

Assessment of Effects on Groundwater

Alternative to Brynderwyn Hills – Brynderwyn Hills Section

2 April 2026

Revision A

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Glossary of Acronyms and Abbreviations

The glossary of acronyms and abbreviations tables in Volumes A and B of the Substantive Application apply to this report and should be referred to in addition to the acronyms and abbreviations below.

Abbreviation / Acronym	Term
ANZECC 2000	Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1
GNS	New Zealand Institute of Geological and Nuclear Sciences (now Earth Sciences New Zealand; ESNZ)
km	Kilometres
km ²	Square kilometres
L/s	Litres per second
m	Metres
m bgl	Metres below ground level
m ³ /day	Cubic metres per day
m/s	Metres per second
NGRM	National Groundwater Recharge Model
VWP	Vibrating Wire Piezometer

Glossary of Defined Terms

The glossary of defined terms tables in Volumes A and B of the Substantive Application apply to this report and should be referred to in addition to the defined terms below.

Term	Meaning
Aquifer	An Aquifer is an underground layer of water-bearing, permeable rock, rock fractures, or unconsolidated materials (gravel, sand, or silt). Groundwater from Aquifers can be extracted using a water well.
Artesian conditions	Artesian conditions refer to groundwater under natural pressure that will rise above ground surface when a bore is drilled into the aquifer. This typically occurs when groundwater is confined by a low permeability (confining) layer like clay and receives recharge from higher elevations. The weight of the water entering the aquifer from the higher elevation creates the pressure which is held in the aquifer by the confining layer.
Chainage	A distance measured along a straight line. For this Project chainage is measured in metres and starts from the western extent of the Project.
Constructed Wetland	A stormwater management device that is a shallow densely vegetated pond that controls the release of stormwater flows related to extended detention for stream erosion protection and intermediate storm control. The wetland also provides water quality treatment.
Depressurisation	Abstracting groundwater in order to lower the groundwater pressures beneath a construction site.
Dewatering	Removal of groundwater or stormwater from a construction site.
Hanging Wetland	A naturally formed wetland located on relatively steep slopes in a localised depression such as gullies. Hanging wetlands are primarily groundwater-fed during low flow conditions.
Hydraulic Conductivity	A measure of permeability of a porous material, such as gravels, sands, clays or silts, and rock fractures.
Natural Inland Wetland(s) or Natural Wetland(s)	Defined in the National Policy Statement for Freshwater Management 2020: A wetland (as defined in section 2 of the Resource Management 1991) that is not: (a) a deliberately constructed wetland, other than a wetland constructed to offset impacts on, or to restore, an existing or former natural inland wetland; or (b) a wetland that has developed in or around a deliberately constructed water body, since the construction of the water body; or (c) a wetland that: (i) is within an area of pasture used for grazing; and (ii) has vegetation cover comprising more than 50% exotic pasture species; unless (iii) the wetland is a location of a habitat of a threatened species identified under clause 3.8 of the National Policy Statement for Freshwater Management 2020.
Numerical Groundwater Model	A computer model that simulates groundwater flow by means of governing equations that represent the physical processes that occur in a groundwater system. Numerical Groundwater Models can simulate hydraulic heads and flows across a predefined area and within a predefined timeframe.
SEEP/W	A finite element numerical modelling software for groundwater flow in porous media, developed by Sequent (2021)

1. Introduction

1.1. Purpose and scope of this report

This report provides an assessment of the actual and potential effects on groundwater (including groundwater effects on wetlands and rivers and their margins) associated with the construction and operation of the Brynderwyn Hills section of the Alternative to the Brynderwyn Hills project (the Project).

This assessment forms part of a suite of technical assessments prepared for the New Zealand Transport Agency Waka Kotahi (NZTA) to inform the Substantive Application under the Fast-track Approvals Act 2024 (FTAA) for the Project. This report should be read in conjunction with Volume A of the Substantive Application.

The construction of the Project involves various excavations to install underground services and to make cuts into the land for the road. Groundwater effects may arise where these excavations are below the groundwater table, because temporary (i.e., during the construction phase) or permanent (i.e., during the operational phase) groundwater drainage will be required at various locations along the alignment of the Project. The locations of the proposed road cuts are shown in **Appendix A** and in a long-section in **Appendix**.

The scope of the assessment includes a description of the existing groundwater environment, the methodology applied in preparing the assessment, determination of the actual and potential effects generated by the Project, and details of the recommended measures to manage and mitigate adverse effects.

1.2. Qualifications

1.2.1. Louise Soltau

My name is Louise Soltau and I am a Principal Hydrogeologist with WSP New Zealand Ltd.

I have a Master of Science degree in geology and geophysics from the University Missouri Rolla, United States of America, obtained in 2000. I have 32 years' experience as a hydrogeologist working in research and consulting. I have been involved as technical specialist for various water resource and infrastructure projects. My experience most relevant to this Project is:

- **Waitematā Harbour Connections, Auckland, New Zealand (2024 - 2025):** NZTA Waka Kotahi, hydrogeology lead. Responsible for preparing the hydrogeology information to support early-stage design and pricing activities by delivering preliminary groundwater assessments for particular design elements (for example Dewatering of the proposed tunnel portal, management of high level settlement risk due to Dewatering during construction), groundwater modelling to inform high-level construction planning and likely environmental effects assessment, factual and interpretive reporting).
- **Cambridge to Piarere (C2P) Expressway – SH1 Construction Water Supply, Cambridge to Piarere, New Zealand (2024 - 2025):** NZTA Waka Kotahi, senior hydrogeologist. Responsible for hydrogeology investigations and water supply planning for the C2P expressway, including managing of the biosecurity hazard of the invasive gold clam (*Corbicula fluminea*) in Lake Karāpiro, specifications and tender processes for production well drilling, construction, and Aquifer testing at Moana Roa Reserve; technical reporting, preparing tender specifications and evaluations for procurement and construction decisions.

I have been involved with the Northland Corridor project since late 2024, when site investigation commenced, as the lead hydrogeologist for geotechnical and planning assessments.

1.2.2. Eric van Nieuwkerk

My name is Eric van Nieuwkerk and I am a Technical Principal – Hydrogeology at WSP New Zealand Ltd.

I have a Master of Science degree in hydrogeology from the Free University of Amsterdam, The Netherlands, which I obtained in 1998. I have 26 years' experience as a Hydrogeologist working for local

government, research institutes and various consultancies in The Netherlands, New Zealand and Australia. I have been involved as technical specialist and project manager in various environmental risk assessments, water resource investigations and civil engineering projects in both urban and rural areas. My experience most relevant to this Project is:

- **Mackays to PekaPeka (M2PP) Expressway project, Kāpiti Coast for NZTA/Waka Kotahi:** This project involved the design and construction of a 13 km-long expressway on the Kāpiti Coast, North of Wellington. The expressway is constructed through soft sedimentary deposits that are prone to land settlement and also support high-valued sensitive wetlands. I developed the design for several water supply wells, undertook Aquifer testing and well performance assessments on these wells, and provided guidance to drilling contractors during installation of these wells. I also assessed the effects of groundwater abstraction from these wells as part of resource consent application. I designed and assessed the effects of several construction Dewatering projects using 3D-groundwater models in Visual MODFLOW. I undertook groundwater level monitoring and wetland water level monitoring during the construction phase and provided compliance reporting to the regional council.
- **Sunshine Coast Airport Expansion Project Hydrogeology Assessment, Sunshine Coast, Queensland, Australia for Sunshine Coast Council:** My responsibility in this project was the analysis of hydrogeological information and development of a hydrogeology conceptual site model for the construction of a new runway. I developed a 3D groundwater and solute transport model (Modflow and MT3DMS) and undertook predictive modelling scenarios to assess changes in groundwater levels and groundwater flow paths to inform the design and construction of a new runway and associated infrastructure. I assessed pathways and control options to manage a large PFAS groundwater contamination plume. I assessed the potential risks of saline intrusion to nearby sensitive wetlands. I was also responsible for the project's management, client contact and reporting.
- **Te Kaha Stadium in Christchurch for Christchurch City Council (2021-2022):** I was involved in the Dewatering design for temporary works as part of the development of the new stadium. I set up a groundwater monitoring network, undertook hydraulic testing, analysis of monitoring data and reporting. I reviewed the hydrogeology and groundwater quality information and developed the hydrogeology conceptual model. I also developed a 3D Numerical Groundwater Model (Modflow) to assess Dewatering volumes, rates and drawdowns during temporary works Dewatering. I completed an assessment of groundwater effects and consenting. I was responsible for all analysis, work package management, client contact and liaison with other experts.
- **The Cambridge to Piarere (C2P) Expressway, Waikato for NZTA/Waka Kotahi (2021-2025):** This project involves the development of a new expressway between Cambridge and Piarere, Waikato, which includes large cuts below the groundwater table requiring permanent drainage. I was the hydrogeology technical lead for the consenting phase of the project. I was responsible for analysis of hydrogeological information and development of a hydrogeology conceptual model for the construction of the new C2P expressway. I arranged field investigation programmes for drilling and installing monitoring wells, water quality sampling and testing, and flow gauging of streams and wetlands. I liaised with the client and legal team, as well as various subject matter experts to understand environmental risks. I developed several 2D and 3D-Numerical Groundwater Models (SEEP/W and Modflow-Surfact) to assess risks of reduction of baseflow in streams and wetlands (i.e., stream depletion) and well interference effects in the wider area.
- **Hawkes Bay Expressway (HBEX), Napier, Ōtaki to North Levin (O2NL) Expressway, Levin, and SH1 Wellington Improvements Roads of National Significance (RoNS) for NZTA/Waka Kotahi:** I am currently involved in three other ongoing expressway projects as hydrogeologist and hydrogeology technical reviewer, supporting other hydrogeologists involved in those projects with construction Dewatering designs, groundwater effects assessments and analysis and interpretation of field investigation data.

I have been involved with the Northland Corridor project since 2024 as a technical reviewer for hydrogeology assessments. In addition, I have contributed to the reporting of hydrogeology assessments included in several geotechnical reports and reviewed the 3D Numerical Groundwater Model developed for Section 1, and various 2D cross sectional models for The Brynderwyn Hills section.

1.3. Code of Conduct

Although this Project is not being considered before the Environment Court, we confirm that we have read the Code of Conduct for expert witnesses as contained in Section 9 of the Environment Court Practice Note 2023. We agree to comply with that Code. We are satisfied that the matters which we address in this Assessment are within our area of expertise, except where we state that we are relying on information provided by another person or expert. We have not omitted to consider material facts known to us that might alter or detract from the opinions we express.

2. Assessment Methodology

2.1. Assessment Framework

This assessment of groundwater effects undertaken for the Project includes site investigations and a desktop assessment. The information collected from these processes has informed the development of a hydrogeology conceptual model and subsequent Numerical Groundwater Model to understand the existing hydrogeological environment and assess effects on groundwater resources. The assessment of potential groundwater effects and a classification of the magnitude of these effects is described in detail in Section 0.

2.2. Desktop Assessment

Data and information relevant to the Project were obtained from publicly available online databases of the New Zealand Institute of Geological and Nuclear Sciences (GNS), which is now Earth Sciences New Zealand (ESNZ), and the Northland Regional Council (NRC). This data and information covers geology, surface water and wetlands, existing water supply wells, and any groundwater abstraction resource consents issued within the Proposed Designation and wider area.

Various relevant reports and textbooks on hydrogeology, geology and hydrology have been reviewed to support the hydrogeology investigations. A reference list of relevant literature is included in Section 7 of this report.

2.3. Field Surveys and Observations

We undertook all site investigations in accordance with relevant geotechnical standards to obtain geological and hydrogeological information for land underlying the Project, and to support the design and consent application packages. In particular, we undertook groundwater level measurements and hydraulic testing during drilling works (discussed in Sections 2.3.1 and 2.3.2 below).

The groundwater and geology information obtained during drilling was used to confirm the optimal design of piezometers to be installed in recently drilled boreholes for Project Investigations.

Hydraulic Conductivity testing was conducted in targeted bores during drilling and in all standpipe piezometers after construction and development. The drilling programme is ongoing, and groundwater information will be refined as drilling progresses.

2.3.1. Groundwater levels

At the time of completing this assessment, a total of 69 boreholes have been completed to investigate and confirm geological, geotechnical, and hydrogeological conditions within and around the Indicative Alignment (**Appendix A**). All boreholes were logged for their soil and rock characteristics.

Groundwater levels were measured during drilling at the end of each drilling shift at the end of the day and before the start of drilling the next day. The groundwater levels obtained during drilling provides an indication of groundwater levels only, because it is influenced by the drilling process. These

groundwater levels were used for the design of the monitoring piezometers. Of the 69 boreholes drilled, 67 were completed as a monitoring piezometer, either as a grouted-in vibrating wire piezometer (VWP), or a standpipe piezometer, which was subsequently equipped with a VWP sensor. Standpipe piezometers were installed according to the New Zealand Environmental Standard for Drilling of Soil and Rock (NZS 4411:2001). VWPs were installed according to manufacturer's specification, in this case Geosense (V1.11 Jan 2019).

The VWPs are automatic pressure transducers that measure water pressure in a form that can be converted to groundwater levels. The VWPs were installed at various depth intervals to record vertical groundwater level gradients. The depths of the VWPs and screen depths of the standpipe piezometers were targeted to specific formations based on the geology, Indicative Alignment and groundwater level information obtained during drilling.

The VWPs are equipped with telemetry loggers and groundwater level data has been continuously updated to the groundwater monitoring portal. A total of 55 VWPs have been installed in 46 bores at the time of reporting. The groundwater level information for these sites is summarised in Table A1 in **Appendix C**. These sites are divided by the indicative Earthworks Zones for the Project, as detailed in Section C4.2.6. of Volume A of the Substantive Application. Groundwater level graphs for all monitoring piezometers are included in **Appendix C**.

2.3.2. Hydraulic Conductivity

We designed and constructed Hydraulic Conductivity testing in accordance with Kruseman and de Ridder (2000). The testing included packer testing and overnight falling head tests of the in-situ formation during drilling works, as well as slug tests in standpipe piezometers, following construction and 'development' (i.e., bore flushing).

Falling head tests were conducted in 19 bores during drilling, packer tests were conducted in four bores during drilling and slug testing was conducted in five of the constructed piezometers. The testing and analyses are ongoing and the Hydraulic Conductivity information available to date is summarised in Table D1 in

Appendix D, with the test analyses included in

Appendix D.

These estimated Hydraulic Conductivities are consistent with reference values from reliable literature, including those reported in Freeze and Cherry (1979) and Kruseman and de Ridder (2000), for fine grained formations like these. Accordingly, the hydraulic conductivity values are considered reliable and acceptable for use in the groundwater model and assessment.

2.4. Hydrogeology Conceptual Models and Numerical Groundwater Modelling

Based on the data and information from field investigations and on a desktop assessment (Section 2.2), the Project's hydrogeologists developed hydrogeology conceptual models of the groundwater system in the vicinity of the Project. A hydrogeology conceptual model is a visual representation of the groundwater flow system (Anderson and Woessner, 1992) combined with a summary of key aspects that define the groundwater system.

The hydrogeology conceptual models formed the basis for the development of numerical models, which have been used to assess hydrogeology effects of the Project on the environment. The Numerical Groundwater Models developed for the Project also incorporate the relevant information obtained during the site investigations. Numerical groundwater modelling has been undertaken in accordance with recommendations and best practices outlined in the Australian Groundwater Modelling Guidelines (Barnett et al, 2012).

2.5. Alignment changes within the Proposed Designation

The Indicative Alignment within the Proposed Designation represents a possible alignment which has been developed for assessment purposes and to illustrate what the Project's final design might look like, and the effects generated by its construction and operation. The alignment that will eventually be built including the design and placement of bridges, culverts, stormwater systems, soil disposal areas and landscaping, will be refined and confirmed during the detailed design stage.

From a hydrogeological perspective, changes in the depth or location of proposed cuts will influence the type and degree of effects of the Project. If the differences are small, we consider that this is unlikely to change the overall conclusions of the assessment of hydrogeological effects as described in Section 4 of this report. However, notable changes of the depth and/or location of the proposed cuts, especially deepening of cuts or the location of the Indicative Alignment, may result in additional hydrogeological effects to those presented in this report.

3. Existing Environment

3.1. Geology and Associated Hydrogeology

3.1.1. Hydrogeologic Units

A hydrogeologic unit is a specific geologic material with particular hydraulic properties that govern groundwater flow within the unit. Each unit is distinct from the properties of adjacent units. Six hydrogeological units have been identified within the Proposed Designation, and these coincide with the main geological units encountered in the Project Area, and summarised below:

- 1. Undifferentiated alluvium:** this unit occurs across the whole Project Area in low-lying areas and within infilled catchments and valleys, with large accumulations along the Ahuroa River and its tributary valleys. The groundwater levels are shallow within the valleys, with preferential flow occurring through paleochannels (ancient, buried river or stream channels) of coarser sediment and gravels. Groundwater levels in the hills are likely to be deeper, and artesian conditions (where groundwater is held under pressure by overlying layers with low permeability) are expected to be encountered near and in the valleys at the break of slopes. The Hydraulic Conductivity varies depending on the soils

intercepted, however are typically low because of the finer grained soils that have been intersected so far. However, higher Hydraulic Conductivity will be associated with sands and gravels.

- 2. The Waipapa Terrane greywacke and argillite:** this unit forms the basement rock along the length of the Proposed Designation, and outcrop in the Brynderwyn Hills. Site investigations are well progressed within the Waipapa Terrane, and variable groundwater levels occur because of the large topographic variability in the landscape. Groundwater levels are deeper near the ridges and hilltops, and shallow within the incised gullies, where this groundwater is naturally discharged to nearby streams. Competent (i.e., unfractured) greywacke is almost impermeable, and groundwater flow mainly occurs in fractured zones, which can be high yielding (i.e., releasing large and persistent volumes of groundwater). Site-specific testing indicated the bulk Hydraulic Conductivity for the formation is low, typically within 4×10^{-9} to 2×10^{-7} metres per second (m/s). However, it is likely that some of the fracture zones have higher Hydraulic Conductivities.
- 3. The Ruarangi Formation:** this formation consists mostly of calcareous sandstone and groundwater flow is likely to occur where fractures in the rock formations are present. Groundwater levels recorded in three bores within the Ruarangi formation were shallow (<5 metres below ground level (m bgl)). However, groundwater levels are expected to generally follow the topography, with deeper groundwater at the local hilltops/ridges and shallower in valleys where groundwater discharges into local creeks. The Hydraulic Conductivity estimated from testing within bores in the Ruarangi formation during drilling is low (2×10^{-8} m/s), which is expected. However, pervasive fractured Ruarangi will have higher Hydraulic Conductivity, as shown from testing in bore BH2B_1104 during drilling. The Hydraulic Conductivity estimated from the testing of the fracture zone from 31.5-32 m in bore BH2B_1104 was three orders of magnitude higher at 4.6×10^{-5} m/s than that of the other tests within the matrix material.
- 4. The Pakiri Formation:** this formation consists of well-bedded, thick sandstone and interbedded sandstones & mudstones. The groundwater level monitoring for the Pakiri bores confirms the presence of a dual groundwater system, with a shallow groundwater table separated from a deeper regional groundwater level that occurs in the fractured part of the Pakiri formation. The Hydraulic Conductivity estimated from site-specific testing indicates a low Hydraulic Conductivity (4×10^{-8} m/s) for the unfractured Pakiri formation, but with a high Hydraulic Conductivity (5.5×10^{-5} m/s) for specific fracture zones within the Pakiri formation.
- 5. The Northland Allochthon:** these geological sequences occur to the south of the Brynderwyn Hills. These sequences comprise a matrix of sheared mudstone with included tectonic blocks of Northland Allochthon, Te Kuiti Group and Waitemata Group lithologies (being classifications of rock based on their properties). Northland Allochthon generally exhibits complex and non-uniform hydrogeological properties due to the highly deformed and fractured nature of the rock. Groundwater flow is predominantly controlled by discontinuities such as faults, shears, and bedding planes rather than direct leaching of groundwater through the rock mass itself. The groundwater levels obtained from monitoring piezometers in the Northland Allochthon indicates mostly shallow groundwater levels (<5 m bgl), however deeper groundwater levels occur in bores drilled at higher elevation. This is expected and consistent with the groundwater levels from monitoring along the NZTA Wellsford to Warkworth Project. The Hydraulic Conductivity from site-specific testing varies between 1×10^{-8} and 1×10^{-6} m/s, which showed typically low Hydraulic Conductivity, but with some specific fracture zones having somewhat higher hydraulic conductivity.
- 6. Dacite intrusions of the Taurikura Group:** these are intrusive volcanic rock formations that intersect other geological formations and occur locally towards the southern end of the Brynderwyn Hills. The dacite is of limited extent and limited groundwater level and Hydraulic Conductivity testing data is available. The groundwater level in the two bores drilled to date indicate a fairly shallow (approximately 7 m bgl) groundwater level in the moderately weathered dacite, with deeper groundwater levels (average of 48 m bgl) within the fractured dacite. Hydraulic Conductivity for the unweathered dacite with limited fracturing is low (1×10^{-8} m/s), but higher Hydraulic Conductivity (1×10^{-7} m/s) is associated with open fractures.

Hydrogeological units encountered across all four Earthworks Zones of the Project broadly coincide with the geological units crossed by the zones. The locations of bores drilled to investigate hydrogeological conditions are illustrated on the map in **Appendix A**.

3.2. Groundwater Recharge

Groundwater recharge is where water moves through the subsurface to replenish groundwater and occurs primarily from land surface recharge (i.e., rainwater infiltration) in the wider Project Area. To evaluate groundwater recharge rates from natural surface water infiltration, GNS (now ESNZ) have created a 1 x 1 km grid country wide National Groundwater Recharge Model (NGRM). The model uses a cell-by-cell soil water balance to estimate rainfall and so gives an indicative value for each 1 km² area. The NGRM indicates varying recharge rates of between 100-500 mm/year over the Brynderwyn Hills area. Based on soil water balance modelling using the Rushton (2006) methodology we assessed the range to be 40-600 mm/year which is generally consistent with the findings from GNS (**Appendix E**).

3.3. Streams

The Indicative Alignment is surface drained by four major watercourses (**Appendix A**):

- The Ahuroa River, draining the Brynderwyn Hills northwards and the area north of the Brynderwyn Hills, mostly to the east of the Proposed Designation. It drains into the Waipū River, which in turn drains into Bream Bay.
- The Waihoihoi River, also drains the northern area of the Brynderwyn Hills and flows to the north into the Waipū River. The Waihoihoi Stream is an upstream tributary of the Waihoihoi River and flows in the Brynderwyn Hills to the west of the Proposed Designation.
- The Piroa Stream, located to the south of the Brynderwyn Hills, draining the area just south of the Brynderwyn Hills and flows through the Waipū Gorge to the north where it drains into the Ahuroa River.
- The Pukekaroro Stream, of which the southern part of the Proposed Designation area drains into, and which flows out into the Kaiwai River south of the Proposed Designation.

These rivers and their tributaries cross the Indicative Alignment in several places and are in close proximity to the proposed cuts, particularly within the Brynderwyn Hills. These cuts are likely to have an effect on the groundwater seepage into the streams that forms the baseflow of many streams and rivers in the dry season.

3.4. Wetlands

Natural and Constructed Wetlands occur within the Proposed Designation. The location of the wetlands where these are confirmed by the Project's ecologists (refer to the Assessment of Effects on Freshwater Ecology - Appendix D7 of Volume B of the Substantive Application) are indicated in **Appendix A**. Most of these wetlands are expected to be groundwater fed.

3.5. Existing Groundwater Bores and Resource Consents

Existing bore locations within 2 km of the Indicative Alignment were obtained from the NRC open data site. There are 31 bores, and these are shown on the map in **Appendix A**. Only five of the existing bores are located within the Proposed Designation, with the majority of the bores outside of the Proposed Designation located near Waipū.

There are 29 existing bores identified as 'active' on the NRC wells database within a 2 km radius of the Indicative Alignment. The purpose of three of the bores are indicated as exploration and monitoring, the

remainder of the bores (26) we have presumed have water supply purposes. The information for the existing active bores is summarised as follows:

- The bore depth is listed for 28 of the active bores, ranging from shallow (11.6 m) to deep (114 m), with an average depth of 32 m.
- Yield information is listed for 21 bores and varies between 0.08 and 7.6 litres per second (L/s), with an average yield of 1.2 L/s.
- For 15 active bores (excluding monitoring and exploration) information is listed indicating their purpose, which includes:
 - Domestic and stock (permitted activity) – 11 bores
 - Construction – 1 bore
 - Irrigation – 3 bores

Typically, stock and domestic water requirements are low and the yields from these bores are also typically low. The yields required for irrigation are generally significantly higher. Irrigation bores are all located within Earthworks Zone 1 and are assumed to have mostly been drilled into the Pleistocene Alluvium, because the depths of these bores vary between 29 and 34 m below ground level (bgl). Based on geological evidence, it is likely that the target for groundwater supply is gravel beds within the alluvium.

Surface water take information within 2 km of the Indicative Alignment was also obtained from the NRC wells database and all existing and active water takes are shown on the map in **Appendix A**. There are no active groundwater takes within 2 km of the Indicative Alignment. One surface water take occurs within the Proposed Designation extent, and six surface water takes occur within 2 km of the Indicative Alignment but beyond the Proposed Designation. The surface water takes near Waipū that are located outside of the Proposed Designation are adjacent to embankment fill areas, and their contributing catchments are expected to be within the Proposed Designation.

3.6. Groundwater Availability

Groundwater management units are defined by NRC in the Regional Plan for Northland (RPN) as follows:

- **Coastal:** being all groundwater systems near the coast and within a 200 m buffer strip along the coast but excluding the Aupouri Aquifer. These Aquifers are sensitive to saline intrusion.
- **Specific – Aupouri:** NRC has significant information on the Aupouri Aquifer and has set specific allocation limits for it, based on a comprehensive assessment of the Aquifer.
- **Other:** inland Aquifers or any Aquifer that does not fit the above descriptions.

The Proposed Designation to the north of the Brynderwyn Hills comprises the mapped Ruakaka Coastal Aquifer, while the remainder of the Proposed Designation is underlain by an unmapped 'Other' Aquifer.

The allocation limit for the Ruakaka Coastal Aquifer has been set at 3,769,116 m³/year of which 2,033,091 m³/year has been allocated. Although there is 1,736,025 m³/year available for allocation, much of this aquifer is indicated as being subject to potential groundwater restrictions due to fully allocated surface water (affecting recharge of the Aquifer).

The Project will require a surface or groundwater take for dust suppression. A separate application for a groundwater take (if preferred) and the effects of the likely groundwater take on the environment will be assessed through a separate application.

3.7. Groundwater Levels and Flow Direction

Groundwater flow is typically defined by groundwater levels measured in bores within an area constructed within similar hydrogeologic units. The groundwater levels are interpolated to define groundwater level contours that in turn can be used to define groundwater flow direction. Often, groundwater level coverage is not sufficient to define the groundwater contours, which is the case in these investigations where most of the bores are clustered in a narrow band around the Indicative Alignment. However, with pervasive shallow groundwater levels expected across the site, the groundwater flow is considered to follow the

topography, because groundwater flows towards the nearest stream or river that are in localised low areas such as gullies and valleys.

A long section of the current ground levels, Indicative Alignment surface and recorded groundwater levels (vertical scale exaggerated; cuts beneath groundwater table indicated) is shown in **Appendix B**.

3.8. Groundwater Quality

Water quality will change as water runs off and discharges into streams or flows through Aquifers. Factors such as land use, geology, hydrogeochemical reactions and travel time through Aquifers will all influence water quality. As such, the composition of naturally occurring surface water and groundwater will often reflect the origin of the water and the pathway it has followed.

The current land use in the Project Area is predominantly farming, and it is likely that the presence of typical contaminant discharges associated with farming such as dissolved reactive phosphorus, nitrate and various heavy metals may occur within the surface- and shallow groundwater. These contaminant sources are likely diffuse meaning they are present across the entire area as opposed to point sources.

Likely groundwater contamination was observed during the drilling of bore BH2B_1160 near the southern end of the Proposed Designation in Earthworks Zone 4. This contamination is being investigated, and findings are presented in the Assessment of Contaminated Land Effects (Appendix D9 of Volume B).

3.9. Existing Structures

3.9.1. Network Utilities

The Transpower Henderson–Marsden 220 kV double-circuit overhead transmission line is located within the Proposed Designation. No as-built structural or foundation drawings for the towers were available at the time of preparing this report.

The First Gas high pressure gas transmission pipeline is also located within the Proposed Designation, south of the Brynderwyn Hills. It is understood that this pipeline will be partially relocated as a part of the Project.

3.9.2. Buildings/Structures

It is assumed that all properties/buildings located within the Proposed Designation near significant cut or fill works will be acquired for the Project, and as such, these properties/buildings have not been considered as part of this assessment.

3.10. Analysis and Interpretation – Hydrogeological Conceptual Model

The data and information described above, and the site-specific groundwater information presented in Section 2, underpins the Hydrogeological Conceptual Model¹. The following subsections describe the Hydrogeological Conceptual Models that characterise the groundwater system in the vicinity of the various indicative Earthworks Zones of the Project.

3.10.1. Earthworks Zone 1

The area is typically flat (shown in the long section in **Appendix B**) and is predominantly underlain by Late Pleistocene and some Holocene River deposits comprising alluvial infill of open valleys and deposits in low lying areas. The alluvium varies from fine sediment (clays and silts) to gravels.

¹ A visual representation of the groundwater flow system (Anderson and Woessner, 1992) combined with a summary of key aspects that define the groundwater system.

The Ruarangi Formation, Waitematā Group outcrops in Earthworks Zone 1 and underlies the alluvial deposits. The Ruarangi Formation mostly comprises calcareous siltstone, muddy sandstone and mudstone and will weather to silts and clay, similar to the alluvium.

Groundwater is mostly shallow within the valley areas, with flow primarily through paleochannels of coarser sediment and gravels. Artesian conditions, where groundwater under natural pressure will rise above ground surface when a bore is drilled into the aquifer, may be encountered near the surrounding hills where silt or clay layers overlie permeable layers recharged by rainfall at the hills.

Hydraulic Conductivity test data to date for the alluvial deposits indicate low Hydraulic Conductivity (1×10^{-9} to 1×10^{-8} m/s).

Hydraulic Conductivity information is sparse (2 bores) for the Ruarangi Formation (refer Section 2.3). However, the low Hydraulic Conductivities (average of 2×10^{-8} m/s) obtained from testing to date is considered representative of the Ruarangi Siltstones. Higher Hydraulic Conductivities (1×10^{-5} m/s) may be associated with fractured Ruarangi Sandstone.

3.10.2. Earthworks Zone 2

The Waipapa Group underlies the whole of Earthworks Zone 2 and comprises greywacke and argillite with some volcanics. Groundwater is likely variable in this area due to the relatively high topographic variability. Several site investigations carried out at the southern part of this span near Brynderwyn Quarry, prior to the site-specific investigations for the Project, have encountered groundwater from near surface to moderate depths. Similar variability in groundwater level during site-specific drilling has been observed. Based on groundwater levels measured during drilling and subsequent groundwater level monitoring, a shallow and regional groundwater level occurs in this zone (refer Section 2.3).

Typically, the regional groundwater is expected to be deeper near the ridges and hilltops, and discharge to streams within the incised gullies. The regional water table should generally follow topography between the ridges and gullies, however with flow most likely being through rock defects the local groundwater pattern may be dependent on tectonic structure such as faults and crush zones and the depth of the weathered profile.

The shallow groundwater table is considered laterally discontinuous and may be perched on top of the low Hydraulic Conductivity, completely weathered sediments of the Waipapa Group. The shallow and regional groundwater levels will merge near the streams.

Hydraulic Conductivity (refer Section 2.3) obtained from in-situ testing indicate a range in Hydraulic Conductivity of 1×10^{-9} to 1×10^{-7} m/s. All tests were conducted in the fractured greywacke. From early packer tests it is likely that some of the highly brecciated (rock that has been broken into angular fragments and then recompacted) zones have very low Hydraulic Conductivity and may form barriers to flow with likely compartmentalisation of flow within the greywacke. In-situ testing of brecciated zones has not been possible to date due to the risk of collapse of the bores.

3.10.3. Earthworks Zone 3

Earthworks Zone 3 is mostly underlain by the Northland Allochthon siltstone and limestone in the low-lying valleys. Groundwater is likely shallow within the Northland Allochthon in this zone. The upper reaches of some streams begin in the general area of the Proposed Designation, indicating potential groundwater discharge to surface water. Recharge in the surrounding hills may create artesian conditions in some parts of the lower valleys within this catchment.

Site-specific testing of the Northland Allochthon siltstone and sandstone indicates the Hydraulic Conductivity is low at approximately 1×10^{-8} m/s (refer Section 2.3).

A single ridge of Pakiri outcrops south of the Brynderwyn Hills within the Proposed Designation. The Pakiri Ridge is fault bounded within the Northland Allochthon. The Pakiri Formation locally consists of well-bedded, thick sandstone and interbedded sandstones & mudstones.

The groundwater levels within the Pakiri formation typically indicate a dual groundwater system with a shallow sometimes perched Aquifer and a regional Aquifer within the fractured Pakiri. There is limited Hydraulic Conductivity data for the bores within the Pakiri Formation in The Brynderwyn Hills section. Groundwater within the regional Aquifer is fracture controlled and the groundwater pressures indicate a typically downward pressure, with deeper fracture zones having deeper groundwater levels.

Limited Hydraulic Conductivity information is available for the Pakiri Formation. Testing on one bore within the Pakiri Ridge indicated a low (4×10^{-8} m/s) Hydraulic Conductivity associated with the matrix Pakiri rock, whereas some fracture zones may have higher (5×10^{-5} m/s) hydraulic conductivity.

3.10.4. Earthworks Zone 4

The Taurikura Group dacite domes are intrusions that outcrop between the Northland Allochthon sediments located south of the Brynderwyn Hills in Earthworks Zone 4 (refer to the long section in **Appendix B**). These dacites are typically massive, fine to medium grained and intrude through and flow out on top of the Northland Allochthon. The groundwater flow is likely to be influenced by the weathering profile and fracturing of the dacite. The two piezometers BH2B_1157 and BH2B_1159 installed for the Project in the dacite is located at a high elevation within the hills. Groundwater level monitoring for piezometer BH2B_1159 indicate a deeper groundwater level (average of 7 m bgl), but perched conditions may occur locally.

The groundwater level within the weathered dacite is likely to be relatively shallow and follow topography. Flow within the un-weathered dacite is likely fracture and structure controlled. Weathered dacite tuff exposures can be problematic for slope stability, as relict defects and incipient fractures may open up rapidly after exposure, leading to increased seepage and potential for erosion or slope movement. The Hydraulic Conductivity testing (four tests) within bore BH2B_1157, indicate a slightly higher Hydraulic Conductivity of 1×10^{-7} m/s within the completely weathered dacite.

Testing data available for the unweathered dacite at this time, indicate a low (1×10^{-8} m/s) Hydraulic Conductivity. The Hydraulic Conductivity of fractured dacite is likely to be controlled by the secondary porosity associated with the fracture flow and likely to vary depending on the intensity and extent of the defects.

4. Assessment of Hydrogeological Effects

4.1. Overview

The proposed construction and operation of the Project have the potential to impact groundwater quantity and quality, which may cause the following actual or potential adverse effects:

- Stream and wetland depletion as a result of temporarily or permanently lowering groundwater levels. The potential ecological effects of this depletion are considered within the Assessment of Effects on Freshwater Ecology (attached as Appendix D7 of Volume B of the Substantive Application) for the Project.
- Groundwater level drawdown interference on nearby water supply wells and surface water takes could reduce the yield of those wells or takes and affecting the supply for domestic, industrial or agricultural uses, such as stock drinking water.
- Land settlement as a result of dewatering (both during construction and long-term drainage after construction) and mechanical settlement (during Project construction), with potential impacts on nearby structures.
- Changes in groundwater flow direction or velocities that have the potential to affect groundwater quality when contaminants are drawn into a drainage system, or into a well that is used for water supply. Contaminants may also be diverted into groundwater dependent wetlands following a change in flow direction.

The drawdown of groundwater levels and changes in groundwater flow can be caused by various activities related to the construction and operation of the Project, such as:

- Large cuts (refer design drawings 10722-PTA-2B0-RD-DRG-0301[A] to 10722-PTA-2B0-RD-DRG-0305[A] in Appendix D of Volume A), which intersect groundwater, will require dewatering during construction as well as permanent road drainage. In particular, the large cuts proposed in Earthworks Zone 2 and various cuts along the Indicative Alignment, could cause drawdown of the groundwater table (refer Table 1).
- Permanent stormwater conveyance and drainage systems will be installed for the Project to keep the road dry by diverting stormwater and groundwater away from the road surface, which will permanently lower the groundwater table.
- The installation of structures such as culverts or bridge piers may require temporary Dewatering or Aquifer Depressurisation, which will temporarily lower the groundwater levels around construction pits.
- NZTA anticipates construction will require groundwater or surface water takes for dust suppression during construction. A separate application for a groundwater take (if preferred) and the effects of the likely groundwater take on the environment will be assessed through a separate application.

Table 1: Details of proposed cuts of the Indicative Alignment that extend below the groundwater level.

Zone	Chainage		Maximum cut depth (m)	Maximum depth below groundwater level (m)
	From (m)	To (m)		
1	No significant cuts below groundwater level			
2	16,800	17,100	13	6.5
	17,400	17,650	10	4.7
	18,550	19,900	60	34
	20,100	20,400	17	15
3	21,100	22,100	32	27
4	24,350	25200	70	35

The Project's groundwater effects have been assessed using numerical groundwater modelling (SEEP/W) developed for the Project based on the Consent Design drawings in Appendix D of Volume A. SEEP/W is a finite element numerical modelling software for groundwater flow in porous media, developed by Seequent (2021). SEEP/W can model simple saturated steady-state problems or sophisticated saturated / unsaturated transient analyses. Several cross-sectional Numerical Groundwater Models were developed in SEEP/W for the following (full description of the model is included in **Appendix B**):

- Assessment of groundwater level drawdown effects associated with the large cuts and Dewatering requirements for the Project. These include effects on surface water systems (wetlands and streams), neighbouring water users (both groundwater and surface water), land settlement and groundwater quality.
- Seepage rates from groundwater into fill locations.

The modelling was used initially to simulate groundwater drawdown from the cut surface during development of the indicative design. As the design has progressed some cuts have become shallower with some lateral shift in the alignment. The current assessment is still applicable yet likely conservative.

We recommend that, with development of a detailed design, if the alignment shifts laterally by more than 20 m from the Indicative Alignment, or the depth of cuts that are more than 2 m below the groundwater level increases by more than 10 %, numerical groundwater modelling should be undertaken to confirm that these changes do not result in greater effects than those assessed in this report. Increased cut depths will require greater drainage, and the footprint of the drainage effect will expand accordingly. With lateral shifts in alignment, some streams will be located closer to the cut and will experience more pronounced effects, while those farther away will be less affected.

4.2. Effects on Groundwater of Construction Dewatering and Depressurisation (Construction Phase)

Several structures including culverts, utility pipelines, stormwater retention basins and bridge piers will be installed below the groundwater table within the Proposed Designation, requiring the use of temporary construction pit Dewatering to create the necessary dry working conditions. In some cases, (sub)artesian Aquifer water pressures may need to be reduced by lowering the groundwater levels beneath the construction pit for pit floor and pit wall stability reasons. This is referred to as Depressurisation. Both Dewatering and Depressurisation will temporarily draw down groundwater levels around the construction pits, and this could affect nearby wetlands, streams or water supply wells as follows:

- Groundwater levels in the area around construction dewatering sites will fall and baseflows to nearby wetlands and streams could be temporarily affected.
- Groundwater drawdown effects on nearby wells are described below in Section 4.4.

The precise locations where construction Dewatering may be required will be determined at the detailed design stage. In general terms, the installation of culverts, pipelines and stormwater retention basins are expected to be completed in a relatively short timeframe of several days or weeks at each site. Bridge piers will typically be installed in valley floors, where groundwater presently seeps into streams and wetlands. Artesian or sub artesian conditions could be present at these locations requiring Depressurisation. Dewatering and Depressurisation for the installation of bridge piers could take several weeks or months.

The maximum Dewatering rate required for construction of structures along the Project is estimated to be 615 cubic metres per day (m^3/day) (or 7.1 L/s). This estimate is based on the Indicative Alignment with the assumption that Dewatering will be required for the construction of 48 culverts and four bridges (i.e., overpasses), and that all of the Dewatering activities would occur simultaneously at any time during the construction phase. Each culvert is assumed to be about 130 m long and 1.5 m wide. Ground improvement and Depressurisation is assumed to be required at two bridge abutments with a 10 x 10 m footprint each. A groundwater level drawdown of 2.5 m is assumed to be required for each Dewatering activity at the trench or pit. A representative Hydraulic Conductivity of 2×10^{-7} m/s is assumed.

Based on the anticipated works required to construct the Indicative Alignment, the impacts of these Dewatering activities are expected to be small-scale, localised and would only occur temporarily.

4.3. Potential effects on Baseflow to Wetlands and Streams from Permanent Dewatering (Operational Phase)

4.3.1. Groundwater Level Drawdown and Baseflow Changes

The drawdown of groundwater levels will cause a reduction of outflow of groundwater into nearby wetlands or streams that are hydraulically connected to groundwater, as conceptually shown in Figure 1.

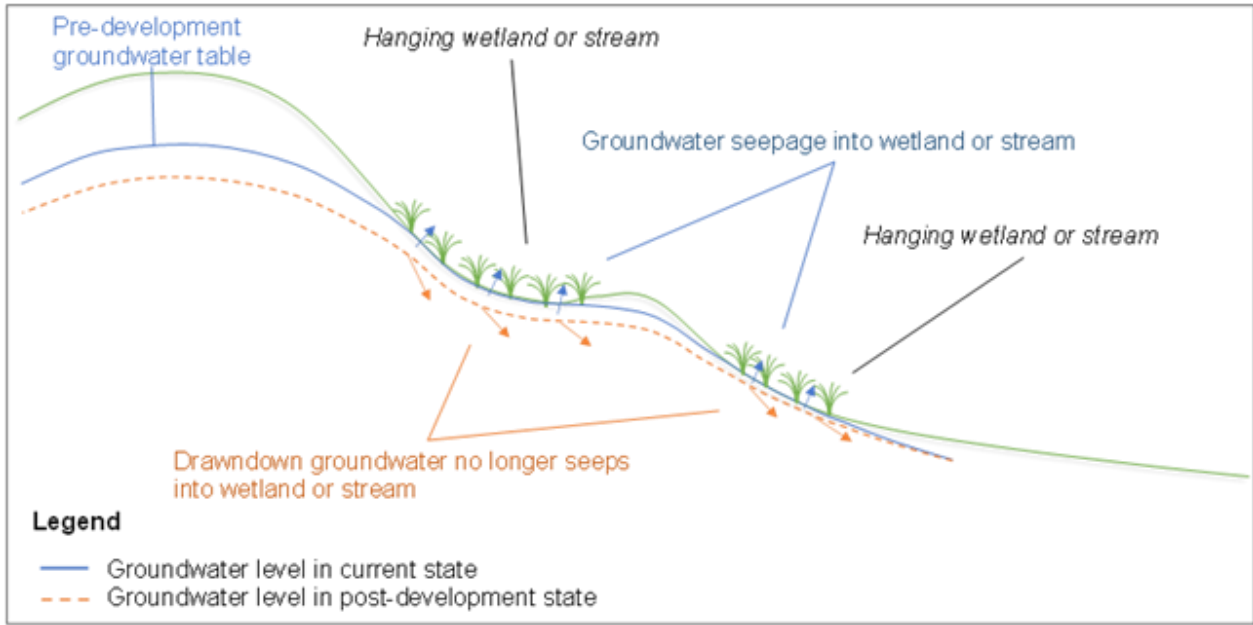


Figure 1: Conceptual diagram showing a change in groundwater outflow to wetlands or streams caused by a drawdown of the groundwater level.

Most of the streams and wetlands in the area surrounding the Project receive water from both rainfall runoff and groundwater seepage. Throughout the year the contribution of rainfall runoff to the flows in streams and wetlands fluctuate considerably, depending on rainfall patterns. During long dry warm spells (typically late-summer) when rainfall is low and evapotranspiration high, the rainfall runoff contribution will fully diminish and flows in wetlands and streams are almost entirely dependent on natural groundwater seepage. This is referred to as the 'baseflow' of streams and wetlands. Whilst groundwater seepage also fluctuates throughout the year, this is notably more constant than rainfall runoff.

Wetland and stream ecological values and habitat depend heavily on the continuation of baseflows. From the hydrological concept shown in Figure 1, it can be seen that a reduction in groundwater levels near streams and wetlands caused by the Project, can result in the reduction or even cessation of groundwater flows to these features, thereby having consequential impacts on the ecological values in these streams and wetlands.

Most of the water abstracted by the Project's permanent drainage system will be diverted to stormwater treatment systems and after that, discharged into nearby surface water downstream of the Indicative Alignment. This means that the lower-lying streams and wetlands near the Project will continue to receive the water that would have previously flowed in via groundwater seepage. The wetlands and streams within proximity to the large cuts will be impacted by the reduction of groundwater inflows. The effect will be greater on streams and wetlands that are closer to the cuts and on streams and wetlands that are above the cut level (for e.g., hanging streams or wetlands). This is because the drainage water cannot be diverted to those wetlands under gravity and pumping would be required. Whilst technically possible, it is unlikely to be feasible to pump water to wetlands for the lifetime of the Project.

Groundwater drawdown and any accompanying potential effects on baseflows to wetlands and streams, are expected to occur where the Indicative Alignment will be cut below the shallow groundwater table as indicated in the long section in **Appendix B**. Drainage systems will be installed to remove stormwater and collect groundwater seepage from the cuts and adjacent embankments which will permanently draw groundwater levels down adjacent to such cuts. Rainfall on sealed road surfaces will no longer infiltrate to groundwater but will be captured and diverted via channels along the road to lower areas where it will flow out into stormwater treatment facilities and then discharge in lower-lying streams and Constructed Wetlands.

4.3.2. Assessment Approach

The effects on baseflows to streams and wetlands has been assessed using a 2D Numerical Groundwater Model developed with SEEP/W (full description of the model is included in **Appendix E**).

The modelling estimates expected drawdown of the groundwater level adjacent to the cut as well as the change in groundwater seepage into nearby wetlands and streams (i.e., baseflow). The modelling also provides an estimate of drainage into the cut for the cross-sectional area of the cut. The groundwater level drawdown and likely change in groundwater seepage is dependent on the depth of the cut, the groundwater level and the hydraulic properties of the geologic unit.

The predicted groundwater drawdown and reductions in baseflows to nearby wetlands and streams because of the construction and operation of the Project are expected to be gradual. The seepage of groundwater into the cut is high initially and gradually decreases over time, hence the change in groundwater level adjacent to the cut will change rapidly initially and then more gradually. It is expected that the groundwater drawdown and baseflow reduction effects are near their greatest extent and will not change much further after 5 years.

The magnitude of effect will be based on the depletion in baseflow in accordance with the effects ratings outlined within Table 2 below.

Table 2: Stream baseflow reduction magnitude categories

Magnitude	Baseflow Effect
Very high	Complete depletion of flow likely; more than 80% reduction in flow.
High	Estimated loss in flow is between 30% and 80%.
Moderate	Estimated loss in flow between about 15% and 30%
Low	Estimated loss in flow between about 5% and 15%
Negligible	Estimated loss in flow is less than 5%

The impact of the groundwater drawdown and changes in environmental baseflows from the Project have been estimated using nine numerical cross-section groundwater models developed in SEEP/W. These cross-sectional models provide a view of the Indicative Alignment's modelled groundwater drawdown and effects on baseflow for the bigger cuts within indicative Earthworks Zones 2 and 3. The cross-sections considered in this assessment are denoted by CS (Cross-Section) and the chainage along the Indicative Alignment as follows:

- **CS-16,800 m to CS-17,100 m:** two cross sectional models were developed at the two larger cuts below the groundwater table in the northern-most part of Earthworks Zone 2, which are formed by the lower-lying undulating part of the Brynderwyn Hills.
- **CS-18,550 m to CS-20,400 m:** four cross-section models were developed that are representative of the variation in groundwater flow and changes in baseflow to the streams (for example hanging valleys) caused by the drainage for large cuts below the groundwater table in the middle and southern part of Earthworks Zone 2. The cuts between CS-20,100 and CS-20,400 are not expected to be below the groundwater table, and likely to have no effects on groundwater.

- **CS-21,100 m to CS-22,100 m:** a single cross-section model was developed that is representative of a deep cut below the groundwater table where the Northland Allochthon overlies the Pakiri Formation in Earthworks Zone 3.
- **CS-24,350 m to CS-25,200 m:** one cross-sectional model was developed at the cut below the groundwater table in the southern part of Earthworks Zone 4, which are in the lower-lying undulating southern part of the Brynderwyn Hills.

The following assumptions were made for the modelling:

- The Hydraulic Conductivity values of the hydrogeological units (Section 3.1.1) were varied in each model within the expected range derived from site-specific testing, by assessing the changes in groundwater levels and flows under both high and low K-value conditions.
- Groundwater levels were simulated based on approximate groundwater levels recorded in monitoring bores on the ridges or upper slopes. We note that direct projection of observed levels onto the cross sections was not feasible due to the sharp variation in topography over short distances in this hilly area. The target levels were therefore interpreted as a general depth below ground level range of 20-33 m beneath ridges and upper slopes.
- The groundwater recharge rate from rainfall was optimised so that the model approximates the recorded groundwater levels. Therefore, a higher recharge rate was used for the high Hydraulic Conductivity value conditions and a lower recharge rate for low Hydraulic Conductivity conditions. However, for the shallow cut within the rolling hills just north of the Brynderwyn Hills, using the same recharge value in a model simulation with a high Hydraulic Conductivity-value would result in a fully saturated model, which does not occur in the field, and is therefore not realistic. Assuming a low recharge provides for a more realistic scenario that better represents field conditions.

The cross-sectional models in SEEP/W only simulate 2-dimensional groundwater flow processes, where in reality groundwater flow processes are 3-dimensional. This limits the accuracy and use of the cross-sectional modelling results, especially in the hills where a dense network of streams influences groundwater flow. Therefore, a conservative approach has been taken in the assessment of the magnitude of baseflow reduction effects as follows:

- The cross-sectional models simulate the groundwater seepage into nearby streams where these intersect with the cross-section line, as shown in overview maps in Figure 2, Figure 4, Figure 6 and Figure 8 below (in Sections 4.3.3 to 4.3.6). The magnitude of baseflow reduction at each stream was calculated as a percentage change, based on the difference between the current state and the state at 5 years after the large cuts have been excavated beneath the groundwater table and the permanent road drainage is operational. The calculated baseflow reduction percentage at each stream intersection point was then applied to all the approximately 100 m long stream reaches nearest to each stream intersection point.
- For stream reaches that are beyond 100 m of any cross-sectional model intersection, a stepped lowering of baseflow reduction magnitude was assumed.
- Because the low and high Hydraulic Conductivity cases described above result in different baseflow reduction changes, the highest derived reduction change was selected for each stream reach.
- Whilst stream reaches at the top of the catchment only receive groundwater seepage during dry periods, all downstream reaches receive both direct groundwater seepage, as well as inflows from upstream. The cross-sectional modelling does not calculate this accumulated baseflows, and therefore it has been assumed that stream catchments that are severely impacted in the upper reaches, will have also reduced accumulated baseflow in their lower reaches. Conversely, where upper catchments impacts are limited or only affect a small number of tributaries, the baseflow reduction impacts in lower reaches will also be limited. Hence, some lower stream reaches show reduced baseflow even beyond the area of 0.1 m groundwater drawdown.
- The groundwater drained by the permanent road drainage systems will be conveyed via the road's stormwater system and will discharge in several streams as indicated in Figure 2, Figure 4, Figure 6 and Figure 8 below. The baseflow of the streams downstream of those stormwater discharge points will therefore not be affected by baseflow reductions from road drainage. This is because

groundwater drainage water will be discharged at those stormwater discharge points even during dry weather.

- Stream reaches that are within the road's cut footprint will be entirely removed and are not classed in this assessment.

4.3.3. Effects from road cut Dewatering, north of Earthworks Zone 2 (CS-16,800 to CS-17,100)

Baseflow reduction magnitude after 5 years are expected to be negligible to moderate in some streams east of the cuts within the CS-16,800 m to CS-17,100 m zone as shown in Figure 2. The upper reaches of the stream adjacent to the local road west of the cuts will likely fall dry, with groundwater no longer seeping into the upper reaches during dry periods (see cross-section in Figure 3). This will reduce the inflows to the downstream wetland which is therefore expected to endure a high baseflow reduction effect. Groundwater levels will be drawn down by more than 0.1 m within an area of no more than about 250 m from the two road cuts in this area.

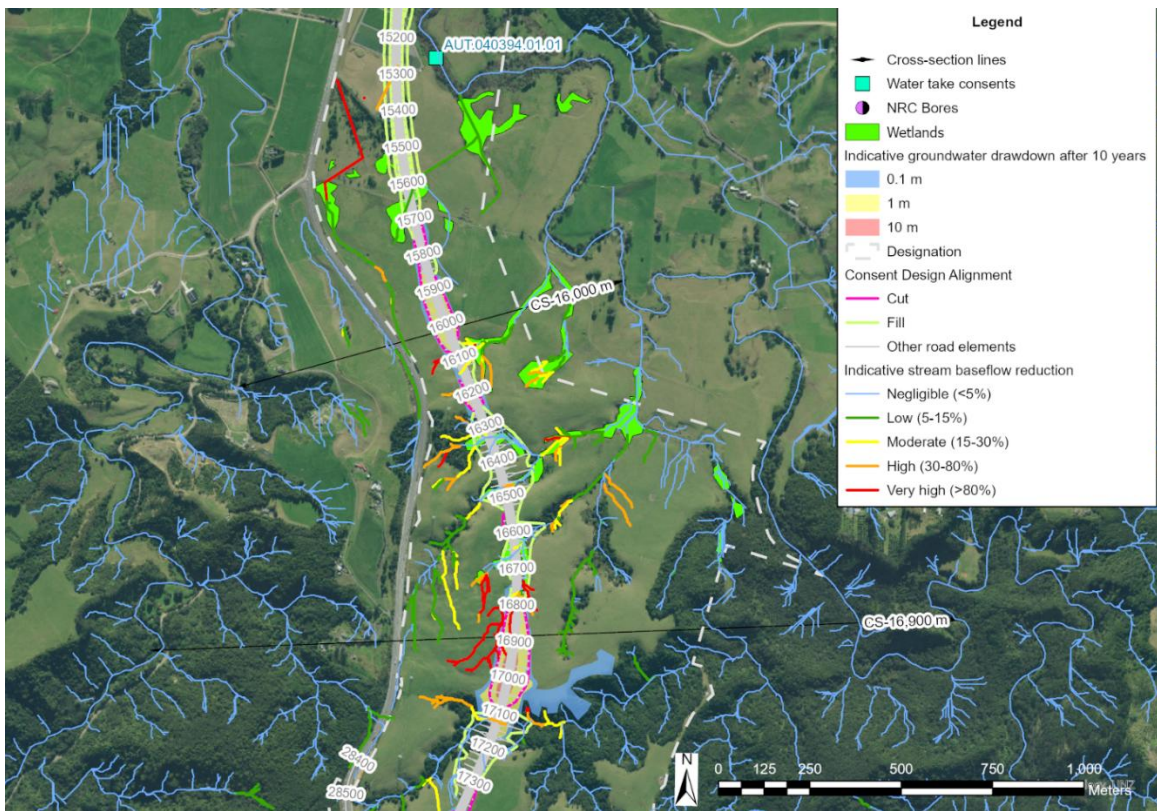


Figure 2: Effects from road cut Dewatering at CS-16,000 m to CS-17,650 m.

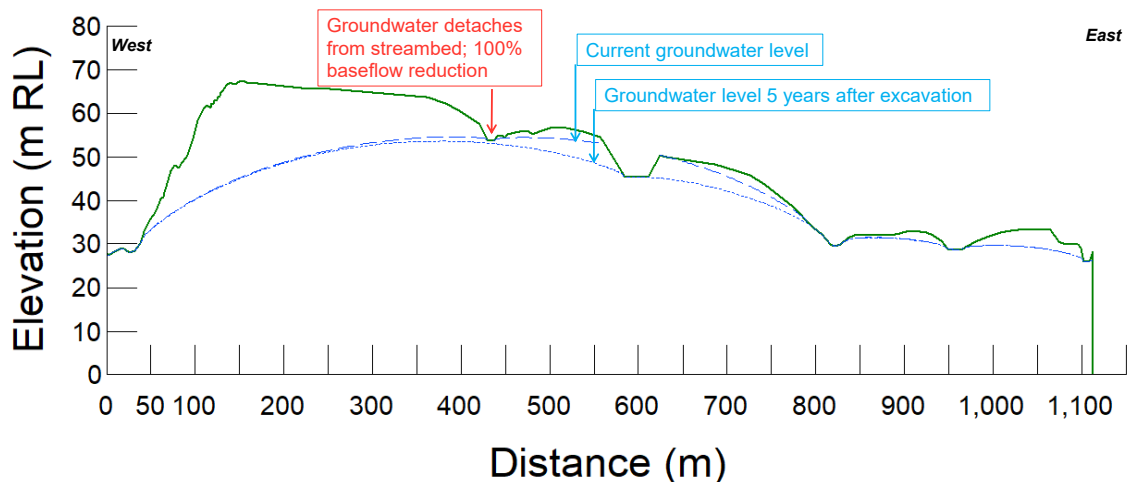


Figure 3: Cross-section CS-16,000 m showing groundwater drawdown from road cut Dewatering

The groundwater drainage rate from the permanent road drainage is expected to be up to 75 m³/day initially, when the cuts have been excavated. This rate will gradually reduce to about 61 m³/day after five years. After this, the groundwater drainage rate is expected to stabilise at that rate.

4.3.4. Effects from road Dewatering in the middle of Earthworks Zone 2 (CS-18,550 m to CS-20,400 m)

The largest cuts beneath the groundwater table will be in the middle of Earthworks Zone 2 in the Brynderwyn Hills. Baseflow reduction magnitude after 5 years are expected to be low to very high for several streams both to the east and west of the cuts within CS-19,100 m to CS-20,100 m as shown in Figure 3. The upper reaches of the streams adjacent to the road that are classed as having very high baseflow reduction impacts, are likely to fall dry, with groundwater no longer seeping into these upper reaches during dry periods (see cross-section in Figure 4; note: only one of the four cross-sections is shown). The stream to the northeast of the roadcut near CS-18,900 m will likely receive stormwater discharge from the road, therefore the downstream part of that stream is unlikely to be affected by baseflow reduction from the permanent road drainage.

Groundwater levels will be drawn down by more than 0.1 m within an area of about 800 m from the two road cuts in this area. Groundwater levels will be drawn down by more than 10 m at a distance of about 150 m from the large cut between CS-19,500 m and CS-19,800 m.

The groundwater drainage rate from the permanent road drainage is expected to be up to 275 m³/day initially, when the cuts have been excavated. This rate will gradually reduce to about 169 m³/day after five years. After this, the groundwater drainage rate is expected to stabilise at that rate.

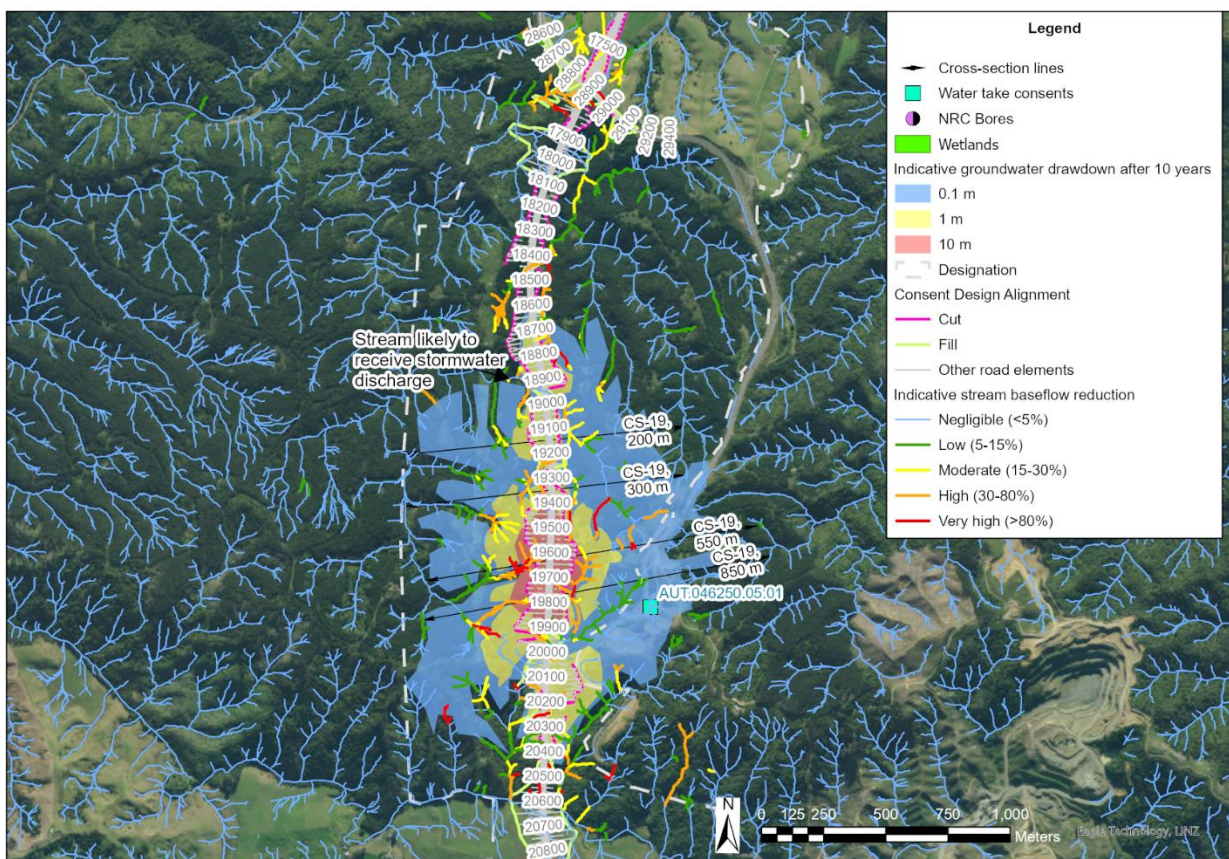


Figure 4: Effects from road cut Dewatering at CS-18,800 m to CS-20,400 m

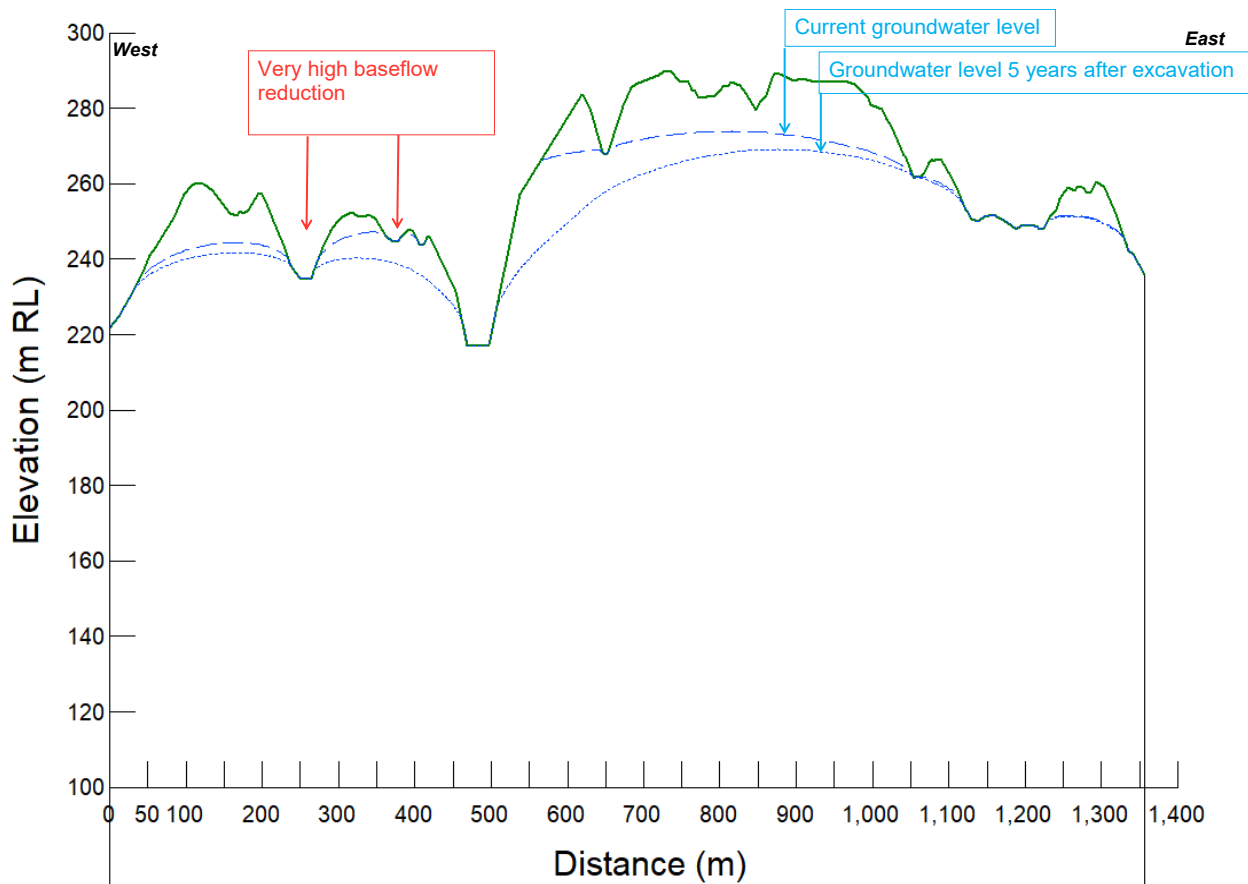


Figure 5: Cross-section CS-19,550 m showing groundwater drawdown from road cut Dewatering

4.3.5. Effects from road Dewatering in Earthworks Zone 3 (CS-21,100 m to CS-22,100 m)

At the southern side of the Brynderwyn Hills in Earthworks Zone 3, the baseflow reduction magnitude after 5 years are expected to be low to very high in several streams both to the east and west of the cuts within CS-20,800 m to CS-21,900 m as shown in Figure 6. The upper reaches of the streams on the western side of the road that are classed as having very high baseflow reduction impacts, are likely to fall dry, with groundwater no longer seeping into these upper reaches during dry periods (see cross-section in Figure 7). A bypass culvert is proposed as part of the stormwater design on the southwest side of this road cut. This means that the nearby stream north of the bypass culvert will no longer receive inflows from the upstream catchment and will also have a very high reduction in baseflow from groundwater seepage. Because the bypass culvert will discharge in the same stream further downstream, the remaining reach of that stream will not be affected by baseflow reduction.

The closest stream gullies on the eastern side of the alignment are unlikely to be groundwater receiving as their streambed is above the groundwater table (Figure 7), thus these will be unaffected by the permanent road drainage. Further east, about 600 m from the road cut, several streams are present that will likely have a very high reduction of baseflow and could fall dry entirely during dry periods. This change in stream baseflow will likely affect the baseflow of Wetland Q08/066 as per the Assessment of Effects on Freshwater Ecology (Appendix D7 of Volume B of the Substantive Application) (Figure 6 below), about 200 m to the north. It is likely that the wetland will also have a very high baseflow reduction and could fall dry during dry periods.

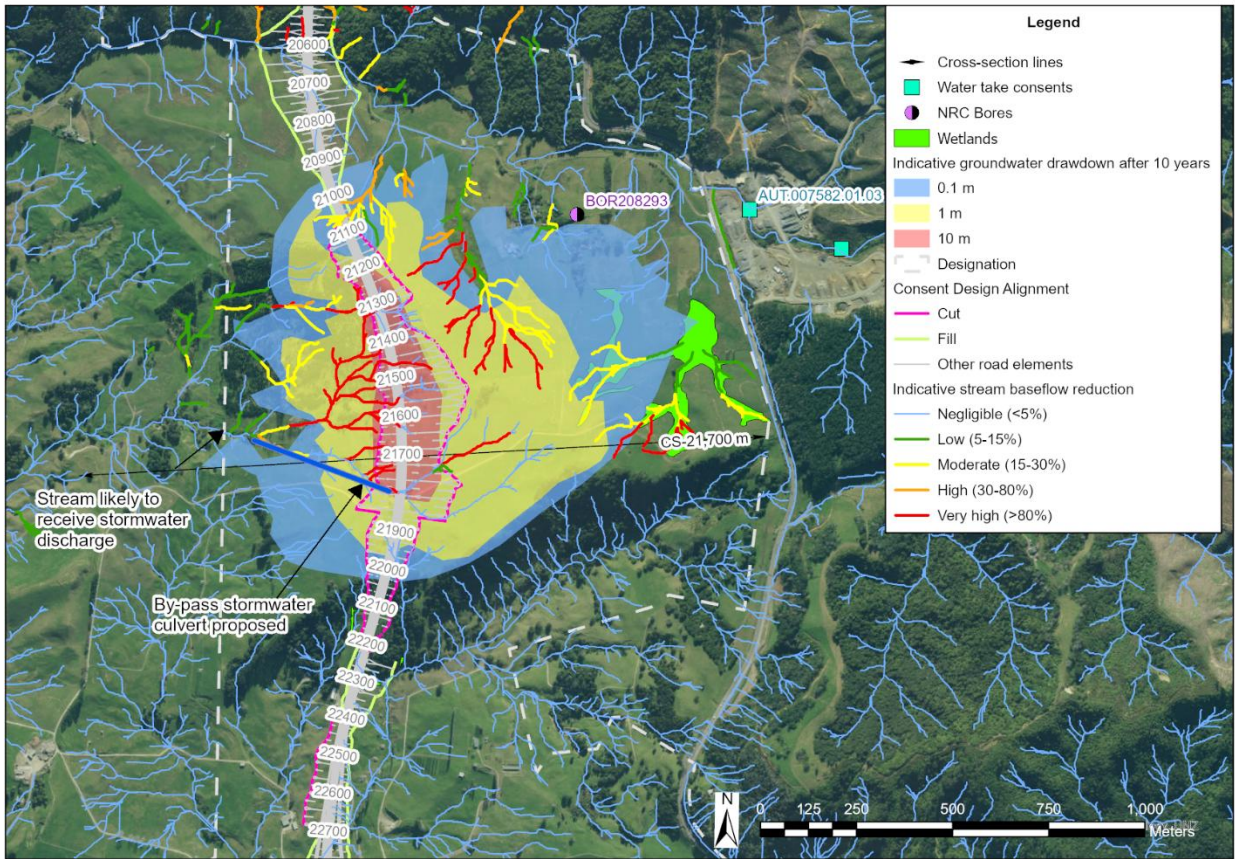


Figure 6: Effects from road cut Dewatering at CS-21, 100 m to CS-22, 100 m

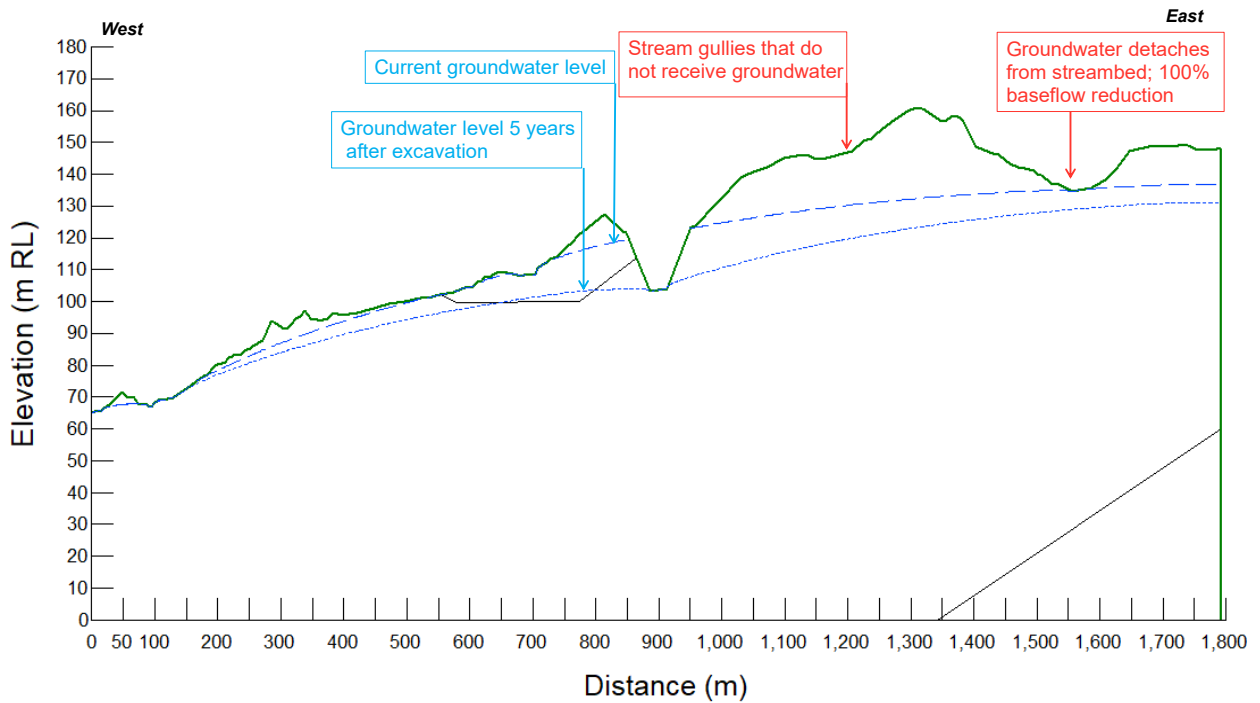


Figure 7: Cross-section CS-21,700 m showing groundwater drawdown from road cut Dewatering

Groundwater levels will be drawn down by more than 0.1 m within an area of about 970 m from road cuts in this area. Groundwater levels will be drawn down by more than 10 m at a distance of about 150 m from the large cut between CS-20,800 m to CS-21,900 m as shown in Figure 6.

The groundwater drainage rate from the permanent road drainage is expected to be up to 1,042 m³/day initially, when the cuts have been excavated. This rate will gradually reduce to about 252 m³/day after five years. After this, the groundwater drainage rate is expected to stabilise at that rate.

4.3.6. Effects from road Dewatering in Earthworks Zone 4 (CS-24,350 m to CS-25,200 m)

Baseflow reduction magnitude after 5 years are expected to be negligible to high in some streams on either side of the smaller road cut in the south of Earthworks Zone 4 as shown in Figure 8. Groundwater levels will be drawn down by more than 0.1 m within an area of no more than about 150 m from either side of the road cut in this area.

However, baseflow reduction magnitude after 5 years are expected to be moderate to high for some streams on either side of the larger road cut in the north of Earthworks Zone 4. Groundwater levels will be drawn down by more than 0.1 m within an area of about 400 m from either side of the road cuts in this area. Groundwater levels will be drawn down by more than 10 m at a distance of about 60 m from the large cut between CS-24,350 m to CS-26,000 m as shown in Figure 8.

The upper reaches of several streams on either side of the road cuts will likely fall dry, with groundwater no longer seeping into the upper reaches during dry periods (see cross-section in Figure 9). This will reduce the inflows to the downstream wetland', although the contribution from other unaffected tributaries may limit the overall impacts. The wetland is therefore expected to endure a low baseflow reduction effect in its upper reaches. The upper reaches of the wetland are in the footprint of the road's fill area and may therefore be excluded from further consideration in impact assessments.

The baseflow of the lower reach of the stream on the southwest side of the road at CS-25,000 m, is unlikely to be affected, despite being located downstream from one of the stream reaches that could fall dry. This is because that stream is likely to receive stormwater discharge from the road.

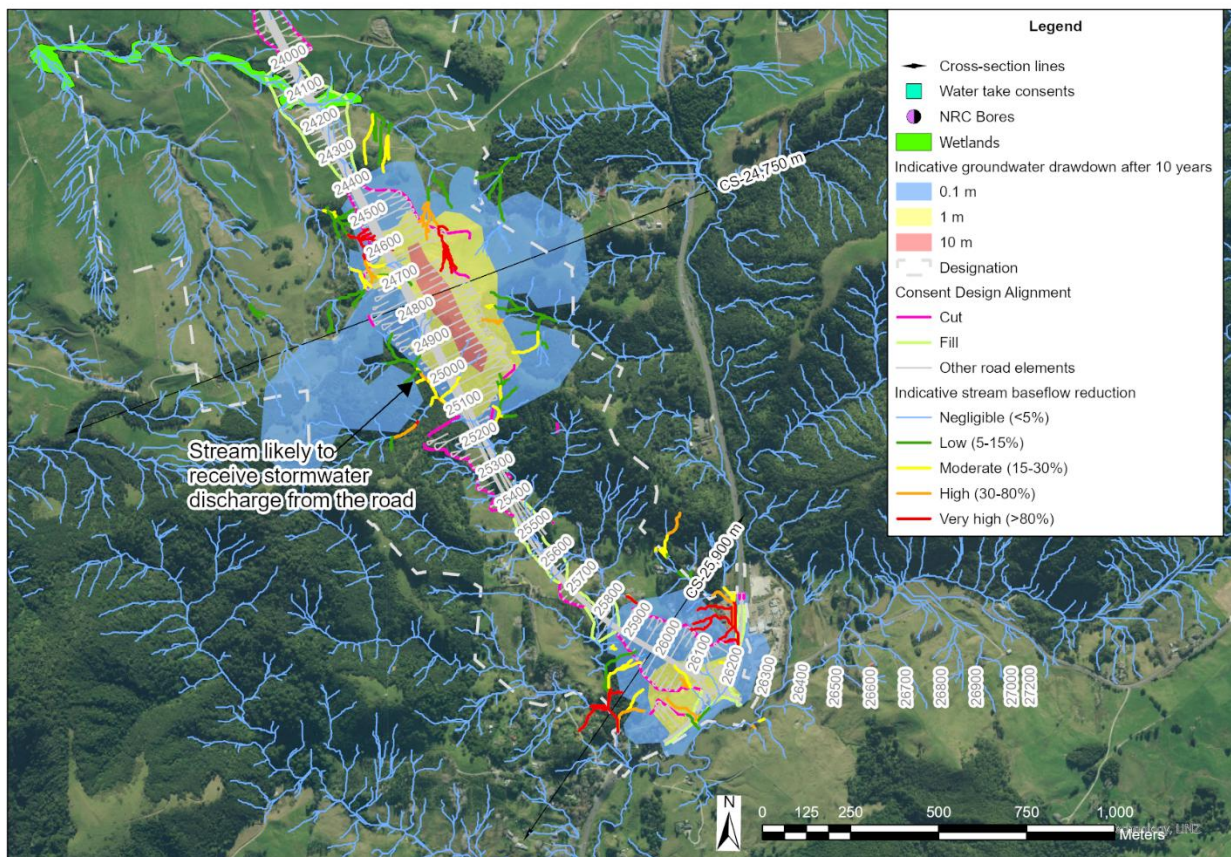


Figure 8: Effects from road cut Dewatering at CS-24,350 m to CS-25,200 m

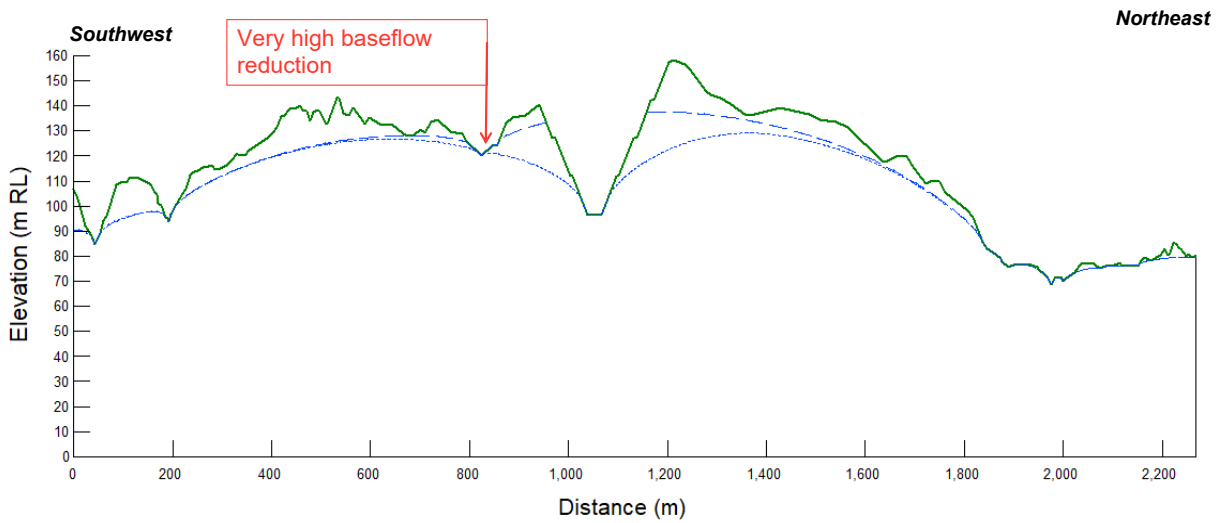


Figure 9: Cross-section CS-24,750 m showing groundwater drawdown from road cut Dewatering

The groundwater drainage rate from the permanent road drainage is expected to be up to 205 m³/day initially, when the cuts have been excavated. This rate will gradually reduce to about 99 m³/day after five years. After this, the groundwater drainage rate is expected to stabilise at that rate.

4.3.7. Summary of Effects from road Dewatering

The baseflow reduction for each stream near the locations where the road will be cut beneath the groundwater table is shown in the overview map in Figure 10. The expected groundwater drawdown contours are also shown in Figure 10, with the 0.1 m drawdown contour being considered the maximum extent of the groundwater effects. Beyond the 0.1 m drawdown contour, the effects on groundwater are expected to be negligible. In total about 37 km of stream will be impacted by more than 5% reduction of baseflows. In Table 3 the total length for each baseflow reduction magnitude category is listed.

The groundwater drainage rate from the permanent road drainage is expected to be up to 1,596 m³/day initially across all the Brynderwyn Hills section, when the cuts have been excavated. This rate will gradually reduce to about 580 m³/day after five years. After this, the groundwater drainage rate is expected to stabilise.

Table 3: Affected lengths of stream for each baseflow reduction magnitude.

Magnitude	Baseflow Effect	Length (m)
Very high	Complete depletion of flow likely; more than 80% reduction in flow.	10,971
High	Estimated loss in flow is between 30% and 80%.	11,589
Moderate	Estimated loss in flow between about 15% and 30%	14,175
Low	Estimated loss in flow between about 5% and 15%	22,126
Negligible	Estimated loss in flow is less than 5%	(all other streams)

The mapped wetlands are positioned near the margins of the drawdown zones and fall within areas of negligible to low baseflow reduction. As a result, the direct effects on the wetlands are considered low, despite some stream-depletion effects on the feeder streams.

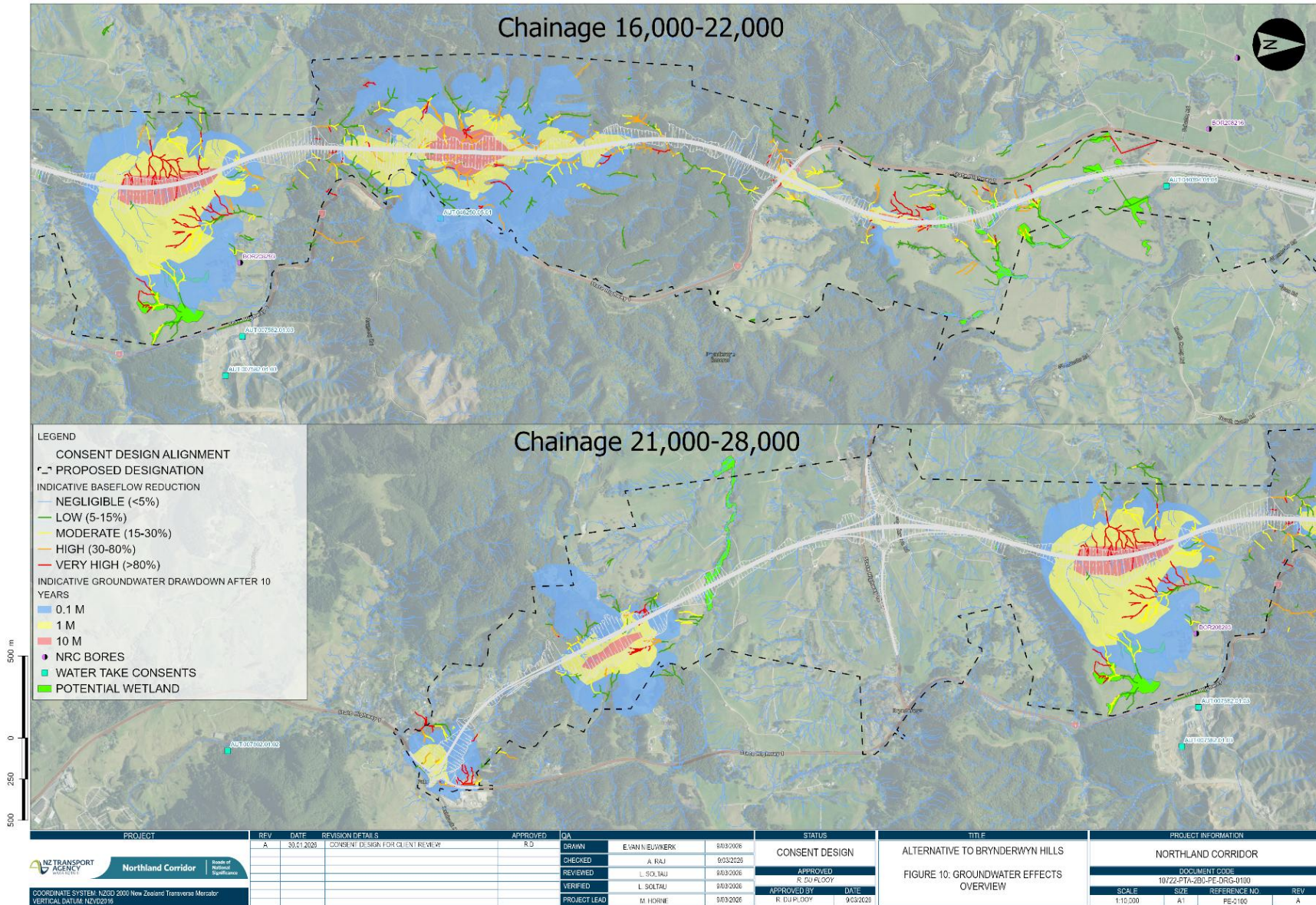


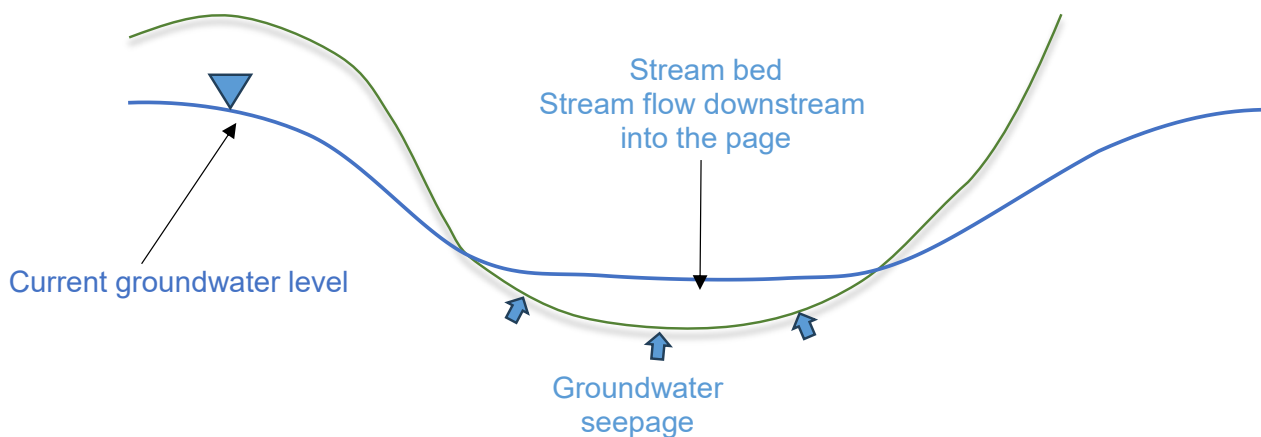
Figure 10: Modelled groundwater level drawdown and stream baseflow reduction magnitude in the Brynderwyn Hills section.

4.4. Potential effect of reduction in groundwater drainage for realigned streams on top of spoil sites.

Filling of stream valleys with spoil from the large road cuts can lead to a reduction in baseflows to streams, where the streams are groundwater fed. Spoil sites will be constructed with drainage at the bottom, to drain existing stream water and avoid wash-out of the spoil material. Streams are likely to be realigned at the top of the spoil material to the side of the spoil pile where possible, so that one side of the stream is still in contact with the stream valley. If a stream was reinstated on top of the fill material, this would lead to a reduction in groundwater seepage as illustrated in the diagram in Figure 11. The reduction in groundwater seepage into the realigned stream will depend on the stream profile and the relative groundwater level.

The effect on the ecology of the stream is addressed in the Assessment of Effects on Freshwater Ecology (Appendix D7 of Volume B of the Substantive Application). It is not possible to quantify the reduction in stream flow resulting from the drainage of groundwater from a specific realigned stream without a detailed design for that realigned stream. Note that where the groundwater level is high, and the spoil does not extend to above the groundwater level, there will still be seepage of groundwater into streams, but it will be reduced depending on the groundwater level and the base level of the realigned stream in the spoil.

Current conditions



Conditions after filling with spoil

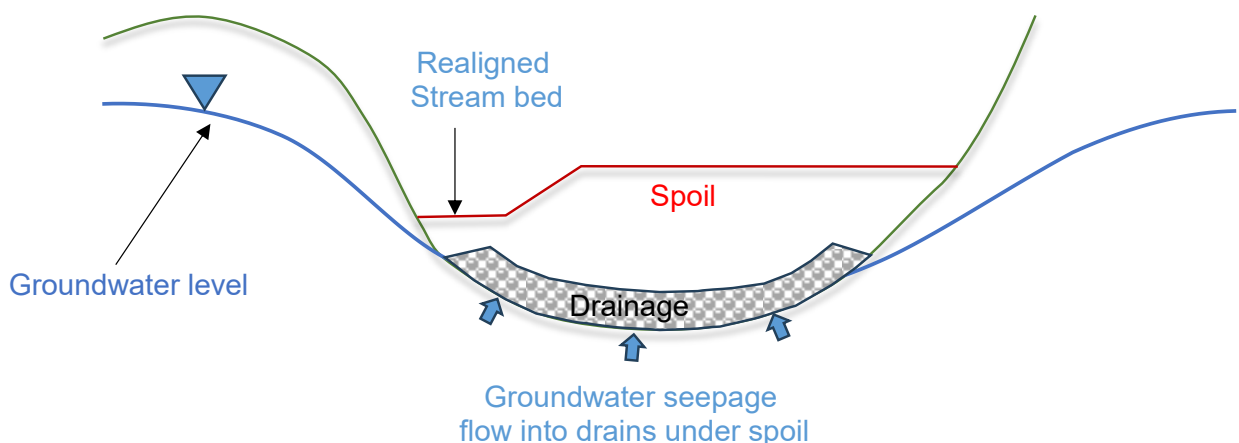


Figure 11: Schematic diagram effects of filling on stream baseflow from groundwater seepage

4.5. Potential effects on Neighbouring Groundwater users

The lowering of groundwater levels can affect people's ability to abstract water from water supply wells. Figure 12 below provides a schematic overview of an abstraction well. If a well is pumped, the well water level will be drawn down. The drawdown in a pumped well (i.e., self-induced drawdown) consists of two components: the Aquifer losses and the well losses. Aquifer losses are the head losses that occur in the Aquifer where the flow is laminar (Kruseman and de Ridder, 2000). Well losses are additional drawdowns caused by friction losses and turbulent flow inside the well, when the well is pumped (Figure 12). The well loss and Aquifer loss can be derived from step test results.

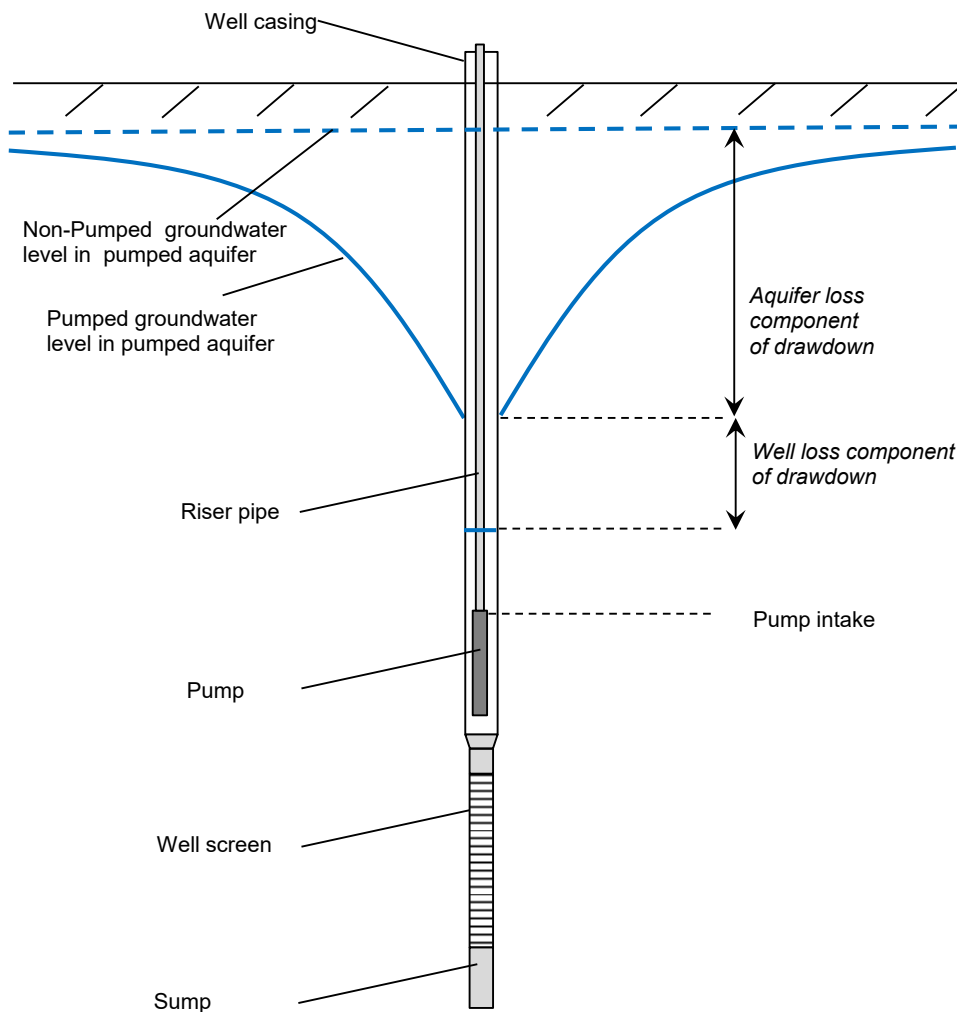


Figure 12: Schematic overview of groundwater abstraction wells

Pumping from a nearby well may draw water levels down in the subject well. Natural groundwater fluctuations may also cause the subject well water level to decline. If the sum of the self-induced drawdown, the drawdown caused by nearby pumping, and seasonal groundwater level decline, falls below the pump intake (Figure 12), no water can be taken from the well. If the well has sufficient depth it is in some cases possible to install the pump deeper into the well so that groundwater can be abstracted again. However, in some cases the well will be too shallow, in which case a deeper well could be considered to secure a water supply.

Water users that abstract water from groundwater-receiving surface water, can also be affected by groundwater drawdown. Because those water takes rely on groundwater seepage at the surface into the

contributing catchments, any groundwater drawdown of more than 0.1 m may affect these surface water takes.

Existing water supply wells and surface water takes within about 2 km of the Indicative Alignment are shown in Figure 10 together with the estimated groundwater drawdown contours caused by the Project. Expected long-term groundwater level drawdowns caused by the Project in existing water supply wells or in the contributing catchments of surface water take nearest the Indicative Alignment are listed in Table 4.

There is very limited information available on consented water supply wells within the Proposed Designation and hence it is not possible to confirm risks to nearby wells. On this basis, a conservative approach has been adopted in respect of potential effects on existing water supply wells. Specifically, if drawdown effects are larger than the seasonal fluctuation (i.e., 1 m refer to Section 3.7), the well is assumed to be affected. The results of the well interference effects assessment are listed in Table 4 and show one water supply well and one surface water take could potentially be impacted by the Project. Take AUT.046250.05.01 is a diversion granted to NZTA for emergency works on SH1. As a result, there is no effect on it resulting from the Project

Table 4: Estimated groundwater drawdown effects on nearby consented water takes.

Well ID	Appellation	Consent Holder / Property Owner	Casing depth (m bgl)	Well depth (m bgl)	Consent AUTH number	Estimated groundwater drawdown (m)
BOR208293	Fee Simple, 1/1, Lot 1 Deposited Plan 417208, 126,600 m ²	Not available - PA	26	47.5	Permitted activity	< 1 m
AUT.046250.05.01	Fee Simple, 1/1, Lot 2 Deposited Plan 422449 and Part Allotment 316A Parish of Waipu, 1,237,945 m ²	NZTA	N/A – surface water take		AUT.046250.05.01	< 1m

4.6. Potential Settlement Effect on Nearby Structures due to groundwater drawdown

The proposed deep cuts along the Indicative Alignment in the Brynderwyn Hills are expected to intersect the groundwater table and require drainage, potentially altering the long-term groundwater flow regime and associated surface-water features connected to it.

Settlement as a result of groundwater drawdown is anticipated to occur only within the Colluvium, Alluvial Deposits, and the residual soils of the Northland Allochthon, Waipapa, Dacite, Ruarangi, and Pakiri formations, because these sediments are considered compressible. Groundwater levels are drawn down in the shape of a cone around the cut from drainage, with the greatest drawdown directly adjacent to the cut and decreasing drawdown further from the excavation. Land settlement can occur from groundwater level drawdown because of dewatering activities, and affect nearby structures or services, particularly if the degree of settlement differs across the structure or service. Settlement that differs across the site is referred to as differential settlement and damage is most likely to occur where differential settlements are greatest. Because of the difference in drawdown with distance from the cut, dewatering settlement is expected to be differential, with the greatest drawdown near the cut and becoming less further away from the cut. In addition, mechanical settlement due to deflections of the cut excavations will occur closer to the cuts.

The underlying rock units are sufficiently stiff and are therefore not expected to experience measurable settlement.

To assess the potential surface settlement resulting from Dewatering, analytical calculations were undertaken. The assessment was carried out using the following equation derived from elastic theory:

$$S = \frac{\Delta\delta' \times H}{E'}$$

Where:
S = Settlement
H = Soil thickness
E' = Soil modulus
 $\Delta\delta'$ = Change in effective stress

The drawdown profiles generated from the SEEP/W model were used to estimate potential settlements and assess the associated effect on adjacent structures. Settlement is generally assessed only where groundwater drawdown extends below the seasonal low groundwater level, as some seasonal settlement will already occur naturally with fluctuations in groundwater levels. Because the groundwater model applies a median groundwater level rather than the seasonal minimum, the predicted drawdown and therefore the settlement assessment is considered conservative.

The potential for structural damage is evaluated with respect to both total and differential settlement, relative to the foundation type and its sensitivity to movement. In practice, the risk of damage to infrastructure is considered negligible where total settlement is less than about 50 mm and differential settlement is within a range of approximately 1in 200 to 1in 300. Structures founded on deep piles socketed into rock are typically far less vulnerable to settlement-related damage than shallow-founded assets.

4.6.1. Settlement Effects from Dewatering the Cut on Transpower Pylons in the Waipapa Geology Region (Ch15,800-20,500 m)

The Waipapa Group forms the underlying geology across all of Earthworks Zone 2 and the southern portion of Earthworks Zone 1, with localised pockets of colluvium present in some areas. SEEP/W modelling was undertaken at a location along the alignment approximately midway between the two pylons near Chainage 16,000 m, representing the Transpower pylon closest to the proposed cuts. The red arrows in Figure 13 below indicate the relative positions of these pylons.

Based on the modelling result presented in Figure 14, the maximum groundwater drawdown under median groundwater conditions is estimated to be approximately 3.3 m at the western pylon and 4.6 m at the eastern pylon after five years, even when accounting for a layer of weaker Colluvium overlying the Waipapa residual soils. As groundwater level measurements are limited to the cut location, it is assumed that groundwater will daylight into the adjacent streams. Using an empirical correlation between settlement and soil elastic modulus, the resulting drawdown-induced settlement at the pylons is estimated to be less than 30 mm. This is well within the damage tolerance of infrastructure. In addition, as most pylons are supported on deep concrete piles, they are expected to be significantly less sensitive to settlement than shallow-founded structures. Accordingly, the settlement impact on these pylons due to Dewatering is considered minimal.



Figure 13: GIS map showing location of Transpower pylons relevant to proposed cuts in Waipapa profile (the closest pylons next to the cuts)

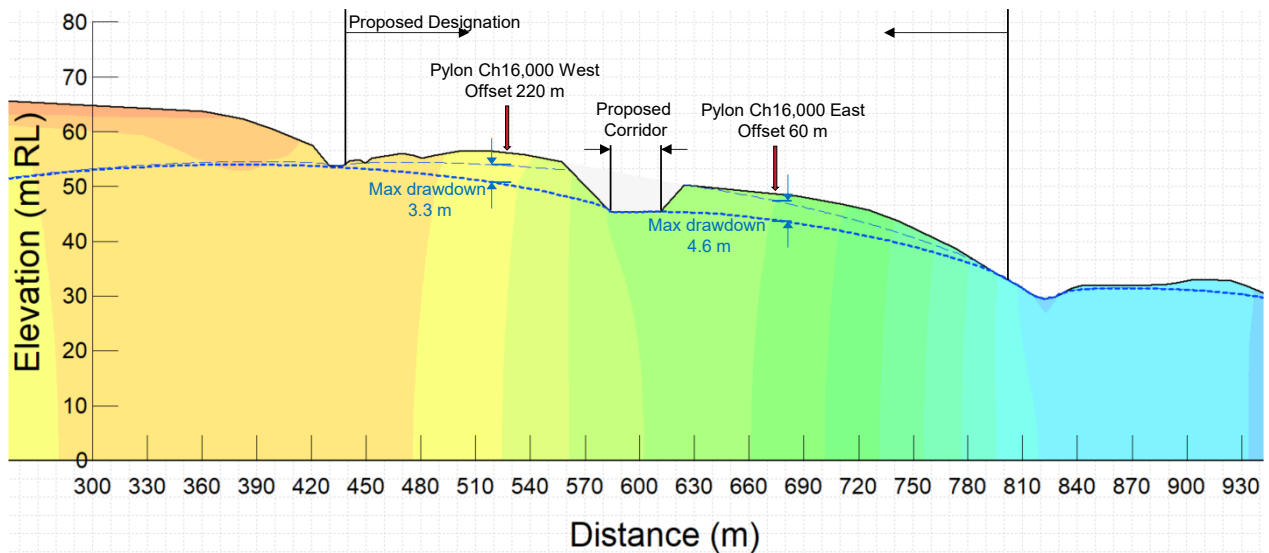


Figure 14: SEEP/W modelling result at Ch 16,000 m showing estimated groundwater profile and drawdown after cuts

Figure 16 illustrates the SEEP/W modelling at a representative location along the alignment, showing the worst-case water drawdown scenario for the Waipapa profile, where the greatest extent of Dewatering occurs at Chainage 19,850 m following the proposed cut. Although this represents the maximum drawdown within the proposed cut area, the nearest Transpower pylon is located a considerable distance from the cut and remains within the zones where the original groundwater level is almost preserved. The

red arrows in Figure 15 below indicates the relative positions of these pylons. Accordingly, the maximum drawdown beneath the pylon is only 1 m, corresponding to a negligible amount of settlement.

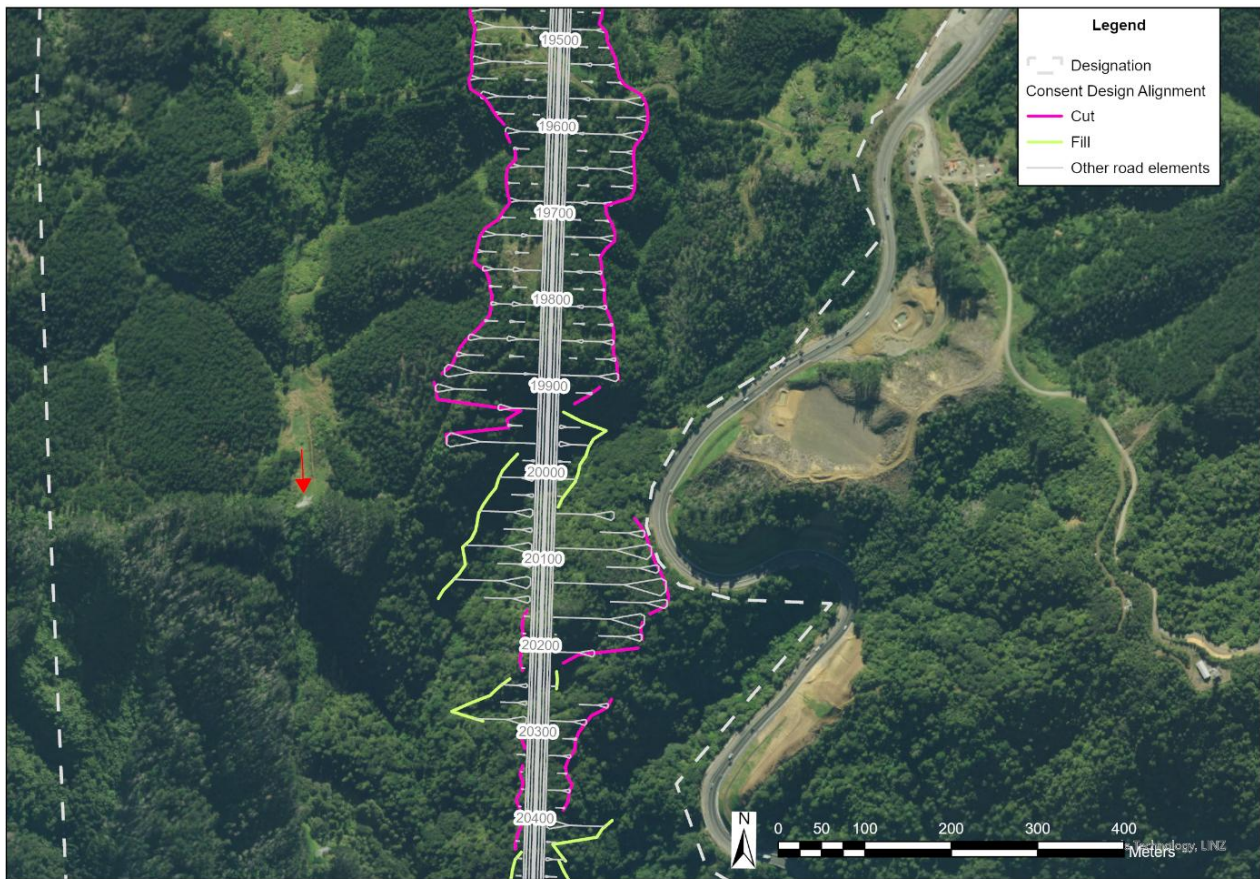


Figure 15: GIS map showing location of Transpower pylon relevant to proposed cuts with the greatest Dewatering drawdown in Waipapa profile (the closest pylons next to the cuts)

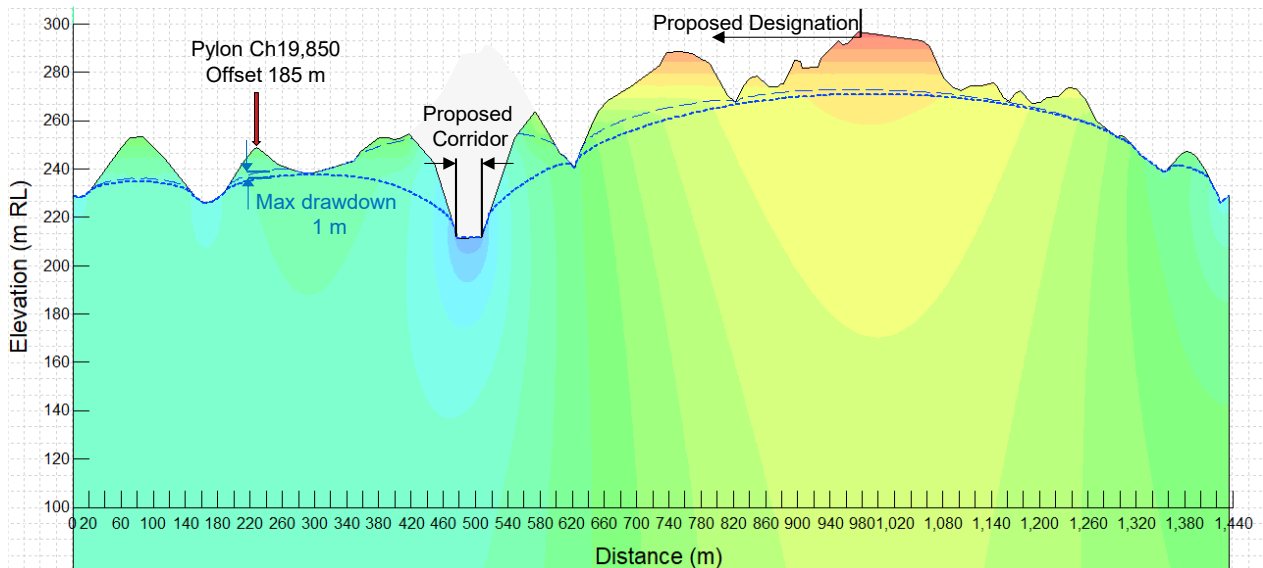


Figure 16: SEEP/W modelling result at Ch 19,850 showing estimated groundwater profile and drawdown after cuts

4.6.2. Settlement Effects from Dewatering the Cut on Pylons in the Northland Allochthon Geology Region (Ch20,600-24,500 m)

The Northland Allochthon Group underlies the entirety of Earthworks Zone 3 and the northern end of Earthworks Zone 4, with some areas considered to have the Pakiri Formation beneath. Based on geology cross sections, the upper 10 m is generally composed of weathered Northland Allochthon soil. SEEP/W modelling was carried out at a point along the alignment where the nearby pylon experiences the greatest Dewatering induced drawdown (around Chainage 21,700 m). The red arrow in Figure 17 shows the relative position of the pylon.

Based on the modelling results shown in Figure 18, the predicted maximum groundwater drawdown at the pylon location is approximately 3.9 m after five years. The median groundwater level was adopted in the assessment, and the soil profile beneath the pylon within the zone of influence was conservatively assumed to consist entirely of Northern Allochthon residual soil. Under these conditions, the worst-case drawdown-induced ground settlement at the pylon, assuming shallow (on-grade) foundations, is estimated to be around 20 mm. As most pylons are supported on deep concrete piles, they are expected to be significantly less sensitive to settlement than shallow-founded structures. Therefore, the settlement impact on the pylons due to Dewatering is considered minimal.

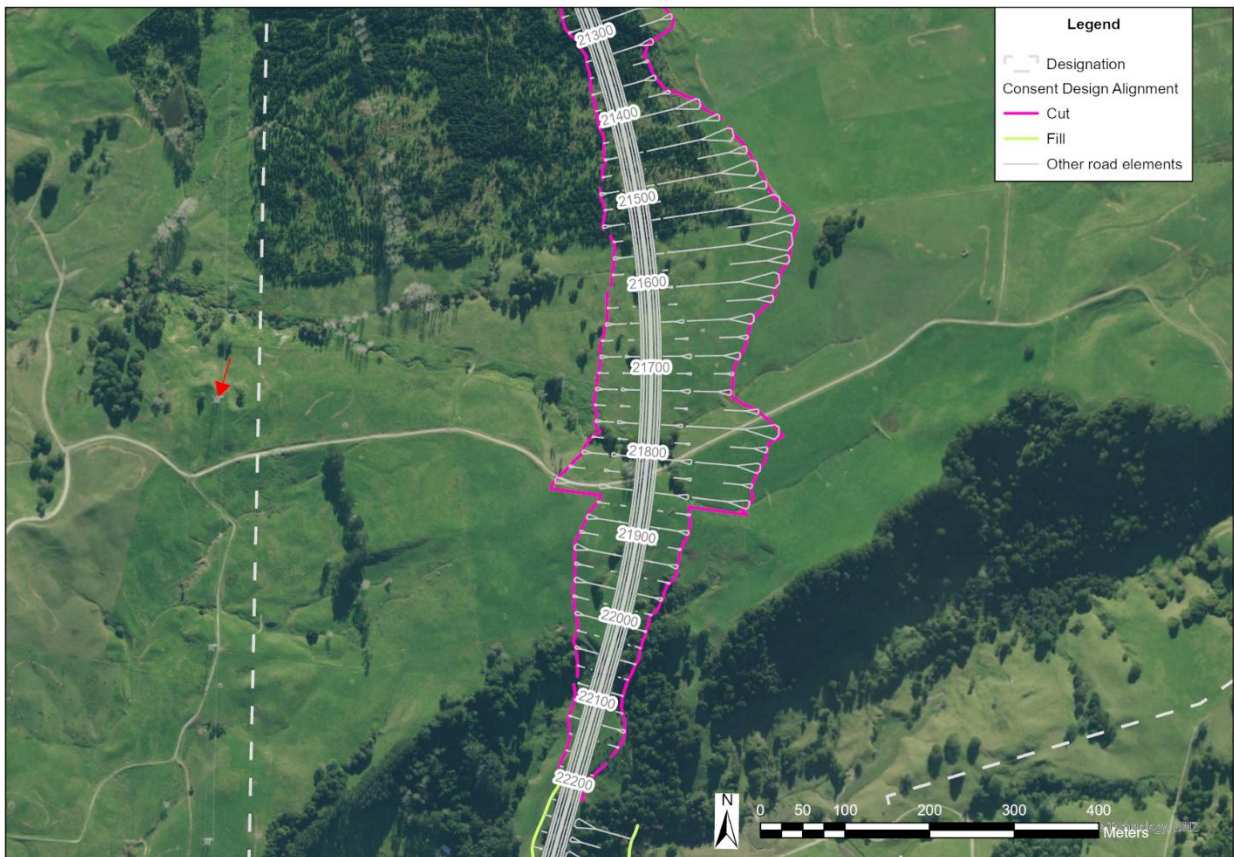


Figure 17: GIS map showing location of pylon relevant to proposed cuts in Northland Allochthon (the closest pylons next to the cuts)

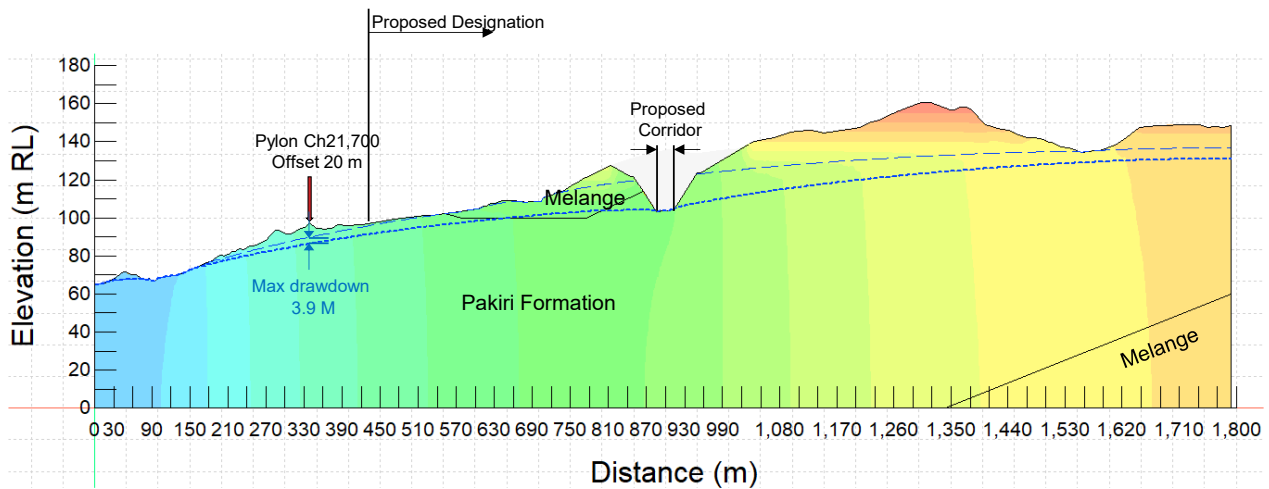


Figure 18: SEEP/W modelling result at Ch 21,700 showing estimated groundwater profile and drawdown after cuts

4.6.3. Settlement Effects from Dewatering the Cut on First Gas Pipeline in Earthworks Zone 4

The First Gas pipeline passes alongside the earthworks cut zone within Earthworks Zone 4, which is predominantly underlain by dacite and Northland Allochthon geology. The section of pipeline currently located within the cut zone will be relocated outside the cut zone as indicated by Figure 19. SEEP/W modelling was undertaken to assess groundwater drawdown beneath the pipeline adjacent to the proposed Earthworks Zone 4 cut areas.

For the dacite geological profile, the worst-case groundwater drawdown occurs at Chainage 24,750 m. Based on the modelling results presented in Figure 20 the maximum groundwater drawdown under the pipeline is estimated to be approximately 5 m. The median groundwater level was adopted in the assessment, and the associated drawdown-induced ground settlement is estimated to be around 20 mm. This estimate is based on a conservative assumption that the pipeline is subjected to the entire ground settlement induced by a 5 m groundwater drawdown, despite being buried at a depth of 1.5 m below ground level. Accordingly, the settlement impact on the pipeline due to Dewatering is considered negligible.

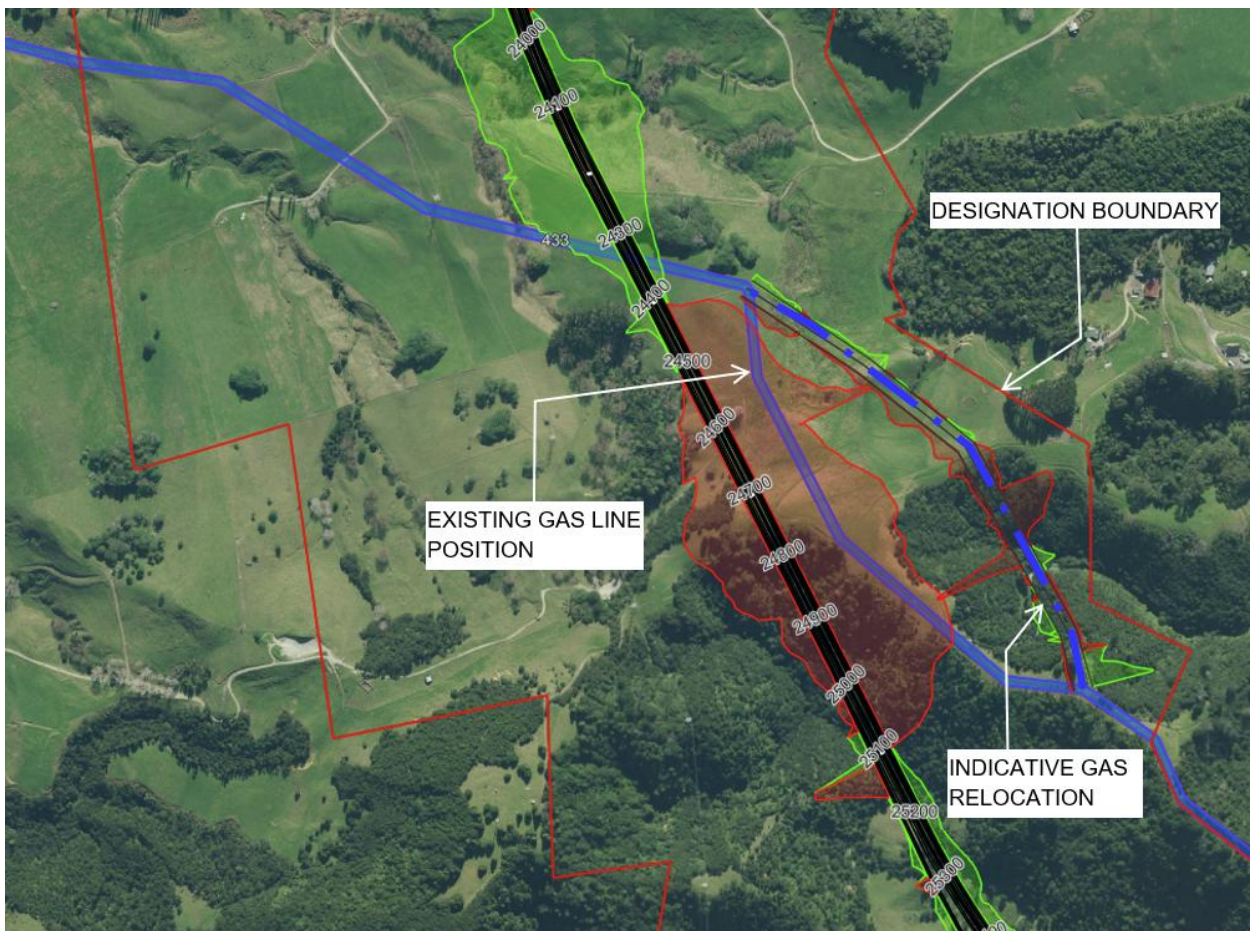


Figure 19: Map showing the existing alignment of First Gas pipeline nearby Earthworks Zone 4 cut zones with preferred relocation route out of the cut zone

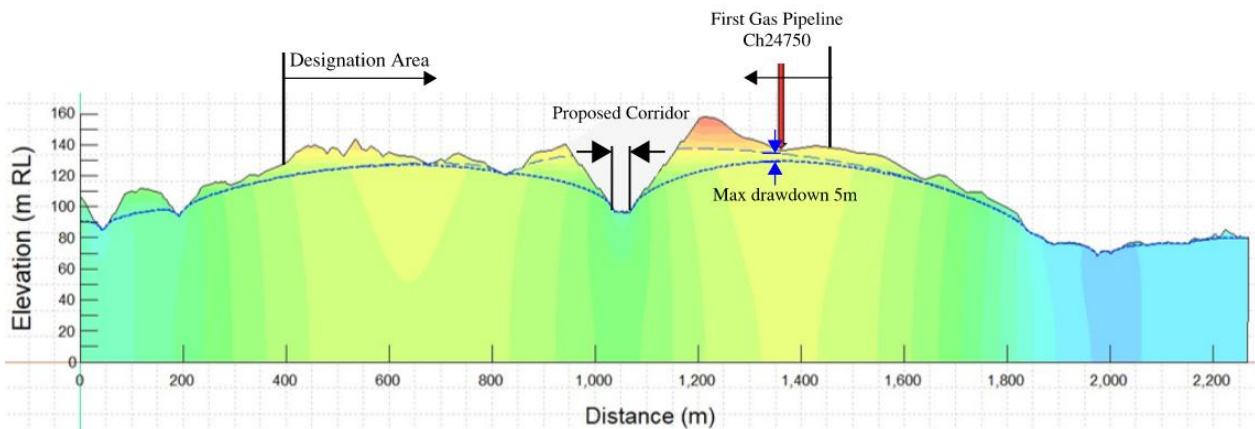


Figure 20: SEEP/W modelling result at Ch 24,750 showing estimated groundwater profile and drawdown after cuts

For the northland allochthon melange geological profile, the worst-case groundwater drawdown occurs at Chainage 25,900 m. Based on the modelling results presented in Figure 21, the maximum groundwater drawdown under the pipeline is estimated to be approximately 6 m. The median groundwater level was adopted in the assessment, and the associated drawdown-induced ground settlement is estimated to be around 50 mm. Again, this estimate is conservatively assumed that the pipeline is subjected to the full ground settlement induced by a 6 m groundwater drawdown. Accordingly, the settlement impact on the pipeline due to Dewatering is considered minimal. In the event that the settlement limits exceed the

pipeline performance requirements, appropriate mitigation measures or a relocation scheme can be adopted at the next stage.

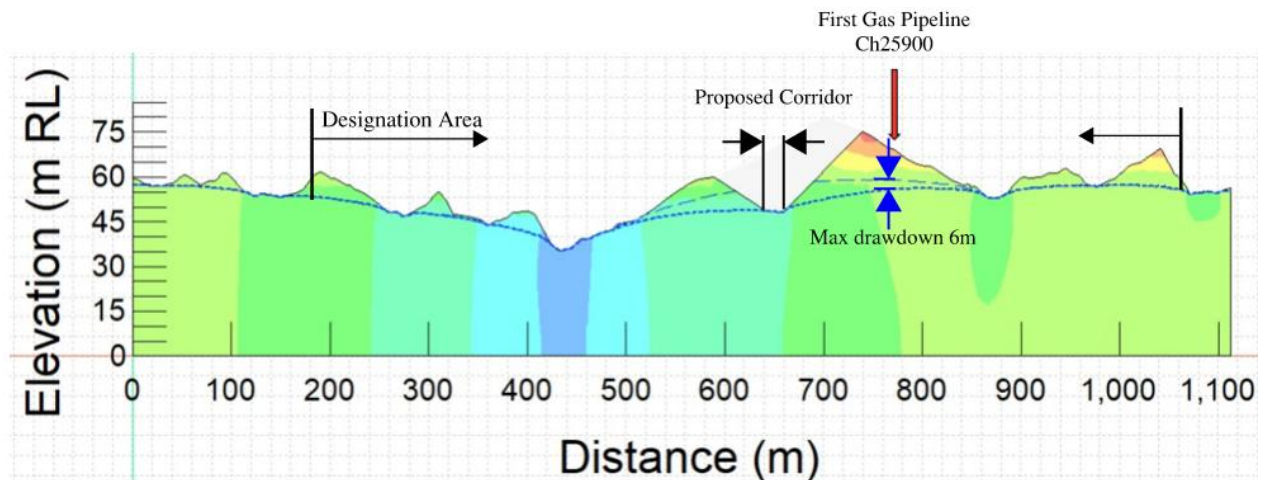


Figure 21: SEEP/W modelling result at Ch 25,900 m showing estimated groundwater profile and drawdown after cuts

4.7. Potential effects on Groundwater Quality

Groundwater sampling at 4 boreholes at the contamination discovery site BH2B_1160 around chainage 26,000 have been undertaken for total and dissolved metals, PAH, MAH, BTEX. Results have been compared to Table 3.4.1 in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1 (ANZECC 2000) at the level of 80 percent protection of species, except for benzene which is to be applied at a level of 1 milligram per litre (95 percent protection of species) and are presented in the Assessment of Contaminated Land Effects (Appendix D9 of Volume B of the Substantive Application).

All results meet the ANZECC 2000 guideline for the relevant samples. However, further assessment is recommended as outlined in the Assessment of Contaminated Land Effects.

5. Environmental Mitigation and Management Measures

5.1. Mitigation

5.1.1. Mitigation options for baseflow reduction

The Assessment of Effects on Freshwater Ecology (included in Appendix D7 of Volume B) assesses the impacts of the groundwater drawdowns predicted in this report on the ecological values in streams and wetlands and identifies where management actions are required. This report broadly sets out the water management options that are available.

Construction Phase

Groundwater and rainfall runoff that is captured on the road surface or by construction Dewatering, can be temporarily diverted to nearby potentially affected wetlands to minimise the impacts.

The impacts of short duration Dewatering activities for the construction of the Project are expected to be localised and temporary. The precise locations where construction Dewatering may be required will be determined at the detailed design stage. Nevertheless, temporary augmentation of wetlands and streams will adequately mitigate the effects. This could be done by water carting or diverting Dewatering water to temporary or permanent stormwater treatment facilities and discharging this water to potentially affected wetlands or streams.

Operational Phase

The effect of drainage of groundwater from the deeper cuts along the alignment will result in a reduction of baseflows to nearby streams and wetlands as discussed above.

Augmentation is not likely available for permanently affected streams and wetlands because the cuts are not only below the local groundwater table, but also below the base of some of the nearby stream segments. Therefore, it is not feasible to divert collected rainwater and stormwater into those nearby streams (refer to Figure 3, Figure 5 and Figure 8 in Section 4.3). To do so would require complex and technically vulnerable permanent pumping systems that require ongoing maintenance and upgrading. It is conceivable that at any time in the future, a system failure remains unnoticed for a prolonged period of time in which case the nearest stream segments dry out during low flow conditions and values are lost. The installation of complex vulnerable pumping systems that are likely to fail at some point in the future is not recommended.

5.1.2. Alternative water supply for affected water takes

Construction Phase

As discussed above, the impacts of short duration Dewatering activities are expected to be localised and temporary, irrespective of where they are located. If existing water takes are nonetheless affected, this impact could be alleviated by temporarily providing an alternative water supply by water carting.

Operational Phase

If any consented water supply wells or surface water takes are affected long-term an alternative water supply could be provided to the affected water users if required, which could include the following:

- A new and deeper water supply well installed at a different location, with a pump installed deeper, both of which would increase the reliability of the groundwater take.
- A surface water take with onsite storage capacity.
- Long-term water carting with onsite storage capacity.

It is recommended that an alternative water supply is discussed with any affected well owner to ensure a suitable solution is selected. Establishment of an alternative water supply as described above is considered sufficient to mitigate adverse effects to the water supply of the well owner.

5.1.3. Mitigation options for land settlement

Settlement effects are minimal to negligible for the Indicative Alignment within the current Proposed Designation. It is considered unlikely that settlement effects will extend beyond the extent of the Proposed Designation, however, it is recommended that potential settlement effects of the Project be confirmed if the alignment shifts more than 20 m at cuts that intercepts the groundwater table by more than 2 m.

5.1.4. Mitigation options for groundwater quality effects

Investigations show that no specific mitigation is required for groundwater quality effects including at the contamination discovery site BH2B_1160 (refer Assessment of Contaminated Land Effects, Appendix D9 of Volume B).

5.2. Monitoring Recommendations

Groundwater monitoring to determine the potential impact of drawdown on specific wetlands is outlined in the Assessment of Effects on Freshwater Ecology (Appendix D7 of Volume B of the Substantive Application).

6. Conclusion

Stream and wetland depletion effects could occur during the construction phase of the Project. However, any potential adverse effects caused by temporary construction Dewatering can be addressed through temporary augmentation of those streams and wetlands if required.

The permanent groundwater drainage and stormwater diversion for the new road during the operational phase may have permanent adverse effects on the baseflow to nearby streams and wetlands.

The effects of loss of baseflow to streams and wetlands are addressed in the Assessment of Effects on Freshwater Ecology (Appendix D7 of Volume B).

Two water takes may be impacted by the Project and an alternative water supply should be considered if impacts are confirmed.

The effects of the Project on groundwater quality have been assessed in relation to the discovery of contaminated soils at BH2B_1160. Results indicate contamination levels are beneath relevant ANZECC 2000 guidelines, and no additional management is required.

Land settlement effects are considered minimal to negligible.

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APPENDICES

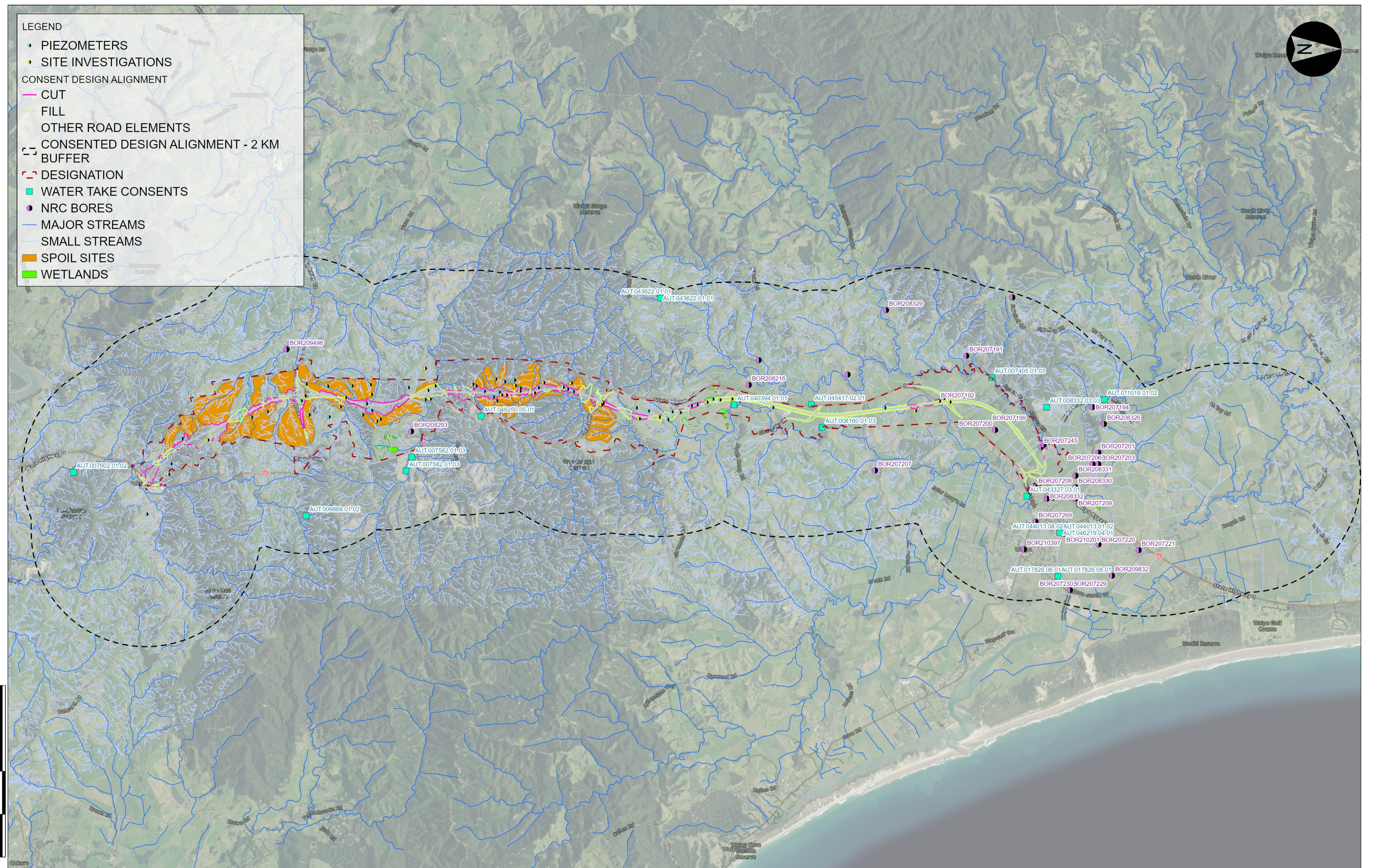


Appendix A

Location map with site-specific investigations,
existing bores and environmental features

LEGEND

- PIEZOMETERS
- SITE INVESTIGATIONS
- CONSENT DESIGN ALIGNMENT
 - CUT
 - FILL
 - OTHER ROAD ELEMENTS
- CONSENTED DESIGN ALIGNMENT - 2 KM BUFFER
- DESIGNATION
 - WATER TAKE CONSENTS
 - NRC BORES
 - MAJOR STREAMS
 - SMALL STREAMS
 - SPOIL SITES
 - WETLANDS



PROJECT	REV	DATE	REVISION DETAILS	APPROVED	QA	STATUS	TITLE	PROJECT INFORMATION			
Northland Corridor	A	11.03.2026	CONSENT DESIGN FOR CLIENT REVIEW	R.D	DRAWN	CONSENT DESIGN	ALTERNATIVE TO BRYNDERWYN HILLS HYDROGEOLOGY ASSESSMENT - FIELD INVESTIGATIONS AND KEY FEATURES OVERVIEW	DOCUMENT CODE			
					CHECKED			APPROVED	10722-PTA-2B0-PE-RPT-0019		
					REVIEWED	R. DU PLOOY		SCALE	SIZE	REFERENCE NO.	REV
					VERIFIED	APPROVED BY		1:30,000	A1	PE-0100	A
					PROJECT LEAD	DATE					

COORDINATE SYSTEM: NZGD 2000 New Zealand Transverse Mercator
 VERTICAL DATUM: NZVD2016

ORIGINAL IN COLOUR DETAIL MAY BE LOST IF COPIED

Appendix B

Long section of current ground level, Indicative
Alignment surface, and recorded groundwater levels

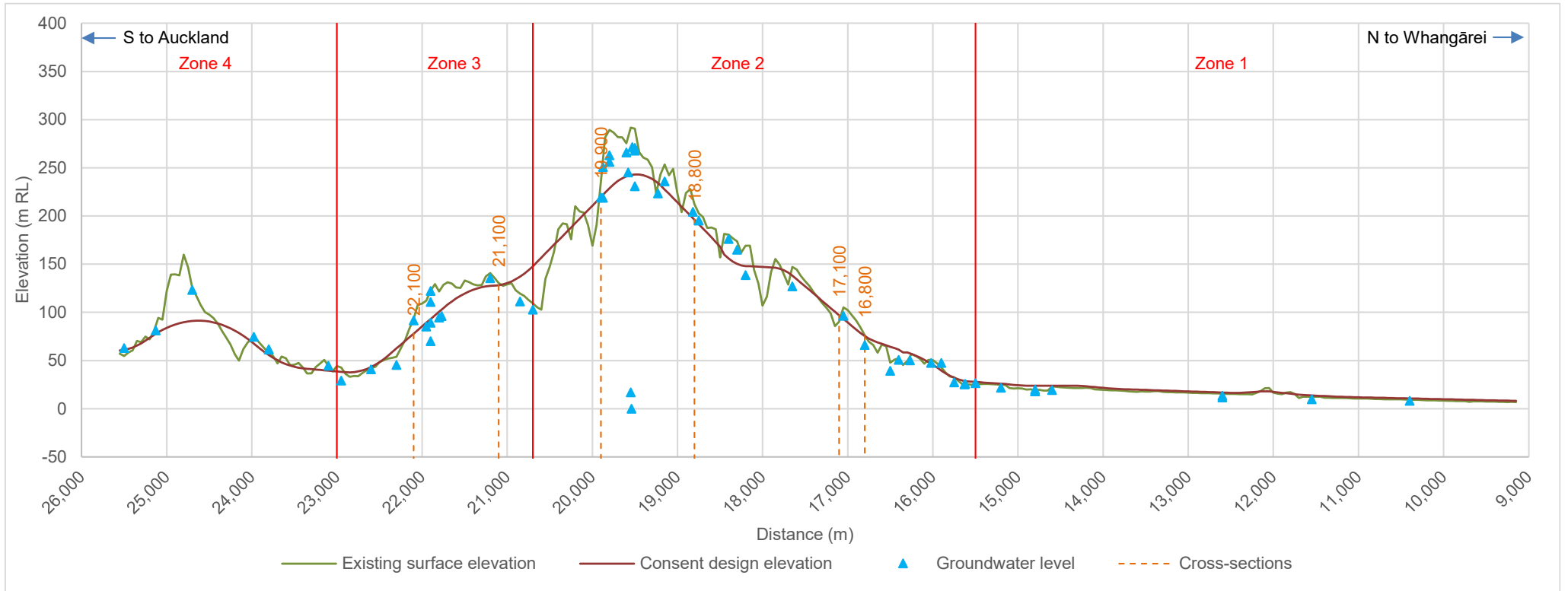


Figure 22: Long section of current ground level, Indicative Alignment surface, and recorded groundwater levels (vertical scale exaggerated; cuts beneath groundwater table indicated).

Appendix C

Groundwater level summary and graphs for all monitoring piezometers

Table A1: Summary of groundwater level information – Brynderwyn Hills section monitoring piezometers

BH ID	Measurement date		Monitoring period (days)	Maximum GWL (m bgl)	Minimum GWL (m bgl)	Median GWL (m bgl)	Lithology ²
	Start	End					
Earthworks Zone 1							
BH2B_1104A_S	23/09/2025	12/11/2025	50	3.18	2.67	2.97	Pleistocene alluvium
BH2B_1104_I	5/09/2025	12/11/2025	68	5.01	4.37	4.62	Pleistocene alluvium
BH2B_1140	19/09/2025	12/11/2025	54	2.75	2.13	2.38	Pleistocene alluvium
BH2B_1104_D	5/09/2025	12/11/2025	68	5.05	4.39	4.65	Slightly to unweathered Ruarangi
BH2B_1105	12/09/2025	11/11/2025	60	4.06	1.57	2.86	Slightly to unweathered Ruarangi
BH2B_1122	20/10/2025	12/11/2025	23	1.77	1.17	1.35	Slightly to unweathered Pakiri
Earthworks Zone 2							
BH2B_1106_S	28/08/2025	12/11/2025	76	0.92	0.37	0.58	Recent alluvium
BH2B_1147	24/10/2025	12/11/2025	19	3.14	2.77	2.91	Recent alluvium
BH2B_1139	20/10/2025	12/11/2025	23	7.15	6.24	6.72	Recent alluvium
BH2B_1107_S	24/10/2025	12/11/2025	19	9.04	8.79	8.93	Pleistocene alluvium
BH2B_1129	20/10/2025	12/11/2025	23	31.88	31.60	31.71	Moderately weathered Waipapa
BH2B_1106_D	28/08/2025	12/11/2025	76	1.15	0.00	0.42	Slightly to unweathered Waipapa
BH2B_1107_D	6/11/2025	12/11/2025	6	19.22	18.99	19.08	Slightly to unweathered Waipapa
BH2B_1109	26/09/2025	12/11/2025	47	32.59	32.00	32.21	Slightly to unweathered Waipapa
BH2B_1111_S	13/10/2025	12/11/2025	30	24.49	23.66	24.06	Slightly to unweathered Waipapa
BH2B_1111_D	10/10/2025	12/11/2025	33	31.58	30.70	31.23	Slightly to unweathered Waipapa
BH2B_1116	12/09/2025	12/11/2025	61	32.85	32.01	32.59	Slightly to unweathered Waipapa
BH2B_1117	19/09/2025	12/11/2025	54	4.64	2.94	3.86	Slightly to unweathered Waipapa
BH2B_1124	12/10/2025	12/11/2025	31	23.03	22.77	22.86	Slightly to unweathered Waipapa

² The study of the physical characteristics of rocks

BH ID	Measurement date		Monitoring period (days)	Maximum GWL (m bgl)	Minimum GWL (m bgl)	Median GWL (m bgl)	Lithology ²
	Start	End					
BH2B_1125	26/09/2025	12/11/2025	47	30.73	29.06	30.15	Slightly to unweathered Waipapa
BH2B_1137_S	23/10/2025	12/11/2025	20	10.31	9.56	9.67	Slightly to unweathered Waipapa
BH2B_1137_D	24/10/2025	12/11/2025	19	17.92	17.60	17.71	Slightly to unweathered Waipapa
BH2B_1144_S	12/09/2025	12/11/2025	61	20.47	19.95	20.23	Slightly to unweathered Waipapa
BH2B_1144_D	12/09/2025	12/11/2025	61	23.25	22.80	23.02	Slightly to unweathered Waipapa
BH2B_1148	26/09/2025	12/11/2025	47	24.77	23.94	24.40	Slightly to unweathered Waipapa
Earthworks Zone 3							
BH2B_1114_S	10/10/2025	12/11/2025	33	5.52	4.54	5.20	Northland Allochthon degraded zone
BH2B_1135	23/09/2025	12/11/2025	51	0.73	0.02	0.54	Northland Allochthon Melange Matrix
BH2B_1131	5/09/2025	12/11/2025	68	2.18	0.58	1.26	Northland Allochthon calcareous sequence
BH2B_1132	5/09/2025	12/11/2025	68	3.16	0.03	2.08	Northland Allochthon calcareous sequence
BH2B_1149	8/09/2025	12/11/2025	65	2.72	1.42	2.18	Northland Allochthon calcareous sequence
BH2B_1150	28/08/2025	11/11/2025	75	1.21	0.73	0.91	Northland Allochthon calcareous sequence
BH2B_1114_D	10/10/2025	12/11/2025	33	15.12	13.14	14.07	Slightly to unweathered Pakiri
BH2B_1130_S	20/10/2025	11/11/2025	22	8.00	7.66	7.83	Slightly to unweathered Pakiri
BH2B_1130_D	20/10/2025	11/11/2025	22	54.97	54.58	54.79	Slightly to unweathered Pakiri
BH2B_1145	12/09/2025	12/11/2025	61	1.66	1.25	1.43	Slightly to unweathered Pakiri
BH2B_1151	19/09/2025	12/11/2025	54	37.50	34.11	36.09	Slightly to unweathered Pakiri
Earthworks Zone 4							
BH2B_1115	28/08/2025	12/11/2025	76	2.54	1.94	2.18	Northland Allochthon Melange Matrix

Appendix D

Hydraulic Conductivity test analysis

Table B1: Summary of Hydraulic Conductivity – Alternative to the Brynderwyn Hills section

Bore ID	Date	Test interval (m bgl)	Hydraulic Conductivity (m/s)	Lithology
Earthworks Zone 1				
BH2B_1101	15/10/2025	12.-23.7	2.7×10^{-8}	Unweathered Ruarangi siltstone and sandstone, fractured
BH2B_1101	16/10/2025	28-34.4	2.7×10^{-8}	Unweathered Ruarangi siltstone, fractured.
BH2B_1101	17/10/2025	33-39.8	1.3×10^{-8}	Unweathered Ruarangi siltstone, fractured.
BH2B_1104	27/8/2025	31.5-32	5×10^{-5}	Unweathered Ruarangi Formation siltstone
BH2B_1104A	15/10/2025	6-12	7×10^{-8}	Holocene alluvium - clay, silty clay
Earthworks Zone 2				
BH2B_1107	14/10/2025	39-50	2.40×10^{-8}	Unweathered Waipapa greywacke, fractured
BH2B_1109	17/9/2025	25-28.2	Essentially impermeable	Moderately to slightly weathered Waipapa greywacke
BH2B_1110	31/10/2025	21-27	8.8×10^{-8}	Unweathered Waipapa greywacke, fractured
BH2B_1117	9/9/2025	17.6-39.95	1.2×10^{-7}	Unweathered Northland Allochthon limestone, fractured
BH2B_1124	29/9/2025	15-30	6.40×10^{-8}	Moderately to highly weathered Waipapa greywacke, grading into slightly weathered, fractured
BH2B_1127	9/10/2025	30-33.3	1.05×10^{-7}	Slightly to unweathered Waipapa greywacke, highly fractured
BH2B_1127	14/10/2025	33-39.7	1.33×10^{-7}	Unweathered Waipapa greywacke, highly fractured, brecciated
BH2B_1128	6/11/2025	44.3-50.3	7.4×10^{-8}	Unweathered Waipapa greywacke, fractured
BH2B_1129	7/10/2025	25.5-39	5.30×10^{-8}	Slightly weathered Waipapa greywacke, fractured
BH2B_1137	30/09/2025	15-25.6	9.80×10^{-8}	Slightly to unweathered Waipapa greywacke, fractured
BH2B_1137	6/10/2025	57-70	2.30×10^{-8}	Slightly to unweathered Waipapa greywacke, fractured
BH2B_1139	14/10/2025	9.5-15.5	6.3×10^{-9}	Holocene alluvium - silty clay, some silty sand
BH2B_1139	12/09/2025	16-21.6	4.60×10^{-8}	Unweathered Waipapa greywacke, fractured
BH2B_1139	16/09/2025	27.15-33.15	3.30×10^{-8}	Unweathered Waipapa greywacke, fractured
BH2B_1144	28/8/2025	40.5-53	3.7×10^{-9}	Unweathered Waipapa greywacke
BH2B_1144	3/9/2025	69.5-75.2	4.5×10^{-9}	Unweathered Waipapa greywacke
BH2B_1147	14/10/2025	5-8	4.00×10^{-8}	Holocene alluvium - clay and gravel
BH2B_1147	22/09/2025	19.5-22.5	1.90×10^{-7}	Unweathered Waipapa greywacke, highly fractured
BH2B_1147	23/09/2025	22.4-25.2	2.00×10^{-7}	Unweathered Waipapa greywacke, highly fractured
BH2B_1148	15/9/2025	21-34.5	2.70×10^{-8}	Moderately to unweathered Waipapa greywacke, brecciated ~29-30 m
BH2B_1148	15/9/2025	21-34.5	2.70×10^{-8}	Moderately to unweathered Waipapa greywacke, brecciated ~29-30 m
BH2B_1153	6/11/2025	28.5-34.5	4.90×10^{-8}	Unweathered Waipapa greywacke, fractured
BH2B_1153	7/11/2025	28.5-40.5	2.26×10^{-8}	Unweathered Waipapa greywacke, fractured

Bore ID	Date	Test interval (m bgl)	Hydraulic Conductivity (m/s)	Lithology
Earthworks Zone 3				
BH2B_1113	30/10/2025	19.6-22.6	1.40×10^{-7}	Unweathered Northland Allochthon limestone, fractured
BH2B_1135	14/10/2025	4.2-7.2	2.4×10^{-8}	Northland Allochthon mélange
BH2B_1130	18/09/2025	66-70.5	5.48×10^{-5}	Unweathered Pakiri sandstone; fractured
BH2B_1130	17/09/2025	37.5-48	3.90×10^{-8}	Unweathered Pakiri sandstone; fractured
BH2B_1149	15/10/2025	6.5-95	2.0×10^{-7}	Northland Allochthon limestone
Earthworks Zone 4				
BH2B_1156	17/10/2025	1.5-6	2.26×10^{-8}	Unweathered, Northland Allochthon limestone, fractured
BH2B_1157	24/10/2025	12-18.3	1.30×10^{-6}	Completely weathered Taurikura dacite
BH2B_1157	29/10/2025	40.5-49.5	8.70×10^{-8}	Unweathered Taurikura dacite
BH2B_1157	3/11/2025	73-85	7.40×10^{-8}	Unweathered Taurikura dacite
BH2B_1157	5/11/2025	80-84	6.5×10^{-8}	Unweathered Taurikura dacite
BH2B_1157	5/11/2025	91-95	1.1×10^{-7}	Unweathered Taurikura dacite
BH2B_1164	12/10/2025	17.2-21.7	1.10×10^{-8}	Northland Allochthon mélange
BH2B_1156	22/10/2025	29-30	1.96×10^{-7}	Unweathered, Northland Allochthon limestone, fractured

Appendix E

SEEP/W groundwater models description

Memorandum

To	NZTA	From	Andrew Raj, Eric van Nieuwkerk
Copy		Document Code	10722-PTA-2B0-PE-MEM-0015
Date	30 March 2026	Pages (including this page)	8
Subject	Alternative to Brynderwyn Hills – Brynderwyn Hills Section: Groundwater Cross Sectional Models for Cut and Fill		

Introduction

This Appendix provides a full description of the numerical groundwater modelling for the Alternative to Brynderwyn Hills – Brynderwyn Hills Section’s (the Project) Indicative Alignment, including the model setup, assumptions, calibration and scenario development. This appendix is to be read in conjunction with the main body of the Assessment of Effects on Groundwater (Appendix D12 of Volume B of the Substantive Application), which forms the basis of the groundwater effects assessment.

Model Objectives

The Project includes proposed areas of significant cut and fill, most notably where the alignment traverses the Brynderwyn Hills. The development of a series of 2-dimensional (2D) cross sectional numerical groundwater models provides for the most practical tool to incorporate the influences such as geology, groundwater recharge, surface water features and the proposed cut and fill profiles on hydrogeological processes. The cross-sectional 2D models can incorporate these processes in much greater detail than simpler analytical tools and also minimise the complexity and associated uncertainties of a fully 3-dimensional model.

The purpose of the Project’s cross sectional groundwater models is to assess the effects of the following activities as described in the main body of the report:

- Identify the potential extent of the groundwater drawdown curve caused by cut excavations
- Assess the potential long-term reduction in baseflow to surrounding streams and wetlands due to cut excavations
- Assess the potential groundwater discharge beneath specified areas of fill along the alignment.

Hydrogeological Conceptual Model

Based on the literature study, interrogation of databases, discussions with various experts, and results from various field investigations, WSP hydrogeologists developed a Hydrogeology Conceptual Model of the groundwater system for the Project and surroundings. This is described in Section 3 in the main body of the Assessment of Effects on Groundwater report. The Hydrogeology Conceptual Model forms the basis for the development of the 2-dimensional numerical groundwater model sections.

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Model Setup

Software

A series of cross-sectional numerical groundwater models were developed in SEEP/W to assess the potential effects the areas of cut and fill could have on nearby streams and groundwater discharge. SEEP/W is a finite element numerical modelling software developed by Seequent (2021) for groundwater flow in porous media. SEEP/W can model simple saturated steady-state problems or sophisticated saturated / unsaturated transient analyses. This is a widely used, industry standard, two-dimensional numerical groundwater modelling tool.

Model State

The groundwater model 2D cross sections have been designed and structured to simulate steady state and transient groundwater flow through the areas of interest, incorporating the observed and conceptual groundwater levels, gradients, groundwater recharge, and discharge zones.

The surface water boundary conditions (i.e., streams, wetlands and surface recharge) applied to the model do not reflect seasonal variations but rather represent an average condition for each boundary. Therefore, the model does not fully simulate catchment-wide seasonal fluctuations in groundwater and does not describe seasonal changes in groundwater-surface water interaction. The model simulates how the proposed activities will change groundwater levels and flows, and baseflows to streams and wetlands, in comparison with the current state of the groundwater system at the site. It does so by an initial (current conditions) steady state simulation followed by transient (i.e., time-dependent) simulations covering a period of five years following the completion of proposed works along the alignment.

Cross Section Locations

Nine cross-section locations were chosen to represent the variable topography and cut profile along the Indicative Alignment. The location and spacing were chosen such that the results of the cross-section assessments could be projected between them for an overall interpretation of the large cut areas within the Brynderwyn Hills. An additional two cross-sections were developed at specified areas of fill to assess the potential groundwater discharge that would need to be managed in the fill sub-drainage. The location of all eleven cross sections is shown in Figure 1.

The cross sections were extended laterally to streams or gullies which would be beyond the drawdown effects of the cuts. This prevented the lateral boundary conditions falsely countering drawdown effect and underpredicting the drawdown curve.

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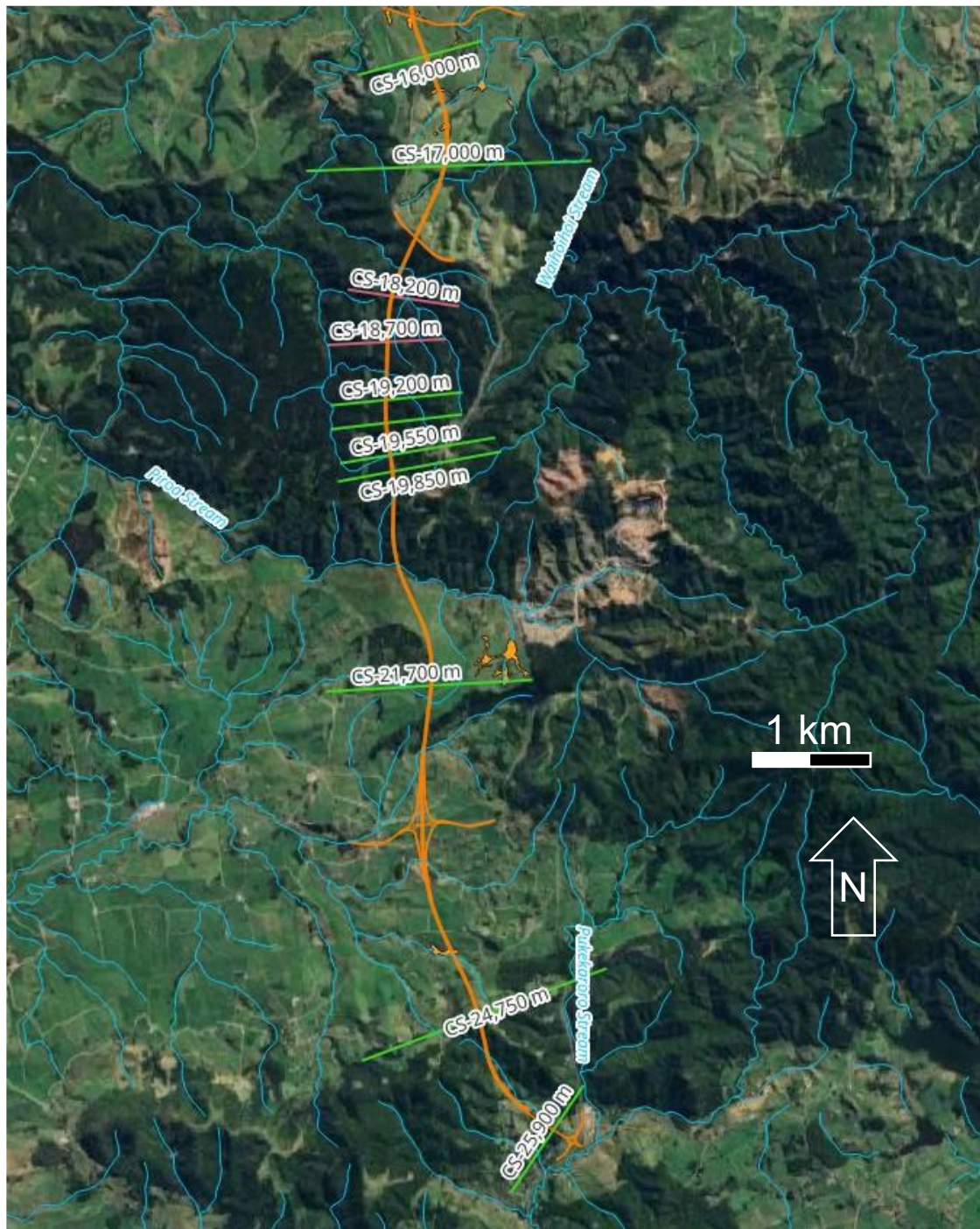


Figure 1: Cross section locations along alignment.

Vertical Datum and Mesh Density

The New Zealand Vertical Datum 2016 (NZVD) has been used as the vertical datum for this model. All cross sections were constructed from 0 m RL to the ground surface elevation, which ranged from approximately 30 m to 300 m RL.

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Cross section widths range from approximately 960 m to 2,300 m, with a global element size of 10 m. The upper part of the sections (within approximately 40 m of the ground surface) were further refined to a 5 m element size, and the cut areas were refined to a 2 m element size. The mesh of section CS-19,850 is shown in Figure 2 to illustrate the general mesh density of the cross sections.

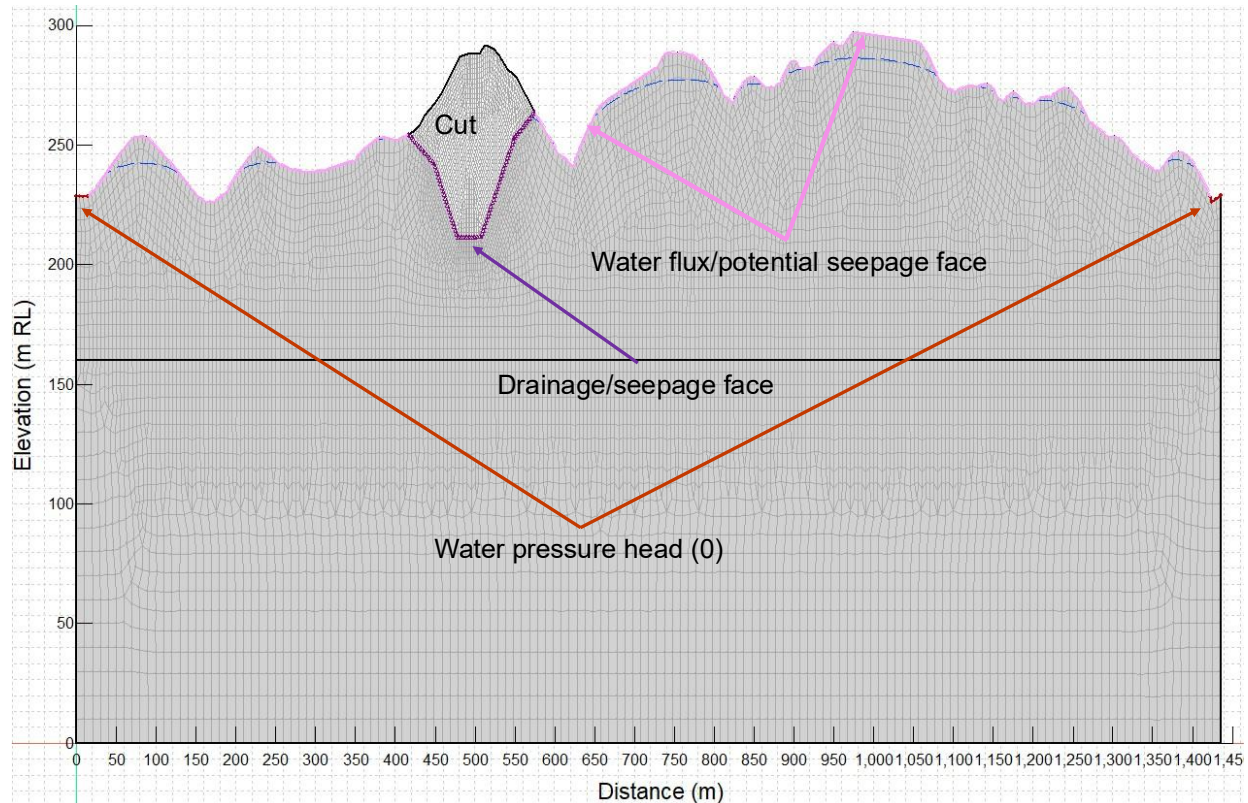


Figure 2: Cross section CS-19,850 typical mesh density and boundary conditions

Boundary Conditions

The following boundary conditions (BC) have been defined in the modelled cross sections to simulate groundwater flow and groundwater/surface water interaction. The typical application of these BCs in the cross sections is illustrated in Figure 2.

Water pressure head (0) – this BC maintains the water pressure head at 0, effectively the upper surface of the water table or stream. The model will add or remove water to maintain the water level at the elevation of the BC. The water pressure head (0) BC was applied to streams at the lateral extent of the cross sections, beyond the potential limit of drawdown effects from the cut excavations.

Drainage/seepage face – this BC will remove water from the model if it rises above the elevation of the drainage BC. Unlike the Water pressure head (0) it will not add water to the model, so while water levels cannot rise above the drain they can drop below the elevation of the drainage BC. This BC was applied along the surface of cut excavations in predictive scenarios to represent surface drainage/dewatering along the cut sections.

Water Flux (recharge)/potential seepage face – this BC will add water at a fixed rate to the ground surface of the model. It was also applied as a potential seepage face which allows it to effectively act as a

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drainage BC if water rises above the ground surface. The water flux BC was applied to the ground surface along the modelled cross sections.

Groundwater Recharge

Groundwater recharge to the cross sections occurs primarily from land surface recharge. This was applied with the water flux BCs along the ground surface. Groundwater levels within the cross sections are dependent on the hydrogeological conductivity and recharge rates. With the conductivity tested onsite the recharge rate was the main parameter optimised to bring water levels to observed ranges. In testing the upper and lower range of hydrogeological conductivity the recharge correspondingly had an upper and lower range to maintain groundwater levels within the observed range.

The New Zealand Geological and Nuclear Science have created a 1 x 1 km grid country wide National Groundwater Recharge Model (NGRM). The model uses a cell by cell soil water balance to estimate rainfall recharge and so gives an indicative value for each 1 km² area. The NGRM indicates recharge rates of 100-500 mm/year in the area of Brynderwyn Hills which was used for the initial values of the optimisation process.

In addition, potential groundwater recharge was assessed using the Rushton (2006) methodology. Groundwater recharge from rainfall is mainly determined by land use and soils type. Rushton (2006) describes a methodology to estimate groundwater recharge from a daily soil moisture balance. This method has been adopted to estimate rainfall recharge for in the model area. The Rushton (2006) soil moisture balance requires the following inputs:

- Rainfall runoff characteristics determined by the SCS curve number method (Soil Conservation Service, 1964 and 1972; Ritzema 1994).
- Proportion of rainfall that is stored near the surface (i.e., 'Fracstor' parameter as described in Rushton, 2006)
- Land use type, which includes crop or vegetation type (e.g., grasslands, indigenous forest, exotic forests, etc.) and sealed surface (e.g., roads, roofs, hardstand areas in urban and infrastructure areas). This has been derived from the 2024 classification in the Land Cover Database version 6.0 from Landcare Research.
- Soil type and Profile Available Water (PAW). This has been derived from the soil moisture spatial layer as defined by Landcare Research.
- Crop factors and rooting depth. These have been based on FAO (1998) and on Irrigation NZ (2015).
- Daily rainfall and evapotranspiration records. Rainfall records from March 2021 to March 2026 have been taken from Northland Regional Councils website for the Waihoihoi at Brynderwyn rainfall gauge, and evapotranspiration records from the from Earth Science New Zealand DataHub for the Whangarei Aero AWS weather station.

The identified land use types in the area have been reclassified into 4 categories that represent rainfall recharge types. Predominant soil type in the area is a poorly drained moderately deep silt. An overview of adopted parameters for the Rushton (2006) rainfall recharge estimations is listed in Table 1.

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Table 1: Estimations and parameter values for groundwater recharge from rainfall at the Alternative to Brynderwyn Hills – Brynderwyn Hills Section

Land use type	Crop factor (-)	Profile available water (mm)	Rooting depth m)	SCS curve number, CN (-)	Proportion of rainfall stored near surface, Fracstor (mm)	Estimated rainfall recharge Oct 2018 - Oct 2022 (mm/day)
Grassland and bare	0.85	148	0.5	86	0.65	1.63
Exotic forest	1.1	132	3.0	86	0.65	0.87
Indigenous forest	0.95	132	1.5	84	0.65	1.40
Urban & infrastructure	0.95	148	0.5	98	0.65	0.11

The dominant land use in the area is pastoral grassland for livestock grazing and the estimated rainfall recharge using the Rushton (2006) method is 1.63 mm/day, or about 35 % of the rainfall, for the March 2021 to March 2026 period. Exotic forest covers much of the Brynderwyn Hills and groundwater recharge there is estimated to be 0.87 mm/day or 19 % of the rainfall in the same period. This is consistent with the findings from SCION (2024) who investigated several production forest sites across New Zealand, including the Mahurangi site in Northland. Based on soil water balance modelling results using the Rushton (2006) methodology presented in Table 1, we assessed the range to be 40-600 mm/year which is generally consistent with the findings from GNS.

At the end of optimisation the upper range K scenarios had a recharge rate of 200 mm/year applied and the lower range K scenarios had a recharge rate of 50 mm/year.

Hydrogeological Units

Hydrogeological units are described in the Hydrogeology Conceptual Model of the groundwater system in Section 3 in the main body of the report. Packer testing onsite gave an order of magnitude range in hydraulic conductivity within hydrogeological units due to the degree of fracturing present. Each 2D section was therefore modelled in a low K and high K scenario to assess a range of potential effects. As packer tests target zones of higher fracturing the tested K values may tend towards the higher range of what the bulk regional K value would be. The hydrogeological units present in the modelled cross sections are summarised in Table 2. The hydrogeological stratigraphy is labelled in each of the cross sections.

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Melange and the Pakiri Formation are present within cross section CS-21,700. The contact of these units was inferred from drill logs in the area. All other sections are solely within the Waipapa Terrane Formation greywacke.

The greywacke range of K was 1×10^{-7} m/s to 1×10^{-8} m/s in the Brynderwyn Hills area and the Pakiri formation range 1×10^{-6} to 1×10^{-7} in section CS-21,700 where Melange is also present in the cross-section profile. The Melange range of K was 1×10^{-7} m/s – 1×10^{-8} m/s.

Model Scenarios

Each 2D cross section was first run in steady state pre-cut/fill to represent the current conditions. The cut sections were then added and the model run in transient conditions for a 5 year period to assess the long term effects of the cut excavation. Sections CS-18,700 and CS-18,200 are in areas of fill rather than cut, and so were run only in steady state to estimate total groundwater discharge in the fill area. All sections but CS-16,000 were run in a high K and low K scenario to assess the potential range of hydraulic conductivity encountered in field investigation, and to see the sensitivity of the models to the K and recharge parameters. Section CS-16,000 showed an excessively high water table in the low K scenario and so only the high K was used. Table 2 summarises the sections and scenarios modelled.

Table 2: Groundwater model scenarios

Section and Scenario	State	Greywacke K (m/s)	Pakiri K (m/s)	Melange K (m/s)	Surface Recharge (mm/yr)
CS-19,850 High K	Transient (5 yr)	1×10^{-7}	N/A	N/A	50
CS-19,550 High K	Transient (5 yr)				
CS-19,300 High K	Transient (5 yr)				
CS-19,200 High K	Transient (5 yr)				
CS-18,700 High K	Steady State				
CS-18,200 High K	Steady State				
CS-19,850 Low K	Transient (5 yr)	1×10^{-8}	N/A	N/A	200
CS-19,550 Low K	Transient (5 yr)				
CS-19,300 Low K	Transient (5 yr)				
CS-19,200 Low K	Transient (5 yr)				
CS-18,700 Low K	Steady State				
CS-18,200 Low K	Steady State				
CS-16,000 High K	Transient (5 yr)	1×10^{-7}	N/A	N/A	50
CS-21,700 High K	Transient (5 yr)	N/A	1×10^{-6}	1×10^{-7}	200
CS-21,700 Low K	Transient (5 yr)	N/A	1×10^{-7}	1×10^{-8}	50

Model Calibration

As part of the calibration process, the model's parameter values are optimised. Model optimisation refers to a procedure to improve the model's ability to simulate recorded groundwater levels, by changing the

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model input parameters within an expected range of those parameters. When all model parameters have been considered in the model optimisation, and the model performance to simulate recorded groundwater levels across the model is adequate, the model can be considered as calibrated.

The target groundwater levels for calibration included the ground elevation at the location of streams identified in aerial photographs and in the site topography where groundwater discharge will occur. Target groundwater levels on the upper slopes, away from the streams, were inferred from groundwater level data available from monitoring wells installed in the area. Direct projection of observed levels onto the cross sections was not feasible due to the sharp variation in topography over short distances in this hilly area. The target levels were therefore interpreted as a general depth below ground level range of 20-33 m beneath ridges and upper slopes. The groundwater level monitoring data in the area where this range is observed is presented in Table 3.

As the hydraulic conductivity range was addressed using low K and high K scenarios, the surface recharge rate was optimised to calibrate the models. Calibration was made with the aim of maintaining consistency of parameters between the multiple cross sections rather than a separate parameter calibration for each cross section. This was achievable with all cross sections save CS-16,000 which required a combination of low recharge rate and high K to avoid modelled groundwater levels across the surface of the section (which does not correspond with field observation).

Table 3: Groundwater level observations from site

Borehole	Elevation	Sensor depth (m bgl)	Mean level (m bgl)
BH2B_1144	215.8	75	23.0
BH2B_1144	215.8	20	20.2
BH2B_1125	236.9	39	30.0
BH2B_1109	230	34	32.2
BH2B_1116	215.7	40.5	32.5

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