Warkworth to Wellsford

Hydrogeology Assessment

July 2019

QUALITY ASSURANCE

Prepared by

Jacobs GHD Joint Venture. Prepared subject to the terms of the Professional Services Contract between the Client and Jacobs GHD Joint Venture for the Route Protection and Consenting of the Warkworth to Wellsford Project.

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GLOSSARY OF ABBREVIATIONS

The table below sets out the technical abbreviations.

Abbreviation/acronym	Term
AEE	Assessment of Effects on the Environment
AUP(OP)	Auckland Unitary Plan Operative in Part
L/s	Litres per second
m	metres
m/day	Metres per day
m^3/day	Metres cubed per day
mAMSL	Metres above mean sea level
mBGL	Metres below ground level
m/s	Metres per second
m^2/s	Metres squared per second
MSE	Mechanically stabilised earth
mRL	Metres reduced level
P-Wk	Pūhoi to Wellsford project
RMA	Resource Management Act 1991
SH(x)	State highway (number)

GLOSSARY OF DEFINED TERMS

The table below sets out the defined terms (and some acronyms above apply)

Term	Meaning
Allochthon	A large block of rock which has been moved from its original site of formation, usually by low angle thrust faulting.
Anisotropy	Anisotropy in an aquifer occurs when there is a difference in conductivity in two different directions. Whenever there is a difference in conductivity, water prefers to travel along the path with least resistance. In other words, water travels preferentially along the direction of higher conductivity.
Bore	Any hole that has been constructed to provide access to groundwater (for example, for monitoring of ground or groundwater conditions, taking of ground or the discharge of stormwater) or for geotechnical investigations.
Chainage	A distance measured along a straight line. For this project chainage is measured in metres and starts from the northern extent of the Project.
Designation	Defined in section 166 of the RMA, as "a provision made in a district plan to give effect to a requirement made by a requiring authority under section 168 or section 168A or clause 4 of Schedule 1 of the RMA".
Earthworks	Defined in section J1 of the AUP, as disturbance of soil, earth or substrate land surfaces. Includes: balding, boring (greater than 250mm diameter); contouring; cutting; drilling (greater than 250mm diameter); excavation; filling; ripping; moving; placing; removing; replacing; trenching; and thrusting (greater than 250mm diameter). Excludes: ancillary forest earthworks; and ancillary farming earthworks.
Groundwater	Natural water contained within soil and rock formations below the surface of the ground.
Ground settlement	The gradual sinking of the ground surface as a result of the compression of underlying material.
Hydraulic conductivity (K)	The ability of an aquifer material to transmit water, measured as the flow rate of water through a cross section of 1 m^3 under a unit hydraulic gradient. Hydraulic conductivity is typically reported in units of metres per day (m/day) or metres per second (m/s).
Hydraulic gradient	The change in level or pressure of water over a unit distance, expressed as a percentage or fraction (e.g. a 1 m pressure change over 100 m horizontal distance is a 1% or 0.01 hydraulic gradient).

Term	Meaning
Indicative Alignment	An indicative road design alignment assessed by the technical experts that may be refined on detailed design within the designation boundary. The Indicative Alignment is a preliminary alignment of a state highway that could be constructed within the proposed designation boundary. The Indicative Alignment has been prepared for assessment purposes, and to indicate what the final design of the Project may look like. The final alignment for the Project will be refined and confirmed at the detailed design stage.
Intermittent stream	Defined in section J1 of the AUP, as stream reaches that cease to flow for periods of the year because the bed is periodically above the water table. This category is defined by those stream reaches that do not meet the definition of permanent river or stream and meet at least three of the following criteria: (a) it has natural pools; (b) it has a well-defined channel, such that the bed and banks can be distinguished; (c) it contains surface water more than 48 hours after a rain event which results in stream flow; (d) rooted terrestrial vegetation is not established across the entire cross-sectional width of the channel; (e) organic debris resulting from flood can be seen on the floodplain; or (f) there is evidence of substrate sorting process, including scour and deposition.
Permeability	The ability of a porous material to allow fluids to pass through it.
Piezometer	A device used to measure groundwater pressure head at a point in the subsurface.
Piezometric surface	An imaginary surface representing the static groundwater level as defined by the level that water resides within a tightly cased bore.
Project	The Ara Tūhono Pūhoi to Wellsford Project: Warkworth to Wellsford section, which extends from Warkworth in the south, to the north of Te Hana.
Project Area	The area within the proposed designation boundary, and immediate surrounds to the extent Project works extend beyond this boundary.
Project works	All proposed activities associated with the Project.
Proposed designation boundary	The boundary of land to which the notice of requirement applies

Term	Meaning
Specific yield	The quantity of water yielded or taken into storage under gravity by a unit change in water level. Specific yield is expressed either as a ratio or as a percentage of the volume of the aquifer, with values typically residing between 0.01 and 0.3 or 1% to 30%.
Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.
Transmissivity	Transmissivity is the aquifer hydraulic conductivity multiplied by the saturated thickness (vertical section) of the aquifer under consideration.
The Dome	The highest elevation within the Dome Forest Conservation Area.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Overview of the Project

The NZ Transport Agency (Transport Agency) is lodging a Notice of Requirement (NoR) and applications for resource consent (collectively referred to as "the Application") for the Warkworth to Wellsford Project (the Project).

This report is part of a suite of technical assessments prepared to inform the Assessment of Effects on the Environment (AEE) and to support the Application. This assessment report addresses the actual and potential groundwater effects arising from the Project. The assessment considers the effects of an Indicative Alignment and other potential effects that could occur if that alignment shifts within the proposed designation boundary when the design is finalised in the future.

1.2 Project description

The Project involves the construction, operation and maintenance of a new four lane state highway. The route is approximately 26 km long. The Project commences at the interface with the Pūhoi to Warkworth project (P-Wk) near Woodcocks Road. It passes to the west of the existing State Highway 1 (SH1) alignment near The Dome, before crossing SH1 just south of the Hōteo River. North of the Hōteo River the Project passes to the east of Wellsford and Te Hana, bypassing these centres. The Project ties into the existing SH1 to the north of Te Hana near Maeneene Road.

The key components of the Project, based on the Indicative Alignment, are as follows:

a) A new four lane dual carriageway state highway, offline from the existing SH1, with the potential for crawler lanes on the steeper grades.

b) Three interchanges as follows:

   i. Warkworth Interchange, to tie-in with the Pūhoi to Warkworth section of the State Highway and provide a connection to the northern outskirts of Warkworth.

   ii. Wellsford Interchange, located at Wayby Valley Road to provide access to Wellsford and eastern communities including Tomarata and Mangawhai.

   iii. Te Hana Interchange, located at Mangawhai Road to provide access to Te Hana, Wellsford and communities including Port Albert, Tomarata and Mangawhai.

c) Twin bore tunnels under Kraack Road, each serving one direction, which are approximately 850 metres long and approximately 180 metres below ground level at the deepest point.

d) A series of steep cut and fills through the forestry area to the west of the existing SH1 within the Dome Valley and other areas of cut and fill along the remainder of the Project.

e) A viaduct (or twin structures) approximately 485 metres long, to span over the existing SH1 and the Hōteo River.

f) A tie in to existing SH1 in the vicinity of Maeneene Road, including a bridge over Maeneene Stream.

g) Changes to local roads:

    i. Maintaining local road connections through grade separation (where one road is over or under the other). The Indicative Alignment passes over Woodcocks Road, Wayby Valley Road, Whangaripo Valley Road, Silver Hill Road, Mangawhai Road and Maeneene Road. The Indicative Alignment passes under Kaipara Flats Road, Rustybrook Road and Farmers Lime Road.

    ii. Realignment of sections of Wyllie Road, Carran Road, Kaipara Flats Road, Phillips Road, Wayby Valley Road, Mangawhai Road, Vipond Road, Maeneene Road and Waimanu Road.

    iii. Closing sections of Phillips Road, Robertson Road, Vipond Road and unformed road affected by the Project.

h) Associated works including bridges, culverts, stormwater management systems, soil disposal sites, signage, lighting at interchanges, landscaping, realignment of access points to local roads, and maintenance facilities.

i) Construction activities, including construction yards, lay down areas and establishment of construction access and haul roads.

For description and assessment purposes in this report, the Project has been divided into the following areas (as shown in Figure 1 below):

a) Hōteo South: From the southern extent of the Project at Warkworth to the Hōteo River

b) Hōteo North: Hōteo River to the northern tie in with existing SH1 near Maeneene Road.

For construction purposes, the Hōteo South section is divided into two subsections being:

- South – from the southern tie in with P-Wk to the northern tunnel portals; and
- Central – from the northern tunnel portals to the Hōteo River.

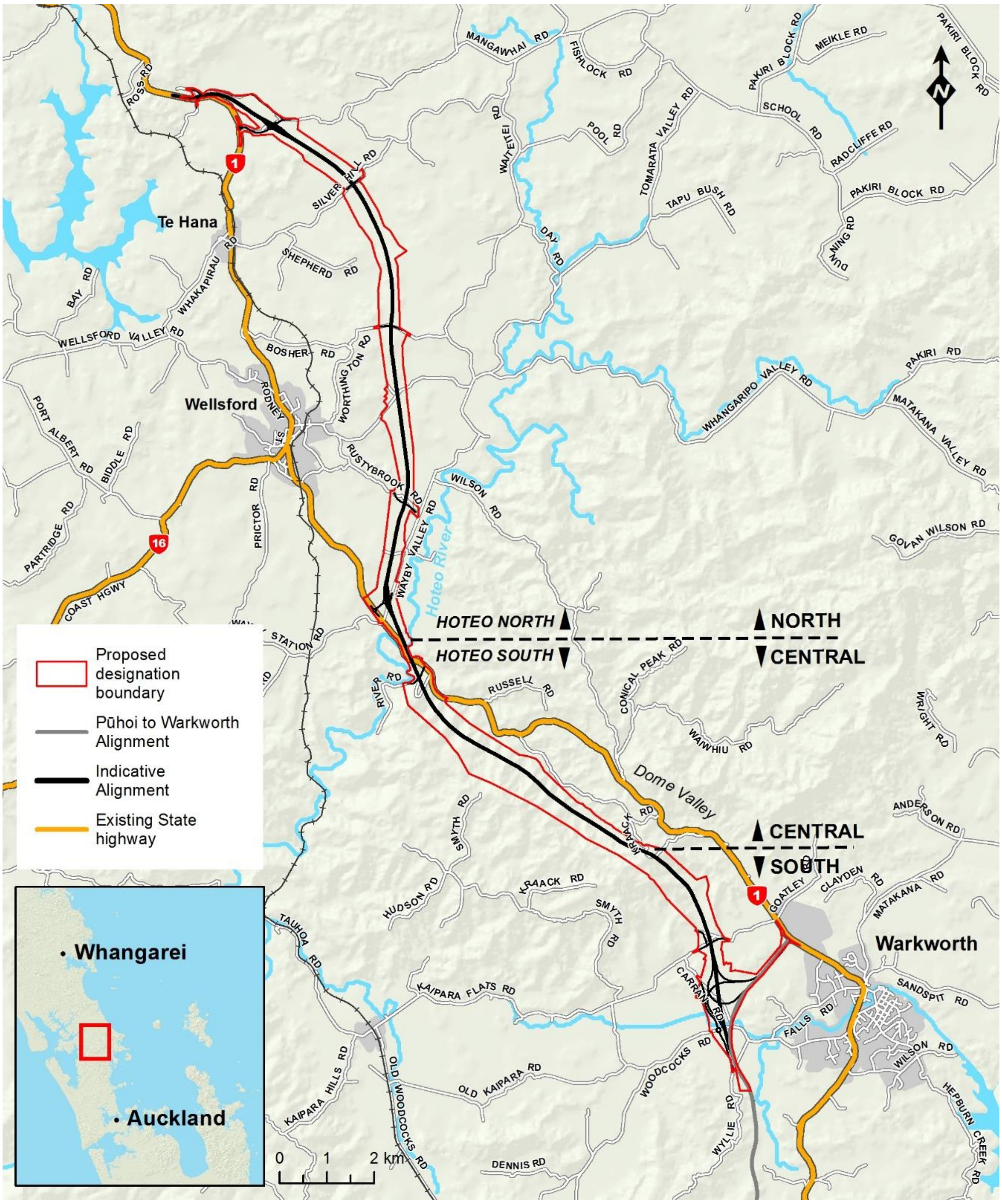

Figure 1 – Project Area

The Indicative Alignment shown on the Project drawings is a preliminary alignment for a state highway that could be constructed within the proposed designation boundary. The Indicative Alignment has been prepared for assessment purposes, and to indicate what the final design of the Project may look like. The final alignment for the Project (including the design and location of associated works including bridges, culverts, stormwater management systems, soil disposal sites, signage, lighting at interchanges, landscaping, realignment of access points to local roads, and maintenance facilities), will be refined and confirmed at the detailed design stage.

A full description of the Project including its design, construction and operation is provided in Section 4: Description of the Project and Section 5: Construction of the AEE contained in Volume 1 and shown on the Drawings in Volume 3.

1.3 Purpose and scope of this report

The purpose of this report is to:

a) Describe current groundwater conditions in the existing environment;

b) Assess the effects of the Project on groundwater; and

c) Identify measures to avoid, remedy or mitigate adverse effects on the groundwater environment.

The scope of the hydrogeology (groundwater) assessment included:

a) Providing a description of the existing environment, in particular the existing geology and hydrogeological conditions and groundwater users;

b) Undertaking groundwater modelling of proposed cuts and tunnels in order to determine the potential for any effects of the Project on groundwater; and

c) Recommending mitigation measures to be employed during the construction, operation and maintenance of the Project to minimise any potential effects on groundwater.

Note: the scope of this report is limited to groundwater effects and does not include any assessment of potential secondary effects such as settlement as a result of potential groundwater drawdown. Settlement is discussed in Section 9 of the AEE.

2 ASSESSMENT METHODOLOGY

Assessment methodology summary

The methodology used for the hydrogeological assessment is summarised as follows:

- Desktop study to determine existing groundwater levels, current groundwater use and abstraction and groundwater/surface water interfaces;
- Site visit to several wetland areas on Phillips Road to assess groundwater interaction;
- Exploratory drilling;
- Review of core drilling and geological logging undertaken by the Project team;
- Piezometer installation;
- Groundwater level recording;
- Hydraulic testing in some boreholes to estimate aquifer hydraulic conductivity;
- 2 dimensional (2D) groundwater model development; and
- Analytical assessment to assess potential groundwater impacts.

2.1 Summary of methodology

We completed an initial desktop study to obtain site specific geological and hydrogeological data for the Project, followed by a field investigation programme undertaken between April and September 2017. The scope of the field investigation included:

- Drilling 28 boreholes vertically, and 6 boreholes drilled inclined at 65 degrees for fault orientation purposes;
- Geotechnical testing (standard penetration tests) in the vertical boreholes;
- Installation of piezometers in 22 boreholes for recording groundwater levels (both single and nested standpipe piezometers, as well as vibrating wire piezometers);
- Regular monitoring of groundwater levels over time; and
- Aquifer hydraulic testing, i.e. packer (Lugeon) testing.

Each of these aspects is discussed in further detail in the following sections. In conjunction with the existing environment information presented in Section 3, we used this information to construct two dimensional groundwater models for areas in the vicinity of the proposed cuts and the tunnels, with the results used as the basis for the assessment of effects presented in Section 4.

2.2 Desktop study

2.2.1 Groundwater levels

We identified two sources of desktop information as being most applicable for existing groundwater levels within the Project Area. These are as follows:

- *Borehole information from Auckland Council* - An indication of groundwater levels in the vicinity of the Project Area was obtained by the Hydrogeology team from borehole records provided by Auckland Council. We have focused on the bores within 2 km of the centreline of the Indicative Alignment. Given the anticipated low permeability of the sub-surface materials (and hence the limited potential extent of drawdown), we considered it very unlikely that bores at greater distances will experience any groundwater impacts. The borehole information collated is presented and discussed in the existing environment section (Sections 3.4 and 3.5).

- *Borehole information from the Pūhoi to Warkworth project* – We compiled the information collected from the 28 boreholes drilled for the Hydrogeology Assessment Report for Pūhoi to Warkworth (Further North, 2013) to provide an indication of groundwater levels along the Indicative Alignment. The data collated is presented in the existing environment section of this report (Sections 3.4 and 3.5).

2.2.2 Groundwater use and abstraction

We assessed potential groundwater use in the Project Area from the borehole records obtained from Auckland Council. We acknowledge that there are many boreholes located outside 2 km from the centreline of the Indicative Alignment. However, this report focuses on the bores within 2 km as it is very unlikely that bores at greater distances will experience any groundwater impacts given the low permeability of the geological units.

The data collated is presented in the existing environment section of this report (Section 3), while Section 4 of this report discusses the potential groundwater effects of the Project in detail.

2.2.3 Groundwater/surface interaction

We completed a desktop review of geological long sections and interpolated groundwater levels along the Indicative Alignment to determine any potential stream and spring locations that have the potential to be affected by the Project. In addition, we completed a review of the Ecological Assessment Report completed for this Project to review any wetland features identified within the proposed designation boundary that also need to be assessed as part of the groundwater assessment. We visited wetlands 17A -24, at 89D Phillips Road (located in the upper Kourawhero catchment between chainage 46600 and 47200 shown on the long sections in Drawing Set: Ground Water Drawings (Volume 3 of the AEE)) on 10 November 2017 in order to determine the level of groundwater sourcing these features. An overview of this information is provided in Section 3.6, with the potential impact of the Project on these identified features discussed in Section 4.

2.3 Exploratory drilling

McMillan Drilling Group drilled a total of 34 boreholes as part of the current phase of the Project between April and September 2017 for both geotechnical and hydrogeological investigation purposes. We helped select each borehole location together with the geotechnical staff to provide the most relevant geological and hydrogeological information. Specific information regarding the drilling program is provided in the Geotechnical Factual Report.

McMillan drilled the boreholes to depths of between 15.0 m and 202.5 mBGL. A summary of the borehole locations and construction details is presented in Appendix A to this report (Table 5). The results of the exploratory drilling with relevance to the hydrogeology of the Project Area are discussed in the existing environment section (Section 3.2).

2.4 Piezometer construction

A piezometer is a small-diameter observation well used to measure the hydraulic head of groundwater in aquifers. Piezometers were installed in 22 boreholes according to specifications and specific details as described in Appendix B to this report.

In summary, the piezometers comprise open standpipes (PVC pipes installed vertically), which allow access for manual groundwater measurements with an electronic tape measuring device (dipper). Each piezometer has a short screen and filter zone that targets a point in the aquifer where hydraulic head is of interest (e.g. bottom of the proposed cut). Eleven of these piezometers were nested, which means that multiple piezometers were installed at variable depths in the one borehole, to allow measurement of groundwater pressures at different levels within the aquifer and hence an assessment of vertical pressure gradients.

Details of groundwater level measurements in the piezometers are discussed in the existing environment section (Section 3.5).

2.5 Groundwater levels

Groundwater monitoring was carried out by the geotechnical team following the installation and development of the piezometers. Multiple groundwater level measurements collected over time are important because this provides an understanding of groundwater level recovery following drilling (this process can take some time in the low permeability units of the Pakiri Formation and Northland Allochthon), as well as groundwater level trends over time (i.e. seasonal variation). Groundwater measurements have been carried out using the following techniques:

- Manually “dipping” the groundwater level with a dip meter (undertaken in 19 piezometers);
- Continuous monitoring (60 min interval) of groundwater levels using vibrating wire piezometers (undertaken in BH1005 and BH1008); and
- Continuous monitoring (30 min interval) using a pressure transducer in BH1004, where artesian heads were consistently higher than the piezometer upstand.

The data collected during this period is presented in Appendix C of this report, and the results are discussed in the existing environment section (Section 3.5).

2.6 Aquifer hydraulic testing

Packer (Lugeon) testing was undertaken on BH1006 and BH1042 to provide information regarding the permeability of fracture zones identified during drilling, as well as different units of geology. Lugeon tests are conducted in order to isolate specific sections of bedrock within a borehole to allow the vertical distribution of hydraulic conductivity to be measured, specifically focussing on targeted fracture zones. During the tests, water is injected at specific pressure 'steps' and the resulting pressure is recorded when the flow has reached a quasi-steady state condition. The steps are used to 'ramp' up and down through the expected pressure range.

During drilling of BH1006, fractured rock was identified in several areas through drilling, including between 154 and 163 mBGL, 175-186 mBGL and 191-194 mBGL, with example bore photos shown in Figure 2. These fractures were all located below the groundwater table, and as such several packer tests were undertaken on this borehole.

Twelve tests were completed on BH1042 in zones of identified fractures (between 115.5 - 118.5 mBGL and 155-158 mBGL), as well as zones of massive sandstone, massive gritstone, and interbedded siltstone/sandstone units. However, due to issues with test setup and equipment during some of these tests, only 6 tests could be analysed. The information obtained through these tests provided an understanding of the permeability of the units tested which was sufficient for the purposes of a robust assessment.

The data was analysed using the Lugeon testing analysis by Hvorslev (1951), with the results outlined in Appendix D.

Figure 2 – BH1006 Core from 154.5 to 157.5 m; 175.5 to 179.6 and 191.3 to 194.3 mBGL showing Pakiri Formation.

2.7 Groundwater modelling

We completed two dimensional (2D) groundwater modelling to assess the potential impacts anticipated to result from cuts/excavations along the Indicative Alignment and the effects of the proposed tunnels. We do not expect groundwater impacts in fill areas as the drainage engineering works will prevent groundwater mounding (rise), hence we have not assessed this effect with groundwater modelling.

2.7.1 Modelling of proposed cuts along Indicative Alignment

The geological units affected by the Project (including Pakiri Formation and Northland Allochthon) are described in Section 3. We completed a review of the major cuts (cuts in excess of 20 m height in Pakiri Formation and in excess of 10 m height in Northland Allochthon) along the Indicative Alignment to determine which cuts were required to be assessed for potential groundwater drawdown. The depth of cuts was assessed in relation to the inferred regional groundwater level, as shown on the long sections in the Ground Water Drawing set (Volume 3 of the AEE). Overall, we assessed seven of the 21 major cuts along the Indicative Alignment, as outlined in Table 1.

Table 1 – Major cut slopes along the Indicative Alignment

Chainage	Geological Unit	Max cut depth (mBGL)	Modelled in Groundwater Assessment? [Reasoning]
Hōteo South			
45890 – 46120	Pakiri Formation	26	No [Regional groundwater level below the bottom of cut]
45430 – 45530	Pakiri Formation	31	No [Effects included within the tunnel modelling]
Hōteo North			
44410 – 44600	Pakiri Formation	31	No [Regional groundwater level below the bottom of cut]
42790 – 43120	Pakiri Formation	31	No [Regional groundwater level below the bottom of cut]
42490 – 42670	Pakiri Formation	28	No [Regional groundwater level below the bottom of cut]
41910 – 42320	Pakiri Formation	46	No [Regional groundwater level below the bottom of cut]
41300 – 41650	Pakiri Formation	27	Yes [Reference – 41500]

Chainage	Geological Unit	Max cut depth (mBGL)	Modelled in Groundwater Assessment? [Reasoning]
40550 – 40800	Pakiri Formation	34	No [Effects to be inferred from results on 40300 – 40550]
40300 – 40550	Pakiri Formation	39	Yes [Reference – 40400]
39850 – 40130	Pakiri Formation	55	Yes [Reference – 39900]
39470 – 39700	Pakiri Formation	30	No [Effects to be inferred from results on 39850 – 40130]
38870 – 39380	Pakiri Formation	43	Yes [Reference – 39200]
36230 – 36480	Northland Allochthon	18	No [Regional groundwater level below the bottom of cut]
34650 – 35000	Northland Allochthon	15	Yes [Reference – 34900]
32780 – 33380	Northland Allochthon	28	Yes [Reference – 33100]
31630 – 32320	Northland Allochthon	25	No [Effects inferred from other Northland Allochthon cut models]
31150 – 31550	Northland Allochthon	26	No [Effects inferred from other Northland Allochthon cut models]
30100 – 30900	Northland Allochthon	12	No [Effects inferred from other Northland Allochthon cut models]
29750 – 30100	Northland Allochthon	14	No [Effects inferred from other Northland Allochthon cut models]
28000 – 28250	Northland Allochthon	12	No [Regional groundwater level below the bottom of cut]
26700 – 27070	Northland Allochthon	34	Yes [Reference – 26900]

We modelled seepage throughout the seven cross sections identified in Table 1 using the Seep/W software package (Geoslope software package suite). We selected this software because it is able to model unsaturated/saturated water flow using a finite element approach through the selected Indicative Alignment cross sections.

Within the model, seepage into the excavated section occurs when the groundwater level is higher than the excavation invert or when precipitation seeps through the unsaturated zone into the excavated area. In addition, this process could result in drawdown (a reduction in the groundwater level) away from the excavation area, as a consequence of the seepage. Consequently, the outputs of the models were used to assess the likely effects on groundwater levels (e.g. drawdown) in the immediate vicinity of the Indicative Alignment.

Two types of model were created at each cross section: steady-state and transient. The steady-state models represent existing groundwater conditions, whereas the transient models forecast the change in groundwater conditions due to the proposed excavation. Steady-state models make use of constant head boundaries at the extents of the models, and do not include a seepage boundary (e.g. the excavation is inactive). On the other hand, the transient models run for 30 days to represent an approximate duration of excavation. As such, the transient models do not use constant head boundaries (e.g. to adequately represent groundwater drawdown), and incorporate a seepage boundary along the walls of the excavated area to activate the excavation. Once the seepage volumes were calculated, groundwater drawdown was calculated using the Theis (1937) Forward Solution.

Specific details (e.g. input parameters and results) for each of the cut models are presented in Appendix E, while the results of the modelling are discussed in the assessment of effects section of this report (Section 4).

2.7.2 Modelling of proposed tunnels

We also modelled the proposed tunnel component of the Indicative Alignment using numerous 2D seepage models and the computer software Seep/W. These models provide the water volume and influx rates that could potentially seep through the tunnel walls as the tunnels are excavated, which were then used to calculate groundwater drawdown effects in the vicinity of the tunnels.

For this modelling, the tunnel was separated into eight individual Seep/W models, with each model covering a 100 m interval of tunnel. Each of the model domains was determined by extending the model from the midpoint of the tunnel to the high or low point of the surrounding catchment divide.

The model was set up with the following assumptions around tunnel construction (which are very conservative, allowing for a “worst case” scenario). After the Northbound tunnel has been excavated, the tunnel will be lined with a very low permeability membrane, which will restrict water flux into the tunnel. Immediately after the Northbound tunnel is finished, the Southbound tunnel will commence excavation along the same model cross sections as the Northbound tunnel. After the Southbound tunnel is completed and lined, the model run continued for one year after tunnel completion so that water recovery could be modelled.

All of the models are set with steady-state conditions to define the static water level by applying constant head boundaries, and then the models transition to transient conditions at the start of the excavation phase. When the tunnel is being excavated, the constant head boundaries are removed and a potential seepage boundary is applied to the area of excavation.

The modelled groundwater inflows outlined above were used to calculate the potential groundwater drawdown as a result of the tunnel excavation. The drawdown was calculated using the Theis (1937) Forward Solution implemented in Aquifer Test.

Specific details (e.g. input parameters, tunnel construction assumptions and results) about the tunnel modelling are presented in Appendix F, while the results of the modelling are discussed in the assessment of effects section (Section 4).

3 EXISTING ENVIRONMENT

Existing environment summary

Several contrasting hydrogeological regimes are found within the Project Area and are strongly influenced by the underlying geological units.

The Project Area is predominately underlain by sedimentary rocks of the Waitemata Group south of the Hōteo River, and Northland Allochthon rocks to the north of the Hōteo River.

The Waitemata Group rocks comprise regular alternating layers (beds) of very weak to moderately strong volcaniclastic sandstone and siltstone of the Pakiri Formation. The Pakiri Formation forms the majority of the steep rugged topography found in the forestry block (Matariki Forest) between Phillips Road and SH1 at Hōteo River Bridge.

The Northland Allochthon rocks generally comprise undifferentiated rocks of the Mangakahia Complex (primarily sheared non calcareous mudstone) and the Motatau Complex (comprising both Mahurangi Limestone and calcareous Mudstone).

The majority of valleys, including the Warkworth, Wayby, Wellsford and Te Hana valleys, have been infilled with deep, soft estuarine and alluvial sediments comprising clay, silt, peat and fine sand.

Ground conditions encountered during drilling and through other exploratory geotechnical investigations match with these geological units.

Permeability of the Northern Allochton is typically very low, and groundwater is typically observed as a line of seepage or minor springs at geological boundaries between units within the formation.

Groundwater in the Pakiri Formation is strongly influenced by incised valleys, with groundwater typically being elevated along ridgelines and depressed along valley sides and floors. Perched and leaky water tables may be present at higher elevations than the local water table in discrete localities, reflecting the interbedded nature of the sandstone/siltstone formation and typically low permeability of the siltstones providing the basal layer for perching.

Recent alluvium within river valleys and estuarine embayments comprises shallow aquifers, with limited groundwater potential.

We assessed the deep groundwater recharge rate for hard rock in the area as 50mm/year, or approximately 3.3% of annual rainfall.

Regional borehole database records from Auckland Council showed a total of 119 boreholes drilled within 2 km of the centreline of the Indicative Alignment. The majority of these bores have been drilled in the vicinity of Warkworth. This area has been identified as the Mahurangi Waitemata High-Use Aquifer Management Area within the AUP(OP).

The piezometers installed for the Project recorded the depth to groundwater within each formation as follows:

- Alluvium: between 0.05 and 0.5 mBGL;
- Pakiri formation: between 1.6 and 125.9 mBGL; and

- Northland Allochthon: between -0.1 (artesian) and 17.8 mBGL.

We obtained limited depth to groundwater information across the Project Area, meaning a piezometric surface could not be generated. However, we assume that groundwater flow directions will display the following characteristics:

- Groundwater flow will follow surface drainage pathways and will change direction as the topographical control changes; and
- Groundwater levels will represent a subdued expression of the topography.

Groundwater/surface water interaction is present in the form of seeps and springs.

3.1 Regional geological units

A detailed description of the geology in the Project Area is presented in Jacobs/GHD (2018) Geotechnical Engineering Appraisal Report, and has been summarised below for the purposes of conceptualisation of the groundwater system. Figure 3 presents an illustration of the regional geology in the Project Area.

The Project Area is predominantly underlain by sedimentary rocks of the Waitemata Group, south of the Hōteo River and Northland Allochthon rocks to the north of the Hōteo River.

The Tertiary age (1.8 to 65 million years ago) Waitemata Group rocks comprise regular alternating layers (beds) of very weak to moderately strong volcaniclastic (clasts of rock of volcanic origin) sandstone and siltstone of the Pakiri Formation. The Pakiri Formation forms the majority of the steep rugged topography found in the forestry block (Matariki Forest) between Phillips Road and SH1 at Hōteo River Bridge. Occasional harder beds of strong coarse-grained andestitic conglomerates and submarine mass flow deposits of re-welded volcanic debris (coarse volcaniclastic grit/conglomerate) are also present within the Pakiri Formation.

The Northland Allochthon rocks are older than the Waitemata Group, and were initially formed about 21 to >65 million years ago. These rocks were transported and emplaced towards the south or south west into the deepening Waitemata Basin from approximately 21 million years ago by a complex process of thrust faulting and submarine land sliding at the same time as the Pakiri Formation was being deposited. Consequently, the Northland Allochthon rocks are severely deformed, crushed and sheared (Winkler, 2003). The above mentioned geological processes have resulted in a complex arrangement and juxtaposition of Waitemata Group rocks with large lenses or disrupted slices of significantly weaker, highly sheared mudstones, siltstones, sandstones and limestones of the Northland Allochthon (Isaac et al., 1994).

The Northland Allochthon rocks generally comprise undifferentiated rocks of the Mangakahia Complex (primarily sheared non calcareous mudstone) and the Motatau Complex (comprising both Mahurangi Limestone and calcareous Mudstone).

Over time, major rivers have eroded deep valleys into the landscape, many of which were 'drowned' and infilled with sediments as a result of sea level rises since the last glaciation. These drowned valleys dominate the east coast of Northland, including the Warkworth, Wayby, Wellsford and Te Hana valleys. These valleys are infilled with deep, soft estuarine and alluvial sediments, often with terrace levels representing previous, higher sea levels or lower land levels (Ballance & Williams, 1992).

Colluvium (sediment resulting from slope movement or downhill creep) is present on many hillslopes and has accumulated near the base of many slopes. This slope movement is a natural process of landscape evolution but has been exacerbated as a result of human impacts on the landscape since the 1820s, including the changing land-use from kauri forest to scrub, pasture, or urban land (Ballance & Williams, 1992).

3.1.1 Exploratory drilling results

The ground conditions encountered during drilling for the Project, as well as those identified through geomorphological mapping, cone penetration testing and test pit investigation methods, match with the regional geological units outlined above. For example, the ground predominantly underlain by sedimentary rocks of the Waitemata Group, south of the Hōteo River and the Northland Allochthon rocks to the north of the Hōteo River.

Geological long sections along the Indicative Alignment have been constructed by the geotechnical team using the collected borehole and groundwater level information collected for the Project. These sections can be found in the Ground Water Drawing Set (Volume 3 of the AEE) as well as a detailed discussion found in Jacobs/GHD (2018) Geotechnical Engineering Appraisal Report with the long sections referenced as GI011 to GI020.

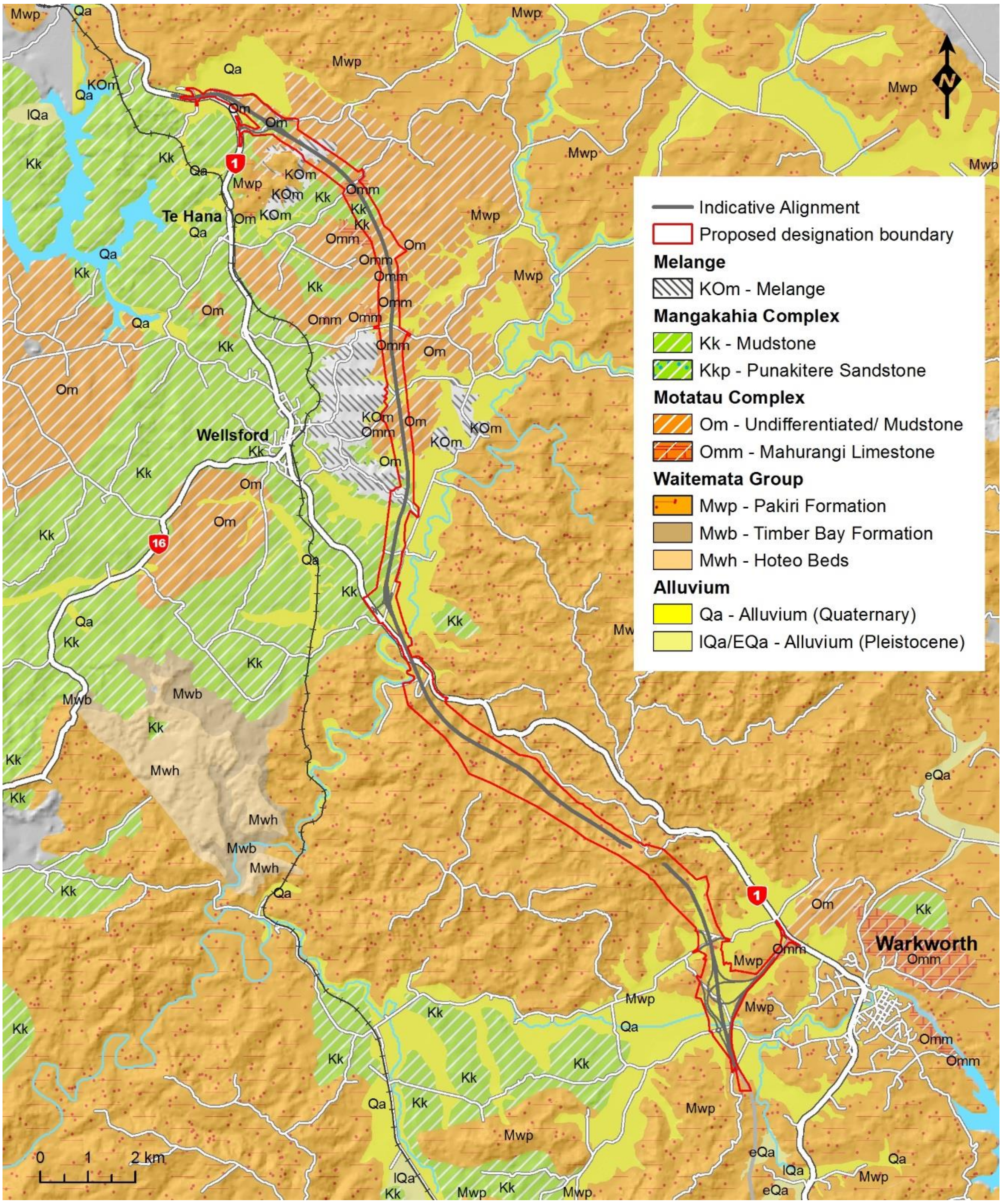

Figure 3 – Regional geology

3.2 Regional groundwater

The hard rock geology and complex geological structure described above has resulted in typically low yielding aquifers in the Project Area (as discussed in detail below). The exceptions are localised zones of higher yields associated with faulting (e.g. Watercare's Sanderson Road bore for Warkworth township located within the Pakiri Formation) and the localised more gravelly components of the generally silty shallow alluvial deposits that infill the valleys.

The hydrogeological regimes of the main geological units encountered within the proposed designation boundary (the Waitemata Group, Northern Allochthon and Tauranga Group) are fundamentally different and are discussed separately for each geological unit. In accordance with the descriptions, Table 2 provides a summary of indicative hydraulic conductivity and storage characteristics for these units, taken from work compiled as part of the Waterview Connection project for the Transport Agency (Tūhono Consortium, 2011) and the Pūhoi to Warkworth hydrogeological assessment (Further North, 2013).

Table 2 – Summary of aquifer hydraulic parameters

Unit	Hydraulic Conductivity K_h (m/s) range	Vertical Anisotropy K_h:K_y ratio	Storativity S_s (m^{-1}) range	Specific Yield S_y
Northland Allochthon	10^{-8}	10	$9x10^{-6}$	0.01
Fresh Waitemata Group	10^{-8} to 10^{-7}	40 to 250	$9x10^{-6}$	0.01
Weathered Waitemata Group	10^{-9} to 10^{-7}	>10	10^{-3}	0.01
Tauranga Group Alluvium	10^{-8} to 10^{-7}	>10	10^{-3}	0.01
Note: K_h – horizontal hydraulic conductivity; K_v – vertical hydraulic conductivity; Vertical anisotropy – flow preferentially flows horizontality rather than vertically.				

3.2.1 Northland Allochthon

Northland Allochthon mudstone and limestone rock can display highly variable and complex hydrogeological conditions relative to various response zone depths. The weathered soils and rocks are highly fissured and fractured but typically comprise poor to very poor permeability rocks with hydraulic conductivities (the ability of the water to transmit water) generally less than 10^{-7} m/s. To place this permeability in context, clean gravels typically have a permeability of 10^{-1} m/s and concrete is 10^{-10} m/s or lower. The ability of the Northland Allochthon aquifer to release groundwater (the specific storage characteristics) is typically low ($9x10^{-6}$ m^{-1}) (Table 2).

Both primary permeability (flow through the bulk unit materials) and secondary permeability (flow along bedding planes and/or fractures) in Northland Allochthon rocks is typically poor due to secondary infill through either weathering products (clay) or precipitation products (limonite or calcite). However, localised zones of high tertiary (conduit) porosity have been experienced in water supply boreholes in the Warkworth area as a result of faulting.

The weathering profile and transition zone within many Northland Allochthon lithologies often act as confined aquifers with low hydraulic conductivity, but with significant elevated pore water pressures.

Drainage from the Northland Allochthon rocks is typically observed as a line of seepage or minor springs at geological boundaries between units within the Northland Allochthon rocks; hence flow rates are typically very low (typically less than 1 L/s).

3.2.2 Waitemata Group (Pakiri Formation)

The Project Area south of the Hōteo River is predominantly underlain by sedimentary rocks of the Pakiri Formation of the Waitemata Group. Perched water tables[1] and leaky[2] water tables may be present and reflect the interbedded nature of the sandstones and siltstones of varying permeability.

Literature based values of hydraulic conductivity for sandstones and mudstones range from 10^{-10} to 10^{-6} m/s (Freeze and Cherry, 1979) and field testing in the Auckland area for the Waitemata Group indicates that practical results generally fall within this published range.

Studies in the Auckland region, such as the work compiled as part of the Waterview Connection project (Tūhono Consortium, 2011) and the Pūhoi to Warkworth hydrogeological assessment (Further North, 2013) presented measured hydraulic conductivities for weathered Waitemata Group materials in the range of 10^{-9} to 10^{-7} m/s, with marginally higher, but still low overall hydraulic conductivity of 10^{-8} to 10^{-7} m/s for unweathered Waitemata Group rocks.

The strongly bedded sequence of thin (typically 0.1 to 0.5 m) alternating siltstone and fine sandstone give rise to vertical anisotropy in hydraulic conductivity (flow preferentially flows horizontality rather than vertically), with horizontal hydraulic conductivity typically 40 to 250 times greater than vertical hydraulic conductivity (Tūhono Consortium, 2011).

As part of our field assessment, Lugeon testing was undertaken on fractures and specific geology zones in two bores (BH1004 and BH1042). Specific details of the testing are outlined in Section 2.6 and Appendix B. The results indicate that the hydraulic properties of the geology in the vicinity of BH1006 and BH1042 are similar to the parameters encountered previously, as shown in Table 2. These results were used to determine the input parameters for the 2D modelling (Section 2.7) completed for the assessment of effects.

3.2.3 Tauranga Group Alluvium

Recent Tauranga Group alluvium, found within river valleys and estuarine embayments within the Warkworth to Wellsford area, comprises shallow aquifers that have limited potential to supply good quality or high yields of groundwater. Hydraulic conductivity of this material ranges from 10^{-8} to 10^{-7} m/s, with the higher end providing high groundwater yields (potentially greater than 20 L/s). However, the lensoidal[3] nature and limited lateral extent of the materials, shallow depth and susceptibility to surface contamination limit use of these aquifers.

3.3 Aquifer recharge

Aquifer recharge is the flow or infiltration of water into the saturated zone of the subsurface profile, and can be from rainfall or from other surface water movement (such as baseflow

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1 A perched groundwater table (or perched aquifer) is a groundwater level within an aquifer that occurs above the regional groundwater table (i.e. in the unsaturated zone). This occurs when there is an impermeable layer of rock or sediment (aquiclude), or relatively impermeable layer (aquitard) above the main water table/aquifer but below the surface of the land. If a perched aquifer's flow intersects the ground surface, on a valley side for example, the water is discharged as a spring.

2 A leaky water table or aquifer is an aquifer which receives groundwater from an overlying aquitard.

3 Thin oval lens or eclipse shaped deposit.

recharge from rivers and surface water bodies). Recharge is controlled by a number of variables, the main ones being rainfall, evaporation, topography, soil type, geology and landuse.

Aquifer recharge was calculated for this assessment for use within the 2D groundwater modelling for cuts and tunnels along the Indicative Alignment. Recharge was calculated using the Warkworth Composite Record (as stated in the Pūhoi to Warkworth Water Assessment Factual Report (Further North, 2013)), as it has the longest (91 years) record. Over the length of the record received from Auckland Council, the average annual rainfall was 1,505 mm/year.

We focussed on deep recharge to the Pakiri Formation and Northern Allochthon, which are the primary rock types in the area. Recharge to the Pakiri Formation and Northern Allochthon rocks is typically only a small proportion of the water balance due to a combination of generally steep topography and low infiltration capacity of the overlying soils; and high potential evaporation (mean annual pan evaporation is approximately 1,300 mm/year). These features promote high surface runoff and soil evaporation, and suppress groundwater recharge.

A deep groundwater recharge rate for hard rock in the area is considered to be 50 mm/year (or approximately 3.3% of annual rainfall). Auckland Council indicates recharge in the Pakiri Formation materials ranges from 2 to 4% of mean annual rainfall (pers comm. Kelset, 2013 working on behalf of Auckland Council). This value was used in the 2D groundwater modelling outlined in Section 2.7, and Appendix E and F.

3.4 Existing groundwater boreholes, use and abstraction

The borehole database records from Auckland Council showed a total of 119 boreholes drilled within 2 km of the centreline of the Indicative Alignment. The locations of the Auckland Council registered boreholes are shown in Figure 4. It should be noted that there is the potential for additional bores to be located in the vicinity of the Indicative Alignment, as some bores may have been drilled but not registered with Auckland Council. Borehole depths (available for 69 boreholes only) range between 15 to 300 mBGL, with an average depth of 136 mBGL.

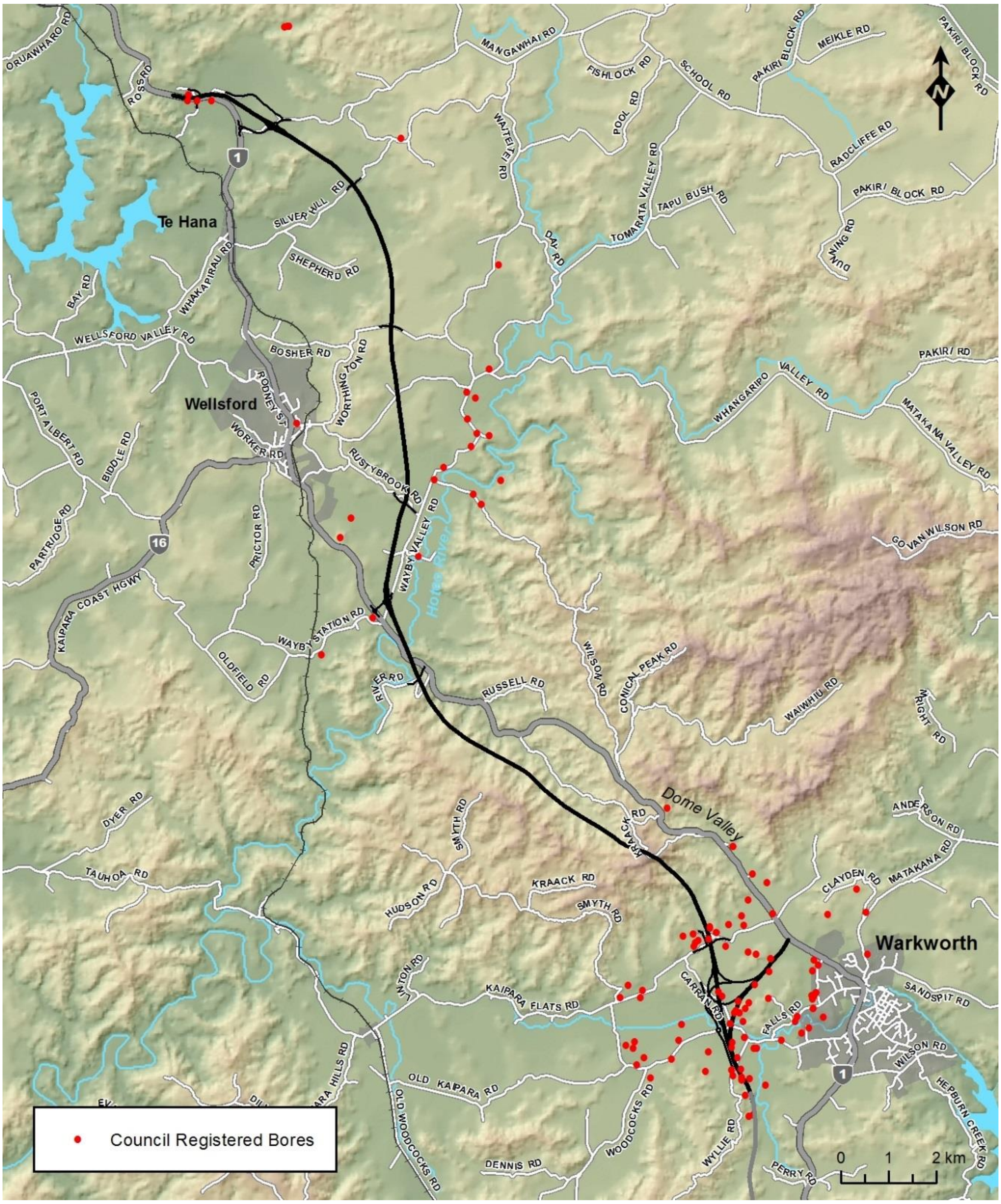

Figure 4 - Registered bores in the Auckland Council database within 2 km of the centreline of the Indicative Alignment.

The majority of these bores have been drilled in the vicinity of Warkworth. This area has been identified as the Mahurangi Waitemata High-Use Aquifer Management Area within the Auckland Unitary Plan (Operative in Part) and includes all rocks of the Waitemata Group but not the overlying Tauranga Group, Mahurangi Limestone or Mangakahia Complex. These boreholes are primarily tapping the Pakiri Formation, with no records of boreholes tapping the Northland Allochthon rocks.

The Auckland Council database states that the boreholes have been drilled primarily for either domestic/stock water supply purposes or as observation piezometers. As such, the bore diameters are variable and range between 50 to 300 mm, with a typical diameter of 100 mm.

Table 3 summarises the information on existing consented groundwater takes within the Project Area. There are currently 8 consented groundwater takes within the Project Area, with the majority of these consented abstractions located in the vicinity of Warkworth.

The allocations for the eight consented groundwater abstractions range between 35 and 4,320 m^3/day, with the total consented groundwater allocation being 5,335 m^3/day. The consented groundwater allocations are stated as being for industrial, irrigation or potable uses. The majority of the yields are low to very low, with the aquifers generally not being conducive within reasonable economic consideration for higher flows required for broad water supply or irrigation purposes. However, the exception is Watercare Services Ltd's municipal supply abstraction in Warkworth, which is consented to abstract groundwater at a rate of up to 50 L/s (4,320 m^3/day). This bore is extremely high yielding, having intersected a highly fractured zone associated with a local fault, and is considered atypical for the rock type and region.

The Auckland Unitary Plan (Operative in Part) states that water takes for an individual's reasonable domestic needs and existing lawful water takes for animal drinking water purposes are permitted, provided specific criteria are met. Permitted groundwater takes are not recorded within the Auckland Council database, however, consent is required to drill a bore. Due to the lack of information regarding the exact number and location of permitted takes within the Project Area, this level of allocation was not assessed in this study. However, the potential effect of the Project on all bores identified within the Auckland Council database has been considered in Section 4.3.

Table 3 – Existing groundwater consents within Project Area

Consent No.	Name	Allocation (m^3/day) [L/s]	Bore Depth (mBGL)	Expiry Date	Purpose
29233	Kiwi Flower Company	35 [0.41]	207	31/05/2023	Irrigation – Market Gardening
34117	Summerset Villages	60 [0.69]	180	31/12/2029	Water Supply
34119	Stockyard Holdings	60 [0.69]	180	31/12/2029	Water Supply
35620	Atlas Concrete	80 [0.93]	161	31/05/2029	Industrial
36585	Bio Marine Properties	100 [1.16]	NA	31/05/2029	Industrial
37251	North Albertland Community Water Supply Association	200 [2.31]	229	31/05/2023	Water Supply
40713	Southern Paprika	500 [5.79]	60	31/05/2029	Irrigation
44353	Watercare Services	4,320 [50.00]	199	04/03/2045	Water Supply

3.5 Groundwater levels

An understanding of groundwater levels, including depth to groundwater, seasonal fluctuations and vertical groundwater gradients is important to inform the assessment of effects from the Project. We have obtained this information from various sources, including the Auckland Council database, previous investigations in the region of the Indicative Alignment, as well as site specific information collected as part of the current investigations.

3.5.1 Depth to groundwater

Twenty-two piezometers were installed by McMillan Drilling Limited during the site specific investigation for the Project, with groundwater levels recorded via manual groundwater level dips, pressure transducer, and by vibrating wire piezometers. Static groundwater levels are shown in Table 6 in Appendix B, with plots of groundwater levels included in Appendix C. Static groundwater levels interpolated from data recorded in the piezometers are also shown on the Geological Longitudinal Sections included in Ground Water Drawing set, drawings GW-011 to GW-020 (Volume3 of the AEE).

The following paragraphs summarise the depth to groundwater from the piezometers by aquifer type.

Tauranga Group Alluvium

Two of the piezometers for this Project were installed within the alluvium, i.e. 1025 and 1027a. Groundwater levels in the alluvium ranged between 0.05 and 0.5 mBGL. These groundwater levels are similar to the range that we reported in the alluvium during the Pūhoi to Warkworth hydrogeological assessment (Further North, 2013), i.e. groundwater levels recorded as typically residing between 0.17 and 0.9 mBGL.

Insufficient groundwater level readings have been undertaken in piezometer 1025 to determine variations in groundwater levels over time. However, we expect that the levels would respond in a similar way to what we observed in the three piezometers in the Pūhoi to Warkworth hydrogeological assessment (Further North, 2013), given the similar geology. The groundwater levels were relatively sensitive to rainfall events and higher stream flows, which confirmed that the alluvium deposits are directly connected to surface processes.

Pakiri Formation

Groundwater levels in the Pakiri Formation (as recorded in 14 piezometers for the Project) are typically deeper and ranged between 1.6 and 125.9 mBGL. This range of groundwater levels within the Pakiri Formation is consistent with the information obtained from the Auckland Council database, with groundwater levels recorded ranging from 0.1 to 73.2 mBGL, with a median depth of 7.6 mBGL.

In contrast to the alluvium, groundwater levels in the Pakiri Formation have shown very little variation over time (as seen in the continuous groundwater level records for piezometers 1004b, 1005 a, b, c, and 1008b), and in many cases (e.g. 1005c and 1008) have continued to recover (decline) following drilling. In the case of piezometer 1004b, groundwater levels have continued to increase since drilling occurred. This increase is the result of the artesian conditions encountered within this bore and difficulties with completely sealing the top of the piezometer to ensure that no groundwater was leaking out of the casing.

None of the piezometers with continuous groundwater level recordings have shown any response to rainfall events that have occurred during the recording period. This lack of response indicates that the aquifer at these locations may be very low permeability and/or partially confined.

These findings are consistent with our findings from the Pūhoi to Warkworth hydrogeological assessment (Further North, 2013) from piezometers in similar geology.

In the strongly alternating sandstones and siltstones deposits of the Pakiri Formation rocks, perched groundwater tables are sometimes encountered above a low permeability siltstone bed. There are four potential examples of perched groundwater in the Project Area, as discussed in further detail in Section 3.5.2.

Northland Allochthon

Four piezometers were installed to record groundwater levels within the Northland Allochthon unit (i.e. 1026, 1027b, 1028 and 1032). Groundwater levels within this unit are generally shallow, with levels recorded ranging between -0.1 (artesian) and 17.8 mBGL. These groundwater levels are consistent with levels recorded for piezometers screened within the Northland Allochthon in the Pūhoi to Warkworth hydrogeological assessment (Further North, 2013).

3.5.2 Vertical groundwater gradients

Nine of the ten nested piezometers are located in the Pakiri Formation, with the remaining nested piezometer located within Northland Allochthon rocks. One of these piezometers (BH1040) lacked groundwater in the shallow piezometer, which suggests that the deeper piezometer represents the local groundwater table and no vertical pressure gradient prevailed within the profile sampled.

Two of the piezometers (1004, screened within the Pakiri Formation and 1027, screened in Northland Allochthon rocks) showed a significant strong and a small positive pressure gradient, respectively. The strong gradient in piezometer 1004 would indicate that this bore was drilled in a discharge area for the regional groundwater table. The small positive pressure in 1027 indicates that the underlying rock has a greater pressure head than the overlying alluvium, which advocates an upward flow potential.

In comparison, seven piezometers screened within the Pakiri Formation showed moderate to strong downward pressure gradients (Table 7 in Appendix B), which means that the shallow groundwater has a higher level than deep groundwater, as shown in Figure 5). This downward pressure gradient is typical of areas with elevated topographic relief and where the geological profile comprises layered low permeability rocks. This combination promotes horizontal seepage along rock layer interfaces, along with lesser rates of downward vertical leakage, resulting in the downward pressure gradients.

The horizontal seepage manifests at the surface on valley sides as seeps (generally higher up the profile) and springs (generally towards the valley floor). Excavations through the shallow groundwater profiles on valley sides may give rise to temporary groundwater discharge during the initial excavation, but the flow is unlikely to be sustained for longer than a few days due to the nature of the geology.

Groundwater levels in piezometers 1016, 1018 and 1019 (as shown in Figure 5) show that the levels in the bottom piezometer overlap or extend upwards past the base of the upper piezometer. This overlap tends to indicate (although is not totally conclusive due to the spacing of the screens) that the groundwater system is continosly saturated beneath the upper groundwater table.

Groundwater levels in the remaining four nested piezometers shown in Figure 5 would tend to indicate multiple perched water tables, which is consistent with our conceptualisation of the interbedded nature of the Pakiri Formation. There is, however, some doubt about shallow groundwater levels recorded in 1010 and 1015 as the measured groundwater was just above the piezometer base. From experience, condensation on the walls of the piezometers, which becomes more prevalent during the cooler winter months, can be mistakenly recorded as a water level by the electronic instrument used to dip the well. Further groundwater level monitoring will provide more information regarding the shallow groundwater levels in these piezometers and will inform detailed design.

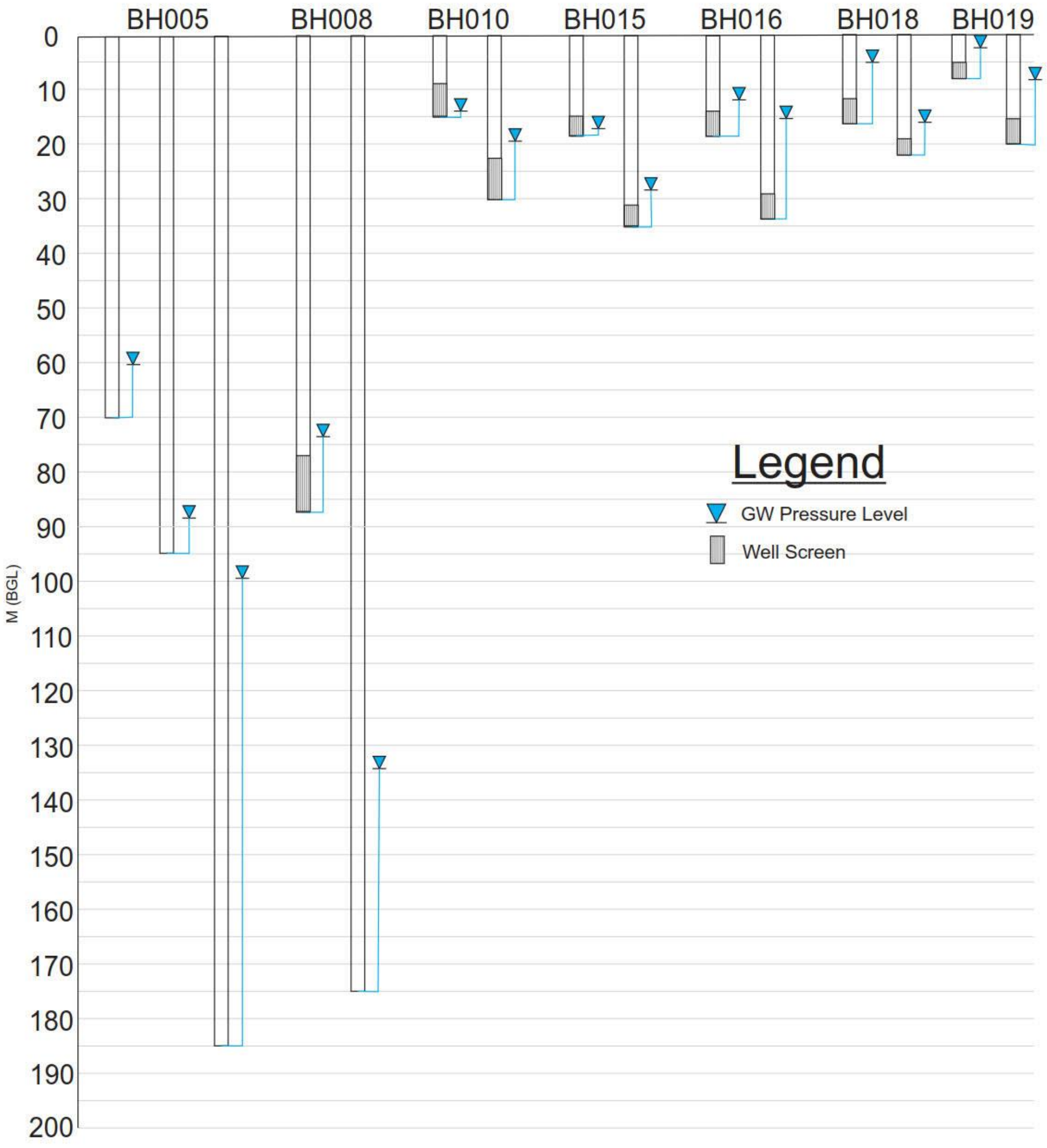

Figure 5 – Groundwater level differences in Pakiri Formation nested piezometers

3.5.3 Groundwater flow direction

Groundwater flow direction is typically defined through analysis of maps showing the piezometric surface, which is an imaginary surface of contour lines, with each contour line representing equal groundwater pressure level. Typically, a piezometric surface is generated from interpolation of groundwater levels measured in boreholes over a wide area.

Limited depth to groundwater information was obtained from the records received from Auckland Council across the Project Area, since 35 of the 41 bores with groundwater level information were located in the vicinity of Warkworth. As such, a piezometric surface could not be generated for the Project Area. However, given the similar geological units and topography of the Indicative Alignment to the Pūhoi to Warkworth project, we have assumed that the groundwater flow directions will broadly be consistent with those identified in the Pūhoi to Warkworth hydrogeological assessment (Further North, 2013), as follows:

- Groundwater flow will follow surface drainage pathways and will change direction rapidly as the topographical control changes.

- Groundwater levels will represent a subdued expression of the topography. Groundwater levels will be typically lower and close to the surface in the valleys' infill alluvium areas, while in the upland areas comprising Pakiri Formation and Northland Allochthon materials, groundwater levels are higher, albeit deeper (i.e. greater distance from the ground surface).

3.6 Groundwater/surface water interaction

It is important to understand the localised interaction between groundwater and surface water as potential changes in groundwater level or flow may affect surface water features such as streams/rivers, springs/seeps, ponds, wetlands, and drains.

In areas underlain by the Pakiri Formation and the Northern Allochthon, the topography is moderately steep to steep, with deeply incised valleys. In these areas, groundwater typically emerges at the base of slopes in the form of seeps, and along geological boundaries (sometimes partway up slopes) in the form of springs. These seepage areas are typically identified from the wetland type and/or green vegetation present year round (as shown by the example illustrated in Figure 6).

Some of these springs and seeps feed small streams, while in areas where alluvium has infilled the valleys, groundwater is responsible for the baseflow in the larger streams and rivers. This situation is the case for wetlands 17A – 24, as identified in the Ecology Assessment Report, at 89D Phillips Road. These wetlands are predominately surface water fed by the numerous streams flowing off the slopes to the north, however, many of these streams will be fed from springs/seeps high up in the catchment.

Figure 6 – Vegetation located at top of spring (dry)

4 ASSESSMENT OF EFFECTS

Assessment of effects summary

Our assessment of hydrogeological effects concluded the following:

- Drawdown from the proposed tunnel is confined to a narrow 500 m corridor parallel to the Indicative Alignment, with the majority of drawdown occurring within 250 m;
- Drawdown from the proposed cuts is confined to a narrow 230 m corridor parallel to the Indicative Alignment;
- There are only nine bores located within the proposed designation boundary. However, none of these bores are located within the calculated drawdown profiles. As such, there will be no effect on all but one of the groundwater users from the proposed construction and operation of the Project. The exception is Bore 386, which is currently located under a proposed fill area. However, we assume as the bore is located within the proposed designation boundary, this land (and the bore) will be purchased by the Transport Agency; and
- No streams were identified in the vicinity of the proposed cuts. Only one potential stream (gully) was identified within 200 m of the tunnel component of the Indicative Alignment. A worst case maximum flow reduction of 0.15 L/s was calculated for surface water in this gully feature. However, this gully is more likely to be a wet area (i.e. wet season groundwater seeps) rather than a permanent stream. As such, we consider the potential reduction in baseflow as a result of the Project, from a flow volume perspective, to be less than minor.

4.1 Introduction

The impact of the Project on groundwater will largely arise from deep excavations and tunnel construction below the regional groundwater table, which can impact on the natural groundwater regime in the following ways:

- Drawdown – groundwater drawdown and associated ground settlement that may have the potential to impact on existing structures and services;
- Surface water resources – reduction in groundwater levels that may affect stream baseflow regimes, and alter present inflows and outflows from springs, streams, rivers, ponds and wetlands; and
- Groundwater quantity – reduction in groundwater quantity (yield) for existing abstraction bores through the alteration of groundwater flow patterns.

The potential groundwater effects with regards to the Project construction and operational activities are divided into the following areas:

- Hōteo South: from the southern extent of the Project at Warkworth to Hōteo River; and

- Hōteo North: Hōteo River to the northern tie in with with existing SH1 near Maeneene Road.

4.2 Potential groundwater drawdown

Drawdown is the reduction in groundwater level resulting from any form of development or activity, for example, pumping from a borehole or drainage through an excavation. The magnitude and maximum extent of drawdown are important considerations as these factors define the potential severity and zone of impact from the activity, respectively.

We have assessed the drawdown for the proposed tunnel (located in the Hōteo South area) and at seven indicative cuts along the Indicative Alignment (all located in the Hōteo North area). Drawdown was assessed using Seep/W modelling and the Theis Forward Solution method as outlined in Section 2.7 and further described in Appendices F and G.

4.2.1 Hōteo South

Groundwater drawdown during construction has been calculated for the proposed tunnel section of the Indicative Alignment, as shown in Figure 7. It can be seen that the drawdown is relatively localised to the area surrounding the tunnels, with estimated drawdown of 0.5 m approximately 500 m from the alignment of the tunnels. Groundwater drawdown of any significance (i.e. say 5 m or greater) is constrained to within 250 m of the tunnels.

This constrained drawdown in the vicinity of the tunnels is typical of construction dewatering effects within low permeability materials. The implication is that there will be negligible impact on either existing groundwater users or groundwater dependent ecosystems outside of this area. This would also apply if the alignment of the proposed tunnels changes within the proposed designation boundary, as all of the geology in this area is consistent with that used in the modelling.

Groundwater drawdown has the potential to induce groundwater settlement in soft compressible sediments, such as alluvium and highly weathered rock or clay. The potential for settlement as a result of the indicative cuts is discussed in the Section 9 of the AEE.

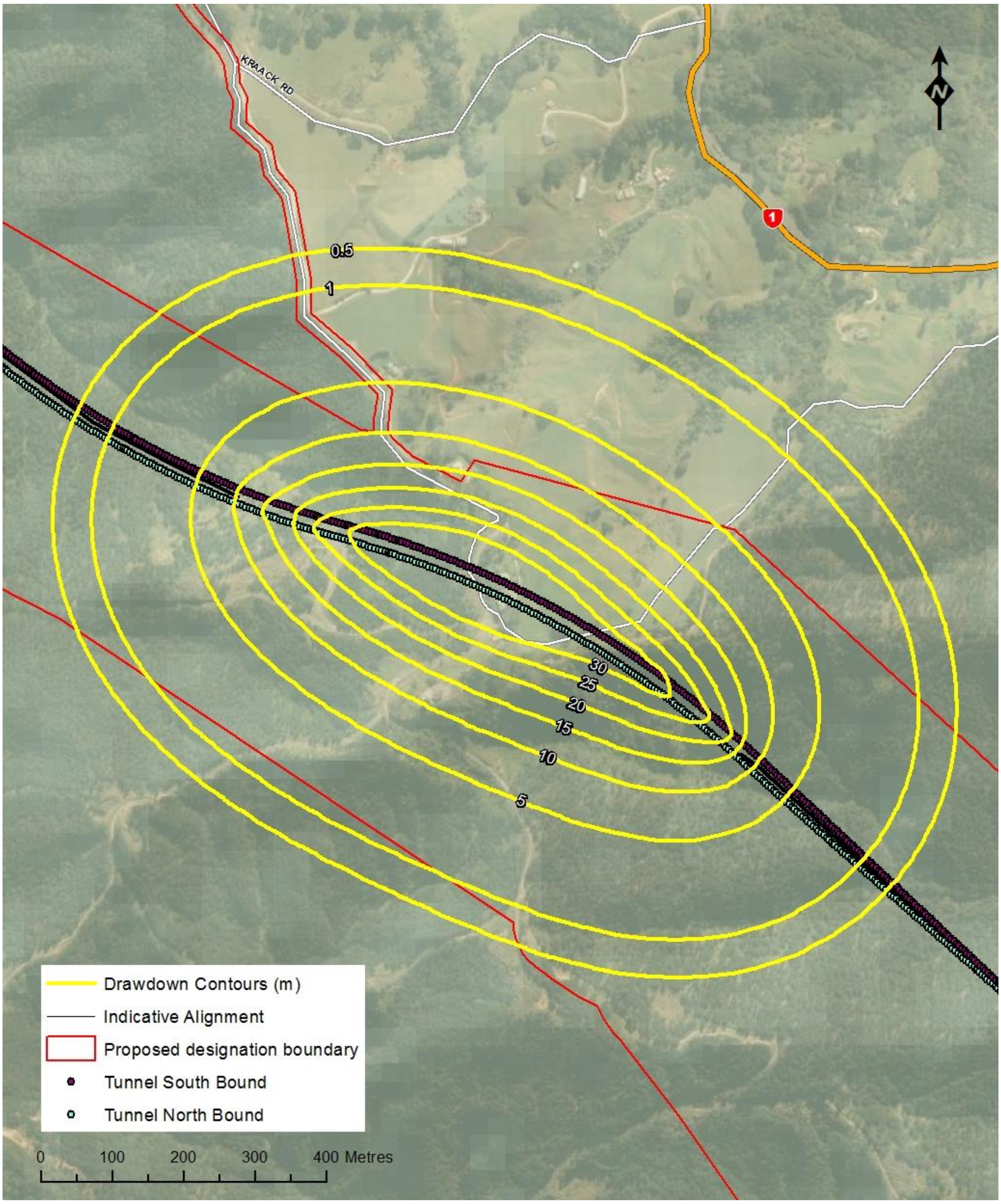

Figure 7 – Calculated drawdown cone from proposed tunnel excavation.

4.2.2 Hōteo North

The effects of seven indicative cuts along the Indicative Alignment are outlined in Table 4. From Table 4 it can be seen that drawdown is very localised to the areas of the cuts. The maximum extent of drawdown (which we have based on a value of 0.1 m of drawdown) is approximately 230 m from the centre of the Indicative Alignment. However, groundwater drawdown of any significance (i.e. 5 m or greater) is constrained to the immediate vicinity of the cut along the Indicative Alignment.

Once again, the relatively small lateral extent of drawdown is typical of construction dewatering effects within low permeability materials, with negligible impact on either existing groundwater users or groundwater dependent ecosystems expected outside of this area. This would also apply if the proposed cuts move within the proposed designation boundary, as all of the geology in this area is consistent with that used in the modelling.

As previously stated, groundwater drawdown has the potential to induce groundwater settlement in soft compressible sediments, such as alluvium and highly weathered rock or clay. The potential for settlement as a result of the indicative cuts is discussed in Section 9 of the AEE.

Table 4 – Calculated drawdown for the indicative cuts

Cut Reference	Drawdown 100 m Distance	Drawdown 150 m Distance	Drawdown 200 m Distance
26900	<0.1	<0.1	<0.1
33100	1.25	<0.1	<0.1
34900	<0.1	<0.1	<0.1
39200	4.5	1.4	0.3
39900	3.0	0.7	0.1
40400	2.4	0.5	<0.1
41500	0.4	<0.1	<0.1

4.3 Potential impact on neighbouring groundwater users

As discussed in Section 3.4, we undertook a search of the Auckland Council bore database within 2 km of the Indicative Alignment to determine if the modelled groundwater drawdown profile would impact any user of a registered groundwater abstraction.

The bore database contained 119 boreholes located within the 2 km radius of the Indicative Alignment. Of these bores, only nine (Bore ID's 155, 386, 4557, 4750, 20742, 21139, 21235, 22105 and 27795) are located within the proposed designation boundary. All but one of these bores are located in the vicinity of Warkworth (between chainage 48500 to 50600). There are no bores located within the calculated drawdown profiles for either the indicative cuts or tunnels. The bores located within the proposed designation boundary are primarily drilled into the alluvium deposits in this area, and as there are no cuts proposed in this area, there will be no effect on all but one of the groundwater users from the proposed construction and operation of the Project within the proposed designation boundary. The exception is bore 386, which is currently located directly underneath the Indicative Alignment in an area of fill. This means the bore will no longer be able to be utilised if the current Indicative Alignment is completed. However, it is assumed as the bore is located within the proposed designation boundary, this land (and the bore) will be purchased by the Transport Agency.

4.4 Potential stream baseflow reduction

We assessed the reduction in groundwater contributions to local streams (i.e. stream baseflow reduction) as a result of the Project through the outputs of the Seep/W modelling, as well as utilising the Theis (Jenkins) Solution.

We completed a review of streams within the calculated drawdown profiles for both the indicative tunnels and cuts. No specific streams have been located within any of the drawdown profiles of the cuts so it is considered that there will be no effect on stream baseflow as a result of the excavations for the Indicative Alignment.

To assess potential changes in the Indicative Alignment within the proposed designation, we considered the level of effects on streams that could occur. The potential effects are related to the stream ecology, and will be dependent on the depth and extent of the excavation, the distance to a stream, and the characteristics of the stream. Works near watercourses should be designed to avoid adverse effects on stream baseflow. If detailed design of the Project requires an excavation that extends below the groundwater table and the excavation is within 200 m of a stream, the change in stream baseflow should be modelled and the design should be refined if necessary with advice from a suitably qualified ecologist.

Several gullies are located within the calculated drawdown profile for the tunnels, and although not specifically identified as streams, an assessment of potential effects has been undertaken on these gullies as a worst case example. We completed an assessment based on one of these gullies being located 200 m from the tunnel excavation.

Figure 8 shows the calculated results, with a maximum potential reduction in streamflow of 0.15 L/s after 400 days. This reduction would be a worst case, with the assumption that the tunnel is not lined until it has been fully excavated. If flow does occur within this gully, it is likely to be small and more likely to be a permanent wet area (i.e. wet season groundwater seeps) rather than a permanent stream. We do not expect that a flow reduction of 0.15 L/s would be detectable over and above the influence of surface runoff. As such, we consider the potential reduction in stream baseflow as a result of the proposed tunnels for the Project is less than minor.

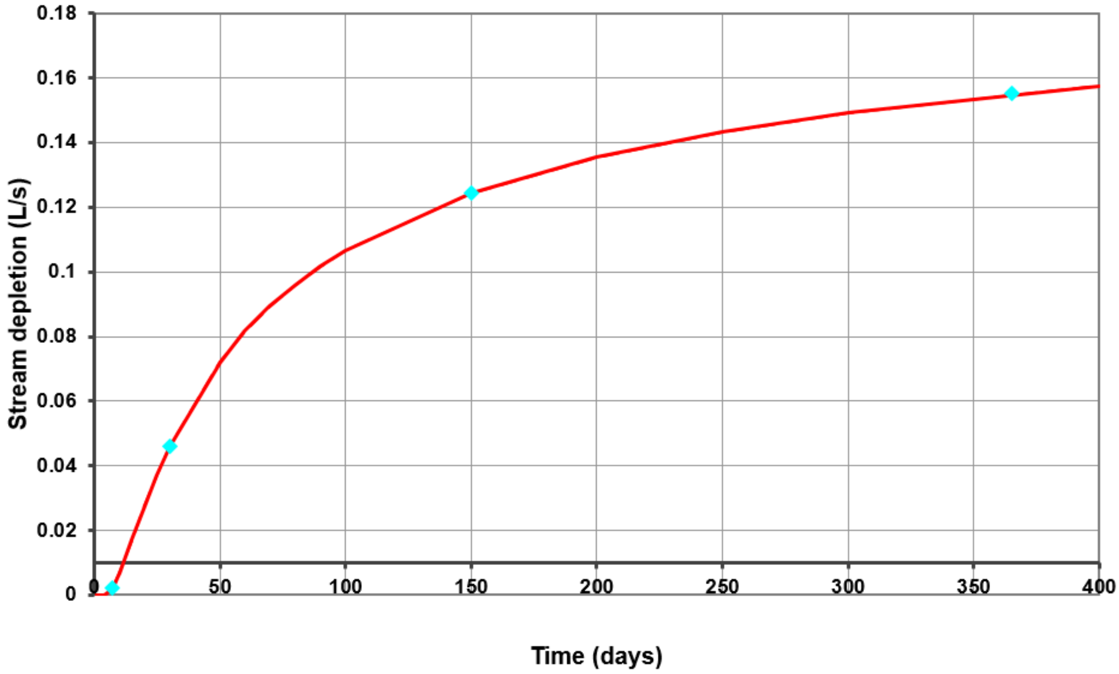

Figure 8 – Calculated stream depletion for a stream 200 m from Indicative Alignment

4.5 Potential construction effects on groundwater

Generally, temporary effects on groundwater from construction activities relate to diversion of groundwater during excavation of the cuts and tunnelling.

Impacts from diversion of groundwater with respect to groundwater level (drawdown), neighbouring bore users, and stream baseflows are discussed in Sections 4.3 to 4.4. Our data analysis focused on long-term impacts and indicated the impact would be less than minor in all cases. Therefore, we consider any temporary impacts, which are expected to be even less than the long-term impacts, will be less than minor.

4.6 Potential operational effects on groundwater

As indicated in Section 4.4, long-term groundwater diversion volumes are small and hence we consider the resulting potential stream baseflow reductions to be less than minor. However, during the operation of the Project, any groundwater diversions will be contained within the Project's surface water drainage system and subsequently discharged to downstream surface water bodies. As groundwater flows to these downstream discharge areas naturally, no significant effect on groundwater is likely.

5 RECOMMENDED MITIGATION

The assessment of potential effects of the proposed cuts and tunnels along the Indicative Alignment has indicated that the effects will be less than minor. As such, we do not consider any mitigation or monitoring is necessary for groundwater impacts from the Project.

6 CONCLUSIONS

The hydrogeological regime of the Project Area comprises very low permeability rocks with no appreciable aquifers within the depth range of the Project excavations. Most bores in the area are greater than 150 m in depth and provide only very small yields (< 1 L/s).

The most significant hydrogeological potential impact from the Project is the reduction in stream baseflows or groundwater flow to wetland areas. However, based on the low permeability rocks encountered in the Project Area, groundwater flow rates are very low and we have assessed impacts on these water courses as less than minor.

No impacts on existing groundwater users, construction or operational impacts are expected due to the following reasons:

- Very low permeability and hence flow rates of the rocks; and
- The surface water containment system will deal with any groundwater diversions and discharge them back into natural water courses.

We do not consider any mitigation or monitoring is necessary for groundwater impacts from the Project, which as stated above we consider to be less than minor.

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APPENDIX A: EXPLORATORY BOREHOLE DETAILS

Table 5 – Borehole details

Borehole ID	Size	Depth (m)	Easting (m)[1]	Northing (m)	Collar Elevation (mRL)
WW-BH1002	HQ	30.00	1744860.91	5973159.89	141.59
WW-BH1003	HQ	65.00	1744724.66	5973179.35	118.19
WW-BH1004	HQ	70.00	1744365.77	5973299.56	156.66
WW-BH1005	HQ	185.00	1744215.93	5973376.27	272.66
WW-BH1006	HQ	210.00	1744006.41	5973542.01	296.10
WW-BH1008	HQ	180.00	1743957.97	5973600.39	252.88
WW-BH1009	HQ	50.00	1743532.03	5973866.19	234.40
WW-BH1010	HQ	43.60	1742887.49	5974645.78	157.31
WW-BH1011	PQ	15.00	1742603.78	5974748.86	85.29
WW-BH1013	HQ	36.00	1741561.31	5975744.63	127.32
WW-BH1014	PQ	50.00	1741489.45	5975949.84	93.23
WW-BH1015	PQ	35.00	1740809.05	5976294.47	61.64
WW-BH1016	PQ	30.00	1740893.16	5976332.68	74.25
WW-BH1017	PQ	30.00	1740704.75	5976267.97	72.81
WW-BH1018	HQ	30.00	1740350.93	5976528.40	94.80
WW-BH1019	PQ	25.00	1740348.31	5976725.18	96.47
WW-BH1020	PQ	25.00	1739732.79	5976886.35	58.80
WW-BH1022	PQ	30.00	1744860.91	5973159.89	91.81
WW-BH1024	HQ	18.26	1739001.59	5978613.02	26.98
WW-BH1025	HQ	15.25	1739194.63	5980627.45	27.82
WW-BH1026	PQ	30.00	1739221.14	5980987.90	62.58
WW-BH1027	HQ	19.55	1739282.91	5981746.82	30.61
WW-BH1028	PQ	30.00	1739121.82	5982756.20	97.56
WW-BH1032	HQ	50.00	1737290.07	5988360.10	91.47
WW-BH1033	HQ	19.95	1736600.37	5988757.93	22.59
WW-BH1034	HQ	70.00	1744590.37	5973261.89	185.81
WW-BH1035	HQ	111.70	1743791.28	5973527.56	215.72
WW-BH1036	HQ	165.00	1743823.97	5973116.03	260.34
WW-BH1037	HQ	71.20	1743600.47	5973687.11	181.83
WW-BH1038	HQ	130.50	1743601.50	5973408.90	208.33

Borehole ID	Size	Depth (m)	Easting (m)[1]	Northing (m)	Collar Elevation (mRL)
WW-BH1039	HQ	70.00	1743957.23	5972943.05	226.13
WW-BH1040	HQ	70.50	1744686.09	5973369.57	199.37
WW-BH1041	HQ	105.00	1744124.74	5973609.20	254.11
WW-BH1042	HQ	165.00	1744342.45	5973536.52	286.82

Note:
1 – All coordinates have been surveyed by Harrison Grierson in NZTM 2000 with Mt Eden 1949 Datum.

APPENDIX B: PIEZOMETER CONSTRUCTION & GROUNDWATER LEVEL DETAILS

The piezometers were constructed according to the following specifications:

- Casing was either 20, 32 or 50 mm internal diameter PVC with self-sealing flush joints;
- The screened sections comprised 1mm machine slotted PVC with an end cap at the base of each piezometer;
- Filter pack (2 mm diameter sorted quartz gravel) was placed to at least 1 m above the top of the screen;
- At least 300mm of quartz blinding sand was placed above the gravel pack;
- A minimum of a 1 m granular bentonite (10 mm) seal was installed above the blinding;
- The remainder of the annulus was backfilled with drill cuttings or similar material; and
- A 1 m surface bentonite seal was installed.

Table 6 – Piezometer installation details and groundwater levels

Borehole ID	Piezometer ID	Ground elevation (mRL)	Depth to bottom of Screen (m)	Screen Length (m)	Aquifer type	Groundwater Level (mBGL) [Date Measured]
WW-BH1004	1004a	156.66	17.5	6	Colluvium	13.5 [15/9/2017]
	1004b		56.5	3	Pakiri	-8.6 [6/11/2017]
WW-BH1005	1005a	272.66	70.0	VW	Pakiri	60.6 [15/09/2017]
	1005b		95.0	VW	Pakiri	91.1 [15/09/2017]
	1005c		185.0	VW	Pakiri	98.9 [15/09/2017]
WW-BH1006	1006	296.10	174.5	3	Pakiri	125.9 [15/9/2017]
WW-BH1008	1008a	252.88	86.0	9	Pakiri	72.9 [15/09/2017]
	1008b		175.0	VW	Pakiri	134.5 [15/09/2017]
WW-BH1010	1010a	157.31	13.0	3	Pakiri	12.5 [15/09/2017]
	1010b		30.0	6	Pakiri	19.4 [15/09/2017]
WW-BH1013	1013	127.32	35.5	2	Pakiri	35.5 [15/09/2017]
WW-BH1014	1014	93.23	6.0	3	Pakiri	1.6 [15/09/2017]
WW-BH1015	1015a	61.64	18	3	Pakiri	16.8 [15/09/2017]
	1015b		35	3	Pakiri	26.5 [15/09/2017]

Borehole ID	Piezometer ID	Ground elevation (mRL)	Depth to bottom of Screen (m)	Screen Length (m)	Aquifer type	Groundwater Level (mBGL) [Date Measured]
WW-BH1016	1016a	74.25	18.0	3	Pakiri	15.7 [15/09/2017]
	1016b		29.0	3	Pakiri	19.6 [15/09/2017]
WW-BH1017	1017	72.81	29.0	3	Pakiri	22.5 [15/09/2017]
WW-BH1018	1018a	94.8	15.0	3	Pakiri	5.2 [15/09/2017]
	1018b		22.5	3	Pakiri	16.8 [15/09/2017]
WW-BH1019	1019a	96.47	7.0	3	Pakiri	1.9 [15/09/2017]
	1019b		20.0	3	Pakiri	7.9 [15/09/2017]
WW-BH1025	1025	27.82	5.0	3	Alluvium	0.5 [7/08/2017]
WW-BH1026	1026	62.58	26.0	6	Northland Allochthon	1.9 [7/08/2017]
WW-BH1027	1027a	30.61	4.0	3	Alluvium	0.05 [8/09/2017]
	1027b		18.7	3	Northland Allochthon	-0.1 [8/09/2017]
WW-BH1028	1028	97.56	28	6	Northland Allochthon	4.1 [8/09/2017]
WW-BH1032	1032	91.47	43.2	6	Northland Allochthon	17.8 [8/09/2017]
WW-BH1033	1033	22.59	4.5	3	Northland Allochthon	0.2 [8/09/2017]
WW-BH1036	1036	260.34	153	12	Pakiri	NA
WW-BH1039	1039a	226.13	6.1	3	Pakiri	NA
	1039b		69.0	3	Pakiri	NA
WW-BH1040	1040a	119.37	19.0	6	Pakiri	Dry [7/11/2017]
	1040b		69.0	3	Pakiri	24.4 [7/11/2017]
WW-BH1041	1041	254.11	103.4	3	Pakiri	85.7 [7/11/2017]

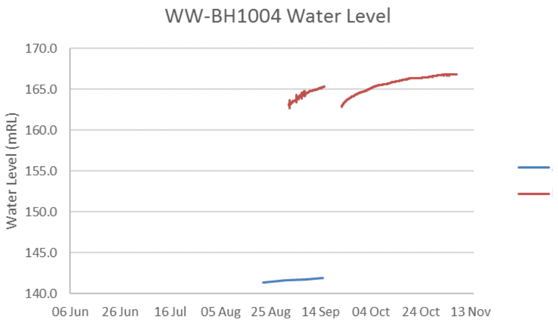
Table 7 – Summary of vertical pressure gradients

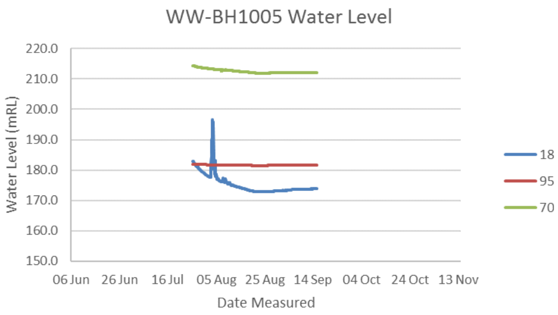
Borehole ID	Aquifer Type	Shallow piezometer		Deep piezometer		Vertical pressure gradient (m/m)[1] [h/L]
		Screen bottom (mBGL)	Static GWL (mRL)	Screen bottom (mBGL)	Static GWL (mRL)	
BH1004	Pakiri	17.5	143.2	56.5	165.3	0.6 [22.1/39]
BH1005	Pakiri	70.0	212.1	180.0	173.8	-0.3

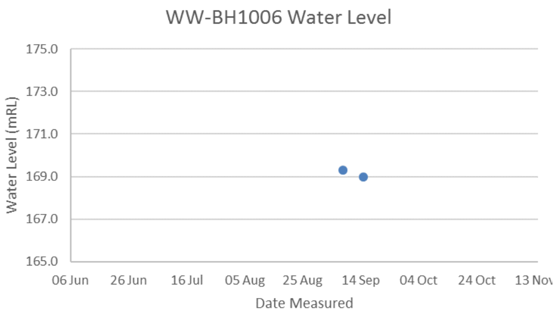
Borehole ID	Aquifer Type	Shallow piezometer		Deep piezometer		Vertical pressure gradient (m/m)[1] [h/L]
		Screen bottom (mBGL)	Static GWL (mRL)	Screen bottom (mBGL)	Static GWL (mRL)	
						[-38.3/110]
BH1008	Pakiri	86.0	179.9	175.0	118.4	-0.7 [-61.5/89.0]
BH1010	Pakiri	13.0	144.8	30.0	137.9	-0.4 [-6.9/17.0]
BH1015	Pakiri	18.0	44.8	35.0	35.1	-0.6 [-9.7/17.0]
BH1016	Pakiri	18.0	58.6	29.0	54.7	-0.4 [-3.9/11.0]
BH1018	Pakiri	15.0	89.6	22.5	78.0	-1.5 [-11.6/7.5]
BH1019	Pakiri	7.0	94.6	20.0	88.6	-0.5 [-6.0/13.0]
BH1027	Northland Allochthon	4.0	30.6	18.7	30.7	0.007 [0.1/14.7]
BH1040	Pakiri	19.0	Dry	69.0	94.9	NA

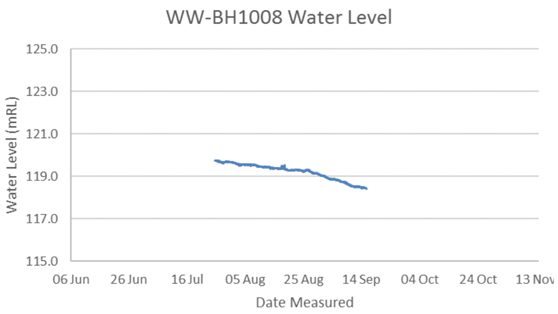
Note:
1 – A positive pressure gradient indicates upward flow potential. The larger the value, the stronger the gradient and hence flow potential.

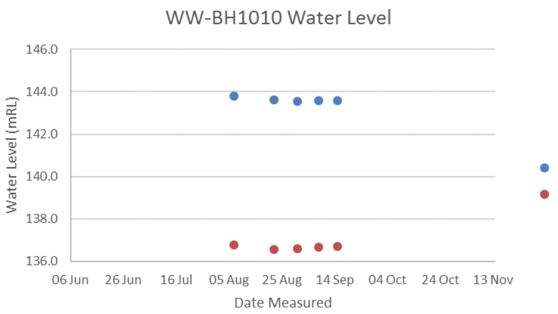
APPENDIX C: GROUNDWATER LEVEL PLOTS

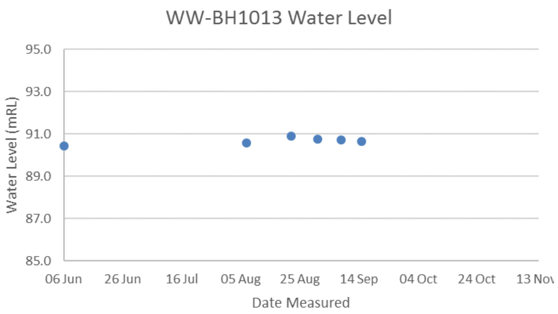


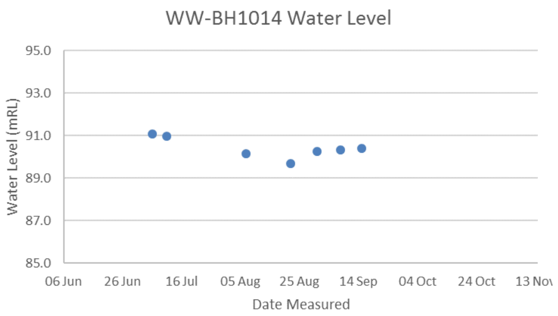


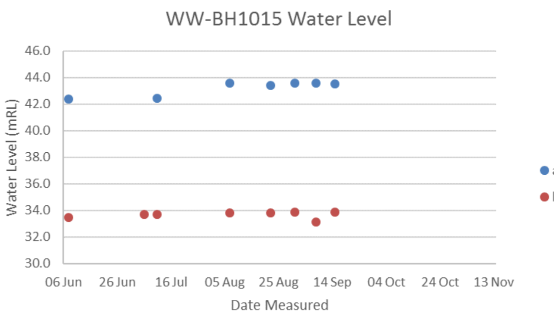


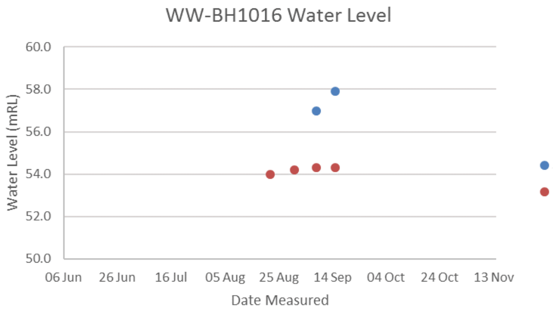


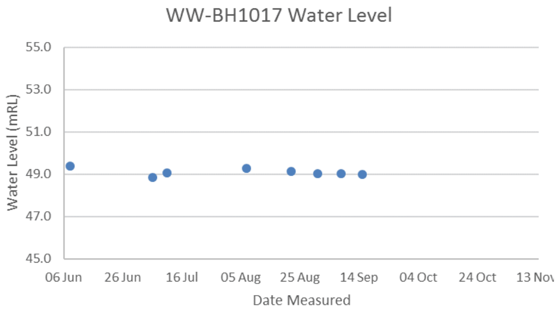


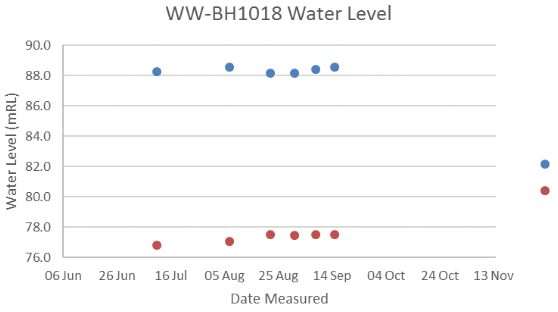







WW-BH1016 Water Level
Water Level (mRL)
60.0
58.0
56.0
54.0
52.0
50.0
06 Jun
26 Jun
16 Jul
05 Aug
25 Aug
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured


WW-BH1017 Water Level
Water Level (mRL)
55.0
53.0
51.0
49.0
47.0
45.0
06 Jun
26 Jun
16 Jul
05 Aug
25 Aug
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured


WW-BH1018 Water Level
Water Level (mRL)
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88.0
86.0
84.0
82.0
80.0
78.0
76.0
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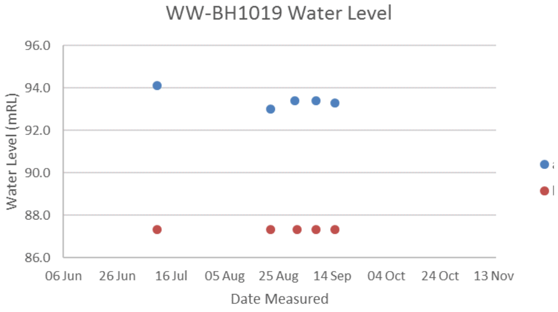
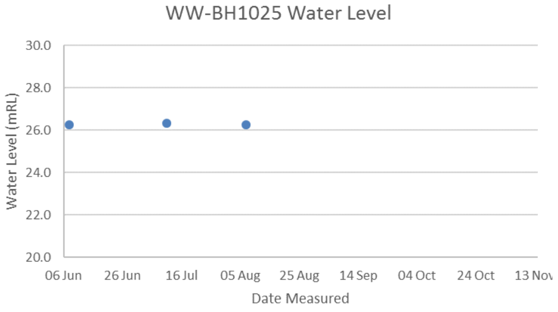
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured


WW-BH1019 Water Level
Water Level (mRL)
96.0
94.0
92.0
90.0
88.0
86.0
06 Jun
26 Jun
16 Jul
05 Aug
25 Aug
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured


WW-BH1025 Water Level
Water Level (mRL)
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28.0
26.0
24.0
22.0
20.0
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26 Jun
16 Jul
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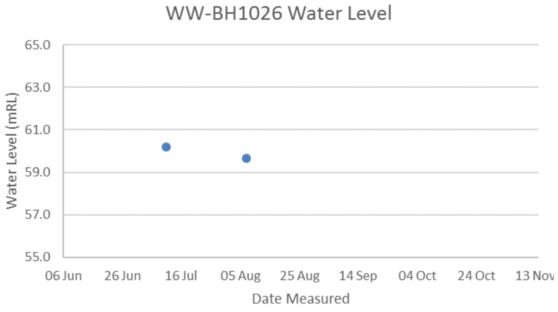
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured


WW-BH1026 Water Level
Water Level (mRL)
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63.0
61.0
59.0
57.0
55.0
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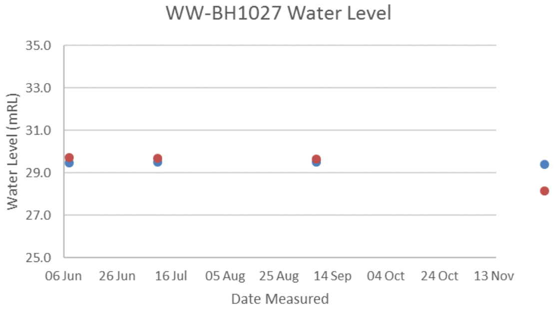
26 Jun
16 Jul
05 Aug
25 Aug
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured


WW-BH1027 Water Level
Water Level (mRL)
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33.0
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25.0
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26 Jun
16 Jul
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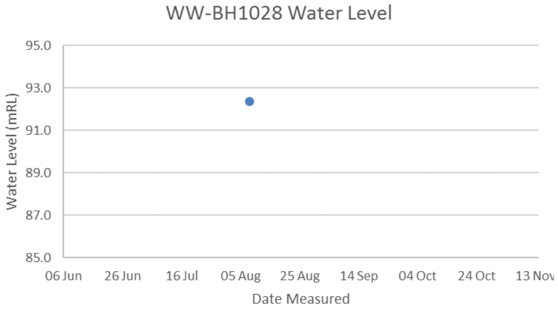
25 Aug
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured


WW-BH1028 Water Level
Water Level (mRL)
95.0
93.0
91.0
89.0
87.0
85.0
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26 Jun
16 Jul
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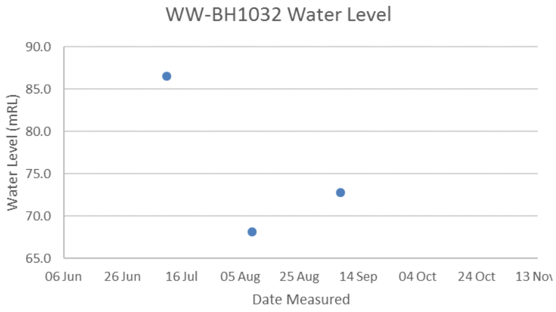
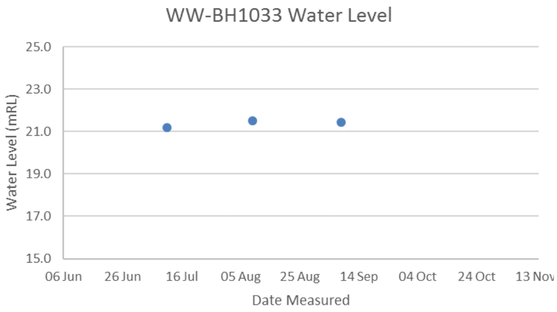
04 Oct
24 Oct
13 Nov
Date Measured



WW-BH1032 Water Level
Water Level (mRL)
90.0
85.0
80.0
75.0
70.0
65.0
06 Jun
26 Jun
16 Jul
05 Aug
25 Aug
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured



WW-BH1033 Water Level
Water Level (mRL)
25.0
23.0
21.0
19.0
17.0
15.0
06 Jun
26 Jun
16 Jul
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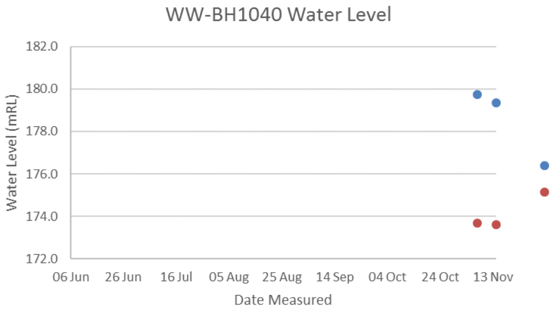
25 Aug
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured



WW-BH1040 Water Level
Water Level (mRL)
182.0
180.0
178.0
176.0
174.0
172.0
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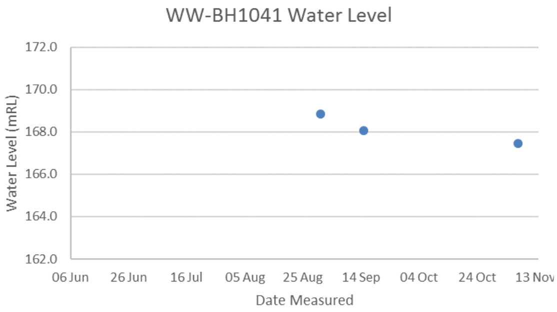
26 Jun
16 Jul
05 Aug
25 Aug
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured



WW-BH1041 Water Level
Water Level (mRL)
172.0
170.0
168.0
166.0
164.0
162.0
06 Jun
26 Jun
16 Jul
05 Aug
25 Aug
14 Sep
04 Oct
24 Oct
13 Nov
Date Measured

APPENDIX D: PACKER TEST RESULTS

The calculated packer test results for BH1006 and BH1042 are outlined in Table 8 and Table 9, respectively.

Table 8 – BH1004 Packer test results

Borehole ID	Test Reference	Test Depth (mBGL)	Geology	Hydraulic Conductivity K (m/s)
BH1006	Test 1	154.75 – 156.5	Fracture Zone – Pakiri	6.7×10^{-6}
BH1006	Test 2	156.5 – 158.25	Fracture Zone – Pakiri	6.7×10^{-6}
BH1006	Retest 1	190.75 – 192.5	Fracture Zone – Pakiri	5.6×10^{-6}
BH1006	Retest 2	192.5 – 193.75	Fracture Zone – Pakiri	7.1×10^{-6}
BH1006	Test 3	155.25 – 156.5	Fracture Zone – Pakiri	6.6×10^{-6}
BH1006	Test 4	156.5 – 157.75	Fracture Zone – Pakiri	3.1×10^{-6}
BH1006	Retest 3	191.25 – 192.5	Fracture Zone – Pakiri	6.9×10^{-6}

Table 9 – BH1042 packer test results

Borehole ID	Test Reference	Test Depth (mBGL)	Geology	K (m/s)
BH1042	Test 1	155 – 158	Fracture zone below proposed tunnel (Pakiri)	NA[1]
BH1042	Test 2	145.5 – 148.5	Massive interbedded sandstone/siltstone – tunnel horizon (Pakiri)	NA
BH1042	Test 3	145.5 – 147.5	Massive interbedded sandstone/siltstone – tunnel horizon (Pakiri)	NA
BH1042	Test 4	135 – 137	Interbedded siltstone/sandstone (Pakiri)	8.84×10^{-6}
BH1042	Test 5	121.7 – 123.7	Massive siltstone (Pakiri)	2.29×10^{-7}
BH1042	Test 6	115.5 – 118.5	Microfractured zone (Pakiri)	8.11×10^{-8}
BH1042	Test 7	105.3 – 108.3	Massive gritstone (Pakiri)	4.29×10^{-8}
BH1042	Test 8	101.6 – 104.6	Massive gritstone (Pakiri)	NA
BH1042	Test 9	101.6 – 104.6	Massive gritstone (Pakiri)	NA
BH1042	Test 10	54.89 – 56.87	Massive gritstone (Pakiri)	NA
BH1042	Test 11	25 – 28	Massive sandstone (Pakiri)	3.26×10^{-8}
BH1042	Test 12	54.9 – 56.9	Massive gritstone (Pakiri)	5.52×10^{-8}

Note:
1 – NA represents a test that either was aborted or had insufficient data for analysis.

APPENDIX E: GROUNDWATER MODELLING – CUT

E1 Introduction

A review of the major cuts (cuts in excess of 20 m height in Pakiri Formation and in excess of 10 m height in Northland Allochthon) along the Indicative Alignment was undertaken to determine which cuts were required to be assessed for potential groundwater drawdown. The depth of cuts was assessed in relation to the inferred regional groundwater level, as shown on the long sections in Appendix F. Overall, seven of the 21 major cuts along the Indicative Alignment have been assessed.

Seepage was modelled throughout the seven cross sections identified in Table 1 using the Seep/W software package (Geoslope software package suite). This software was selected because it is able to model unsaturated/saturated water flow using a finite element approach through the selected Indicative Alignment cross sections.

Models were set up using the maximum cut depth in order to model the worst case scenario, with model boundaries determined by extending the model 250 m from the midpoint of the Indicative Alignment in both directions.

Within the model, seepage into the excavated section occurs when the groundwater level is higher than the excavation invert or when precipitation seeps through the unsaturated zone into the excavated area. In addition, this process could result in drawdown (a reduction in the groundwater level) away from the excavation area, as a consequence of the seepage. Consequently, the outputs of the models were used to assess the likely effects on groundwater levels (e.g. drawdown) in the immediate vicinity of the Indicative Alignment.

We created two types of model at each cross section: steady-state and transient. The steady-state models represent existing groundwater conditions, whereas the transient models forecast the change in groundwater conditions due to the proposed excavation. Steady-state models make use of constant head boundaries at the extents of the models, and do not include a seepage boundary (e.g. the excavation is inactive). On the other hand, the transient models run for 30 days to represent an approximate duration of excavation, based on an average rate of 4,000 m^3/day per excavator and three excavators per site. It should be noted that the groundwater levels within the models reach steady-state (groundwater levels are initially reduced and then stabilise at a new reduced level) after approximately one day. However, for the purposes of providing a conservative estimate of drawdown as a result of the cut (i.e. seepage will continue to occur once the cut has been completed) we have completed the assessment over 30 days. After this time, seepage into the excavation area will stabilise and will be directed through to a collection system.

The transient models do not use constant head boundaries (e.g. constant head boundaries are removed in these models to adequately represent groundwater drawdown), and incorporate a seepage boundary along the walls of the excavated area to activate the excavation. Once the seepage rates were calculated, groundwater drawdown was calculated using the Theis (1937) Forward Solution along the alignment.

Input parameters used within the Seep/W models are provided in Table 10 and Table 11, while the input parameters used for the drawdown analysis is outlined in Table 12. The results for each individual cut model are outlined in the individual sections below.

Table 10 – Model geological input parameters

Unit	Geological Description	Hydraulic Conductivity (m/d)	Rainfall Recharge (mm/yr)
Pakiri Formation (Unconsolidated)	Highly weathered and weak silty clay and sand	0.01364	50
Pakiri Formation (Consolidated)	Massive sandstone and interbedded siltstone	0.00864	
Northland Allochthon	Mudstone and limestone	0.0043	

Table 11 – Model construction and input parameters

Cut Reference	Max. Cut Depth (m)	Geology	Closest Borehole	Piezo Depth (mBGL)
26900	34	Northland Allochthon	BH1032	43.2
33100	35	Northland Allochthon	BH1028	28.0
34900	15	Northland Allochthon	BH1026	26.0
39200	38	Pakiri	BH1022	NA – Backfilled
39900	21	Pakiri	BH1019 BH1020	20.0 NA – Backfilled
40400	22	Pakiri	BH1018 BH1016 BH1017	22.5 29.0 29.0
41500	31	Pakiri	BH1014 BH1015	6.0 35.0
Dibbles Road		Pakiri	BH1018 BH1016 BH1017	22.5 29.0 29.0

Table 12 – Theis forward solution input parameters

Cut Reference	Transmissivity (m^2/d)	Storativity	Pumping Rate[1] (m^3/d)
26900	0.0129	0.001	0.5
33100	0.0473		4.1
34900	0.0301		0.3

Cut Reference	Transmissivity (m^2/d)	Storativity	Pumping Rate[1] (m^3/d)
39200	0.0864		5.0
39900	0.0950		4.2
40400	0.0950		3.6
41500	0.0605		0.9
Note: 1 – pumping rates calculated from Seep/W modelled seepage rates and multiplied to incorporate the length of the cut			

E2 Results

The results of the Seep/W modelling are shown in Figure 9 to Figure 22, as well as being outlined in Table 13.

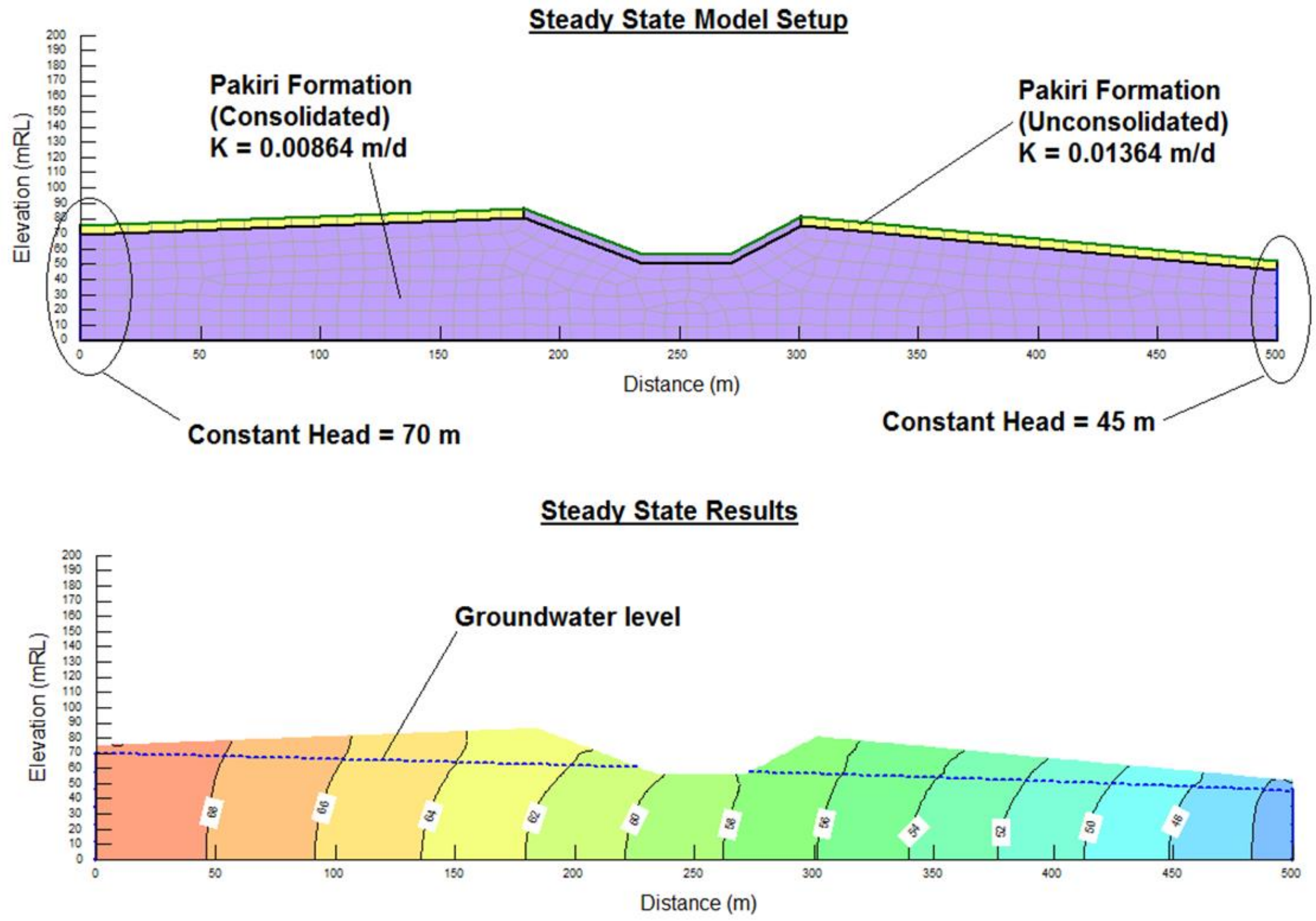


Figure 9 – Steady State Model Setup and Results for cut 26900

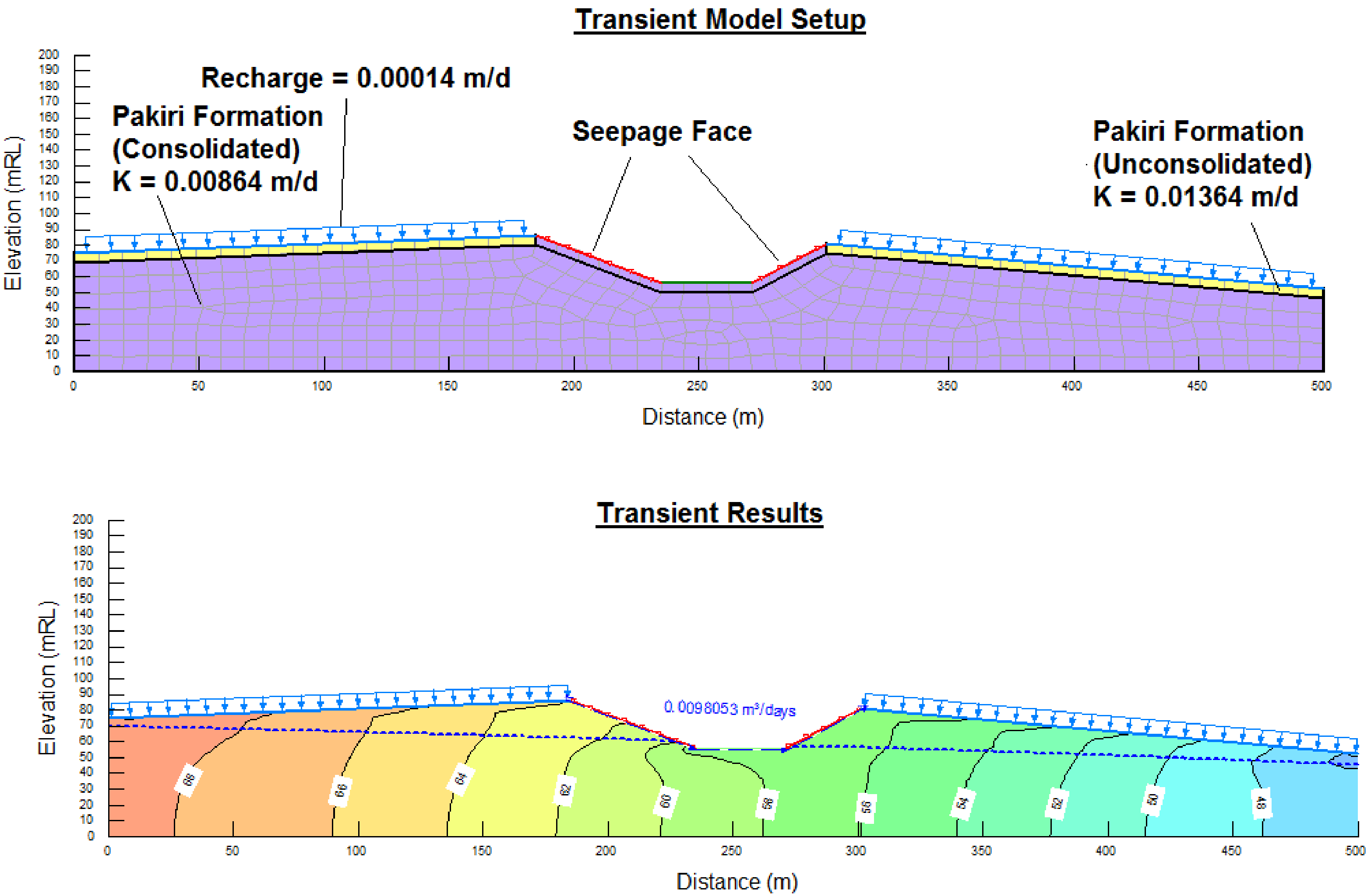


Figure 10 – Transient Model Setup and Results for cut 26900 (after 30 days)

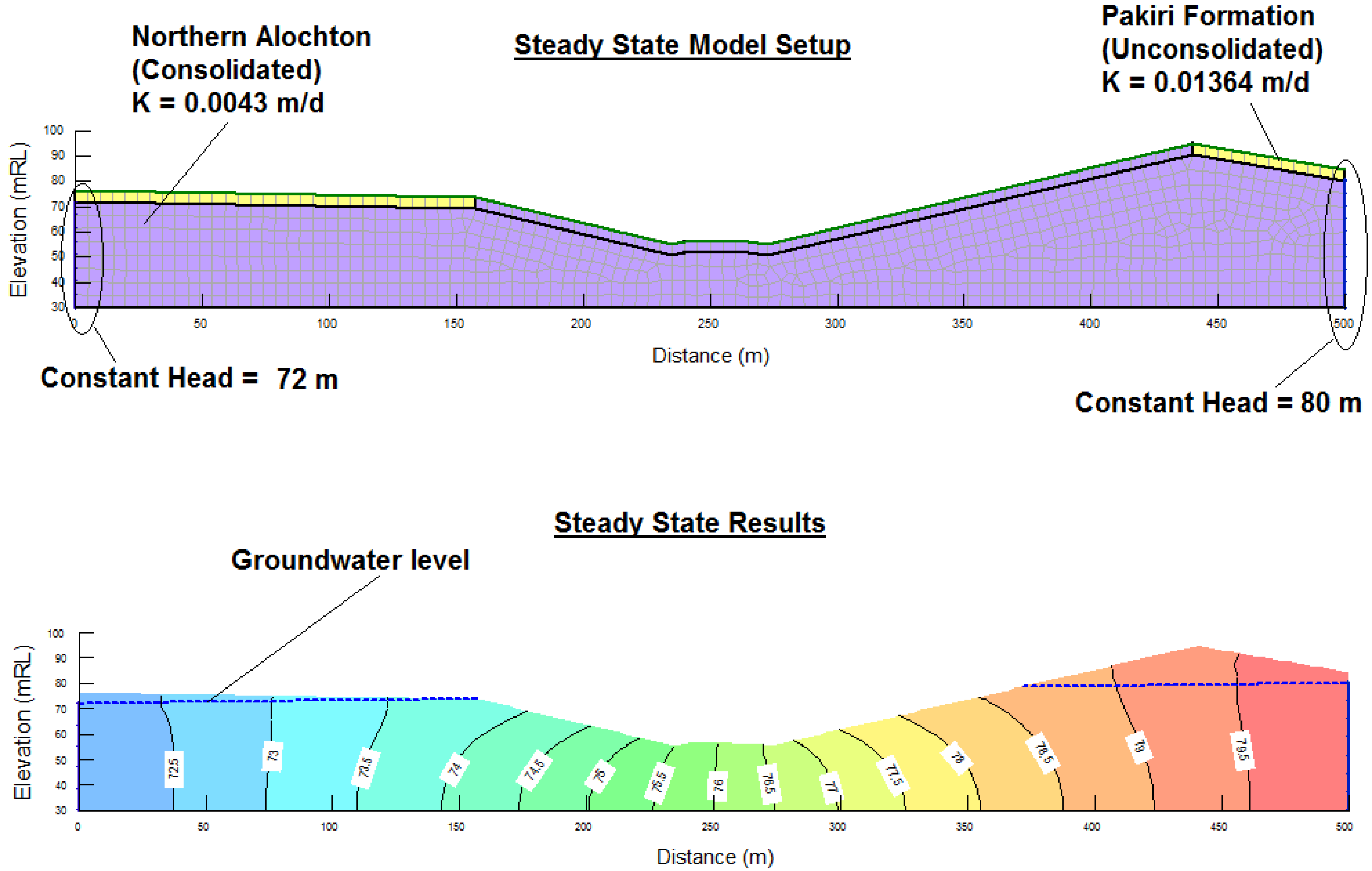


Figure 11 – Steady State Model Setup and Results for cut 33100

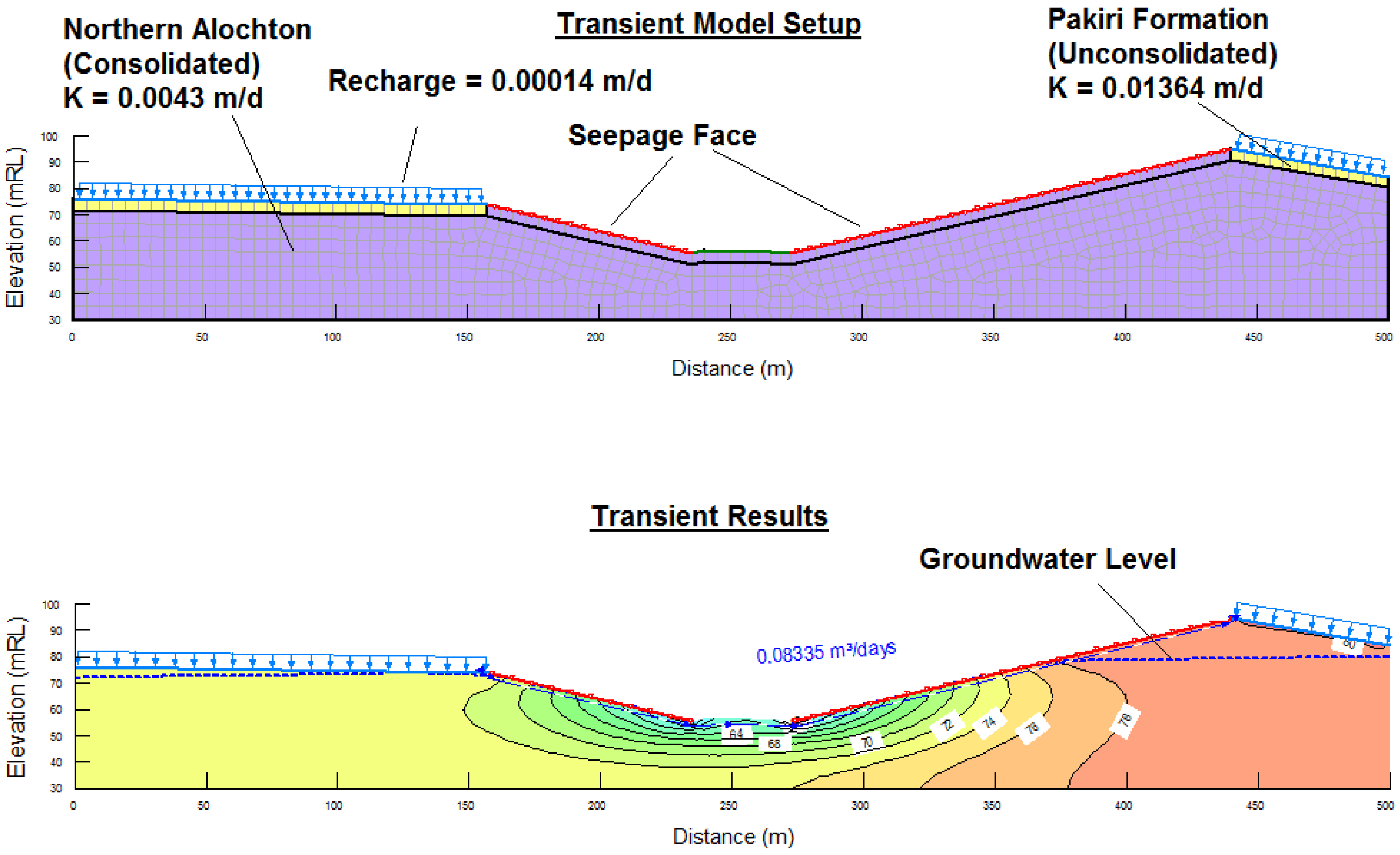


Figure 12 – Transient Model Setup and Results for cut 33100 (after 30 days)

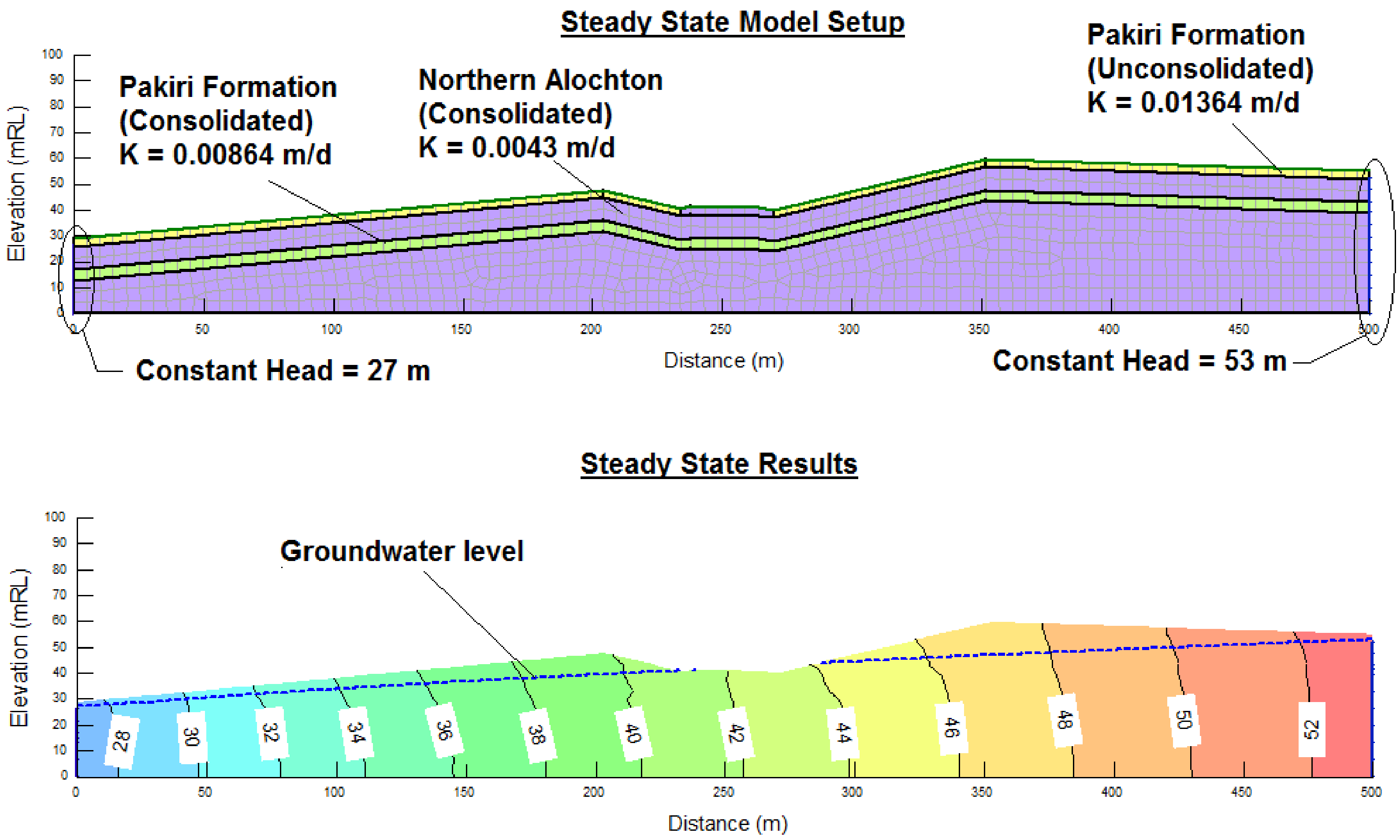


Figure 13 – Steady State Model Setup and Results for cut 34900

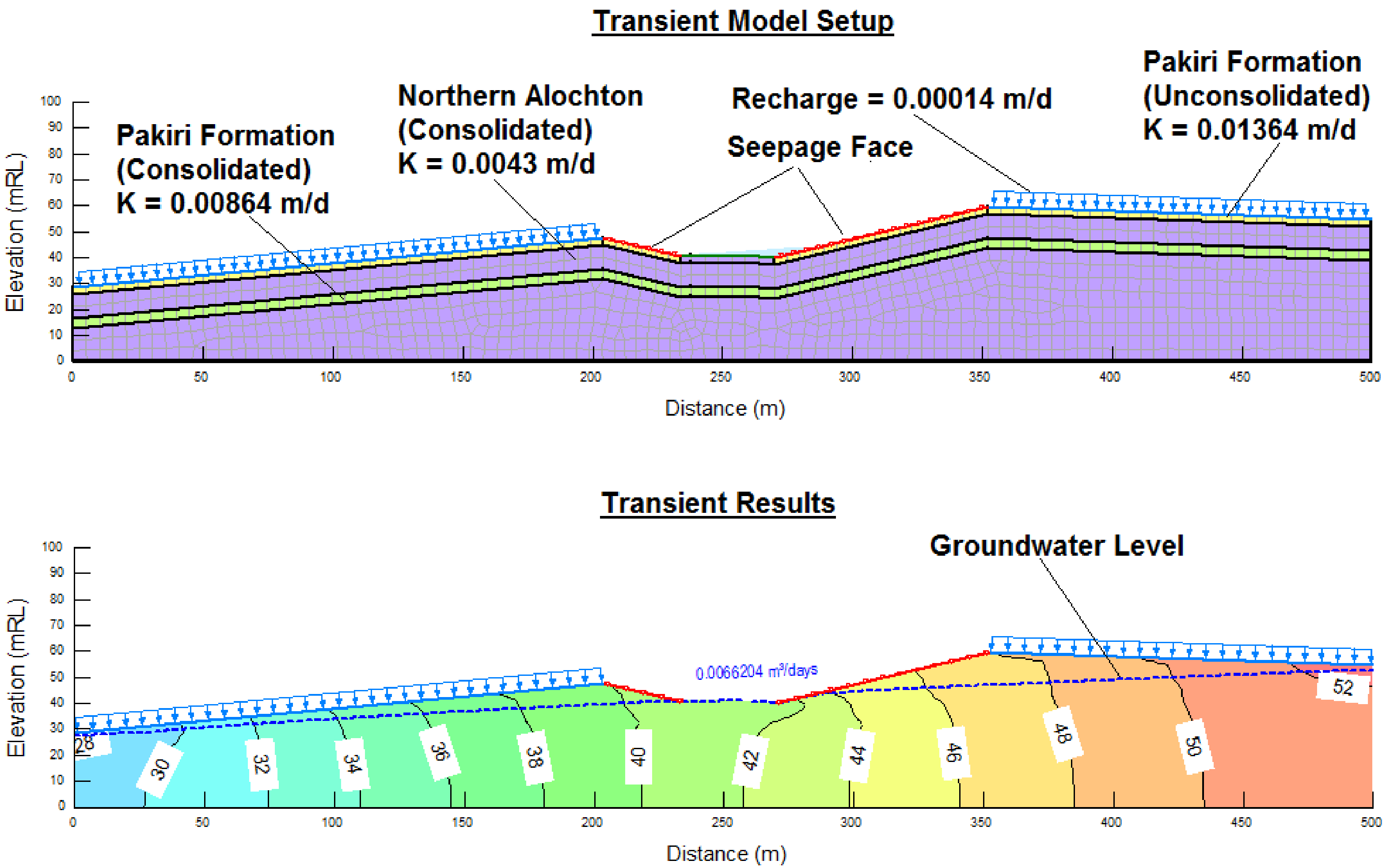


Figure 14 – Transient Model Setup and Results for cut 34900 (after 30 days)

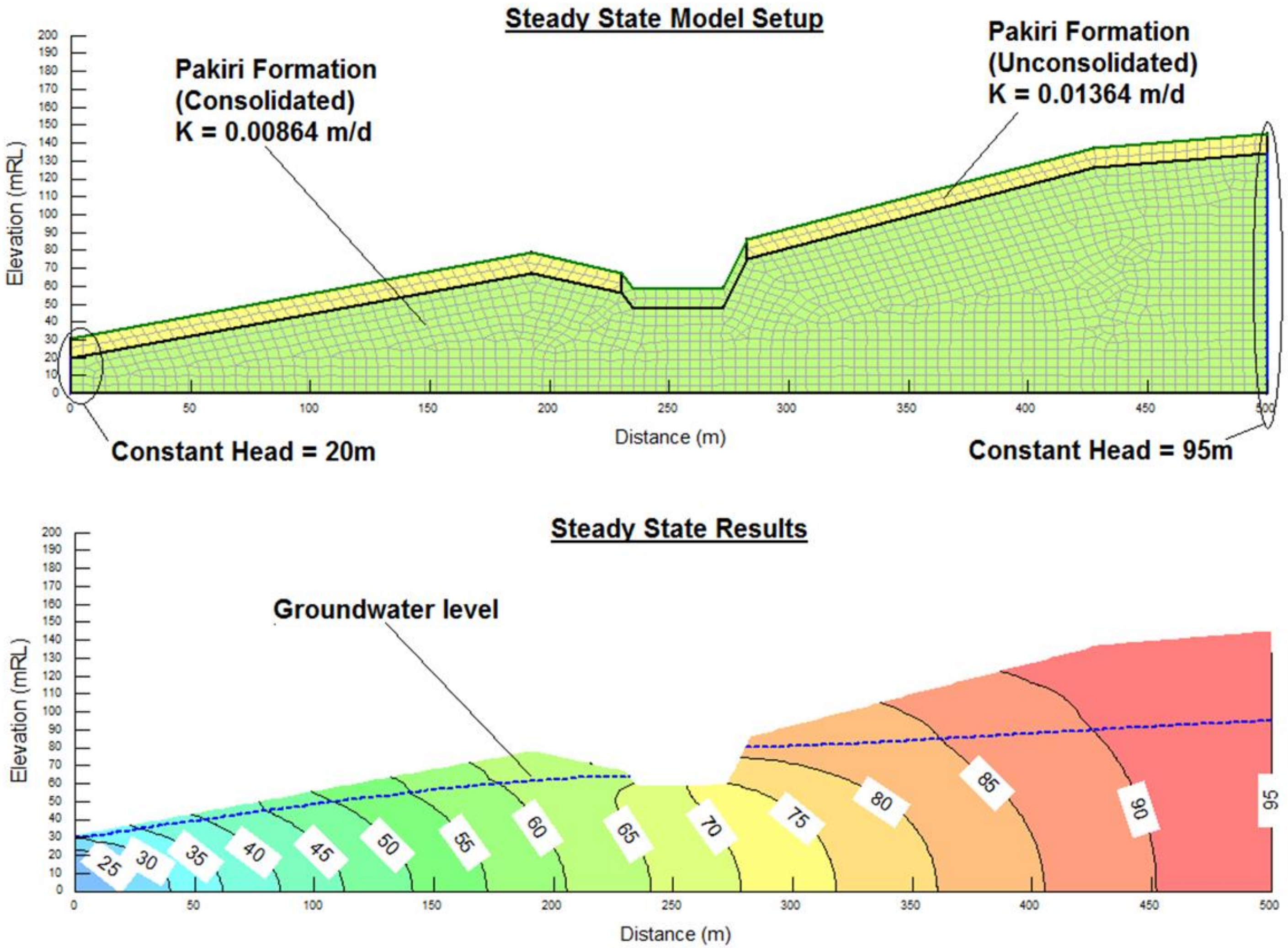


Figure 15 - Steady State Model Setup and Results for cut 39200

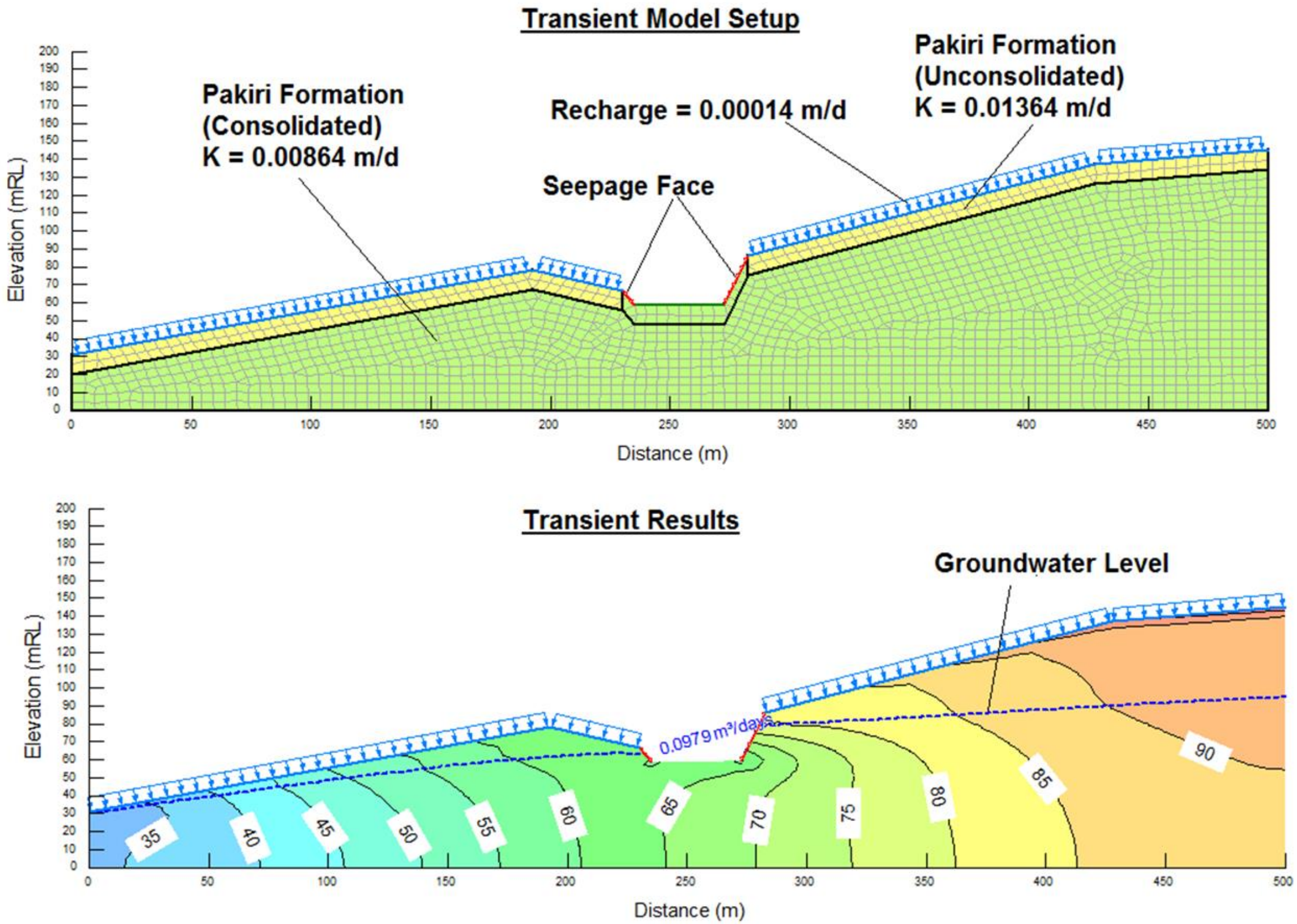


Figure 16 – Transient Model Setup and Results for cut 39200 (after 30 days)

GHD JACOBS

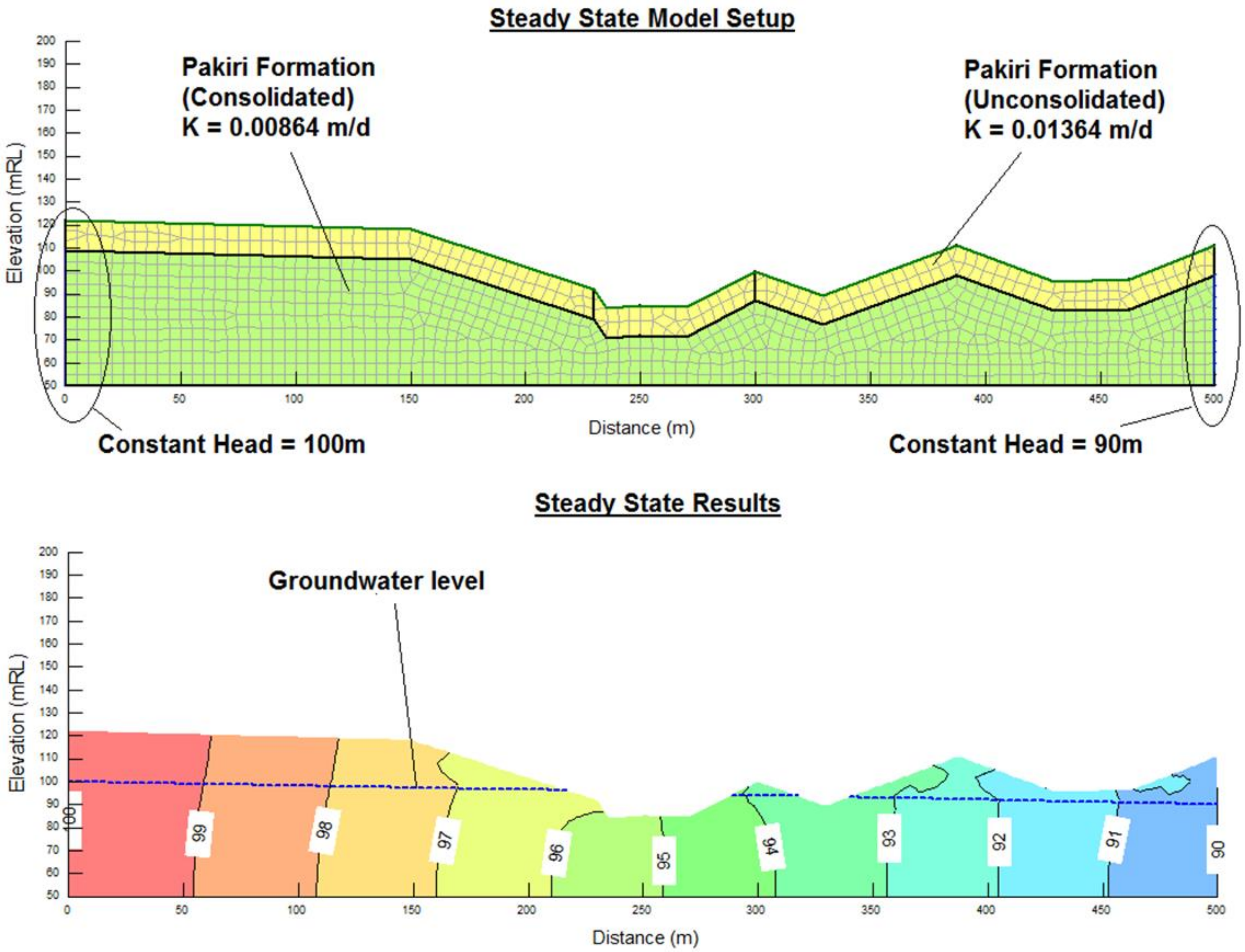


Figure 17 – Steady State Model Setup and Results for cut 39900

GHD JACOBS

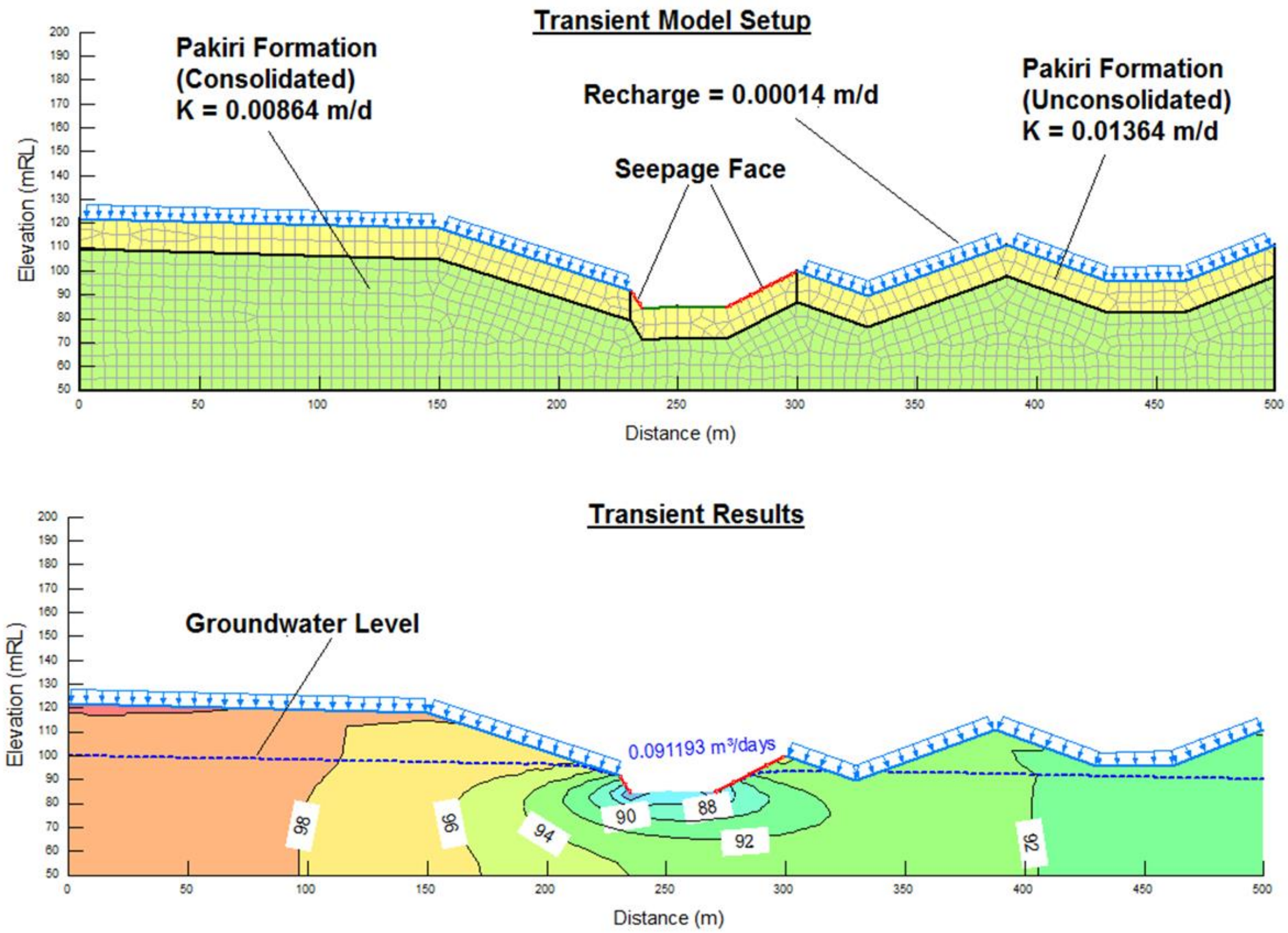


Figure 18 – Transient Model Setup and Results for cut 39900 (after 30 days)

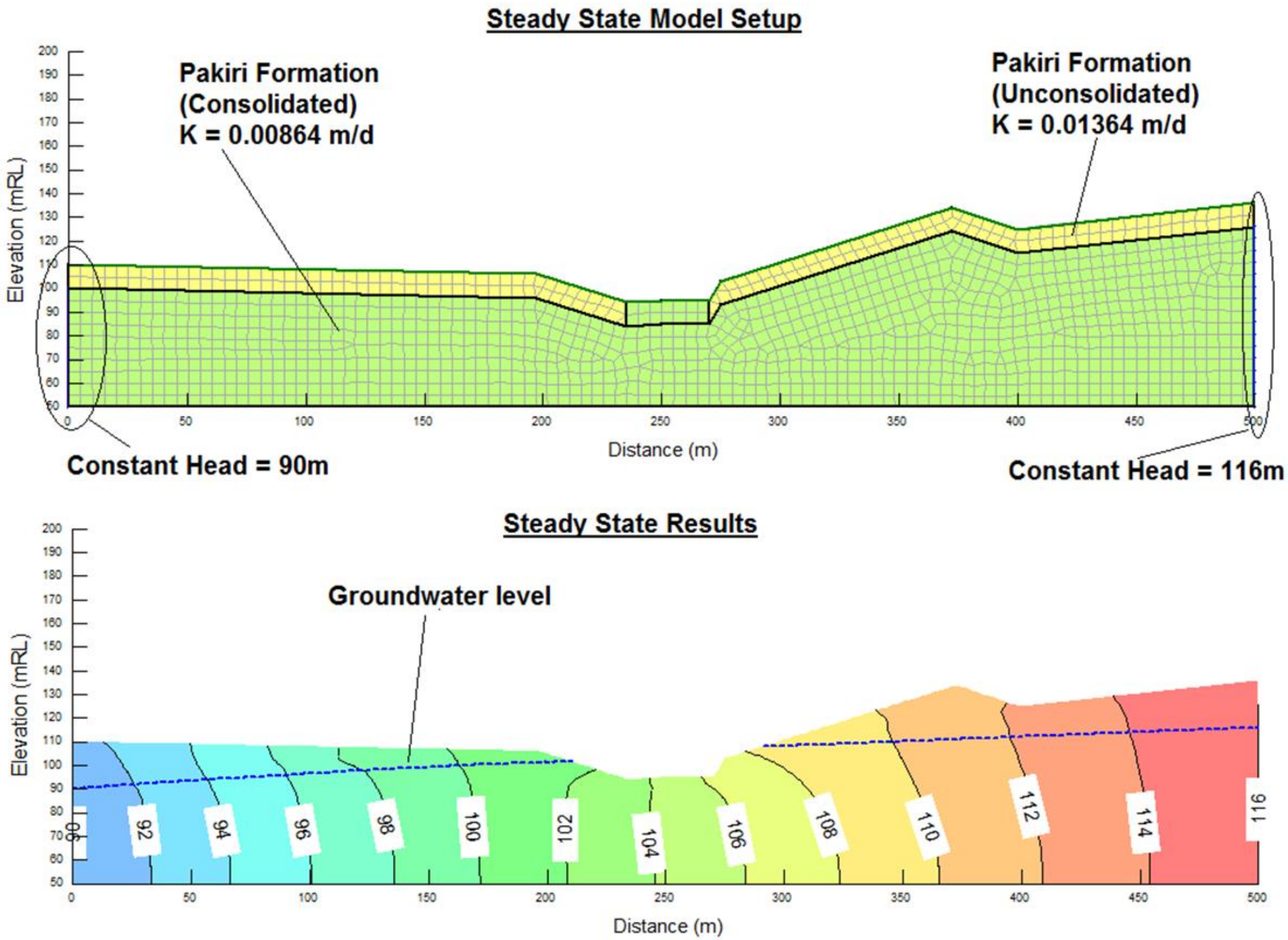


Figure 19 – Steady State Model Setup and Results for cut 40400

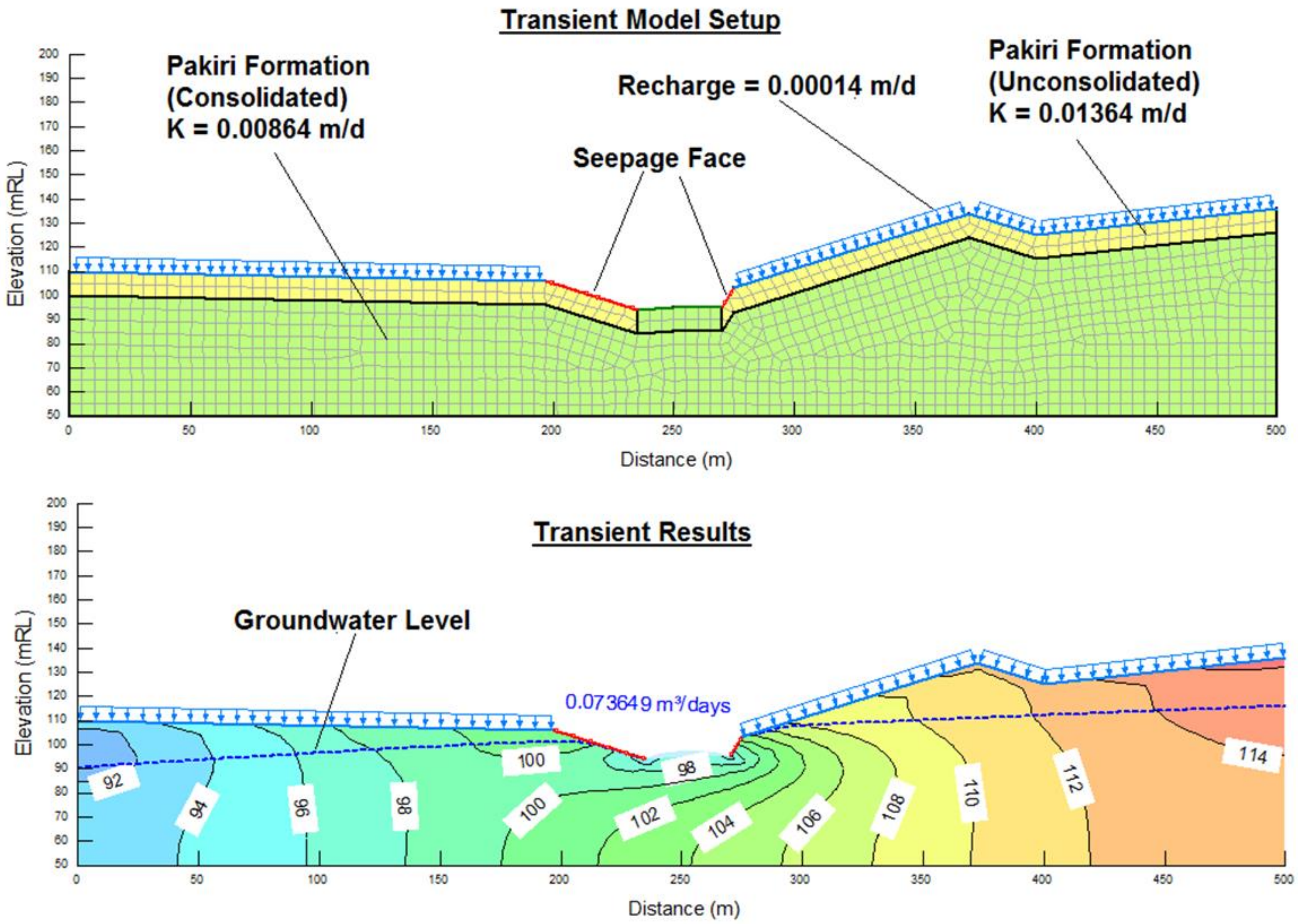


Figure 20 – Transient Model Setup and Results for cut 40400 (after 30 days)

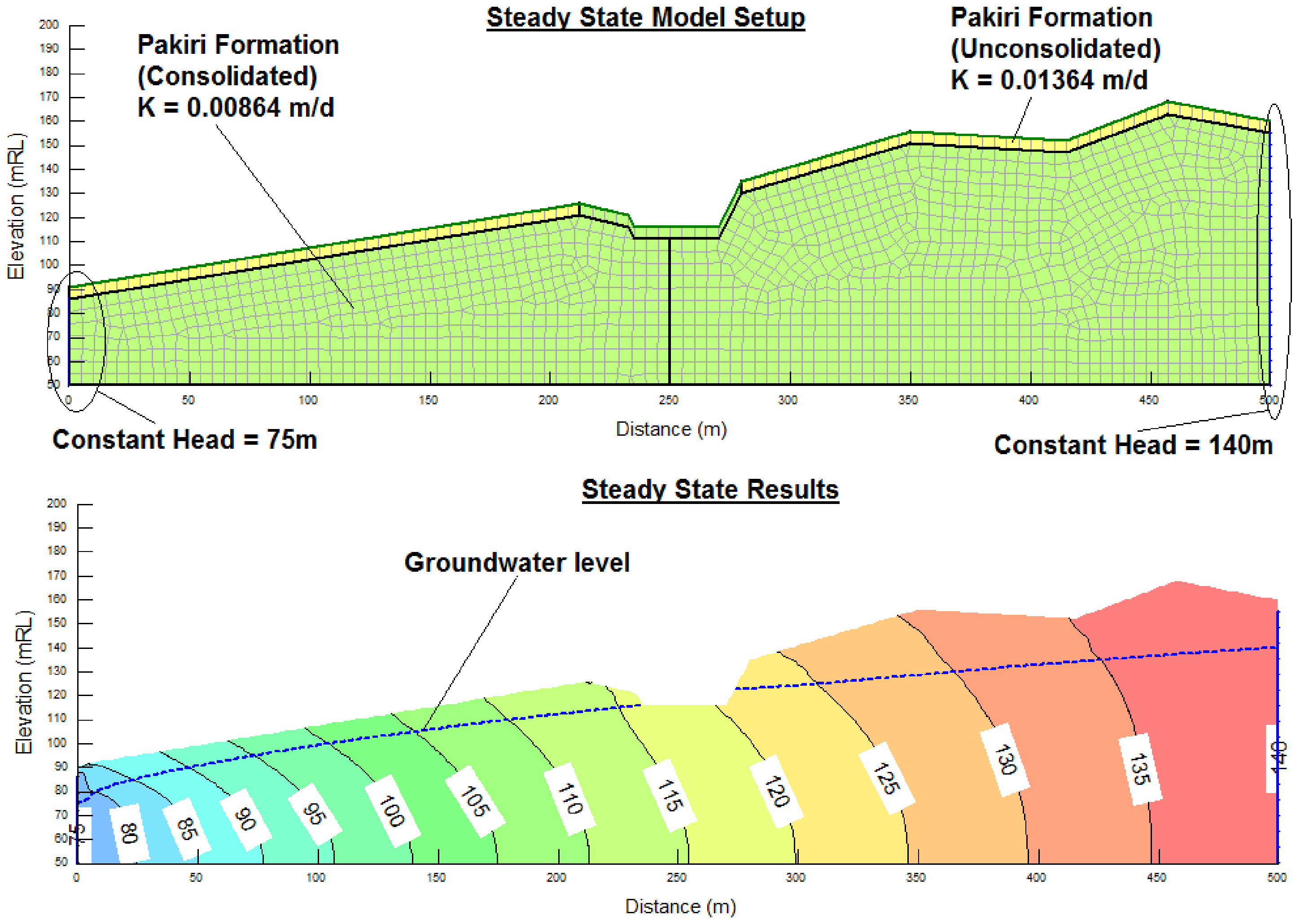


Figure 21 – Steady State Model Setup and Results for cut 41500

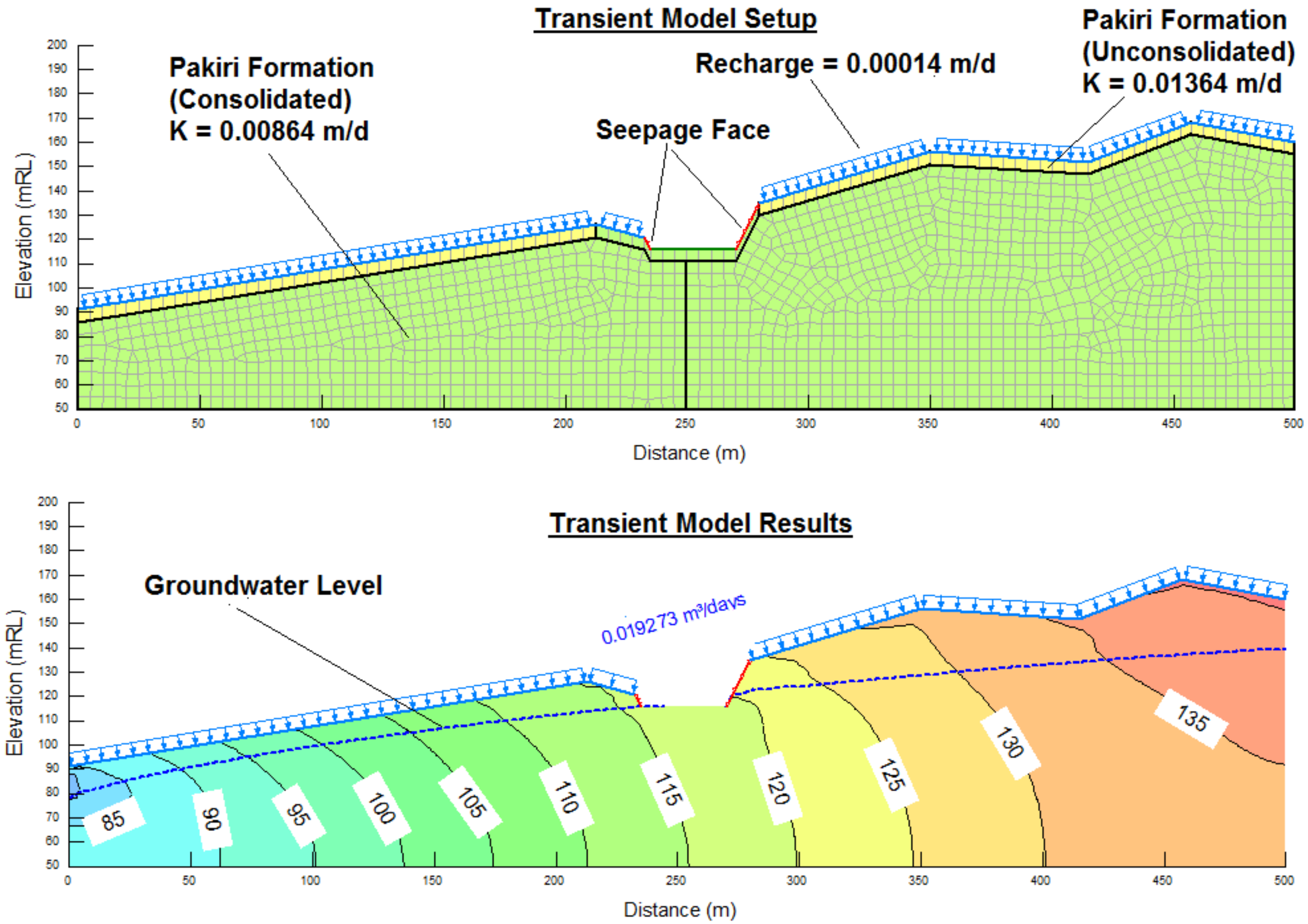


Figure 22 - Transient Model Setup and Results for cut 41500 (after 30 days)

Table 13 – Groundwater leakage rates from Seep/W modelling

Cut Reference	Maximum Leakage Rate (m^3/d)
26900	0.01
33100	0.083
34900	0.007
39200	0.09
39900	0.09
40400	0.07
41500	0.02

Table 14 – Theis forward solution drawdown results after 30 days

Cut Reference	Drawdown 100 m Distance	Drawdown 150 m Distance	Drawdown 200 m Distance
26900	<0.1	<0.1	<0.1
33100	1.25	<0.1	<0.1
34900	<0.1	<0.1	<0.1
39200	4.5	1.4	0.3
39900	3.0	0.7	0.1
40400	2.4	0.5	<0.1
41500	0.4	<0.1	<0.1

APPENDIX F: GROUNDWATER MODELLING – TUNNEL

F1 Introduction

The approach undertaken in this assessment for modelling groundwater effects due to the proposed tunnel construction involved constructing numerous two-dimensional seepage models using Seep/W. These models indicate the water volume and influx rates that will seep through the tunnel walls as the tunnels are excavated, which were then used to calculate groundwater drawdown effects in the vicinity of the tunnels.

The proposed tunnel consists of a twin tunnel arrangement (Northbound and Southbound), which has an approximate total length of 1,680 m, or 840 m per tunnel. It has been assumed for the purposes of our modelling that the Northbound tunnel will be completed first, followed by the excavation of the parallel Southbound tunnel approximately 30 m away from the Northbound tunnel. The constructed tunnels are proposed to be 9 m high by 13 m wide, and will be excavated by roadheader at an assumed rate of 15 m/week.

F2 Model setup and boundary conditions

Model setup

The tunnel was separated into 8 individual Seep/W models, with each model covering a 100 m interval of tunnel. Each of the model domains were determined by extending the model from the midpoint of the tunnel to the high or low point of the surrounding catchment divide.

The model was set up with the following assumptions around tunnel construction. After the Northbound tunnel has been excavated, the tunnel will be lined with a very low permeability membrane, which will restrict water flux into the tunnel. Immediately after the Northbound tunnel is finished, the Southbound tunnel will commence excavation along the same model cross sections as the Northbound tunnel (in reverse order). After the Southbound tunnel is completed and lined, the model run continued for one year after tunnel completion so that water recovery could be modelled.

Hydrogeology

During the geotechnical site investigation, boreholes with piezometers were installed along the tunnel alignment. The bores shown in Table 15 were used to determine the tunnel alignment's local geology, hydraulic conductivities, and static water levels, while Table 16 outlines the geology and hydrogeological inputs used for the model.

Table 15 – Borehole information along tunnel alignment

Borehole	Geology	Piezometer Type	Bore Depth (mBGL)	Piezo Depth (mBGL)	Groundwater Level (mBGL)
WW–BH1040	Pakiri Formation	a– Standpipe b – Standpipe	70.5	a – 16 b – 67.5	19.2 [14/11/2017] 25.1 [14/11/2017]
WW–BH1042	Pakiri Formation	NA – Backfilled	165	No Piezo	NA
WW–BH1041	Pakiri Formation	Standpipe	105	103.4	85.5 [15/9/2017]

Table 16 – Seep/W tunnel model inputs

Geological Unit	Geological Description	Unit Depth (mBGL)	Hydraulic Conductivity (m/s)
Pakiri Formation (Unconsolidated)	Highly weathered weak silty clay and sand	7	1.58×10^{-7}
Pakiri Formation (Consolidated)	Massive sandstone and interbedded siltstone	50	1.00×10^{-7}

Boundary conditions and assumptions

All of the models are set with steady-state conditions to define the static water level by applying constant head boundaries, and then the models transition to transient conditions at the start of the excavation phase. When the tunnel is being excavated, the constant head boundaries are removed and a potential seepage boundary is applied to the area of excavation. Table 17 shows boundary conditions and tunnel depths used for modelling.

The following model assumptions were made for the Seep/W models:

- Rainfall recharge is 50 mm/year (3.3 % of annual rainfall);
- Constant head boundaries are based on the static water levels located at the tunnel, and are extended out to the model domain;
- Tunnel excavation at an advancement rate of 15 m/week;
- The tunnel liner will be installed along the entire tunnel immediately after the excavation of each tunnel is completed; and
- The tunnel liner will have a very low permeability, for modelling purposes this permeability was set at 10^{-10} m/s.

Table 17 – Seep/W model boundary conditions and tunnel depths

Model Cross Section#	Static Water Level (mRL)	Tunnel Depth (mRL)	Rainfall Recharge (mm/yr)
100	160	131	50
200	170	135	
300	180	138	
400	190	141	
500	190	143	
600	185	143	
700	176	142	
800	150	141	

F3 Results

Each Seep/W model provides an estimate for groundwater inflow into the tunnel. The modelling suggests maximum inflow rates during the Northbound excavation will range from 11.0 to 36.2 m^3/day/100m, and 9.8 to 30.4 m^3/day/100m for the Southbound excavation. Table 18 shows the maximum groundwater inflows for the Northbound and Southbound excavation. Figure 23 displays the total inflow rate over the entire 1,600 m of tunnel.

Table 18 – Modelled groundwater flow into proposed tunnels

Model Cross Section #	Maximum Groundwater Inflow (m^3/day/100m)	
	Northbound	Southbound
100	23.5	20.1
200	27.0	21.4
300	20.2	22.7
400	35.8	30.4
500	36.2	29.6
600	31.9	25.1
700	24.7	20.5
800	11.0	9.8

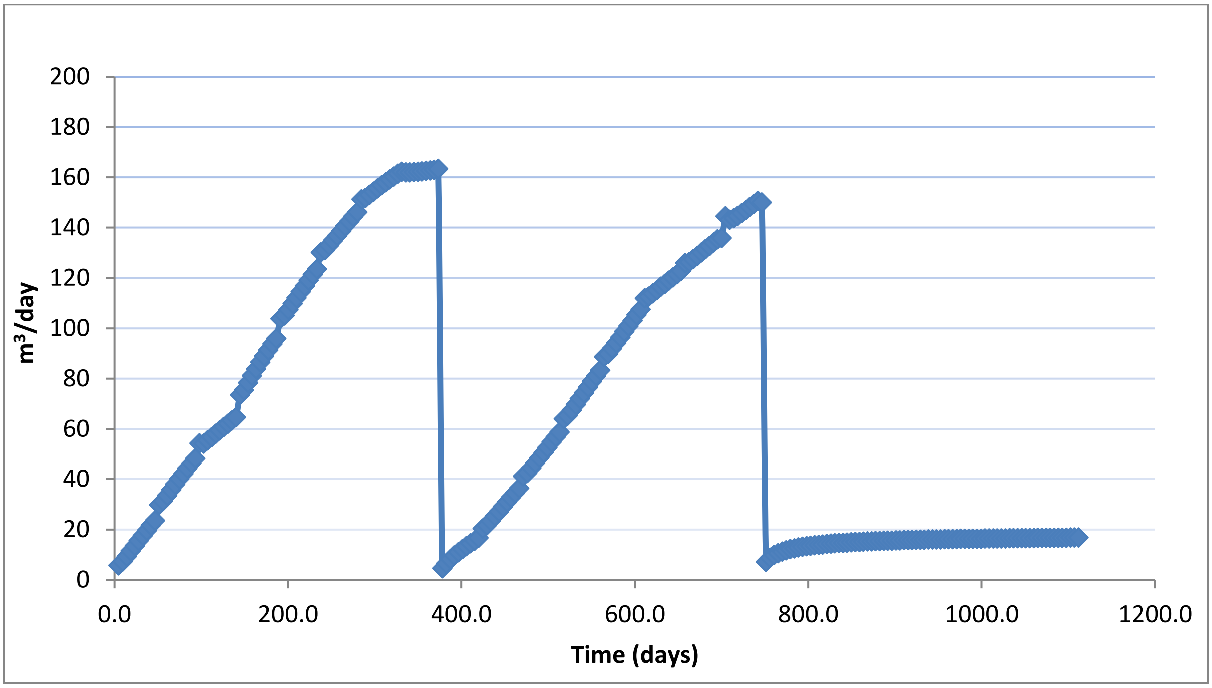


Figure 23 – Modelled tunnel inflows over entire tunnel length (1,600 m)

The modelled groundwater inflows outlined above were used to calculate the potential groundwater drawdown as a result of the tunnel excavation. The drawdown was calculated using the Theis (1937) Forward Solution implemented in Aquifer Test. Dummy bores were applied along the tunnel alignment, and the average pumping rates into the tunnel were applied to each bore. Table 19 displays the average pumping rates and aquifer parameters used for the drawdown model. Figure 24 displays the maximum drawdown due to tunnel excavation.

Table 19 – Input parameters used in drawdown assessment

Model #	Average Pumping Rate (L/s)	Transmissivity (m^2/d)	Storativity
100	0.1265	8.64	0.001
200	0.1458		
300	0.1287		
400	0.2115		
500	0.2311		
600	0.2081		
700	0.1840		
800	0.0873		

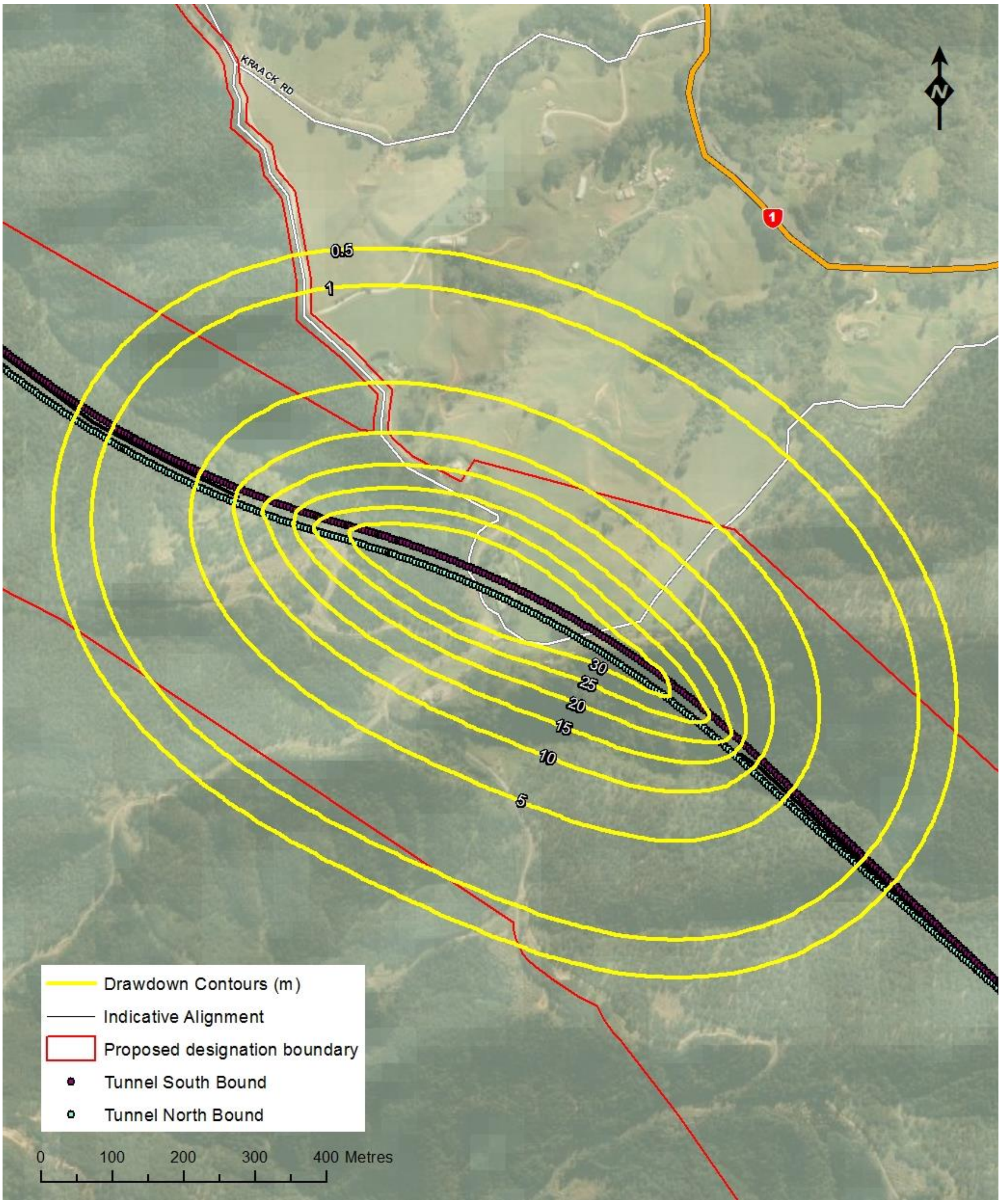


Figure 24 – Calculated drawdown cone from proposed tunnel excavation.