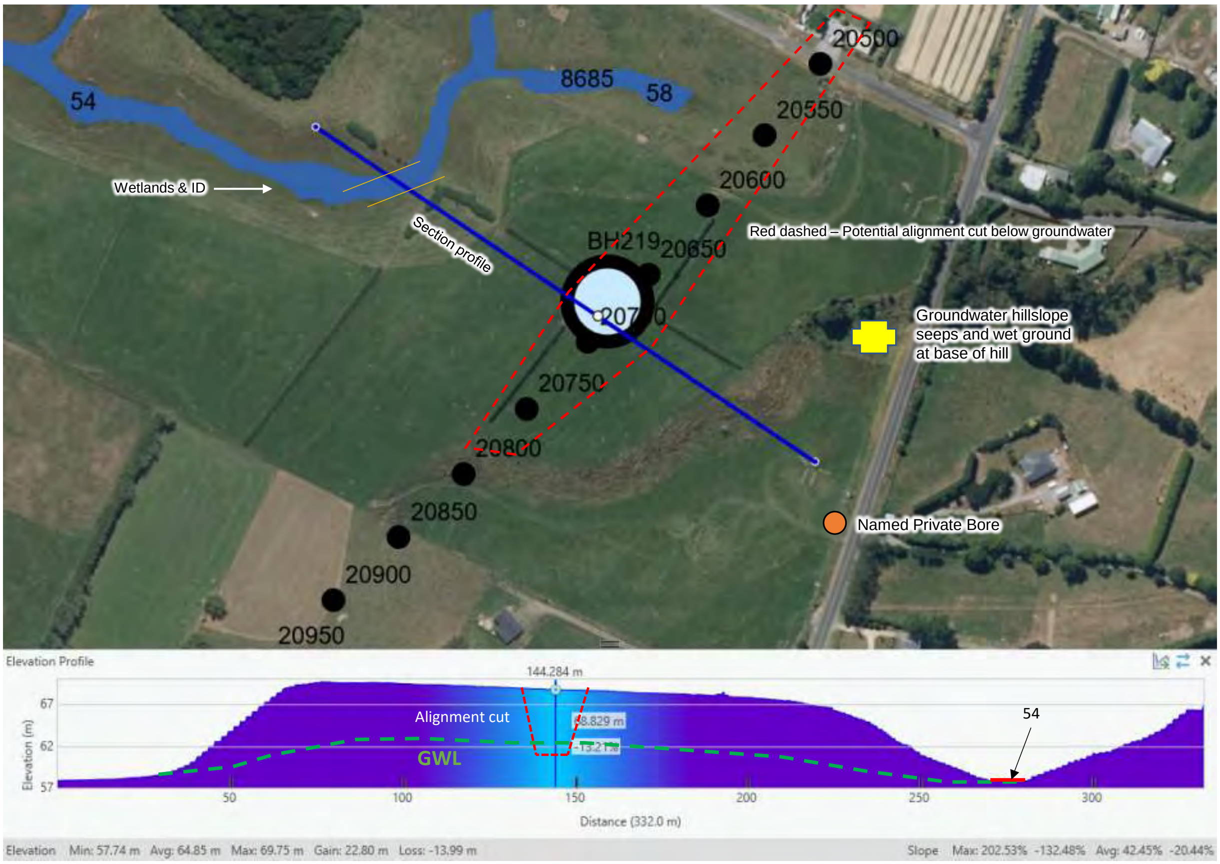

Figure 3-2: Site B - Cross-section and aerial plan showing interpreted GWL, alignment cut, wetlands, hillslope seep and un-named private bore

3.3 Site C (CH 26600 – 27250)

The maximum cut through this area is approximately 9 m deep at the swale invert. Here the alignment cuts through Q2 and Q3 alluvial deposits, largely consisting of silty clay, sandy clay, down to 24 m depth with minor thin sand layers based adjacent borehole BH109 with largely silt down to 10 m depth at BH308, overlying silty gravels and silt. Overall, the sediment within this area is of low permeability. For this type of sediment, hydraulic conductivity values in the range of 0.0001 – 1 m/d would be expected based on Look (2014).

Investigation boreholes BH308 and BH109 are screened 4 – 15 mbgl and 4 – 10 mbgl respectively, monitoring the highest GWL's. The green dashed line shows the highest predicted GWL through the cut and was mostly based on monitoring bore data collected during the investigations (Figure 3 3). This is believed to be the regional groundwater table and not a perched aquifer.

The alignment will intercept the regional groundwater table, which may be as high as 5 m above the design swale invert during high winter / high rainfall events. There are no wetlands nearby. There are multiple bores (listed on Horizons GIS database) near the cut. These are shown as pink dots with depth and ID labels. Most bores are screened deeper than the expected zone of influence (nominally 20 mbgl).

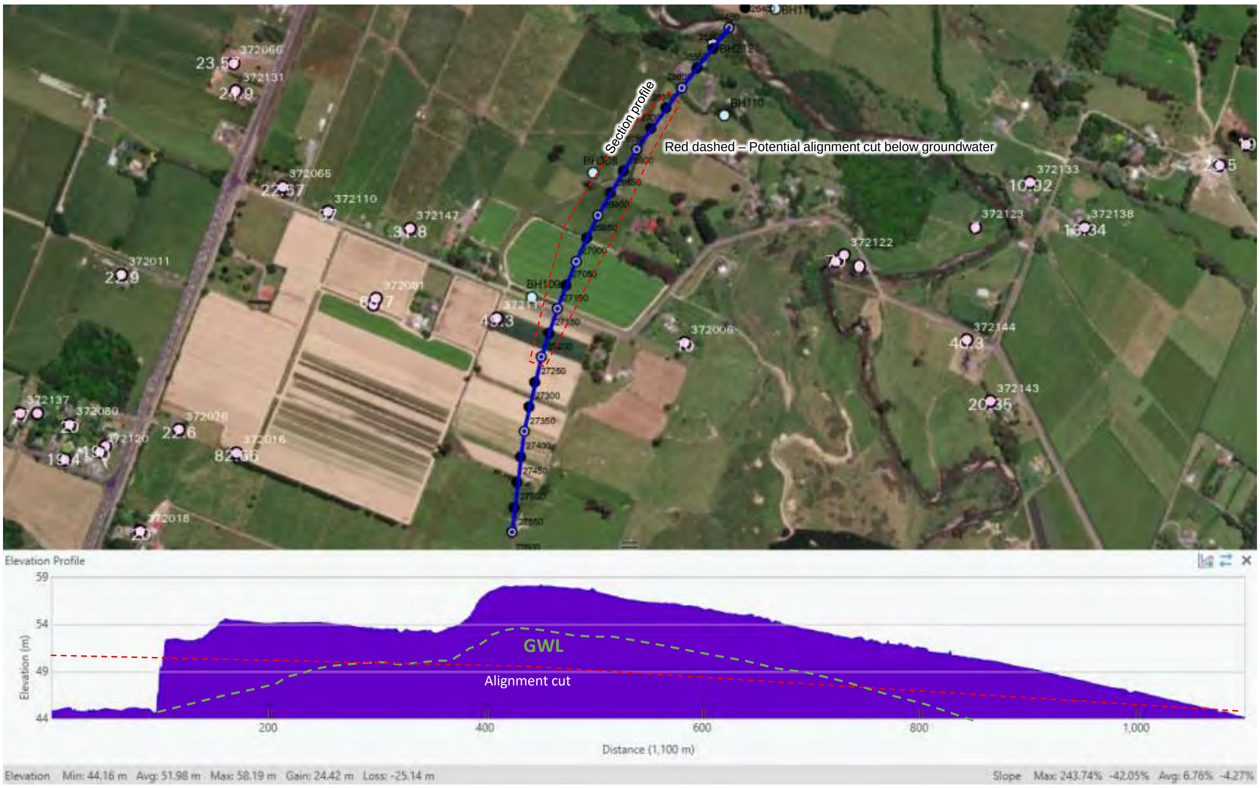

Figure 3-3: Site C - Cross-section and aerial plan showing interpreted GWL, alignment cut, and Horizons bores (shown pink, bore depth centred over point). No wetlands present within aerial image shown

The nearest bore is ID 372111 located 110 m west of the alignment cut, at a similar elevation to ground level at the cut (1 – 2 m lower elevation), and screened from 40.4 – 49.3 mbgl with an initial depth to groundwater of 30.6 m when drilled. Given the relatively deep bore depth and groundwater level, and the cut is occurring in low permeability sediment, an effect on reliability of supply is considered unlikely. The next closest bore is ID 372006. The bore is 10 m deep, located 250 m east of the cut, and had a depth to groundwater of 3 m when drilled. Though this bore is shallow and moderately close to the cut, it is unlikely that the drawdown from the cut will reach this bore given the low permeability of material that the cut is through, which significantly reduces the radius of influence. For using Sichardts Formula (cited in CIRIA, 2000) for steady-state, plane flow, drawdown of 5 m at the cut and hydraulic conductivity is on the high side of 1 m/d, the predicted radius of influence is only 26 m. Hence, even if the drawdown is larger than predicted, it is considered unlikely that this will have any effect on the reliability of supply from this bore. Given the separation distance any drawdown effects in other neighbouring bores is considered extremely unlikely.

Given the low permeability of the sediments in this area, seepage flows from the batters are not expected to be high. However, construction should expect groundwater discharges from batters and saturated conditions at subgrade level. This is likely to make compaction issues during foundation preparation.

3.4 Site D (CH 28950 – 29200)

The maximum cut (down to swale invert) through this area is approximately 9 m deep into Q2 alluvial deposits, consisting predominantly of silts and clays with thinner beds of sands and gravels. Investigation borehole BH107 screened from 4 - 15 mbgl was used to estimate the highest GWL. However, the borehole is approximately 200 m from the alignment, so accuracy of GWL predictions is limited. The green dashed line indicates the assessed highest GWL (Figure 3 4) believed to be the regional groundwater table and not a perched aquifer.

Construction will intercept the regional groundwater table by up to 3 m at the deepest point when groundwater levels are high. However, during periods of average to low rainfall conditions, the groundwater level may be 1 m or lower based on GWL variation in BH224 located at the northern end of the cut.

There are no wetlands near the alignment cut, but a Tawa forest fragment exists 90 m to the west. Based on the wetland and forest hydrology assessment in the Stantec (2022) report, the adjacent forest fragment is not considered to rely on groundwater as a water source, hence any potential effects from lowering the water level are considered unlikely .

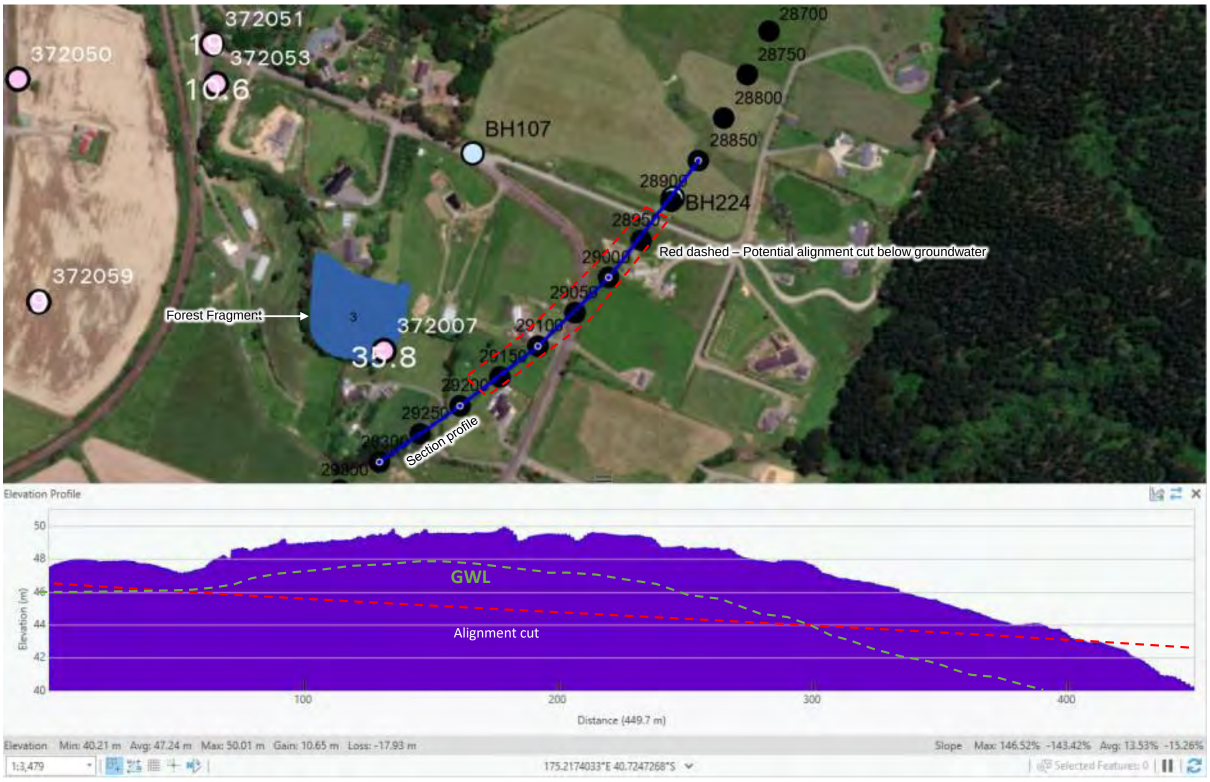

Figure 3-4: Site D - Cross-section and aerial plan showing interpreted GWL, alignment cut, forest fragment and Horizons bores (shown pink)

The nearest bore to the alignment cut is 35.8 m deep bore 372007, located 120 m away. The bore had an initial static depth to water of 17 m when drilled. Given the large available drawdown from this bore and relatively small amount of drawdown that may occur, any effects on the reliability of supply are considered unlikely. The remaining bores are more than 420 m away and as such, any effects on reliability of supply are considered unlikely.

Modest groundwater discharges and seeps from the batters are expected during construction dependent on the thickness of sand or gravel beds encountered. Construction should expect out flows from batters and saturated conditions at subgrade level. This is likely to make compaction issues during foundation preparation.

3.5 Site E (CH 31750 – 31850)

Figure 3 5 to Figure 3 7 show cross-sections at different angles to the alignment cut at Site E. The maximum cut depth (relative to swale invert) through this area is approximately 17 m. The cut occurs through Q5 beach deposits, consisting of interbedded silt and sand deposits. Investigation borehole BH204 is screened between 16 and 19 mbgl and due to the downward vertical hydraulic gradient present in the groundwater along the alignment, is assessed to be monitoring GWL's several metres below what might be expected on site. The green dashed line on Figure 3 5 represents the maximum GWL as assessed; however, accuracy is limited due to the lack of monitoring of the shallow GWL's. The GWL's plotted represent regional and perched groundwater.

The thickness and lateral extent of perched groundwater and is unclear (Figure 3-5 & Figure 3-6). However, the alignment cut is expected to intercept perched groundwater draining or partially draining sand/gravel lenses lying on top of lower permeability silt/clay material.

It is considered likely that GWLs could be lowered beneath wetlands 70, 71, 72, 18, 19, and 69 (Figure 3-7). Groundwater levels beneath the Tawa forest block adjacent to CH31,950 are not expected to be lowered assuming its largely perched groundwater near the forest. In addition, there are no private bores nearby, hence no affects are expected.

Onsite walkovers identified small groundwater seeps from wetlands 71 and 72. Construction should, at a minimum expect seeps and possibly higher groundwater discharges from any higher permeability sand/gravel lenses within batters that will require drainage measures and saturated conditions at subgrade level. This is likely to make compaction issues during foundation preparation.

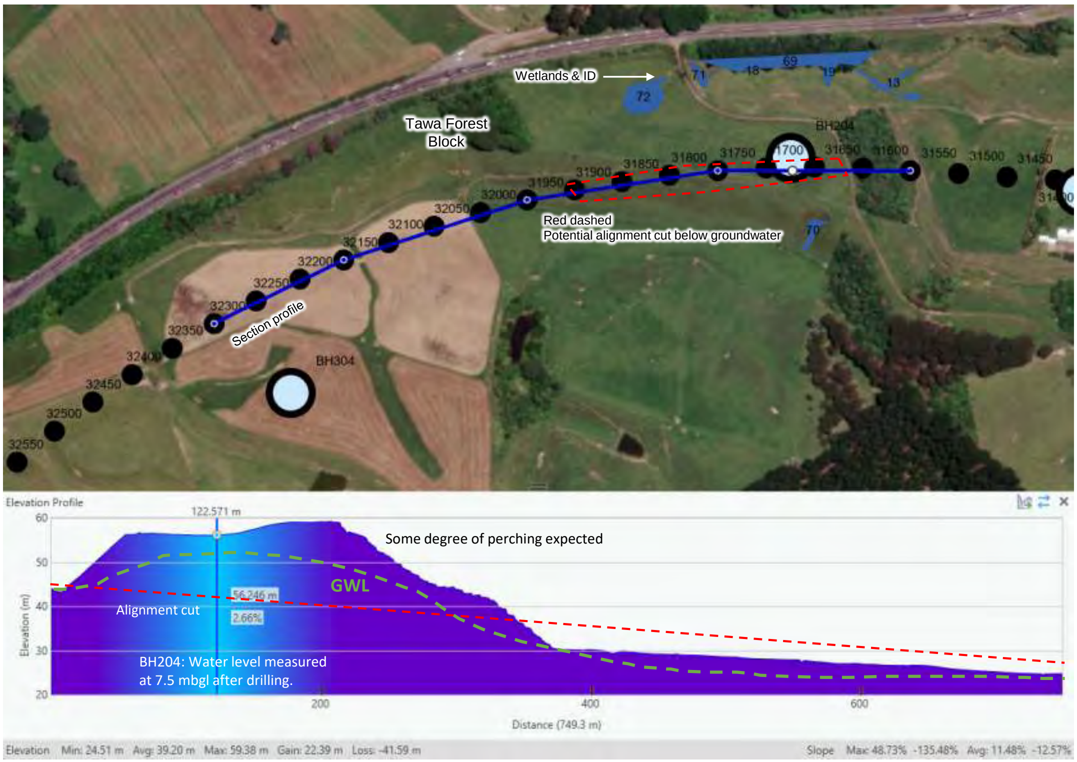

Figure 3-5: Site E - Cross-section and aerial plan showing interpreted GWL, alignment cut, wetlands and Horizons bores (shown pink)

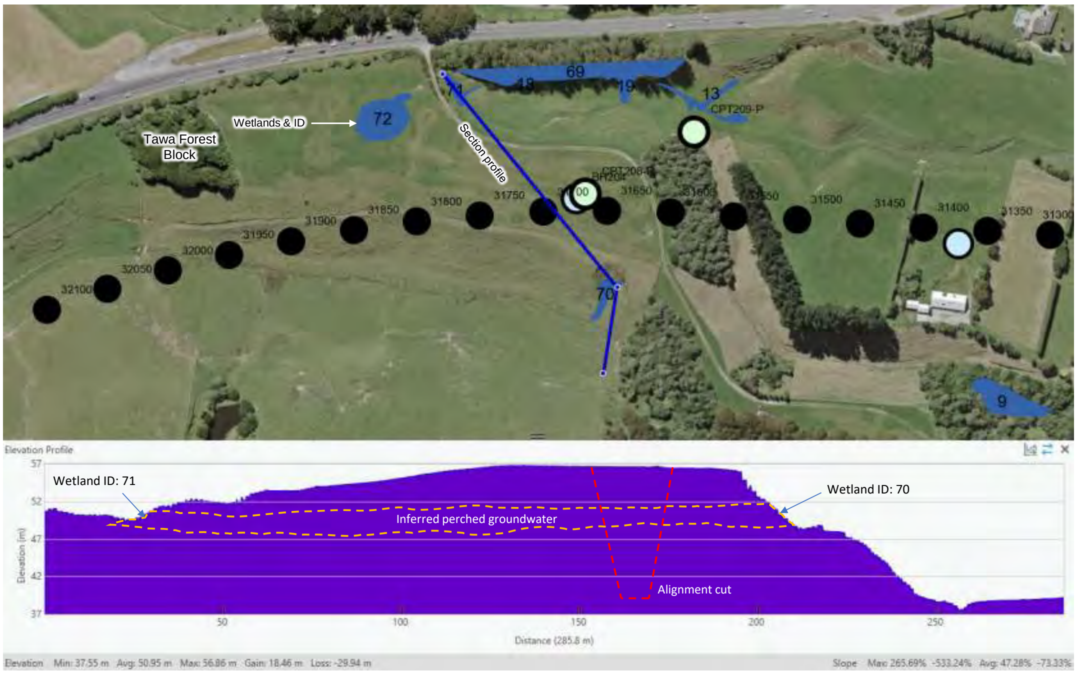

Figure 3-6: Site E - Cross-section and aerial plan showing alignment cut, interpreted perched groundwater and wetlands

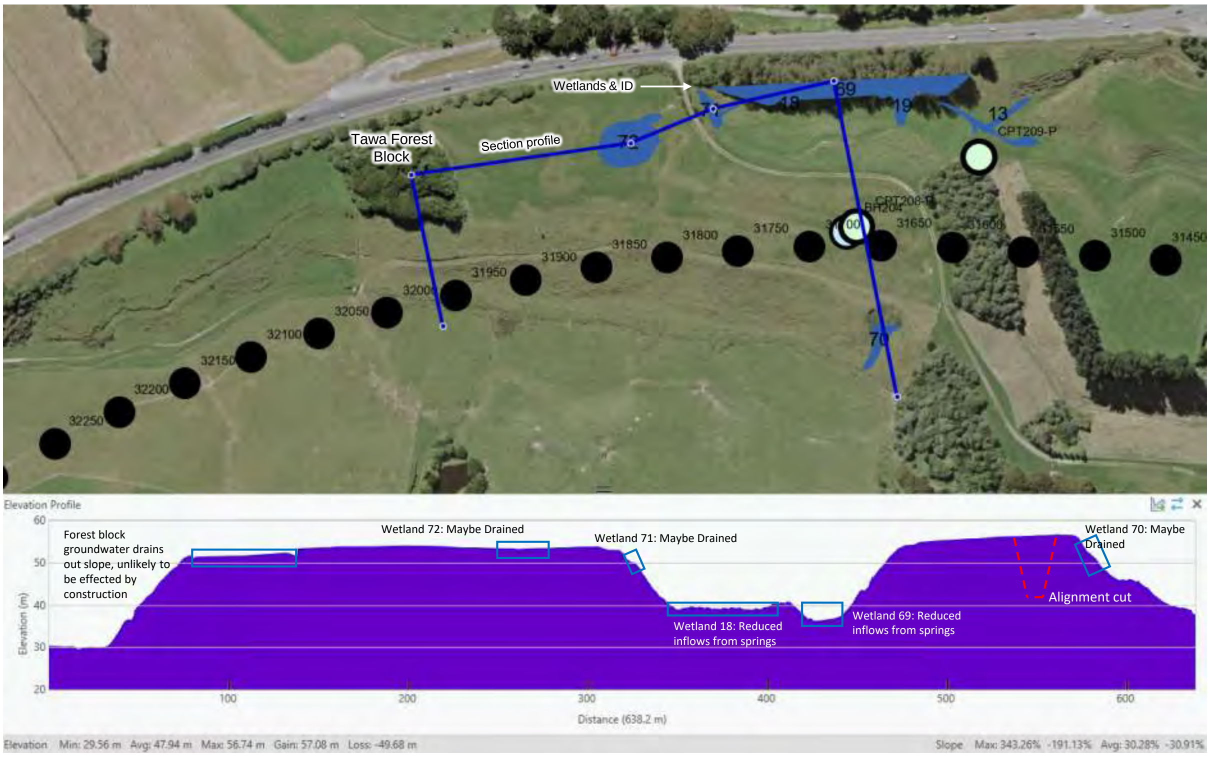

Figure 3-7: Site E - Cross-section and aerial plan showing alignment cut, interpreted perched groundwater and wetlands

3.6 Site F (CH 33400 – 33600)

The cut through this area is approximately 5 m deep (down to swale invert) and into Q5 beach deposits, consisting of sand with occasional silt lenses. The GWL indicated on Figure 3-8 as a green dashed line has been inferred from site investigation CPT102, which was assessed to have a GWL of 29.6 mRL at its time of boring. The adjacent boreholes BH301 and BH302 are screened between 2 and 15 mbgl and have monitored GWL's between 20 – 21 mRL over a limited period (7-days), this may indicate the groundwater measured in CPT102 is perched. The green dashed line may the highest perched GWL based on data from CPT102.

Construction may intercept a perched and / or regional groundwater table. There are multiple wetlands within 500 m of the cut. The wetlands are within low-lying areas either feed by surface flows, hillslope seepages or a combination of both. It is likely that supplementary flows of surface water, drained from the cut batters, can be directed towards these wetlands. In addition, the wetlands will still be fed from surface water / overland flows upstream of the cut. Some seepages may be above the base of the natural depression resulting in difficulty directing batter seepages towards wetlands.

Groundwater hillslope seeps observed to date appear have very low flows, suggesting low permeability material, and limited lateral drawdown extents occurring from the cut. However, moderately permeable sands may be present beneath the site, hence higher seepage flows are possible. Construction should expect some out flows from batters and saturated conditions at subgrade level. This is likely to make compaction issues during foundation preparation.

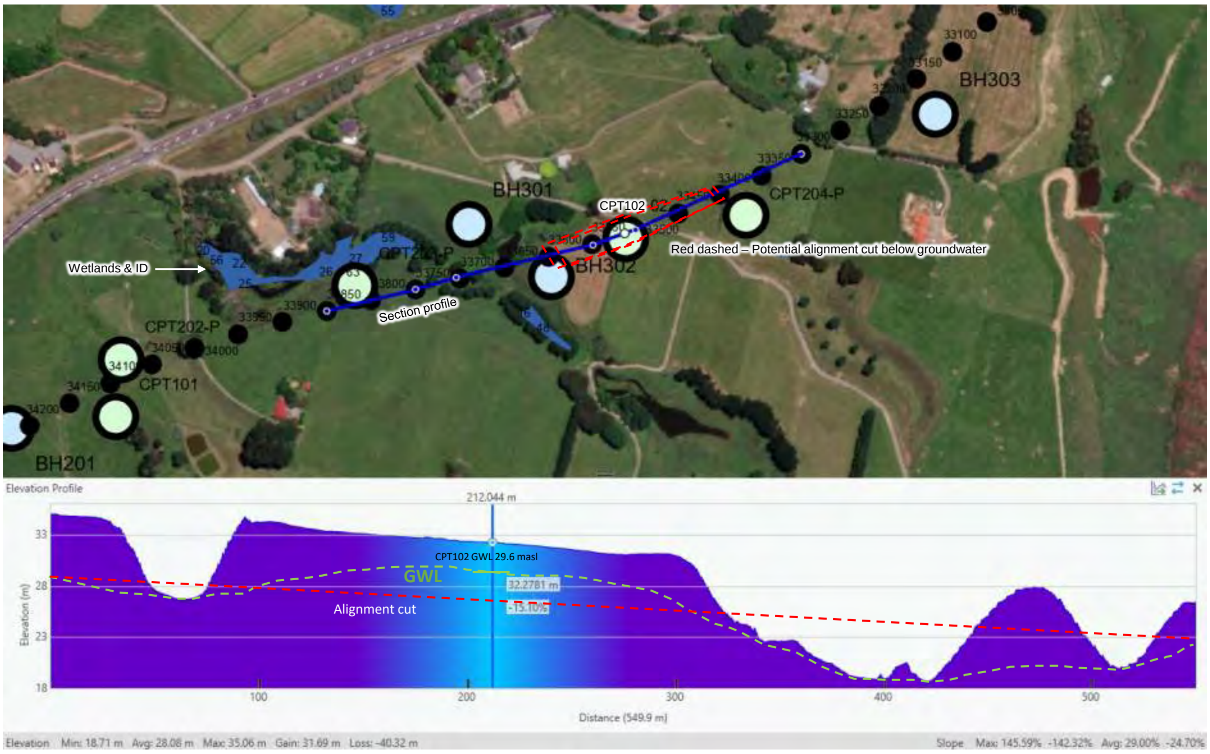

Figure 3-8: Site F - Cross-section and aerial plan showing alignment cut, interpreted GWL, wetlands, investigation boreholes/CPT's (light green) and Horizons bores (light blue)

4 References

CIRIA, (2000). Groundwater control. Design and practise, pp, 148-149.

Look, B.G. (2014). Handbook of geotechnical investigation and design tables. Second Edition. CRC Press. Taylor & Francis Group, London, UK.

Stantec (2022). Ōtaki to North Levin Highway – Hydrogeology and Groundwater Investigation. Prepared for Waka Kotahi, Rev 3, May 2022.

Appendix H TEMPORARY GROUNDWATER DEWATERING

Stantec

ŌTAKI TO NORTH LEVIN HIGHWAY
Temporary Dewatering – Assessment of Effects

7 July 2022

Prepared for:
Waka Kotahi NZ Transport Agency

Prepared by:
Mark Scaife

Project Number:
310203848

Revision	Description	Author	Date	Quality Check	Date	Independent Review	Date
C	Draft for internal review	MAS	7/4/22	JPD	18/5/22		
D	Draft for client review	MAS	30/5/22	JPD / VD	27/5/22		
1	Final for client use	MAS	07/0722	VLD	07/07/22		

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ASSESSMENT OF TEMPORARY DEWATERING

1. Introduction

This document has been prepared to assess the potential groundwater level changes from temporary dewatering for construction of culverts, underpasses, and treatment of poor foundations along the new Ōtaki to North Levin SH1 Road alignment. The assessment has been completed to the most recent design, Design Freeze 4 (DF4.0) and provides background information for hearing evidence, Technical Assessment G – Hydrogeology.

Temporary dewatering at the sites where groundwater is encountered, will be limited to the construction phase, and is expected to last up to three months at each site.

2. Scope

This report provides a brief assessment of the potential drawdown in Groundwater Levels (GWL's) adjacent to sites where groundwater is likely to be encountered and the potential impacts on nearby private bores (listed on Horizons and Greater Wellington regional council databases) and structures. The assessment also shows the predicted drawdown at nearby wetlands identified by Wildlands (Technical Assessment J: Terrestrial Ecology). However, this report does not include any assessment of the potential impacts on wetland ecology.

3. Methodology

2.1 Drawdown

Table 1 summarises the criteria used to filter out and identify culvert, underpass and ground improvement sites where drawdown effects from groundwater dewatering may occur. The list of structures is provided in Appendix A. The geological and hydrogeological characteristics at each site were assessed using information provided in the geotechnical factual and interpretive reports (Stantec 2021a, Stantec 2021b) and Stantec hydrogeology report (Stantec, 2022).

Table 1: Criteria used to identify drawdown effects on neighbouring bores, wetlands and structures.

Step	Criteria	No	Yes
1	Will dewatering for excavation be deeper than the lowest seasonal GWL (which is higher than the lowest predicted GWL)	Further assessment not required	Further assessment required (Go to Step 2)
2	Will the excavation be in fine-grained (silt/clay) material, and neighbouring bores, wetlands and structures > 50 m away, or drawdown at the excavation is small (<1 m)	Further assessment required (Go to Step 3)	Further assessment not required

Step	Criteria	No	Yes
	and neighbouring bores, wetlands, and structures > 50 m away		
3	Using 1D analytical model (discussed in further detail within the main body) will there be drawdown at neighbouring wetlands, private bores or structures?	Further assessment not required	Further assessment required (Go to Step 4)
4	Assess where dewatering is required along culvert alignment. Is the drawdown at a neighbouring: 1) Bore > 20% of available drawdown? 2) Wetland > 5 cm, and the wetland dependent on groundwater? 3) Structure > 0.5 m	Further assessment not required	Further assessment required

The following provides detail on the rational for each of the criteria steps summarised in Table 1.

Step 1 (Table 1), it was assumed that any effects on neighbouring bores, wetlands and structures will be minor so long as groundwater levels beneath the excavations are not drawn deeper than the natural seasonal low groundwater level (lowest groundwater level in an average rainfall year), i.e., groundwater levels at the excavation remain within the normal natural seasonal range. Note, this is higher than the very lowest predicted GWL, which could result in potential adverse effects.

Step 2 (Table 1), neighbouring bores, wetlands and structures were excluded if:

1. The excavation occurred in silt/clay material and the sites were more than 50 m away. It was assumed that the dewatering radius of influence from the excavation will be small (< 50 m) in fine-grained (silt/clay) material due to its low permeability. The 50 m radius of influence was calculated using the Sichardt equation (cited in Kyrieleis & Sichardt, 1930) for steady state radial flow (more conservative than plane flow) for 4 m drawdown at the excavation (to be conservative) and Theis (1935) after 90 days of dewatering. Both methods assumed a conservative (high) hydraulic conductivity value of silt/clay of 0.05 m/d. The specific yield used for Theis (transient model) was 0.07 (average value between silt and clay) and aquifer thickness 15 m.

2. Drawdown at the excavations was small (<1 m) and the sites were more than 50 m away.

Step 3 (Table 1), a Theis (1935) time-distance drawdown model was used to predict the drawdown and average dewatering flow rate from the excavation. This was only required for two culvert sites. The model assumes an infinite aquifer extent and no leakage; therefore, results are conservative (i.e., predicted drawdown and dewatering flow rates higher than those likely to occur).

The model setup included:

- 22 evenly spaced well points placed 2 m outside the footprint of the site or ground improvement. Excavation areas are:
    - Culverts as per design (Table 2)
- drawdown to 1 m below the entire base area of the excavation. Excavation depths for each structure based on:
    - Culverts: downstream invert RL
- continuous groundwater abstraction (dewatering) for 90 days
- average specific yield (used in replace of storativity) of 0.25 for sand and or gravel and 0.18 for silt (Fetter, 2001)
- conservative (in this case high) hydraulic conductivity derived from nearby bore log lithologies based on generic ranges presented in Fetter (2001)
- aquifer thickness based on the site lithological recorded in nearby borehole and cone penetration tests (CPT).

4. Results

4.1 Drawdown

A total of 68 sites were initially assessed at Step 1 (Table 1). Using the criteria listed in Table 1, a total of 13 sites were assessed for Step 2. Of these, two sites required analytical modelling for Step 3. Two sites were identified as showing potential effects on wetlands based on Step 4. Details of the three sites identified in Step 4 are summarised in Table 2. The two sites were ‘New Culvert 4’ and ‘New Culvert 11’.

Wetlands

Modelling (Step 3) indicated that dewatering at New Culvert 4 would potentially lower the groundwater to below the seasonal lowest level at the EWG5 and EWG4 (Table 2).

EWG5 is expected to have a high dependence on groundwater. The impacts from temporarily dropping the seasonally lowest GWL’s at this wetland would need to be assessed by an ecologist.

The culvert alignments of New Culvert 11 indicated that dewatering was unlikely to reach depths that would result in a more than minor drop of the seasonal lowest GWL’s below the wetland.

Bores

No bore’s were identified as effected by drawdown from temporary dewatering works.

Structures

No structures were identified as effected by drawdown from temporary dewatering works.

Table 2: Summary of assessed sites

Site (Chainage in m)	Average dewatering flow rate (L/s)	Culvert Length / Width (m)	Drawdown from lowest seasonal GWL to 1 m below the base of the excavation to install the structure (m)	Lithology at site (based on nearest borehole / CPT)	Wildlands Wetland ID	Distance to wetland from dewatered excavation (m)	Maximum drawdown at the wetland after 90 days (m)	Predicted lowest seasonal GWL at wetland (mBGL)	Predicted lowest GWL at wetland including drawdown from dewatering (mBGL)
New Culvert 4 (33355)	5	70 / 1.5	1.1	Sand	EWG5	40	0.8	2.0	2.8*
New Culvert 11 (31540)	0.5	107 / 0.9	0.9	Silt	EWG4	30	0.5	3.0	3.5**

Table 2 notes:

*New Culvert 4 maximum expected dewatering depth 40 m from wetland. Wetland topographically and hydraulically above excavation, full dewatering effects expected.

**New Culvert 11, excavated site topographically above wetland by approximately 3 m. Unlikely that drawdown will lower water levels at wetland.

4.2 Dewatering Flow Rates

The predicted groundwater dewatering flow rates from the excavations in low permeability fine-grained (silt/clay) material were very low and ranged from 0.1 to 1 L/s.

The predicted groundwater dewatering flow rates from the excavations in moderate /high permeability coarse-grained (sand/gravel) material ranged from 1 to 10 L/s.

Actual dewatering flow rates will vary from those predicted, based on the actual ground conditions at the sites and groundwater levels at the time of dewatering.

5. References

Fetter, C.W. (2001). Applied hydrogeology (4th Ed). New Jersey. Prentice Hall.

Kyrieleis, W., Sichardt, W. (1930). Grundwasserabsenkung bei Fundierungsarbeiten, Springer, Berlin.

Stantec (2021a). Geotechnical Factual Report. SH1 Ōtaki to North Levin. Prepared for Waka Kotahi. New Zealand Transport Agency. September 2021.

Stantec (2021b). SH1 Ōtaki to North Levin. Geotechnical Interpretation Report. Prepared for Waka Kotahi. NZ Transport Agency.

Stantec (2022). Ōtaki to North Levin Highway – Hydrogeology and Groundwater Investigation. Prepared for Waka Kotahi, Rev 3, May 2022.

Theis, C.V. (1935). The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage. *American Geophysical Union Transactions*, Vol. 16, pp. 519-524.

Appendix A: Structures

Structure ID	Chainage (m)	Minimum predicted GWL (mRL) WGN1953	Downstream Invert (mRL) WGN1953	Step Eliminated
Greenwood extension	34560	20.4	23.2	Step 1
New Culvert 1.	34040	17.0	17.6	Step 2
New Culvert 2.	34040 offline	N/a	15.2	N/a
New Culvert 3.	33670	15.0	18.3	Step 1
New Culvert 4.	33355	26.0	26.1	Step 4
New Culvert 5.	32937	21.0	21.9	Step 2
New Culvert 6.	32580	23.0	23.8	Step 2
New Culvert 6.1	32500	23.0	24	Step 2
New Culvert 7.	32370	23.0	23.9	Step 2
New Culvert 8.	32120	26.0	26	Step 2
New Culvert 11.	31540	40.0	40.1	Step 4
New Culvert 12.	31150	48.5	57.7	Step 1
New Culvert 13.	30880	47.0	49.8	Step 1
New Culvert 17.	29515	37.0	37.9	Step 2
New Culvert 18.	29320	38.0	38.6	Step 2
New Culvert 19.	28816	44.0	44.1	Step 2
New Culvert 20.	28555	42.0	41.8	Step 4
New Culvert 22.	28260	37.8	39.8	Step 1
New Culvert 23.	28060	39.0	39	Step 2
New Culvert 25.	27650	39.0	40	Step 1
New Culvert 27.1	26289	42.1	44.3	Step 1
New Culvert 28.	25750	47.5	52.7	Step 1
New Culvert 29.	25408	47.5	48.9	Step1
New Culvert 30.	25107	46.7	46.9	Step 2
New Culvert 31.	24280	34.0	37.2	Step 1
New Culvert 32.1	23680	30.0	31.7	Step 1
New Culvert 34.2	21650	42.8	43.5	Step 2
New Culvert 35.1	20350	62.0	62.9	Step 2
New Culvert 35.3	19990	61.0	62.2	Step 1
New Culvert 35.5	19780	60.0	61.4	Step 1
New Culvert 36.	19480	56.6	60.3	Step 1
New Culvert 36.1	19260	57.3	59.7	Step 1
New Culvert 36.2	18890	51.5	58	Step 1
New Culvert 36.3	18690	57.7	58.9	Step 1
New Culvert 36.4	18430	57.0	58.1	Step 1

Structure ID	Chainage (m)	Minimum predicted GWL (mRL) WGN1953	Downstream Invert (mRL) WGN1953	Step Eliminated
New Culvert 36.5	18090	55.5	57.9	Step 1
New Culvert 36.5	17800	53.6	57.9	Step 1
New Culvert 36.5	17480	53.0	57.1	Step 1
New Culvert 36.5	17400	53.2	57	Step 1
New Culvert 36.6	17210	53.6	56.7	Step 1
New Culvert 36.6	16820	51.5	53.7	Step 1
New Culvert 36.57	16320	53.0	49.1	Step 1
New Culvert 36.6	16150	43.0	48.4	Step 1
New Culvert 37.	15920	43.0	48.8	Step 1
New Culvert 37.5	15560	46.1	47.3	Step 1
New Culvert 38.	13570	24.0	26.9	Step 1
New Culvert 39.	12880	21.8	23.05	Step 1
New Culvert 40.	12690	21.3	23.4	Step 1
New Culvert 41.	12070	20.5	21.718	Step 1
New Culvert 42.	10990	32.0	33.6	Step 1
New Culvert 42.2	10670	41.1	41	Step 1
New Culvert 42.3	10560	42.2	42.1	Step 1
Underpass	10400	44.5	44.5	Step 1
Underpass	11100	34.5	34.5	Step 1
Underpass	13200	22	22	Step 1
Underpass	18200	55	55	Step 1
Underpass	32900	21.5	21.5	Step 1
SH1 Crossing near Taylors	34300	N/a	N/a	Step 1
Waiauti Stream Bridge South	30350	N/a	N/a	Step 1
Waiauti Stream Bridge North	30200	N/a	N/a	Step 1
Honi Taipua	28900	N/a	N/a	Step 1
North Manakau Road	27100	N/a	N/a	Step 1
Waikawa Stream Bridge	26500	N/a	N/a	Step 1
Kuku East Road Bridge	24000	N/a	N/a	Step 1
Kuku Stream Bridge	23750	N/a	N/a	Step 1
Ohau River bridge	22600	N/a	N/a	Step 1
Muhunoa East Road Bridge	21500	N/a	N/a	Step 1
Queens Street	16100	N/a	N/a	Step 1
Rail Bridge	10700	N/a	N/a	Step 1

Appendix I GROUNDWATER MOUNDING

ŌTAKI TO NORTH LEVIN HIGHWAY

Assessment of Environmental Effects
Groundwater Mounding Assessment from Stormwater Soakage to Ground - East of Levin

7 July 2022

Prepared for:
Waka Kotahi NZ Transport Agency

Prepared by:
James Dommisse

Project Number: 310203848

Revision	Description	Author	Date	Quality Check	Date	Independent Review	Date
A	Draft for internal and client review	James Dommisse	24/5/22	Vanessa Dally / Ken Clapcott	19/5/22		
1	Final for client use	James Dommisse	07/07/22	Vanessa Dally	07/07/22		

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1 Stormwater Soakage Facilities

The Ōtaki to North of Levin (Ō2NL) Project (the Project) has five stormwater soakage facilities called Facility 5, 6, 7, 8 and 9 shown in Figure 1-1. The facilities are designed to capture, treat and discharge to ground all stormwater from the Project within the lake Horowhenua Catchment. Across the remainder of the Project, excess stormwater will be discharged into surface water. The five facilities are located east of Levin, from approximately 500 m north of Queen Street to approximately 500 m south of Tararua Road (chainages 15400 - 18900). Each facility is located approximately 450m to 700 m apart. Apart from during extreme events (i.e., very high rainfall / and or high groundwater levels) there will be no discharges to surface water from these facilities.

The five soakage facilities range between 50 m to 150 m wide and 150 m to 300 m long. The facilities are comprised of a treatment train consisting of sediment forebay, constructed wetland and overflow basin. The base of the sediment forebay and overflow basin are expected to be constructed between 1.0 m to 1.5 m below existing ground level. The maximum water depth in the sediment forebay, constructed wetland and overflow basin will be 1 m to 1.5 m, meaning that the maximum water level will be approximately equal to natural ground level.

Stormwater will be initially discharged into the unlined sediment forebay to allow fine sediment and sand to drop out of suspension, before being discharged into the constructed wetland. The constructed wetland will be lined with silt / clay or geo-material to reduce soakage to ground and help maintain at least 0.25 m depth of water. Any residual stormwater will be discharged into the overflow basin. The current system is designed so that discharges into the overflow basin occur during 1 in 2-year or greater rainfall events. In terms of surface area, the constructed wetland makes up approximately 50% of the facility area, the overflow basin 35% and sediment forebay 15%.

For the sediment forebay and overflow basin especially where the highest infiltration rates are needed, it is expected that the top 0.5 m to 3.5 m of naturally occurring silt and clay material (Table 2-1) will be removed and then replaced with higher permeability coarse grained sand and gravel.

The sediment forebay and to a lesser extent the overflow basin will clog, resulting in reduction of hydraulic conductivity overtime due to a build-up of fine-grained sediment. This will be managed by periodic cleaning to maintain sufficient hydraulic conductivity and seepage rates.

Appendix A shows the surface area of each facility and the catchment run-off area as well as the mean annual rainfall-runoff and 1-100 year 24-hour rainfall-runoff volumes. Further details of the facility sizes and water balance is provided in the Stormwater Technical Report (Design Completion Report - Volume II, Appendix B).

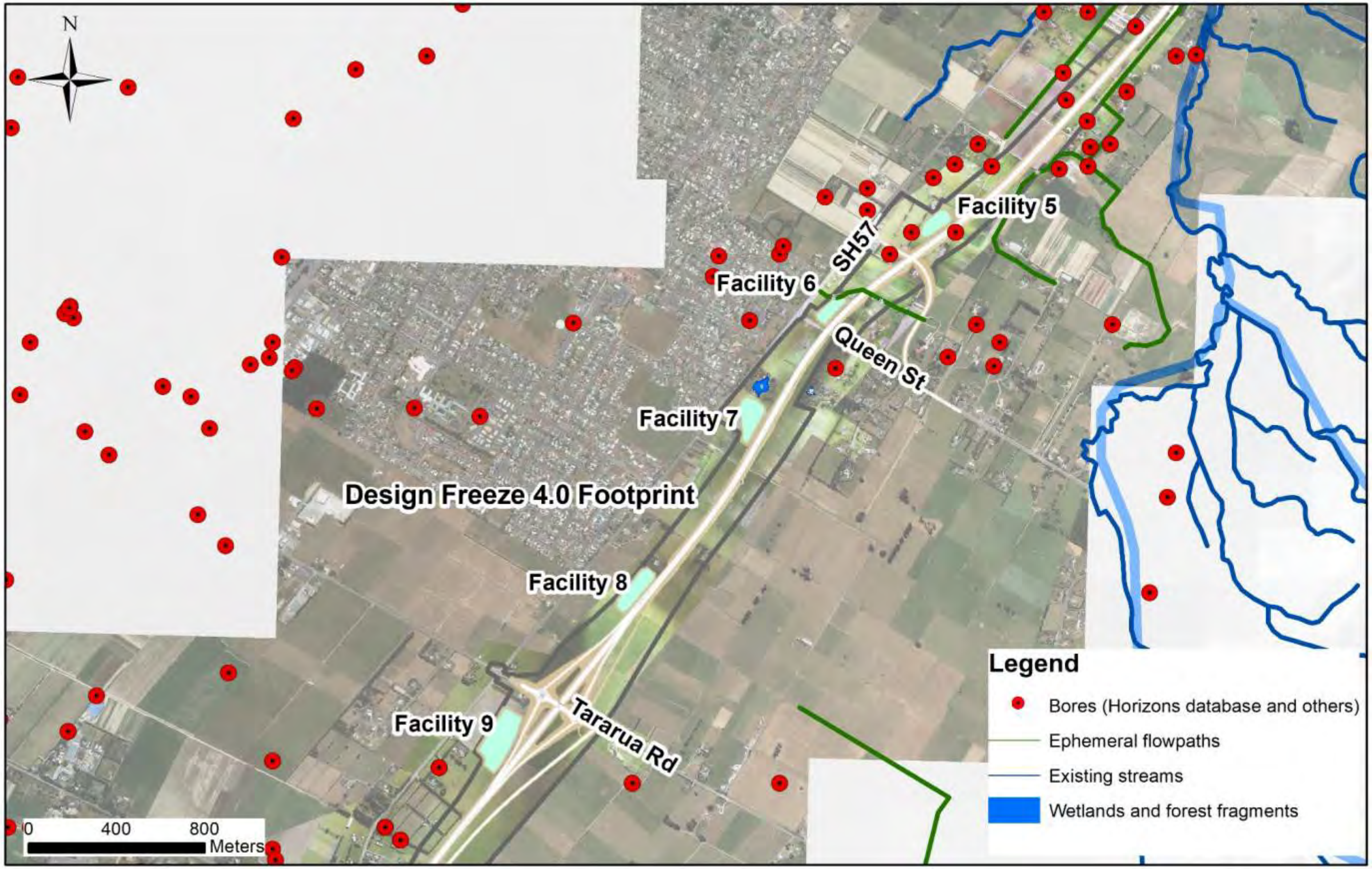


Figure 1-1: Stormwater soakage (to ground) facilities, bores, constructed wetlands/forest fragments and surface water features.

2 Geology

Table 2-1 provides a brief description of the surficial sediments, geological units present, and highest observed and predicted groundwater levels based on available borehole / test pit data within 5 m to 50 m of each Facility. Further borehole and test pit log data are provided in Appendix B and the interpretive geotechnical report (Stantec, 2021b).

Table 2-1: Summary of groundwater conditions beneath the soakage facilities.

Facility	Chainage (m)	Geological Units Recorded During Investigations	Highest Observed (O) and Predicted (P) Depth to Groundwater (Water Table) Below Land Surface (m)	Upper Material Description	Upper Material Depth Range Below Natural Ground Level Near Each Facility (m)
5	15400 – 15550	Q5b	3.5 (O)[1] / 3.0 (P)[1a]	Loess	0 - 2
6	16000 – 16150	Q2a/Q3a & Q5b	1.8 (O)[2] / 1.3 (P)[1a]	Loess	0 - 3.3
7	16600 – 16800	Q2a/Q3a	3.0 (P)[3] / 2.3 (P)[3b]	Loess	0 - 0.7
8	17500 – 17750	Q2a/Q3a	7.9 (O)[4] / 5.9 (P)[4b]	Sandy GRAVEL some silt	0 - 28.5
9	18500 – 18900	Q2a/Q3a	4.6 (P)[5] / 2.6 (P)[5b]	Clayey GRAVEL / Loess	0 - 1.1

[1] Highest observed groundwater level recorded in monitoring bore BH223S screened from 4.5 m to 7.5 m below ground level and located 50 m from Facility 5

[1a] Highest predicted groundwater level based on Eigen model prediction in BH228S. BH228 located 200 m north of Facility 6 and 800 m south of Facility 5

[2] Highest observed groundwater level recorded in monitoring bore BH229S screened from 5.7 m to 8.7 m below ground level and located 20 m from Facility 6

[3] Interpolated groundwater level based on monitoring bores either side of Facility 7

[3b] Highest predicted groundwater level based on Eigen model prediction in GHD-BH01. GHD-BH01 located 250 m south of Facility 7.

[4] Highest observed groundwater level recorded in monitoring bore BH230S screened from 2 m to 15 m below ground level and located 20 m from Facility 8

[4b] Highest predicted groundwater level based on Eigen model prediction in BH118 being 2m lower during investigation period compared to maximum value predicted. BH118 located 500 m south of Facility 8.

[5] Interpolated groundwater level based on monitoring bores either side of Facility 9.

Facilities 5, 6, 7 and 9 are likely to be located on 0.5 m to 3.5 m of loess consisting of silty CLAY and gravelly silty CLAY. At Facility 5 this is underlain by Q5b SAND and silty SAND to at least 20 m depth. At Facilities 6 and 9 this is underlain by Q5B and Q2a/Q3a sandy GRAVEL with some silt in places down to possibly 20 m depth or more. Facility 7 is likely to be underlain by at least 4 m of Q2a/Q3aGRAVEL with some sand and cobbles. In contrast, loess may be absent at Facility 8. This site is likely to be underlain by Q2a/Q3a sandy GRAVEL with some silt, and silty cobbly GRAVEL extending to a depth of 28 m or more below ground.

Based on the nearest borehole and test pit logs (5 m to 50 m away), there does not appear to be any low permeability layers that might result in impeded drainage and perched groundwater. However, the sub-surface geology and hydraulic properties beneath the facilities will be confirmed through future site-specific field investigations.

3 Hydrogeology

The five soakage facilities occur within the Horowhenua Groundwater Zone. Hydraulic properties of unconfined groundwater in the Q2a and G5b deposits are important for assessing the degree of mounding. The dominant hydraulic properties effecting groundwater mounding at these sites are aquifer transmissivity and specific yield. The higher the values for these two parameters, the smaller the groundwater mounding. Hydraulic properties of the Q2a and Q5b deposits in the Horowhenua area where the facilities are located are summarised in Table 2, from Gyopari (2005). These values have been used to predict the amount of groundwater mounding from the soakage facilities.

Table 3-1: Hydraulic properties of the Q2a and G5b after Gyopari (2005).

Geological Unit	Transmissivity (m^2/d)	Thickness (m)	Horizontal Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Specific Yield (dimensionless)
Q2a	No Data	30	40*	1*	0.2*
Q5b	47 – 62**	50	7*	1*	0.1 – 0.2** (0.2*)
* Based on model calibration, ** Based on historic pumping test data					

The mean annual land surface recharge beneath the facilities ranges from 35% to 40% of the mean annual rainfall based on soil moisture balance modelling undertaken for this investigation (Stantec 2002). With a mean annual rainfall at Levin of 1.1 m/yr, this equates to a land surface recharge rate from rainfall of approximately 0.4 m/yr, equal to 0.001 m/d.

4 Infiltration Rates

4.1 Infiltration Testing

Infiltration rates are required to calculate groundwater mounding from the soakage facilities. Table 4-1 shows infiltration rates and hydraulic conductivity values presented in the Stantec (2022) hydrogeology report at locations near the five soakage facilities ranging from approximately 0.3 m/d to 1.7 m/d for sand and sandy gravel. The values are similar to the vertical hydraulic conductivity values of 1 m/d determined for the Q2a and Q5b in the Horowhenua area by Gyopari (2005). The silty clay had the lowest hydraulic conductivity value of 0.03 m/d (high for a clay).

Table 4-1: Soil infiltration test and hydraulic conductivity results (Stantec, 2021).

Test Pit ID	Soil Infiltration Rate (m/d)	Hydraulic Conductivity (m/d)	Test Zone Depth (m)	Test Zone Material Description
TP208S	0.3	0.5	0.20 – 1.65	0.2 – 0.65: Clayey SILT 0.65 – 1.45: Silty CLAY 1.45 – 1.65: SAND, minor silt
TP264BS	0.7	0.8	0.10 – 1.50	0.1 – 0.2: Clayey SILT 0.2 – 0.85: Silty CLAY 0.85 – 1.25: SAND (fine to coarse) 1.25 – 1.5: Sandy GRAVEL
TP266B	1.7	1.2	0.10 – 1.45	0.1 – 0.2: Clayey SILT 0.2 – 0.7: Silty, clayey GRAVEL 0.7 – 1.45: Sandy, Cobbly GRAVEL
TP280BS	1.5	1.1	0.20 – 1.45	0.2 – 0.55: Silty CLAY, minor sand 0.55 – 1.45: SAND (fine) with trace silt
TP288S	Not Assessed	0.03	0 – 1.50	0 – 0.15: GRAVEL 0.15 – 1.5: Silty CLAY

4.2 Infiltration Below Constructed Wetlands

The constructed wetland part of the stormwater soakage facilities will be lined with silt/clay or a geomembrane to reduce water loss and maintain at least 0.25 m depth of water. In some cases, the naturally occurring clay/silt material could be used if necessary. Vertical specific discharge (seepage) (q_v) (m/d) from the base of the constructed wetlands was predicted using Darcys Law in Equation 1 and Equation 2.

$$q_v = K_v . i$$ **Equation 1**

$$i = \frac{H + \Delta l}{\Delta l}$$ **Equation 2**

where K_v = vertical hydraulic conductivity (m/d) of the silty / clay layer, i = vertical hydraulic gradient (m/m), H = depth of water above the base of the constructed wetland (m), Δl = thickness of the clay/silt or liner below the base of the constructed wetland (m).

Assuming a K_v of 0.0001 m/d (generic value) to 0.03 m/d (Table 4-1) for the silt / clay, a thickness of 0.5 m (Δl) and an average water depth of 0.5 m above the base of the constructed wetland, the vertical specific discharge from the base of the constructed wetland would be 0.0002 m/d to 0.06 m/d. For Facilities 5, 6, and 9, which may have thick silt/clay deposits present, average seepage rates to groundwater may be more than an order of magnitude less. In comparison, the average groundwater recharge rate from rainfall is approximately 0.001 m/d.

4.3 Infiltration Below Overflow Basin and Sediment Forebays

Most of the infiltration to ground is expected to occur through the overflow basin during high rainfall events and sediment forebay to a lesser extent. For the sediment forebay, and particularly the overflow basin to be effective means of discharging stormwater to ground, any low permeability loess that may be present, will need to be removed to allow unimpeded drainage to the more permeable sand and gravel material below.

Based on the soakage pit tests undertaken at shallow depths (1.5 m) (Table 4-1), infiltration rates beneath the overflow basin into natural sand and gravel dominated material may range from about 0.1 m/d to 2 m/d. These values are not particularly high and suggest the material is poorly sorted or containing a moderate amount of fine-grained material. In addition, the sediment forebay is designed to settle out and store fine grain material and sand. As such, the infiltration rate will decrease more quickly over time and to a higher degree compared to the overflow basin.

4.4 High Water Table Effects on Infiltration

So far, the discussion has assumed that infiltration occurs under a vertical hydraulic gradient of 1.0 so that groundwater is disconnected (not in contact with) from the bottom of each facility. However, at Facility 5, 6, 7 and 9, monitoring data suggests that the highest groundwater level may come close to the base of the facilities (< 1.0 m depth). This would result in more horizontal flow, a reduction in the vertical gradient to less than 1.0 and lower infiltration rates. Based on the Massmann (2003) model presented for Facility 6 (Appendix D), the infiltration rate would be expected to drop by an order of magnitude to around 0.005 m/d to 0.1 m/d.

5 Groundwater Mounding Predictions

Groundwater mounding predictions beneath and adjacent to the five stormwater soakage facilities were undertaken using Function W_6 from Hunt (2012). This transient analytical model predicts the groundwater level rise in an unconfined aquifer where specific yield is used instead of storativity, and leakage from an overlying confining layer is ignored. The model assumes the aquifer is homogeneous, isotropic (Kv = Kh), and infinite lateral extent. The groundwater model inputs are aquifer transmissivity, specific yield, groundwater recharge rate and time from the start of the recharge (recharge duration).

5.1 Aquifer Hydraulic Properties

Aquifer hydraulic properties beneath each soakage facility were based on the groundwater model calibrated values of horizontal hydraulic conductivity and specific yield determined by Gyopari (2005) for the Q2a and Q5b sediments. Aquifer transmissivity was estimated based on the aquifer thickness reported by Gyopari (2005) shown in Table 3-1.

5.2 Groundwater Recharge Rate and Duration

Groundwater mounding of the water table beneath and adjacent to the five soakage facilities was predicted using Function W_6 separately beneath the constructed wetland (Case 1), beneath the sediment forebay and overflow basin under average conditions (Case 2) and beneath the overflow basin during a 1-100 year rainfall event (Case 3). Each case is summarised below:

Case 1 – Beneath the Constructed Wetland: Mounding after 365 days continuous seepage based on a groundwater recharge rate of approximately 0.001 m/d. The value was calculated assuming a conservative (high) specific discharge through the base of the constructed wetlands of 0.002 m/d (see Section 4.2), minus the existing land surface recharge from rainfall (approximately 0.001 m/d).

Case 2 – Beneath the Sediment Forebay and Overflow Basin (Average Conditions): Mounding after 365 days continuous seepage. A conservative approach was taken by multiplying the mean annual rainfall of 1.1 of m/yr, by the total catchment area for each facility to give a total annual volume. The assessment is conservative because it assumes all rainfall-runoff is discharged into the facilities with no evaporative losses. The total annual volume for each facility was divided by 365 days to give an average daily volume, and then applied to the sediment forebay area.

Case 3 – Beneath the Overflow Basin (1-100 Year Event): This involved calculating the maximum recharge rate and time required to discharge all the 1–100-year rainfall-runoff into ground from the overflow basin plus small part (5%) area of the sediment forebay, whilst ensuring the water table did not rise higher than 0 m below ground level which is the highest design water level for the soakage facilities. This is the worst-case scenario for maximum stormwater discharges to ground and groundwater mounding. For Case 3, the maximum available mounding was determined as the difference between ground level and the highest predicted groundwater (shown Table 2-1), minus the groundwater mounding from Case 1 and Case 2. During the 1-100 year event, it is assumed that most of the stormwater will be diverted to and discharged into ground from the overflow basin.

5.3 Results

Groundwater mounding predictions are shown in Appendix C. A summary of the results is provided below.

Case 1: The groundwater mounding predictions show little or no effects beneath the constructed wetlands as expected given they will be lined and infiltration rates to groundwater will be low.

Case 2: Directly beneath the sediment forebay and overflow basin, groundwater mounding predictions range from 7 cm to 60 cm based on the annual rainfall runoff divert from the catchment of each facility. These predictions are considered conservative given the assumption that 100% of the mean annual rainfall run-off was discharged into each facility, hence actual mounding may be in the order of 50% less.

Case 3 - The limited unsaturated zone thickness at Facility 6 and its location north of Queen Street on lower permeability Q5b sands greatly reduced the groundwater recharge rate and increased the time required for the 1-100 year rainfall event to be totally discharged into ground. For Facility 6, the maximum groundwater recharge rate was 0.7 m/d after 9 days. In comparison, the predicted infiltration rate for Facility 6 was predicted using the empirical model of Massmann (2003) for infiltration from a pond or trench. The Massmann (2003) model accounts for the effects of depth to water table on surface infiltration. For Facility 6, infiltration rates during conditions similar to what might be expected during the 1-100 year rainfall event ranged from approximately 0.001 m/d to 0.1 m/d (Appendix D). Therefore, the low groundwater recharge rate for Facility 6 predicted using Function W_6 is not unexpected given the effects of a high-water table limiting infiltration. The second Facility north of Queen Street, Facility 5, also had an even lower groundwater recharge rate of 0.3 m/d and larger time to discharge all the water of 16 days.

In contrast, Facility 8 south of Queen Street is located on more permeable Q2a/Q3a gravels, has a larger unsaturated zone and it was predicted that the 1-100 year rainfall-runoff could be discharged into groundwater within 0.8 days, at a rate of up to 6.6 m/d. In theory, the soakage tests shown in Table 4-1 and lower vertical hydraulic conductivity values predicted by Gyopari (2005) suggest that the actual infiltration rate will be less than 6.6 m/d. This would in theory limit groundwater recharge to a lower rate, hence the groundwater mound would also be lower and spread more gradually from the site compared to what was predicted.

6 Assessment of Effects

Figure 6-1 and Figure 6-2 show the location of the five stormwater soakage facilities in relation to nearby bores listed on Horizons GIS database (plus one private bore not listed on the database), wetland/forest fragments located outside the Design Freeze 4.0 footprint and nearby surface water bodies. The existing streams (blue) generally flow all year round and the ephemeral streams (green) are often dry and flow after heavy rainfall.

6.1 Wetlands and Forest Fragments

Facilities 5, 8, and 9 are more than 250 m from a forest fragment or wetland and therefore unlikely to affect groundwater levels apart from during very small mounding (< 0.25 m) during a 1-100 year rainfall event based on the groundwater mounding predictions (Appendix C).

Facility 6 is located 200 m down-gradient of wetland (FID 13). At this distance, any groundwater mounding effects will probably be less than 5 cm during average rainfall conditions and less than 1 m mounding for less than a week during a 1-100 year rainfall event.

Facility 7 is located 10 m south of Forest (FID 01) and 150 m down-gradient of Forest (FID 45) (Figure 6-1). During average rainfall conditions (Case 1 and Case 2), groundwater mounding beneath Forest (FID 01) is predicted to be small (< 10 cm) with no mounding below Forest (FID 45).

During a 1-100 year rainfall event (Case 3), soakage from Facility 7 may result in 2 m groundwater mounding at the nearest edge of Forest (FID 01) and 0.2 m mounding at the furthest edge of Forest (FID 01) for a relatively short period of time (< 1 weeks) (Appendix D). The highest groundwater level beneath Forest (FID 01) including soakage may range from approximately 0.5 m to 2.0 m during a 1-100 year rainfall event. The maximum predicted mounding beneath Forest (FID 45) 150 m away from Facility 7 is 0.5 m during a 1-100 year rainfall event. The predicted mounding from Facility 7 under average (Case 1, Case 2) conditions is small relative to the natural groundwater level variation of approximately 1.5 m to 5.0 m below ground level at these sites, and the highest groundwater mounding will only occur for a short period of time (< 1 week) under extreme weather conditions, as a result of Facility 7.

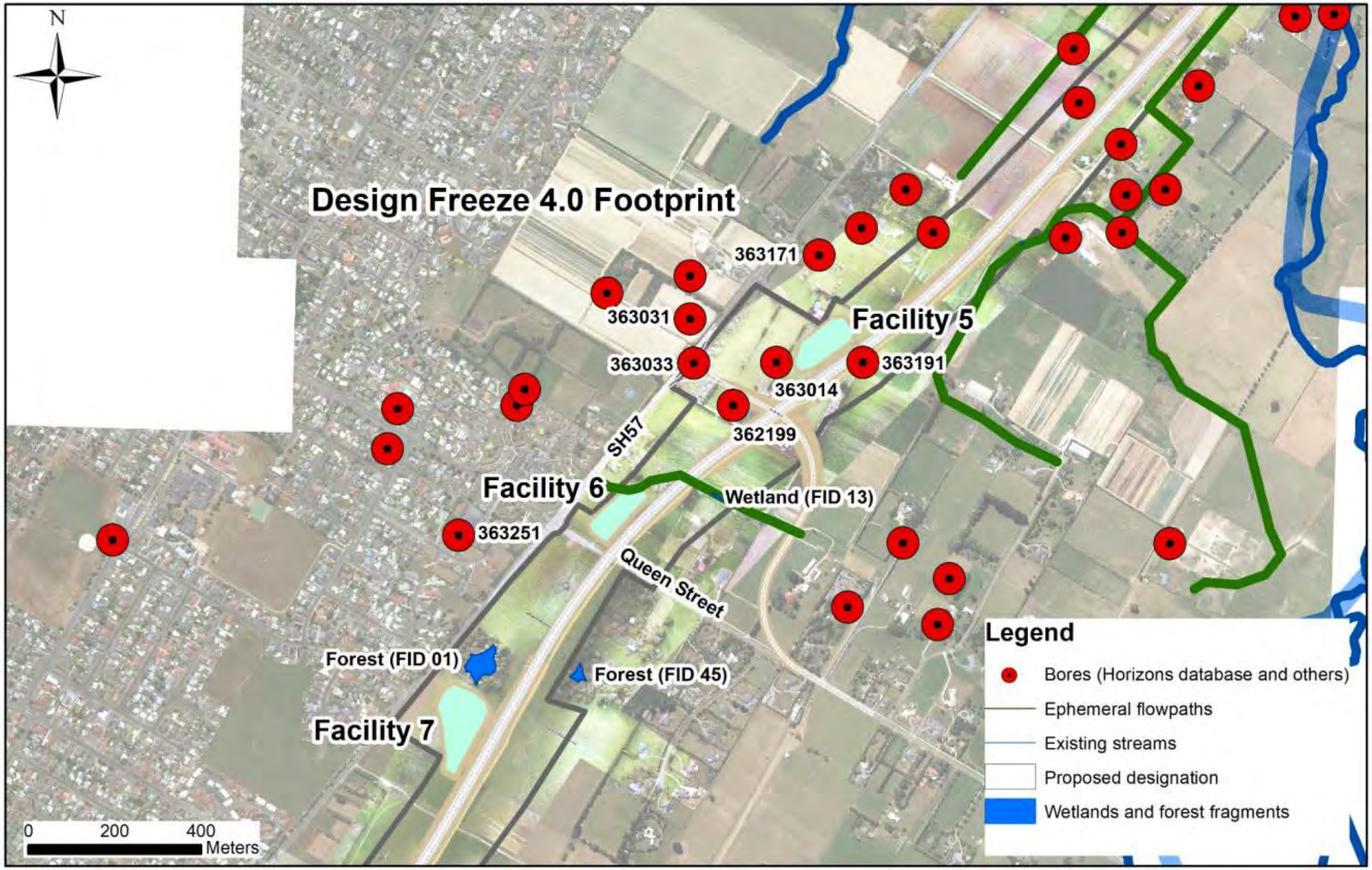


Figure 6-1: Stormwater soakage facilities 5, 6, 7, bores, wetlands/forest fragments and surface water features.

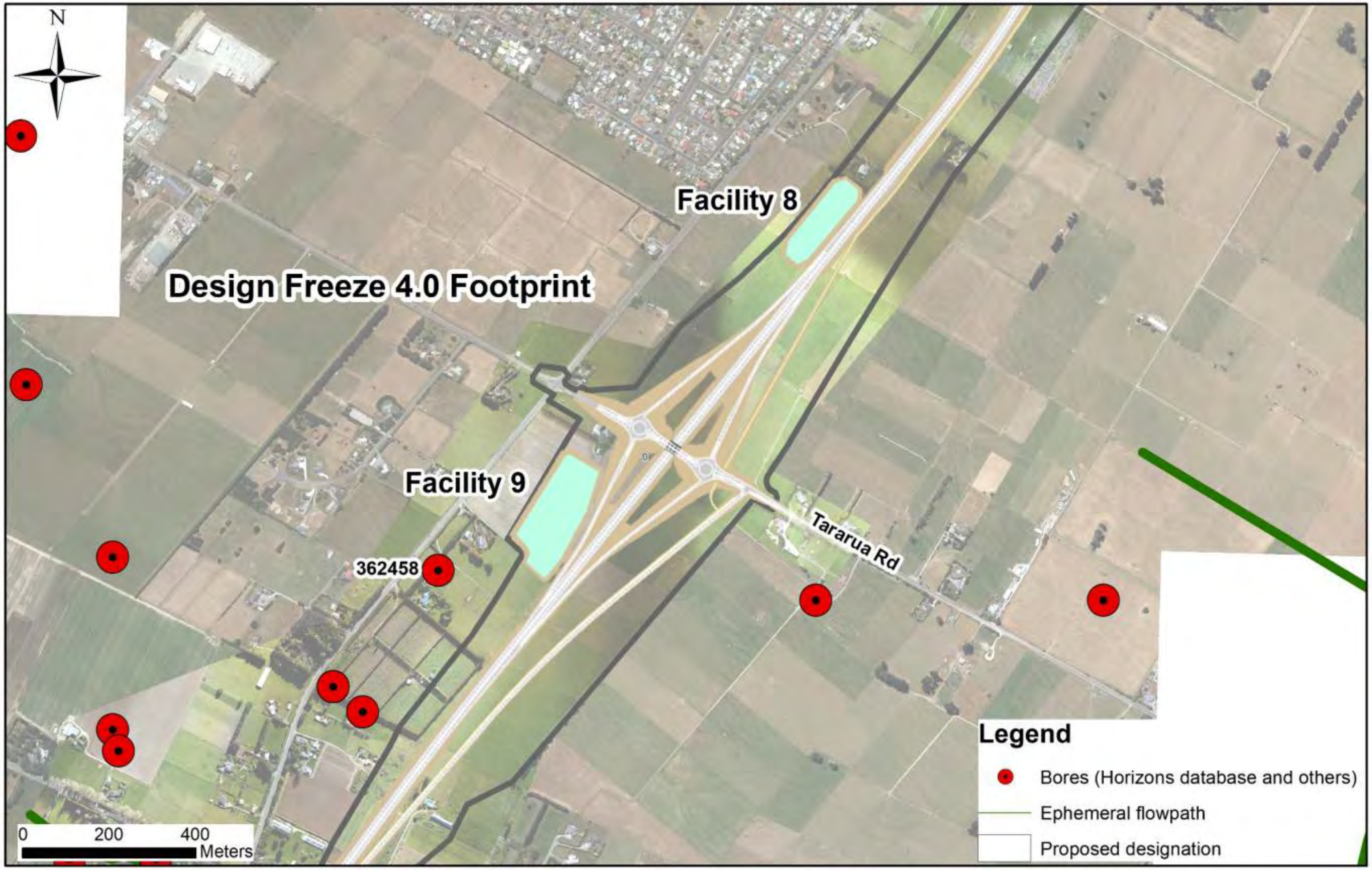


Figure 6-2: Stormwater soakage facilities 8, 9, bores, wetlands/forest fragments and surface water features.

6.2 Existing Groundwater users

Bores labelled in Figure 6-1 and Figure 6-2 (from Horizons GIS database) are located adjacent to and down-gradient (40 m to 250 m away) from the soakage facilities and are listed in Table 6-1. The bores are moderately deep and have a moderately deep depth to groundwater. None of the bores are listed on Horizons GIS database as being used for community or domestic supply.

Table 6-1: Nearby and down-gradient bores listed on Horizons GIS database.

Horizons Bore ID	Bore Depth Below Ground (m)	Screen Depth Below Ground (m)	Depth to groundwater (m)	Use(s)
362199	No Data	No Data	No Data	Not Specified
363014	34	No Data	No Data	Not Specified
363031	25	No Data	8	Not Specified
363033	37	No Data	18	Irrigation
363171	36	No Data	22	Not Specified
363191	97	96 – 99	26	Not Specified
363251	30	28 – 30	24	Industrial Supply

6.2.1 RELIBAILITY OF SUPPLY

Groundwater levels in bores adjacent to the five soakage facilities are most likely to rise because of soakage facility discharges to ground. This will have a positive effect of increasing the reliability of supply, hence no adverse effects are expected.

6.2.2 WATER QUALITY

Stormwater discharged from the soakage facilities may infiltrate through the ground and enter the groundwater capture zone of down-gradient bores.

Potential stormwater contaminants listed in the Water Quality Technical Assessment H are TSS, chemical oxygen demand, biological oxygen demand, oil / grease, TPH, polycyclic aromatic hydrocarbons, heavy metals (cadmium, copper, lead, nickel, zinc), faecal bacteria and nutrients (nitrogen and phosphorus).

The water Quality Technical Assessment H states that the concentration of nutrients and faecal bacteria in stormwater are typically less than that found in runoff from agricultural land, which is the current, dominant land use surrounding and upgradient of the bores. Therefore, any increased risk of contamination from pathogens and nutrients in down-gradient bores over and above the current risk from upgradient agricultural land uses is considered unlikely.

The soakage facilities are also designed to treat stormwater and remove contaminations before they discharge into ground. For example, the sediment forebay and constructed wetland parts of the soakage facilities provide detention and treatment of sediment, heavy metals, nutrients and hydrocarbons, with the constructed wetlands sized to treat 90% of storm events (Water Quality Technical Assessment H). Compared to the surface water discharges of stormwater at other locations along the road alignment, the soakage facilities will also provide additional treatment (removal of contaminants) as water passes through the vadose zone (unsaturated) beneath the overflow basin prior to entering groundwater. Further reduction in contaminant concentrations will occur (mechanical dispersion and diffusion) within the groundwater. It is therefore concluded that that any reduction in the quality of groundwater abstracted from the adjacent and down-gradient bores listed is unlikely.

6.3 Surface Water and Flooding

6.3.1 FACILITY WATER LEVELS

Flooding can occur when the water table rises above ground level. Since the water level in the Facilities will be kept no higher than ground level, the water table immediately adjacent to the facilities during a high rainfall event should also be no higher than ground level.

6.3.2 AVERAGE TO LOW RAINFALL CONDITIONS (CASE 1 AND CASE 2)

Groundwater mounding from seepage beneath the facility constructed wetlands (Case 1) and mounding beneath the facility sediment forebay / overflow basin from moderate to small rainfall events (Case 2) will be minimal. Groundwater mounding predictions (Appendix C) are less than 10 cm to 60 cm directly beneath the facilities and reducing with increasing distance.

As such, the soakage facilities are not considered to result in any increased frequency or magnitude of surface flooding or adverse effects on existing buildings as listed in Table 6-2 and discussed in Section 6.3.3.2.

6.3.3 HIGH RAINFALL EVENTS (CASE 3)

Groundwater mounding from the facilities will be greatest during a high rainfall event. At Facilities 8 and 9 where the natural groundwater level is generally deepest and groundwater mounding from a 1-100 year rainfall event could be largest, the peak groundwater level may occur within a 1 to 6 days and be restricted to within 100 m of the overflow basin.

Where groundwater levels are naturally high north of Queens Street (Facility 5, 6), the vertical hydraulic gradient between the soakage facility and water table will reduce. When this occurs, the rate of infiltration from the soakage facilities during a 1-100 year rainfall will also reduce as illustrated in Appendix D. This will limit the rate of groundwater recharge and resultant groundwater mounding, hence reducing the potential for flooding. A similar effect may also occur in Facilities 7 and 9. Despite the lower infiltration rates the higher groundwater levels, less permeable ground and maximum facilities water levels at ground level could result in some saturated ground

6.3.3.1 Existing Buildings

Table 6-2 lists the distance from each Facility to the nearest building (plus a 50 m buffer) located outside the proposed designation and the highest predicted groundwater level including the effects of mounding during a 1-100 year rainfall event.

Table 6-2: Soakage facility locations from nearest building outside the proposed designation

Facility	Distance to Nearest Building Outside Designation Plus 50 m (m)	Naturally Highest Groundwater Level without Mounding (mBGL) (1-100 year rainfall event)	Highest Groundwater Level (Case 3) at Building plus 50m with Predicted Mounding (mBGL) (1-100 year rainfall event)
5	55	3.0	1.0
6	100	1.3	0.8
7	110	2.3	1.5
8	210	5.9	5.9
9	120	2.6	1.3
mBGL = metres below ground level			

Distance to nearest building outside designation plus 50 m (Table 6-2) was calculated as the distance from each facility to the nearest building (based on current facility locations shown in Figure 6-1 and Figure 6-2). The extra 50 m assumes that the overflow basin will not be located adjacent to any building, but rather it will be designed to be located as far away as possible.

The highest groundwater level (Case 3) next to each building is probably conservative. The overflow basins may be located further than the distances shown in Table 6-2, and measures to control groundwater levels as discussed in Section 6.3.3.3 will be implemented.

6.3.3.2 Surface Water Features

During a large event i.e.,1–100-year event (Case 3), a positive effect is that stormwater discharges to ground from the soakage facilities will reduce peak flows and potential flooding in surface water bodies.

Immediately north of Facility 6, it is likely that some stormwater from this facility could discharge into the swale drain crossing SH57 (Figure 6-1) during high rainfall events and when timed with high groundwater levels. During periods of low or average rainfall this is unlikely because both groundwater levels and recharge from Facility 6 will be relatively low.

6.3.3.3 Groundwater Level Control – Detailed Design

Potential effects of stormwater soakage to ground on groundwater during high rainfall events will be minimised or eliminated by implementing the following into soakage facility detailed design:

1. Surface drains to divert any overland flow away from soakage facilities.
2. Groundwater cut off drains to ensure groundwater levels do not either 1) rise to close or 2) rise above ground level near key sites during high rainfall events (i.e., the buildings listed in Table 6-2).

3. Provision to pump out standing water from the overflow basin and discharge to surface water.

4. Location of overflow basin as far from any buildings as possible.

5. Locate Facility 5 further south to provide greater distance from the nearby building.

In addition to the points raised above, existing ephemeral water ways like the swale drain just north of Facility 6 (Figure 6-1) will also provide some degree control and help reduce the extent of high groundwater levels during high rainfall events.

6.4 Groundwater Recharge

Stormwater soakage to ground will provide more recharge to groundwater than if the stormwater was discharged directly to surface water. This is beneficial for maintenance / enhancement of water levels in down-gradient surface water bodies such as Lake Horowhenua (which is partially fed by groundwater) and spring fed streams that flow into Lake Horowhenua.

7 References

Gyopari (2005). Horowhenua Lakes Assessment of Groundwater – Surface Water Interaction. Prepared for: Horizons Regional Council.

Hunt (2012). Groundwater Analysis Using Function.xls. Bruce Hunt. Civil Engineering Department University of Canterbury. E-mail: bruce.hunt@kinect.co.nz. Last Update: 14 January 2012.

Massmann, J.W. (2003). A design manual for sizing infiltration ponds. Prepared for Washington State Transport Commission. October 2003.

Stantec (2021a). Geotechnical Factual Report. SH1 Ōtaki to North Levin. Prepared for Waka Kotahi. New Zealand Transport Agency. September 2021.

Stantec (2021b). SH1 Ōtaki to North Levin. Geotechnical Interpretation Report. Prepared for Waka Kotahi. NZ Transport Agency.

Stantec (2022). Ōtaki to North Levin Highway – Hydrogeology and Groundwater Investigation. Prepared for Waka Kotahi, Rev 3, May 2022.

APPENDICIES

Appendix A Facility Area, Catchment Area, and Inflow Rates

Facility Details						Mean Stormwater Inflows		1-100 Year (24hr) Stormwater Inflow
Facility (ID)	Facility Catchment Area (FCA)	Total Facility Area (TFA)	Constructed Wetland (W)	Sediment Forebay (SF)	Overflow Basin (OF)	Mean Daily Discharge to Each Facility Volume from Catchment Based Average Annual Rainfall of 1.1m/yr x Catchment Area / 365 Days (MD)	Groundwater Mounding Case 2 Mean Discharge Rate to Sediment Forebay and Small Amount to Overflow Basin (MDR)	**Volume over 24 Hours** (excludes direct rainfall on Facility surface)
-	m^2	m^2	m^2	m^2	m^2	m^3/d	m/d	m^3/d
			W = TFA x 0.5	SF = TFA x 0.15	OB = TFA x 0.35	MD = (1.1 x FCA) / 365	MDR = MD / (TFA x 0.25)	-
5	51,600	9,642	4,821	1,446	3,375	156	0.063	19,064
6	38,300	8,253	4,127	1,238	2,889	115	0.054	19,064
7	66,800	15,093	7,547	2,264	5,283	201	0.052	28,597
8	50,500	14,795	7,398	2,219	5,178	152	0.040	31,774
9	288,300	21,947	10,974	3,292	7,681	869	0.158	55,605

Appendix B Material Descriptions and Estimated Range of Hydraulic Conductivity and Transmissivity

Facility	Nearest Borehole (BH) or Test Pit (TP) / (Distance, m)	Material Below Facility Based on Nearest Borehole End of Hole (EOH) End of Sampling (EOS)	Geological Unit(s)
5	BH223 / 20	0m – 2m: Silty CLAY	Loess
		2m – 19.8mEOH: SAND (medium to fine) and Silty SAND (medium to fine)	Q5b
6	BH229 / 10	0.5m – 3.3m: Silty CLAY	Loess
		3.3m – 12.1m: SAND (fine to medium), minor silt	Q5b
		12.1m – 19.7mEOH: SAND and silty SAND	
	TP287 / 20	0.3m – 1.1m: Silty CLAY	Loess
		1.1m – 1.4m: Cobbley, silty clayey GRAVEL	Q2a/Q3a
		1.4m – 3.8mEOH: Sandy, cobbley GRAVEL, trace silt	
	BH222 / 50	0.1m – 1.5m: Gravelly silty CLAY and clayey, silty, clayey, gravelly COBBLES	Tt
		0.1m – 1.5m: Sandy GRAVEL, minor silt and silty sandy GRAVEL	Q2a/Q3a
		1.5m – 22m: SAND (fine to coarse), minor/trace silt.	Q5b
		22m –30.14mEOH: Silty, clayey GRAVEL	
7	TP255 / 20	0,2m – 0.7m: Silty CLAY, clayey SILT, Gravelly silty CLAY	Q2a/Q3a
		0.7m – 3.7mEOH: GRAVEL with some sand and cobbles	
8	BH230 / 10	0.2m – 28.5mEOS: Sandy GRAVEL with some silt and silty cobbly GRAVEL	Q2a/Q3a
9	TP246 / 5	0m – 1.1m: Silty CLAY, clayey SILT, Gravelly silty CLAY	Loess
		1.1m – 3.9mEOH: Sandy GRAVEL some cobbles, trace silt to some clay	Q2a/Q3a

Appendix C Groundwater Mounding Predictions

Facility Areas	Parameter	Symbol	Units	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9
Case 1- Wetland	Mean width	a_w	m	49.1	40.6	61.4	54.4	66.3
	Mean length	b_w	m	98.2	101.6	122.9	136.0	165.6
	Surface area ($A_w = a_w \times b_w$)	A_w	m^2	4,821	4,127	7,546	7,397	10,974
	Mean annual rainfall recharge equal to 35% of mean annual rainfall	RR_w	m/d	0.0011	0.0011	0.0011	0.0011	0.0011
	Average water depth	H	m	0.5	0.5	0.5	0.5	0.5
	Maximum vertical hydraulic conductvity of silt / clay liner	K_v	m/d	0.001	0.001	0.001	0.001	0.001
	Thickness of silt / clay liner	Δl	m	0.5	0.5	0.5	0.5	0.5
	Hydraulic head (H + ΔL)	Δh	m	1.0	1.0	1.0	1.0	1.0
	Mean annual infiltration rate $q_v = K_v (\Delta h+\Delta l) / \Delta L)$	q_v	m/d	0.0020	0.0020	0.0020	0.0020	0.0020
	Additional groundwater recharge rate ($RW_W = q_v - RR_w$)	RW_w	m/d	0.0009	0.0009	0.0009	0.0009	0.0009
	Additional groundwater recharge volume ($QW_W = RW_w \times A_w$)	QWw	m^3/d	4.2	3.6	6.6	6.4	9.5
	Mounding prediction time	t_w	d	365	365	365	365	365
	Additional recharge (RWw) below centre of wetland (Function W_6) - **Case 1**	h_w ($x_{=0m}$,$y_{=0m}$,$t_{=365d}$)	m	**0.015**	**0.003**	**0.003**	**0.003**	**0.004**
Case 2 - Sediment Forebay Plus Some Overflow Basin	Mean width	a_s	m	34.8	28.8	43.5	38.6	46.8
	Mean length	b_s	m	69.5	72.1	86.9	96.4	116.9
	Surface area ($A_s = a_s \times b_s$)	A_s	m^2	2,417	2,079	3,776	3,716	5,468
	Average daily volume	$Q_{s\text{-}avg}$	m^3/d	156	115	201	152	869
	Additional average daily recharge	$R_{sD\text{-}avg}$	m/d	0.063	0.054	0.052	0.040	0.158
	Mounding prediction time	ts_{avg}	d	365	365	365	365	365
	Mounding from additional recharge (RsD-avg) below centre of basin (Function W_6) - **Case 2**	h_{savg}($x_{=0m}$,$y_{=0m}$,$t_{=365d}$)	m	**0.58**	**0.11**	**0.10**	**0.07**	**0.41**
Case 3 - Overflow Basin Plus Some Sediment Forebay	Mean width	a_s	m	44.0	36.5	55.0	48.8	59.2
	Mean length	b_s	m	88.0	91.3	110.0	122.0	148.0
	Surface area ($A_s = a_s \times b_s$)	A_s	m^2	3,872	3,331	6,050	5,954	8,762
	1-100 year event (over 24 hours)	$Q_{s\text{-}100}$	m^3/d	19,064	19,064	28,597	31,774	55,605
	1-100 year event (over 24 hours) plus rainfall	$QSR_{\text{-}100}$	m^3/d	19,281	19,251	28,937	32,108	56,097
	1-100 year event (over 24 hours) maximum groundwater recharge volume per day with out excessive mounding	$QS_{sD1\text{-}100}$	m^3/d	**1,189**	**2,193**	**10,188**	**39,435**	**9,273**
	1-100 year event (over 24 hours) maximum groundwater recharge rate per day with out groundwater level going higher than 1 m below ground level ($RS_{s1\text{-}100} = QS_{sD1\text{-}100} / A_s$)	$RS_{s1\text{-}100}$	m/d	**0.3**	**0.7**	**1.7**	**6.6**	**1.1**
	Test pit soil infiltration rate test results on sand and sandy gravel material adjacent to overflow basins	**i**	**m/d**	**0.3 - 1.7**				
	Time from start of 1-100 year event to discharge the total stormwater discharge to ground	$t_{s1\text{-}100}$	**d**	**16.2**	**8.8**	**2.8**	**0.8**	**6.0**
	Mounding from additional recharge (RSs1-100) below centre of basin (Function W_6) - **Case 3**	$h_{s1\text{-}100}$ ($x_{=0m}$,$y_{=0m}$,$t_{=}$)	m	**2.4**	**1.2**	**2.2**	**5.8**	**2.1**
Unconfined Aquifer Properties	Geological unit	-	-	Q5b	Q2a	Q2a	Q2a	Q2a
	Specific yield	Sy	m^3/m^3	0.2	0.2	0.2	0.2	0.2
	Horizontal hydraulic conductivity	K_h	m/d	7	20	40	40	40
	Horizontal hydraulic conductivity	K_v	m/d	1	1	1	1	1
	Average saturated aquifer thickness	b	m	23	38	38	38	38
	Lowest transmissivity ($T = K_a \times b$)	T	m^2/d	158	750	1,500	1,500	1,500
Unsaturated Zone Thickness	**Highest predicted groundwater level (metres below ground level - mBGL)**	G_M	**mBGL**	**3.0**	**1.3**	**2.3**	**5.9**	**2.6**
	Highest predicted groundwater level plus moundingfrom Case 1 and Case 2	GW_M	**mBGL**	**2.4**	**1.2**	**2.2**	**5.8**	**2.2**
	Highest permissbale groundwater level of 0 metres below ground beneath centre of overflow basin	GWS_M	**mBGL**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Transient Groundwater Mounding - Unconfined Aquifer

After Hunt (2012) using Function W_6

Facility 5

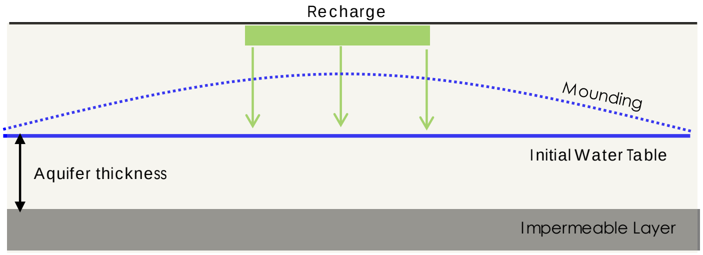
Aquifer thickness	B	23	m
Hydraulic conductivity	K	7	m/d
Transmissivity = KB	T	161	m^2/d
Specific yield	Sy	0.20	-

Recharge volume	Q	1,189	m^3/d
Recharge rate	R	0.307	m/d
Time since start of recharge	t	16.2	d
Highest static groundwater level	H_{max}	2.4	mBGL

Reference

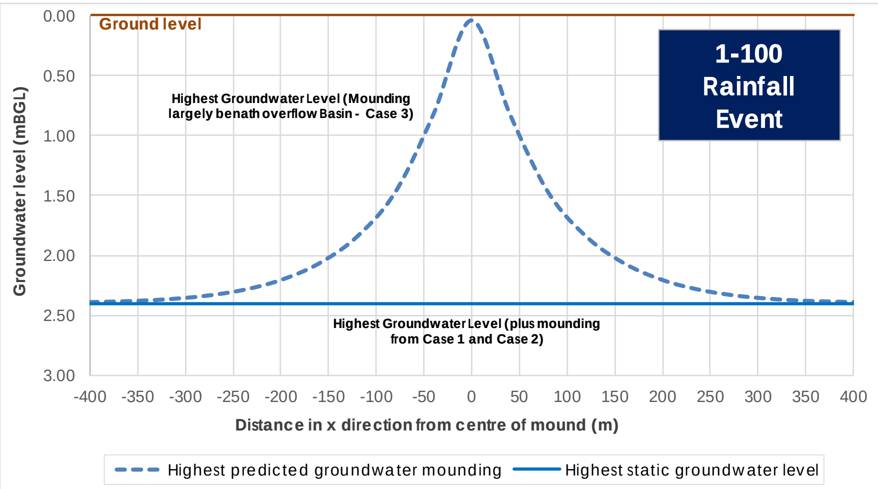
Hunt, B. (2012). Groundwater analysis using Function.xls. Civil Engineering Department, Canterbury University.

Recharge area - x direction	x_a	44	m
Recharge area - y direction	y_a	88	m
Total recharge area	A	3,872	m^2



x direction (m) / y direction (m) / Groundwater mounding (m)

y \ x	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	0	40	80	120	160	200	240	280	320	360	400
-400	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-360	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
-320	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00
-280	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.06	0.05	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00
-240	0.00	0.00	0.01	0.01	0.02	0.04	0.05	0.07	0.09	0.11	0.11	0.11	0.09	0.07	0.05	0.04	0.02	0.01	0.01	0.00	0.00
-200	0.00	0.01	0.01	0.02	0.04	0.06	0.09	0.12	0.16	0.19	0.20	0.19	0.16	0.12	0.09	0.06	0.04	0.02	0.01	0.01	0.00
-160	0.00	0.01	0.02	0.03	0.05	0.09	0.14	0.20	0.27	0.33	0.35	0.33	0.27	0.20	0.14	0.09	0.05	0.03	0.02	0.01	0.00
-120	0.00	0.01	0.02	0.04	0.07	0.12	0.20	0.30	0.42	0.54	0.59	0.54	0.42	0.30	0.20	0.12	0.07	0.04	0.02	0.01	0.00
-80	0.01	0.01	0.03	0.05	0.09	0.15	0.26	0.41	0.63	0.88	1.01	0.88	0.63	0.41	0.26	0.15	0.09	0.05	0.03	0.01	0.01
-40	0.01	0.01	0.03	0.06	0.10	0.18	0.31	0.51	0.83	1.34	1.88	1.34	0.83	0.51	0.31	0.18	0.10	0.06	0.03	0.01	0.01
0	0.01	0.01	0.03	0.06	0.11	0.19	0.33	0.55	0.93	1.58	2.36	1.58	0.93	0.55	0.33	0.19	0.11	0.06	0.03	0.01	0.01
40	0.01	0.01	0.03	0.06	0.10	0.18	0.31	0.51	0.83	1.34	1.88	1.34	0.83	0.51	0.31	0.18	0.10	0.06	0.03	0.01	0.01
80	0.01	0.01	0.03	0.05	0.09	0.15	0.26	0.41	0.63	0.88	1.01	0.88	0.63	0.41	0.26	0.15	0.09	0.05	0.03	0.01	0.01
120	0.00	0.01	0.02	0.04	0.07	0.12	0.20	0.30	0.42	0.54	0.59	0.54	0.42	0.30	0.20	0.12	0.07	0.04	0.02	0.01	0.00
160	0.00	0.01	0.02	0.03	0.05	0.09	0.14	0.20	0.27	0.33	0.35	0.33	0.27	0.20	0.14	0.09	0.05	0.03	0.02	0.01	0.00
200	0.00	0.01	0.01	0.02	0.04	0.06	0.09	0.12	0.16	0.19	0.20	0.19	0.16	0.12	0.09	0.06	0.04	0.02	0.01	0.01	0.00
240	0.00	0.00	0.01	0.01	0.02	0.04	0.05	0.07	0.09	0.11	0.11	0.11	0.09	0.07	0.05	0.04	0.02	0.01	0.01	0.00	0.00
280	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.06	0.05	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00
320	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00
360	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
400	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00



Transient Groundwater Mounding - Unconfined Aquifer

After Hunt (2012) using Function W_6

Facility 6

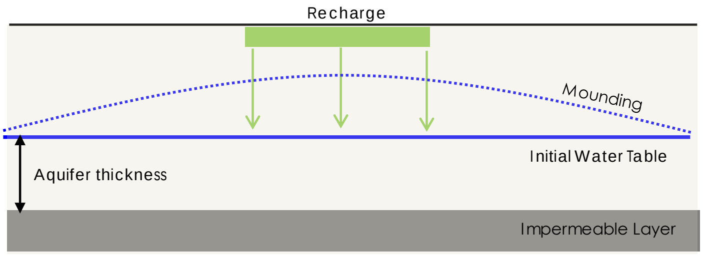
Aquifer thickness	B	38	m
Hydraulic conductivity	K	20	m/d
Transmissivity = KB	T	760	m^2/d
Specific yield	Sy	0.20	-

Recharge volume	Q	2,193	m^3/d
Recharge rate	R	0.658	m/d
Time since start of recharge	t	8.8	d
Highest static groundwater level	H_{max}	1.2	mBGL

Recharge area - x direction	x_a	37	m
Recharge area - y direction	y_a	91	m
Total recharge area	A	3,332	m^2

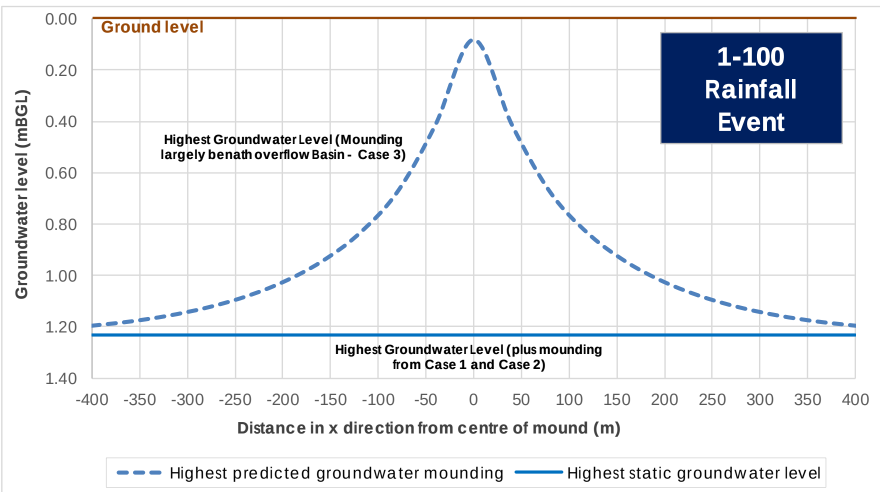
Reference

Hunt, B. (2012). Groundwater analysis using Function.xls. Civil Engineering Department, Canterbury University.



x direction (m) / y direction (m) — Groundwater mounding (m)

y \ x	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	0	40	80	120	160	200	240	280	320	360	400
-400	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01
-360	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.01	0.01
-320	0.01	0.02	0.02	0.03	0.04	0.05	0.05	0.06	0.07	0.08	0.08	0.08	0.07	0.06	0.05	0.05	0.04	0.03	0.02	0.02	0.01
-280	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.10	0.11	0.11	0.11	0.10	0.09	0.07	0.06	0.05	0.04	0.03	0.02	0.02
-240	0.02	0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.15	0.15	0.15	0.14	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0.02
-200	0.02	0.03	0.05	0.06	0.08	0.10	0.13	0.16	0.19	0.20	0.21	0.20	0.19	0.16	0.13	0.10	0.08	0.06	0.05	0.03	0.02
-160	0.03	0.04	0.05	0.07	0.10	0.13	0.17	0.21	0.25	0.28	0.29	0.28	0.25	0.21	0.17	0.13	0.10	0.07	0.05	0.04	0.03
-120	0.03	0.04	0.06	0.09	0.12	0.16	0.21	0.27	0.33	0.39	0.41	0.39	0.33	0.27	0.21	0.16	0.12	0.09	0.06	0.04	0.03
-80	0.03	0.05	0.07	0.10	0.13	0.18	0.25	0.33	0.43	0.54	0.60	0.54	0.43	0.33	0.25	0.18	0.13	0.10	0.07	0.05	0.03
-40	0.04	0.05	0.07	0.10	0.14	0.20	0.27	0.38	0.52	0.73	0.96	0.73	0.52	0.38	0.27	0.20	0.14	0.10	0.07	0.05	0.04
0	0.04	0.05	0.07	0.11	0.15	0.21	0.28	0.39	0.56	0.82	1.15	0.82	0.56	0.39	0.28	0.21	0.15	0.11	0.07	0.05	0.04
40	0.04	0.05	0.07	0.10	0.14	0.20	0.27	0.38	0.52	0.73	0.96	0.73	0.52	0.38	0.27	0.20	0.14	0.10	0.07	0.05	0.04
80	0.03	0.05	0.07	0.10	0.13	0.18	0.25	0.33	0.43	0.54	0.60	0.54	0.43	0.33	0.25	0.18	0.13	0.10	0.07	0.05	0.03
120	0.03	0.04	0.06	0.09	0.12	0.16	0.21	0.27	0.33	0.39	0.41	0.39	0.33	0.27	0.21	0.16	0.12	0.09	0.06	0.04	0.03
160	0.03	0.04	0.05	0.07	0.10	0.13	0.17	0.21	0.25	0.28	0.29	0.28	0.25	0.21	0.17	0.13	0.10	0.07	0.05	0.04	0.03
200	0.02	0.03	0.05	0.06	0.08	0.10	0.13	0.16	0.19	0.20	0.21	0.20	0.19	0.16	0.13	0.10	0.08	0.06	0.05	0.03	0.02
240	0.02	0.03	0.04	0.05	0.06	0.08	0.10	0.12	0.14	0.15	0.15	0.15	0.14	0.12	0.10	0.08	0.06	0.05	0.04	0.03	0.02
280	0.02	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.10	0.11	0.11	0.11	0.10	0.09	0.07	0.06	0.05	0.04	0.03	0.02	0.02
320	0.01	0.02	0.02	0.03	0.04	0.05	0.05	0.06	0.07	0.08	0.08	0.08	0.07	0.06	0.05	0.05	0.04	0.03	0.02	0.02	0.01
360	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.01	0.01
400	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01



Transient Groundwater Mounding - Unconfined Aquifer

After Hunt (2012) using Function W_6

Facility 7

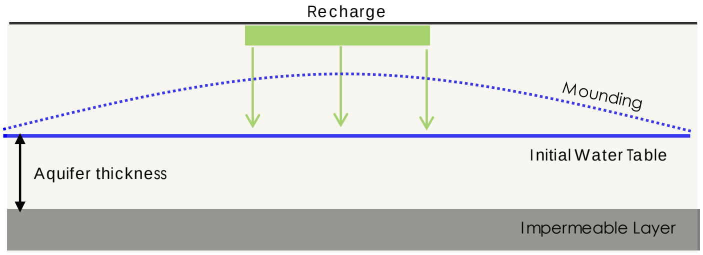
Aquifer thickness	B	38	m
Hydraulic conductivity	K	40	m/d
Transmissivity = KB	T	1,520	m^2/d
Specific yield	Sy	0.20	-

Recharge volume	Q	10,188	m^3/d
Recharge rate	R	1.740	m/d
Time since start of recharge	t	2.8	d
Highest static groundwater level	H_{max}	2.2	mBGL

Recharge area - x direction	x_a	48	m
Recharge area - y direction	y_a	122	m
Total recharge area	A	5,856	m^2

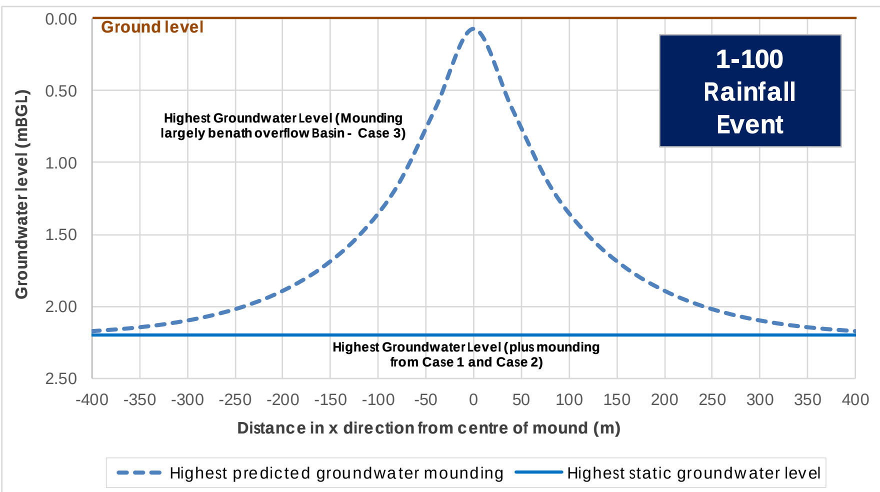
Reference

Hunt, B. (2012). Groundwater analysis using Function.xls. Civil Engineering Department, Canterbury University.



Groundwater mounding (m) — x direction (m) across, y direction (m) down

y \ x	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	0	40	80	120	160	200	240	280	320	360	400
-400	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.00
-360	0.00	0.01	0.01	0.02	0.02	0.03	0.04	0.04	0.05	0.05	0.06	0.05	0.05	0.04	0.04	0.03	0.02	0.02	0.01	0.01	0.00
-320	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.09	0.09	0.08	0.07	0.06	0.04	0.03	0.02	0.02	0.01	0.01
-280	0.01	0.01	0.02	0.03	0.05	0.07	0.09	0.11	0.12	0.14	0.14	0.14	0.12	0.11	0.09	0.07	0.05	0.03	0.02	0.01	0.01
-240	0.01	0.02	0.03	0.05	0.07	0.09	0.13	0.16	0.19	0.21	0.22	0.21	0.19	0.16	0.13	0.09	0.07	0.05	0.03	0.02	0.01
-200	0.02	0.03	0.04	0.06	0.09	0.13	0.18	0.23	0.28	0.32	0.34	0.32	0.28	0.23	0.18	0.13	0.09	0.06	0.04	0.03	0.02
-160	0.02	0.03	0.05	0.08	0.12	0.18	0.24	0.33	0.41	0.48	0.51	0.48	0.41	0.33	0.24	0.18	0.12	0.08	0.05	0.03	0.02
-120	0.02	0.04	0.06	0.10	0.15	0.22	0.32	0.44	0.58	0.71	0.77	0.71	0.58	0.44	0.32	0.22	0.15	0.10	0.06	0.04	0.02
-80	0.03	0.05	0.07	0.12	0.18	0.27	0.39	0.56	0.78	1.05	1.21	1.05	0.78	0.56	0.39	0.27	0.18	0.12	0.07	0.05	0.03
-40	0.03	0.05	0.08	0.13	0.20	0.30	0.45	0.66	0.97	1.43	1.91	1.43	0.97	0.66	0.45	0.30	0.20	0.13	0.08	0.05	0.03
0	0.03	0.05	0.08	0.13	0.20	0.31	0.47	0.70	1.04	1.58	2.13	1.58	1.04	0.70	0.47	0.31	0.20	0.13	0.08	0.05	0.03
40	0.03	0.05	0.08	0.13	0.20	0.30	0.45	0.66	0.97	1.43	1.91	1.43	0.97	0.66	0.45	0.30	0.20	0.13	0.08	0.05	0.03
80	0.03	0.05	0.07	0.12	0.18	0.27	0.39	0.56	0.78	1.05	1.21	1.05	0.78	0.56	0.39	0.27	0.18	0.12	0.07	0.05	0.03
120	0.02	0.04	0.06	0.10	0.15	0.22	0.32	0.44	0.58	0.71	0.77	0.71	0.58	0.44	0.32	0.22	0.15	0.10	0.06	0.04	0.02
160	0.02	0.03	0.05	0.08	0.12	0.18	0.24	0.33	0.41	0.48	0.51	0.48	0.41	0.33	0.24	0.18	0.12	0.08	0.05	0.03	0.02
200	0.02	0.03	0.04	0.06	0.09	0.13	0.18	0.23	0.28	0.32	0.34	0.32	0.28	0.23	0.18	0.13	0.09	0.06	0.04	0.03	0.02
240	0.01	0.02	0.03	0.05	0.07	0.09	0.13	0.16	0.19	0.21	0.22	0.21	0.19	0.16	0.13	0.09	0.07	0.05	0.03	0.02	0.01
280	0.01	0.01	0.02	0.03	0.05	0.07	0.09	0.11	0.12	0.14	0.14	0.14	0.12	0.11	0.09	0.07	0.05	0.03	0.02	0.01	0.01
320	0.01	0.01	0.02	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.09	0.09	0.08	0.07	0.06	0.04	0.03	0.02	0.02	0.01	0.01
360	0.00	0.01	0.01	0.02	0.02	0.03	0.04	0.04	0.05	0.05	0.06	0.05	0.05	0.04	0.04	0.03	0.02	0.02	0.01	0.01	0.00
400	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.00



Transient Groundwater Mounding - Unconfined Aquifer

After Hunt (2012) using Function W_6

Facility 8

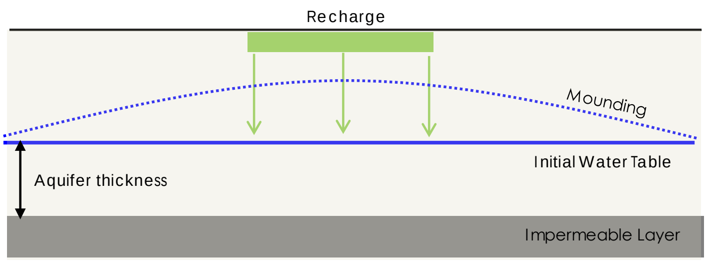
Aquifer thickness	B	40	m
Hydraulic conductivity	K	38	m/d
Transmissivity = KB	T	1,520	m^2/d
Specific yield	Sy	0.20	-

Recharge volume + rainfall	Q	39,435	m^3/d
Recharge rate	R	6.734	m/d
Time since start of recharge	t	0.80	d
Highest static groundwater level	H_{max}	5.8	mBGL

Recharge area - x direction	x_a	48	m
Recharge area - y direction	y_a	122	m
Total recharge area	A	5,856	m^2

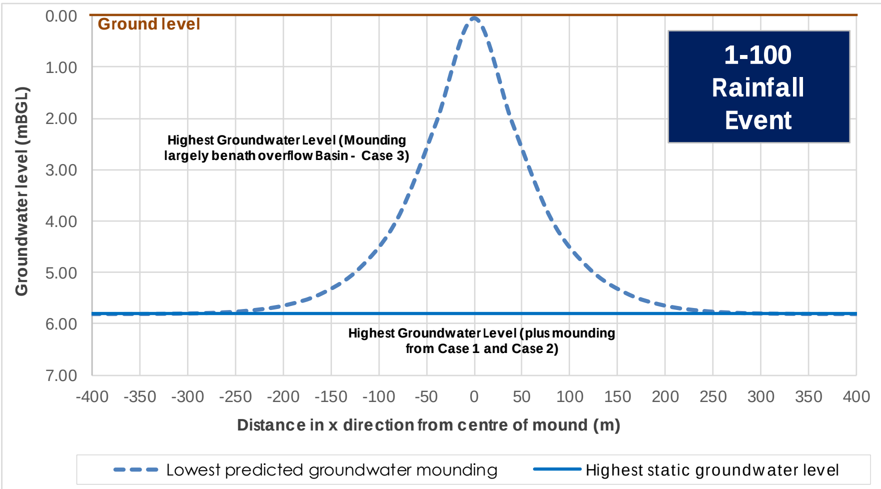
Reference

Hunt, B. (2012). Groundwater analysis using Function.xls. Civil Engineering Department, Canterbury University.



x direction (m) / y direction (m) — Groundwater mounding (m)

y \ x	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	0	40	80	120	160	200	240	280	320	360	400
-400	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-360	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-320	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-280	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.03	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
-240	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08	0.08	0.08	0.06	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00
-200	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.09	0.15	0.20	0.22	0.20	0.15	0.09	0.05	0.02	0.01	0.00	0.00	0.00	0.00
-160	0.00	0.00	0.00	0.01	0.02	0.05	0.10	0.20	0.33	0.46	0.52	0.46	0.33	0.20	0.10	0.05	0.02	0.01	0.00	0.00	0.00
-120	0.00	0.00	0.00	0.01	0.03	0.08	0.18	0.37	0.66	0.99	1.15	0.99	0.66	0.37	0.18	0.08	0.03	0.01	0.00	0.00	0.00
-80	0.00	0.00	0.00	0.02	0.04	0.12	0.28	0.59	1.15	1.96	2.52	1.96	1.15	0.59	0.28	0.12	0.04	0.02	0.00	0.00	0.00
-40	0.00	0.00	0.01	0.02	0.06	0.15	0.36	0.80	1.65	3.21	4.98	3.21	1.65	0.80	0.36	0.15	0.06	0.02	0.01	0.00	0.00
0	0.00	0.00	0.01	0.02	0.06	0.16	0.39	0.89	1.86	3.71	5.75	3.71	1.86	0.89	0.39	0.16	0.06	0.02	0.01	0.00	0.00
40	0.00	0.00	0.01	0.02	0.06	0.15	0.36	0.80	1.65	3.21	4.98	3.21	1.65	0.80	0.36	0.15	0.06	0.02	0.01	0.00	0.00
80	0.00	0.00	0.00	0.02	0.04	0.12	0.28	0.59	1.15	1.96	2.52	1.96	1.15	0.59	0.28	0.12	0.04	0.02	0.00	0.00	0.00
120	0.00	0.00	0.00	0.01	0.03	0.08	0.18	0.37	0.66	0.99	1.15	0.99	0.66	0.37	0.18	0.08	0.03	0.01	0.00	0.00	0.00
160	0.00	0.00	0.00	0.01	0.02	0.05	0.10	0.20	0.33	0.46	0.52	0.46	0.33	0.20	0.10	0.05	0.02	0.01	0.00	0.00	0.00
200	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.09	0.15	0.20	0.22	0.20	0.15	0.09	0.05	0.02	0.01	0.00	0.00	0.00	0.00
240	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.08	0.08	0.08	0.06	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00
280	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.03	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
320	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
360	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
400	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



Transient Groundwater Mounding - Unconfined Aquifer

After Hunt (2012) using Function W_6

Facility 9

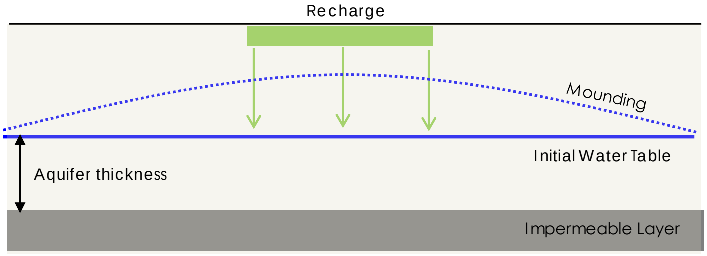
Aquifer thickness	B	40	m
Hydraulic conductivity	K	38	m/d
Transmissivity = KB	T	1,520	m^2/d
Specific yield	Sy	0.20	-

Recharge volume + rainfall	Q	9,273	m^3/d
Recharge rate	R	1.058	m/d
Time since start of recharge	t	6.00	d
Highest static groundwater level	H_{max}	2.2	mBGL

Recharge area - x direction	x_a	59	m
Recharge area - y direction	y_a	148	m
Total recharge area	A	8,762	m^2

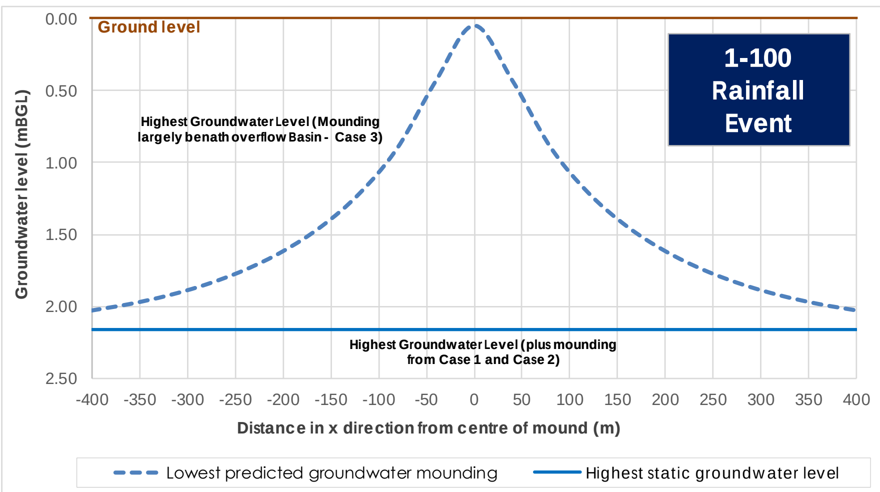
Reference

Hunt, B. (2012). Groundwater analysis using Function.xls. Civil Engineering Department, Canterbury University.



x direction (m); y direction (m); Groundwater mounding (m)

y \ x	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	0	40	80	120	160	200	240	280	320	360	400
-400	0.03	0.04	0.05	0.07	0.08	0.09	0.11	0.12	0.13	0.13	0.14	0.13	0.13	0.12	0.11	0.09	0.08	0.07	0.05	0.04	0.03
-360	0.04	0.06	0.07	0.09	0.10	0.12	0.14	0.16	0.17	0.18	0.18	0.18	0.17	0.16	0.14	0.12	0.10	0.09	0.07	0.06	0.04
-320	0.05	0.07	0.09	0.11	0.13	0.16	0.19	0.21	0.23	0.24	0.25	0.24	0.23	0.21	0.19	0.16	0.13	0.11	0.09	0.07	0.05
-280	0.07	0.08	0.11	0.14	0.17	0.20	0.24	0.27	0.30	0.32	0.33	0.32	0.30	0.27	0.24	0.20	0.17	0.14	0.11	0.08	0.07
-240	0.08	0.10	0.13	0.17	0.21	0.26	0.30	0.35	0.40	0.43	0.44	0.43	0.40	0.35	0.30	0.26	0.21	0.17	0.13	0.10	0.08
-200	0.09	0.12	0.16	0.20	0.25	0.31	0.38	0.45	0.51	0.56	0.58	0.56	0.51	0.45	0.38	0.31	0.25	0.20	0.16	0.12	0.09
-160	0.10	0.14	0.18	0.23	0.30	0.38	0.47	0.56	0.66	0.74	0.77	0.74	0.66	0.56	0.47	0.38	0.30	0.23	0.18	0.14	0.10
-120	0.11	0.15	0.20	0.26	0.34	0.44	0.55	0.69	0.84	0.98	1.05	0.98	0.84	0.69	0.55	0.44	0.34	0.26	0.20	0.15	0.11
-80	0.12	0.16	0.22	0.29	0.38	0.49	0.64	0.82	1.04	1.31	1.50	1.31	1.04	0.82	0.64	0.49	0.38	0.29	0.22	0.16	0.12
-40	0.13	0.17	0.23	0.31	0.40	0.53	0.69	0.91	1.20	1.63	1.98	1.63	1.20	0.91	0.69	0.53	0.40	0.31	0.23	0.17	0.13
0	0.13	0.17	0.23	0.31	0.41	0.54	0.71	0.94	1.27	1.73	2.12	1.73	1.27	0.94	0.71	0.54	0.41	0.31	0.23	0.17	0.13
40	0.13	0.17	0.23	0.31	0.40	0.53	0.69	0.91	1.20	1.63	1.98	1.63	1.20	0.91	0.69	0.53	0.40	0.31	0.23	0.17	0.13
80	0.12	0.16	0.22	0.29	0.38	0.49	0.64	0.82	1.04	1.31	1.50	1.31	1.04	0.82	0.64	0.49	0.38	0.29	0.22	0.16	0.12
120	0.11	0.15	0.20	0.26	0.34	0.44	0.55	0.69	0.84	0.98	1.05	0.98	0.84	0.69	0.55	0.44	0.34	0.26	0.20	0.15	0.11
160	0.10	0.14	0.18	0.23	0.30	0.38	0.47	0.56	0.66	0.74	0.77	0.74	0.66	0.56	0.47	0.38	0.30	0.23	0.18	0.14	0.10
200	0.09	0.12	0.16	0.20	0.25	0.31	0.38	0.45	0.51	0.56	0.58	0.56	0.51	0.45	0.38	0.31	0.25	0.20	0.16	0.12	0.09
240	0.08	0.10	0.13	0.17	0.21	0.26	0.30	0.35	0.40	0.43	0.44	0.43	0.40	0.35	0.30	0.26	0.21	0.17	0.13	0.10	0.08
280	0.07	0.08	0.11	0.14	0.17	0.20	0.24	0.27	0.30	0.32	0.33	0.32	0.30	0.27	0.24	0.20	0.17	0.14	0.11	0.08	0.07
320	0.05	0.07	0.09	0.11	0.13	0.16	0.19	0.21	0.23	0.24	0.25	0.24	0.23	0.21	0.19	0.16	0.13	0.11	0.09	0.07	0.05
360	0.04	0.06	0.07	0.09	0.10	0.12	0.14	0.16	0.17	0.18	0.18	0.18	0.17	0.16	0.14	0.12	0.10	0.09	0.07	0.06	0.04
400	0.03	0.04	0.05	0.07	0.08	0.09	0.11	0.12	0.13	0.13	0.14	0.13	0.13	0.12	0.11	0.09	0.08	0.07	0.05	0.04	0.03



Appendix D Predicted Infiltration Rates at Facility 6

Facility 6 - Infiltration Loading Calculations and Discharge Areas

Based on Massmann (2003)

Clogging (m)	Water Depth in Overflow Basin Above Ground Level (m)	Depth to Water Table Below Ground Level (m)	Hydraulic Conductivity, K (m/d)	Total Base Area for One Cell Excluding Side Slopes, A_{cell} (m^2)	Hydraulic Gradient, i m/m	Cell Size Correction Factor, CF_{size} -	Infiltration Rate, f (m/d)	Total Number of Cells -	Total Length of Cell Bottom (m)	Length of Cell Bottom (m)	Width of Cell Bottom (m)	Cell Side Slopes (3:1 typical) -	Length of Cell Including Side Slope (m)	Width of Cell Including Side Slope (m)	Cell Dimension Correction Factor CF_{aspect} -	Clogging Correction Factor, $CF_{silt/bio}$ -	Adjusted Infiltration Rate, f_{corr} (m/d)	Loading Rate to One Cell (m^3/d)
High clogging	0	0.5	0.3	3,332	0.010	0.8	0.00	1	91	91	37	0	91	37	1.03	0.3	0.001	3
	0	0.9	0.7	3,332	0.017	0.8	0.01	1	91	91	37	0	91	37	1.03	0.3	0.004	12
	0	1.3	1.1	3,332	0.023	0.8	0.03	1	91	91	37	0	91	37	1.03	0.3	0.008	26
	0	1.7	1.5	3,332	0.029	0.8	0.04	1	91	91	37	0	91	37	1.03	0.3	0.013	45
	0	2.1	2.0	3,332	0.035	0.8	0.07	1	91	91	37	0	91	37	1.03	0.3	0.022	72
Moderate clogging	0	0.5	0.3	3,332	0.010	0.8	0.00	1	91	91	37	0	91	37	1.03	0.6	0.002	6
	0	0.9	0.7	3,332	0.017	0.8	0.01	1	91	91	37	0	91	37	1.03	0.6	0.007	24
	0	1.3	1.1	3,332	0.023	0.8	0.03	1	91	91	37	0	91	37	1.03	0.6	0.016	52
	0	1.7	1.5	3,332	0.029	0.8	0.04	1	91	91	37	0	91	37	1.03	0.6	0.027	90
	0	2.1	2.0	3,332	0.035	0.8	0.07	1	91	91	37	0	91	37	1.03	0.6	0.043	145
No clogging	0	0.5	0.3	3,332	0.010	0.8	0.00	1	91	91	37	0	91	37	1.03	1.0	0.003	10
	0	0.9	0.7	3,332	0.017	0.8	0.01	1	91	91	37	0	91	37	1.03	1.0	0.012	40
	0	1.3	1.1	3,332	0.023	0.8	0.03	1	91	91	37	0	91	37	1.03	1.0	0.026	87
	0	1.7	1.5	3,332	0.029	0.8	0.04	1	91	91	37	0	91	37	1.03	1.0	0.045	151
	0	2.1	2.0	3,332	0.035	0.8	0.07	1	91	91	37	0	91	37	1.03	1.0	0.072	241
Median							**0.03**										**0.01**	**45**

Reference

Massmann, J.W. (2003). A design manual for sizing infiltration ponds. Prepared for Washington State Transport Commission. October 2003
United States Environmental Protection Agency (2006). Process Design Manual. Land Treatment of Municipal Wastewater Effluents. EPA/625/R-06/016. September 2006.

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