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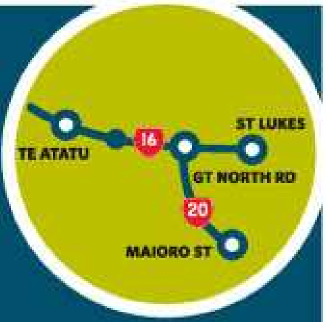
Roads of national significance

16 20 Western Ring Route – Waterview Connection



Assessment of Groundwater Effects

Beca

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1. Introduction/Summary Statement

1.1 The Western Ring Route

In 2009, the government identified 'roads of national significance' (RoNS), and set priority for investment in these as New Zealand's most important transport routes. The RoNS are critical to ensuring that users have access to significant markets and areas of employment and economic growth.

The Western Ring Route (WRR) is identified as a RoNS. The WRR comprises the SH20, SH16 and SH18 motorway corridors and, once completed, will consist of 48 km of motorway linking Manukau, Auckland, Waitakere and the North Shore.

The strategic importance of the WRR is to provide an alternative route through the region to reduce dependency on SH1, particularly through the Auckland Central Business District (CBD) and across the Auckland Harbour Bridge. The WRR will also provide for economic growth, unlocking potential for development along its length by improving trip reliability and access from the west to the south of the region, and from the CBD to the southern Auckland isthmus and airport.

1.2 The Waterview Connection (The Project)

The Waterview Connection Project is the key project to complete the WRR, providing for works on both State Highway 16 (SH16) and State Highway 20 (SH20) to establish a high-quality motorway link that will deliver the WRR as a RoNS.

Completion of the Manukau and Mount Roskill Extension Projects on SH20 mean that this highway will extend from Manukau in the south to New Windsor in the north, terminating at an interchange with Maioro Street and Sandringham Road. Through the Waterview Connection Project (the Project), the NZTA proposes to designate land and obtain resource consents in order to construct, operate and maintain the motorway extension of SH20 from Maioro Street (New Windsor) to connect with SH16 at the Great North Road Interchange (Waterview).

In addition, the Project provides for work on SH16. This includes works to improve the resilience of the WRR; raising the causeway on SH16 between the Great North Road and Rosebank Interchanges, which will respond to historic subsidence of the causeway and “future proof” it against sea level rise. In addition, the Project provides for increased capacity on the SH16 corridor; with additional lanes provided on the State Highway between the St Lukes and Te Atatu Interchanges, and works to improve the functioning and capacity of the Te Atatu Interchange.

The Project will be the largest roading project ever undertaken in New Zealand. The Project includes construction of new surface motorway, tunnelling and works on the existing SH16 (Northwestern Motorway) as well as a cycleway that will connect between the Northwestern and SH20 Cycleways.

1.3 The Assessment of Groundwater Effects

This assessment addresses the interaction of the construction and long-term operation of the tunnels with groundwater.

2-dimensional and 3-dimensional groundwater modelling has been undertaken to assess the effects of the proposed driven tunnels, cut-and-cover tunnel, portals and approaches on the existing groundwater regime.

The assessment assumes that the driven twin tunnels will be progressed on two fronts from the southern portal. The northbound tunnel will commence first, with a 50 m lag between the northbound and southbound tunnels. The tunnels will be excavated in two sections: the upper half being excavated and shotcreted first, followed by the lower half.

Seven hydrogeological units are identified; fill, basalt of the Auckland Volcanic Field (AVF), Tauranga Group sediments (TGA), weathered East Coast Bays Formation (WECBF), weathered Parnell Grit (WPG), East Coast Bays Formation sandstones and siltstones (ECBF) and Parnell Grit (PG). Their distribution is shown in long-section in Appendix A.

Water level monitoring undertaken over the period 2001-2003 and 2006 to 2010 indicates a north to northwesterly gradient on the regional water table towards the coast. The gradient within the Tauranga Group and East Coast Bays Formation is 3 % to 4 % with seasonal variation of up to ± 1 m. Water levels in the basalt are on average 2 m higher than in the underlying Tauranga Group and East Coast Bays Formation of the Waitemata Group and have a seasonal variation of ± 1.5 m on average.

Numerical groundwater modelling has been undertaken in order to provide an assessment of effects on the existing groundwater regime associated with the short term construction and long term operation of the driven tunnel, portals and approaches.

For the northern portals and approaches, the short term dewatering associated with construction is expected to result in drawdown of up to 6 m immediately adjacent to the structural walls, with measureable drawdown extending less than 130 m and negligible effect on Oakley Creek base flow.

Modelling suggests that the northern and southern portals and approaches could be permanently drained, resulting in a drawdown of groundwater levels of up to 10 m, with measureable drawdown extending some 300 m from the portals.

For the construction of ‘undrained’ driven tunnels, short term drawdown of around 8 m to 15 m immediately adjacent to the tunnels is predicted, but this rapidly reduces away from the tunnels with measureable drawdown typically extending less than 100 m. Where the tunnel is driven through more permeable Parnell Grit, a greater magnitude and extent of drawdown is predicted to occur. This could be mitigated by pre-grouting, adopting shorter construction timeframes and managing the open/drained tunnel length.

In the long term the tunnels will be sealed to limit the inflow of groundwater. In the long term, a maximum drawdown of up to 3 m immediately adjacent to the tunnels is anticipated, with measureable drawdown extending less than 100 m from the tunnels.

At the southern portal, a permanent drain in the basalt to relieve pressure on retaining walls is proposed. Therefore the greatest magnitude and extent of drawdown occurs for the long term steady state conditions. Drawdown of 2 m to 13 m is expected in the compressible soils immediately adjacent to retaining walls, with measureable drawdown typically extending less than 50 m (and no more than 100 m) from the walls.

The anticipated drawdown effects of the Project are considered in the Assessment of Settlement Effects report to be less than minor, with a large number of potential mitigation options available to assist in the management of effects.

Monitoring of water levels in boreholes screened within the fill through the summer of 2009/2010 and ongoing investigations in the winter of 2010 suggests that there is almost no water residing within the fill in this area. The potential to spread contaminants through the underlying low permeability soils in response to drawdown is therefore almost nil.

Analyses suggest a reduction of inflows to Oakley Creek by about 6 % over the length of the approaches to the southern portal, reducing to less than 2 % over the length of the driven tunnel and by about 2 % over the length of the northern cut and cover tunnel. This effect is considered to be less than minor.

A monitoring programme will be established prior to construction to record groundwater effects and allow appropriate responses to be triggered should actual effects differ from those predicted.

2. Project Description

The components of the Waterview Connection Project addressed in this assessment of effects are outlined below.

2.1 Sector 7

This sector comprises the 'underpass' of the Great North Road section of tunnel and runs from the northern portal at Waterview Park, crosses beneath Great North Road in a southerly direction, and connects with the deep tunnels (Sector 8) in the vicinity of Waterview Downs. The Great North Road Underpass will be approximately 400 m long and 31 m wide. It varies from 30 m deep at the southern end to typically 10 m deep at the northern end.

2.2 Sector 8

The motorway continues from the cut and cover tunnel section in Sector 7 in a southerly direction into two deep tunnels (with an approximate maximum depth of 65 m in the vicinity of Phyllis Street) through to Alan Wood Reserve, passing beneath Avondale Heights/ Springleigh, the North Auckland Rail Line and New North Road. The tunnels will emerge at grade approximately halfway along the length of Alan Wood reserve. The two tunnels are approximately 2.5 km long and will be approximately 15 m apart. The southern ventilation building and stack will be located above ground on the edge of sectors 8 and 9.

2.3 Sector 9

The driven tunnels emerge into Alan Wood Reserve at the southern portals. The two carriageways will continue through Alan Wood Reserve, under the proposed Richardson Road bridge and continue to join up with the existing SH20 motorway section at the Maioro Street Intersection. The motorway alignment will require realignment of sections of Oakley Creek, and realignment of the Stoddard Road tributary. The motorway alignment through Hendon Park and Alan Wood reserve will be raised above the 100 year flood event.

3. Methodology

3.1 Introduction

This report considers the interaction of the construction and long term operation of the tunnels with groundwater. Some of the interactions need to be understood to inform tunnel design and some need to be understood in order to identify, and if necessary mitigate, potential effects on the environment. Issues investigated that inform design include the:

- Rate of inflow of groundwater to the tunnels, portals and excavations during construction and in the long term;
- Uplift pressures beneath portal and tunnel floors, and groundwater pressures on tunnel lining; and
- Efficacy of limiting these effects by wall and tunnel design elements and construction sequencing.

Issues investigated that might impact on the environment include the:

- Potential to cause groundwater drawdown that might result in ground settlement and affect existing structures;
- Potential to affect Oakley Creek base flows and flow regime by drawing down groundwater levels and altering present inflow and outflow from the Creek;
- Potential to spread contaminants residing in areas of past landfilling by drawing groundwater down at the tunnel where it passes beneath such areas;
- Potential to affect yield or quality of water at existing abstraction bores or springs by altering groundwater flow patterns; and
- Opportunities to mitigate potential environmental effects through design and construction sequencing.

3.2 Tunnel Construction Methodology

The proposed construction methodology is described in Chapter 5 of the Assessment of Environmental Effects (AEE). A summary of key construction method assumptions made in the assessment of the interactions with groundwater is given here.

Construction of the cut-and-cover section of the tunnel at the northern end will commence prior to any work on the driven tunnel. Construction of that section will occur in 2 stages:

Stage 1

- Diaphragm walls constructed for the southbound tunnel at the driven tunnel portal;
- A ramp excavated from north to south to allow access to the driven tunnel portal.
- Diaphragm walls and piles constructed for the northbound tunnel at the driven tunnel portal; and
- Traffic on Great North Road diverted to allow the lid of the cut-and-cover tunnel to be constructed.

Stage 2

- Install remaining sections of diaphragm walls and piles on 2 fronts;
- Excavate tunnel from ground level to 3 m below lid level and construct lid;
- Excavate to 1 m below prop and install internal propping;
- Excavate to 1 m below second prop, then third prop in deeper sections;
- Excavate to 0.5 m below carriageway elevation and install waterproofing, base-course and slab; and
- Place fill over lid to finished ground level.

Preliminary analyses suggest that it would be viable for the floor of the northern and southern cut-and-cover sections of the tunnel to be unsealed (drained) in the long term. This assessment considers both sealed and unsealed options, with the preferred design option being a drained (unsealed) slab.

Analyses assume that the driven twin tunnels will be progressed on two fronts from the southern portal, with the northbound tunnel commencing first and a 50 m lag maintained between the northbound and southbound tunnels. Should the constructors instead wish to progress each tunnel from opposite ends (i.e. one tunnel from the north and one from the south), the effects will be less than those described here because of the greater separation of work fronts. The tunnels will be excavated in 50 m lengths. The tunnels will be excavated in two sections: the upper half being excavated and shotcreted first, and the lower half following. As tunnelling proceeds, the cross-passages will be excavated 50 m behind the main excavation front.

During excavation, temporary support will be installed directly behind the open face and will comprise combinations of bolts, lattice arches, grouted spiles and sprayed steel fibre reinforced shotcrete. The permanent support will comprise a waterproof membrane and either cast in-situ concrete or sprayed shotcrete. Installation of the tunnel lining may be undertaken progressively behind the excavation face (assumed base case for modelling) ~~will~~ or could commence following completion of both driven tunnels (up to 2 years later, considered as an alternative modelling scenario).

Due to the higher groundwater table within the basalt, a grout curtain cutoff will be constructed to limit groundwater flows into the portal area both during construction and in the long term. Once the grout curtain is in place, the basalt will be excavated out in a series of narrow benches. Secant pile walls (piles of around 900 mm diameter) will then be constructed along each side of the portal. These will be tied back with multiple rows of ground anchors and excavation extended down in stages to road formation level. The portal will remain permanently unsealed.

Once excavation is complete the ventilation building will be constructed in a conventional bottom up construction sequence with the building of pads and support columns. Construction of the southern portal and ventilation building is estimated to take around 18 months.

3.3 Approach to Modelling

Both 2D and 3D groundwater modelling have been undertaken in order to more fully assess the likely effects of the construction and long-term operation of the proposed driven tunnels, cut-and-cover tunnel, portals and approaches on the existing groundwater regime.

The 3D model was developed to consider overall groundwater flow trends and broad scale effects resulting from the tunnel emplacement. As such the model is large in scale, with coarse cell dimensions and is not used for the evaluation of drawdown in close proximity to the tunnel (i.e. drawdown adjacent to retaining walls, differential heads and drawdown-induced settlement immediately adjacent to structure). Three-dimensional groundwater flow modelling was carried out using the computer software Visual MODFLOW Pro v4.3 (Schlumberger, Canada).

Because of the complex geology and 3D nature of flow (in particular in this case where the major component of flow is approximately along the length of the tunnel), the 3D model is used for assessment of:

- Effects on water balance and groundwater flows into and from Oakley Creek;
- Magnitude of drawdown at more than 100 m from the tunnel centreline (in combination with the outputs from the 2D modelling);
- The extent of drawdown; and
- Effects of dual tunnel construction sequencing.

In order to examine the effects of the tunnels on groundwater flow around the tunnel structure and walls in more detail, 2D groundwater seepage modelling (SEEP/W 2007) was undertaken. Because of the finer scale of the 2D models, and the software's ability to model unsaturated flow (such as that which occurs when an excavation is dewatered) the 2D modelling was used to consider the likely effects in immediate proximity to the tunnel (100 m either side). However, as regional groundwater flow is roughly perpendicular to the 2D sections, this modelling cannot be used to assess effects on Oakley Creek. The 2D model is used for assessment of:

- The rate of groundwater seepage into the tunnels, both during construction and in the long term;
- Uplift pressures beneath the tunnel floor;
- The influence of pile depth on drawdown and uplift pressures;
- The amount of drawdown and how it varies along and within 100 m either side of the tunnels; and
- The effects of constructing cross-passages between the dual tunnels.

4. Assessment Matters

As part of the Project NZTA will apply for consent to use, take and divert groundwater. The potential effects of this application are:

- The potential to affect Oakley Creek Base Flows;
- The potential to spread contaminants from landfill areas; and
- The potential to drawdown (or lower) groundwater to the extent that it results in ground settlement that causes damage to existing structures.

We note that groundwater drawdown in itself is not an effect, but potential effects result from drawdown such as pore pressure reduction that might result in ground settlement, or changes to groundwater flow and direction that might affect surface water or movement of contaminants.

4.1 Potential to affect Oakley Creek Base Flow and Flow Regime

Drawdown of groundwater in the vicinity of Oakley Creek to facilitate tunnel construction might alter the contribution of groundwater that naturally flows towards Oakley Creek; it might also increase the volume of water that naturally discharges through the bed of the Creek to recharge the underlying groundwater system.

4.2 Potential to Cause Ground Settlement and Damage to Existing Structures

Drawdown of groundwater at the tunnel will result in a cone of depression (lowering) of the groundwater table/s that extends outwards from the tunnels. The amount of drawdown will decrease with distance from the tunnels. The drawdown of groundwater below the normal seasonal variation can cause settlement of compressible soils, which in turn may result in settlement of structures founded on or in those soils, depending on the amount of settlement that is induced and how this changes beneath the structure, the nature of the structure and its foundations.

The potential magnitude and extent of groundwater drawdown within compressible soils is estimated in this report. The potential effect of the settlement on structures is addressed in the Technical Report G.13 *Assessment of Ground Settlement Effects*.

The walls of the completed tunnels will have a lower permeability than the surrounding ground and may locally act as a barrier to groundwater flow, resulting in a rise in groundwater level. However, because the dominant groundwater flow direction is approximately along the length of the tunnel, this mounding effect would be less than minor.

4.3 Potential to Spread Contaminants

Drawdown of groundwater at the tunnel could result in draw-in of contaminants that normally reside within near-surface materials, such as landfill or areas of basalt used for stormwater discharge. Details of contaminant investigations for the Project are described in the Technical Report G.9 *Assessment of Land and Groundwater Contamination.*

4.4 Monitoring

The assessment of the existing groundwater flow regime and changes that might occur as a result of tunnel construction presented here is made from computer modelling developed from, and calibrated to, in-situ investigations and both in-situ and laboratory testing. It is therefore important to check that actual changes in groundwater levels and quality, during and post-construction are similar to those predicted. This is normally done by undertaking a comprehensive monitoring programme that includes:

- recording water levels in selected piezometers adjacent to and at distance from the tunnels;
- checking indicators of contamination in selected piezometers; and
- installing settlement marks on key structures and surveying their level.

The monitoring programme is designed to give early warning of changing conditions. Because drawdown in the ECBF occurs some time before drawdown and resultant settlement in the TGA is experienced, changes can be made to limit drawdown if monitoring indicates higher than anticipated drawdown; it therefore acts as an early warning system.

This approach is supported by previous large dewatering projects (Sky Tower, Britomart, New Lynn Rail Trench etc) where although the predicted levels of drawdown in compressible soils often occurred, the predicted level of settlement did not, as the dewatering period was not long enough for the full amount of settlement predicted to occur. At the recently completed New Lynn Rail Trench (NLRT) project, drawdown to the predicted groundwater level was recorded in piezometers and pressure cells immediately behind the tunnel walls in the TGA. However, no associated settlement has been recorded at ground or building pins installed for settlement monitoring.

Monitoring normally begins at least a year prior to commencement of construction and continues for a similar period after completion of construction. A draft monitoring programme is set out in the Waterview Technical Report G21 *Construction Environmental Management Plan (CEMP).*

5. Existing Environment

5.1 Geological Setting

The Project area is located in the western-central suburbs of Auckland, within an incised stream valley between Mt Albert volcano and the Great North Road / Blockhouse Bay Road ridge.

The geology of the study area and distribution of geological units is described in the Technical Reports G.28 *Geotechnical Factual Report 500 Series* and G. 29 *Geotechnical Factual Report 700 Series*. Investigation point locations, along with the tunnel alignment and sectors, are shown in Figure 1. A 3D projection of the geology beneath the alignment is presented in Figure 2 and a geological map of the area (derived from Kermode, L. 1992 Geology of the Auckland Area 1:50,000, Geological Map), is included as Figure 3. Records of investigation drilling carried out are presented in the Technical Reports G.28 *Geotechnical Factual Report 500 Series* and G. 29 *Geotechnical Factual Report 700 Series*.

5.2 Hydrogeological Units and their Properties

A long-section showing the geology grouped into hydrogeological units (that is, units that have similar hydrogeological properties) along the tunnel alignment is attached in Appendix A (also presented in the Waterview Connection Project SH16/SH20 - Geotechnical Interpretative Report).

Seven hydrogeological units have been recognised and are described (including a summary of hydrogeological properties derived for each unit from field test data) in Appendix E.

Figure 2 shows the broad distribution of these hydrogeological units in three dimensions.

The seven hydrogeological units are:

1. **Fill,** variable in nature and thickness (including some pockets of industrial waste);

2. **Auckland Volcanic Field (AVF),** high permeability, variably jointed basalt lava flows;

3. **Tauranga Group Alluvium (TGA),** low permeability, compressible clays, silts and sands;

4. **Weathered East Coast Bays Formation (WECBF),** low permeability silts, sands and clays;

5. **Weathered Parnell Grit (WPG),** soft to firm sensitive silts and clays;

6. **East Coast Bays Formation (ECBF),** low permeability interbedded sandstone and siltstone; and

7. **Parnell Grit (PG),** high permeability, coarse volcanogenic sandstone.

All geotechnical and hydrogeological parameters can be expected to vary a little from place to place. However the soil or rock mass as a whole will generally behave according to the mean or typical value. However, where confirmed by field test data, this spatial variability has been considered as outlined in Appendix E. Variability in parameters is also considered through sensitivity analyses (Appendix G).

5.3 Groundwater Levels, Gradients and Direction of Flow

Recorded groundwater levels are contoured in Figures 3a (regional) and 3b (perched), and tabulated in Appendix B.

In general the water levels indicate a northerly gradient falling to close to sea-level at the coast. Within the deeper East Coast Bays Formation, water levels range from around Reduced Level (RL) 43 m at the Mount Albert end of the alignment to RL 2 m near the Waterview Interchange with levels consistent with inferred Oakley Creek water levels.

Water levels within the basalt, TGA, WECBF and WPG range from RL 43 m (near Alan Wood Park) to RL 20 m (near Phyllis Street). These levels are on average 2 m (but up to 7 m) higher than those in the underlying East Coast Bays Formation.

These levels and disparity in trends of groundwater elevation vs. depth (refer Appendix E3) suggest that there is some disconnect between water levels in the lower ECBF and PG rock, and water levels in the soils and basalt. Some connection is indicated by pumping tests (as discussed in Section 5.7), suggesting leakage from the upper perched aquifer to the lower ECBF aquifer.

Water levels in the basalt and residual soils respond directly to rainfall events and have a strong relationship with screen elevation. Water levels in the underlying ECBF reflect the regional aquifer system draining to the northwest (i.e. into the Waitemata Harbour). The water levels in the ECBF do not respond directly to rainfall (although seasonal variations occur).

A discussion on the recorded groundwater levels in each unit is given in Appendix E.

5.4 Groundwater Quality

Testing of groundwater abstracted from within the ECBF rocks has indicated that in most areas water quality is typical of that found at other sites in Auckland. Groundwater quality is discussed in Technical Report G.9 Assessment of Land and Groundwater Contamination.

5.5 Groundwater Use

A review of the Auckland Regional Council (ARC) well database has identified 5 existing water wells within the Project area (as indicated on Figure 1). Four of the five wells have expired consents and therefore are unlikely to be in use; no information is available for the remaining well.

Small volumes of groundwater are taken from basalt springs in the Unitech grounds. In some areas up-gradient of the project, stormwater is being discharged to the basalt aquifer. Both these activities are considered to be of a volume too small to significantly affect the wider water balance; however they are considered in the assessment of effects.

5.6 Surface Water

5.6.1 Oakley Creek

Long term continuous monitoring of Oakley Creek flows is available from the Metrowater gauge located at Underwoods Park. Qualitative assessment of the data from Underwoods Park indicates that the Creek can be described (on the basis of Base Flow Index, BFI) as a flashy river with significant flow variations and a low base flow component (Appendix D). This means that the majority of flow in the Creek is sourced from quick flow i.e. rainfall runoff, stormwater discharges etc. About a third of Creek flow is sourced from stored sources such as in-stream flow from up-gradient, up-gradient groundwater recharge or local groundwater recharge. As groundwater recharge along the length of the alignment comprises only a small portion of all flows, the potential reduction in groundwater leakage is likely to have a negligible effect on the Creek.

Additional gauges are proposed (2 have been installed and 3 further gauges are proposed) to check the relationship between Oakley Creek and groundwater.

5.6.2 Springs

Groundwater springs emerge from basalt in the Unitech grounds. Limited flow data is available on the springs which are likely to have been modified over time and currently feed a shallow pond.

5.7 Hydrogeological Properties

Some 171 No. in-situ hydraulic conductivity tests have been undertaken including packer tests in East Coast Bays Formation and Parnell Grit rock and rising head tests in completed piezometers in all units. Six pumping tests have also been undertaken in pumping wells screened in the basalt, East Coast Bays Formation and Parnell Grit.

The results of this field testing have been used to determine the typical (geometric mean), and range of hydraulic conductivities for each unit. A summary of hydraulic conductivities is given below and in Appendix C and a more comprehensive discussion of test results is given in Appendix E.

Within the **East Coast Bays Formation (ECBF),** testing yields (horizontal) hydraulic conductivities that vary over 3 orders of magnitude. This is as expected for a fractured rock aquifer where hydraulic conductivity, tested in the narrow zone adjacent to the borehole, is dependent on local variations in fracture spacing and rock mass porosity (i.e. localised zones of higher or lower than 'typical' hydraulic conductivity can be expected). The results are consistent with the range of values obtained in this material on other projects in Auckland (Table 5.1). There is no evidence (in the core logs, in-situ test results or pumping testing) to suggest that significant zones of higher than typical hydraulic conductivity may be present in the study area.

A horizontal hydraulic conductivity of the order of 10^{-7} m/s is indicated for the **Tauranga Group Alluvium (TGA)**. The pumping tests suggest that when dewatered, the ECBF may locally under-drain the TGA, resulting in some drawdown in water levels within the TGA. The results of pumping tests for this Project indicate that in most cases the drawdown in the TGA occurs relatively quickly (within 1 – 5 days) after commencement of dewatering in the ECBF. Therefore in areas where compressible soils may be dewatered, it may be necessary to limit the dewatering period in order to lessen the potential for adverse effects (ground settlement), should such effects be indicated. This is discussed in more detail in Appendix E.

Table 5.1 – Comparison of Hydrogeological Properties

Unit	SH16/SH20 K (m/s)	Vic Park Tunnel[1] K (m/s)	New Lynn Rail Box[2] K (m/s)	Britomart[3] K (m/s)	Three Kings Quarry[4] K (m/s)
Auckland Volcanic Field Basalt lava flows (Basalt)	$K_h = 1.2 \times 10^{-5}$ to 5.0×10^{-5} $K_v = 5.0 \times 10^{-5}$	Not present	Not present	$K_h = 7.0 \times 10^{-5}$ $K_v = 1.0 \times 10^{-5}$	$K_h = 2.0 \times 10^{-4}$ $K_v = 2.0 \times 10^{-4}$
Tauranga Group Alluvium (TGA)	$K_h = 1.0 \times 10^{-7}$ to 2.3×10^{-7} $K_v = 1.0 \times 10^{-7}$ to 3.5×10^{-8}	$K_h = 2.0 \times 10^{-7}$ $K_v = 2.0 \times 10^{-8}$	$K_h = 3.0 \times 10^{-7}$ $K_v = 5.0 \times 10^{-8}$	$K_h = 2.0 \times 10^{-7}$ $K_v = 7.0 \times 10^{-9}$	Not present
Weathered East Coast Bays Formation, Waitemata Group (WECBF)	$K_h = 2.0 \times 10^{-7}$ $K_v = 2.0 \times 10^{-8}$				Not present
Weathered Parnell Grit, Waitemata Group (WPG)	$K_h = 4.0 \times 10^{-7}$ to 4.6×10^{-7} $K_v = 1.5 \times 10^{-7}$ to 4.0×10^{-8}				
East Coast Bays Formation, Waitemata Group rock (ECBF)	$K_h = 3.5 \times 10^{-7}$ to 5.7×10^{-7} $K_v = 5.7 \times 10^{-8}$	$K_h = 1$ to 5×10^{-7} $K_v = 1.0 \times 10^{-8}$	$K_h = 1.0 \times 10^{-7}$ $K_v = 1.0 \times 10^{-8}$	$K_h = 5.0 \times 10^{-7}$ $K_v = 5.0 \times 10^{-8}$	$K_h = 1.5 \times 10^{-8}$ $K_v = 1.5 \times 10^{-9}$
Parnell Grit, Waitemata Group Rock (PG)	$K_h = 3.0 \times 10^{-5}$ to 2×10^{-6} $K_v = 1.0 \times 10^{-6}$ to 9.0×10^{-6}	Not present	Not present	Not present	Not present

SH16/20: range indicates the difference in calibrated values for 2D and 3D models

[1] "Vic Park Tunnel Project – Hydrogeological and Engineering Assessments Report" Beca, 2006

[2] "New Lynn Rail Trench – Assessment of Groundwater Effects Addendum Report" Beca, 2008-07-23

[3] "Groundwater Effects Assessment of Queen Street Station" PDP, 2000

[4] "Groundwater Modelling of the Waitemata near Three Kings Quarry" PDP, 2003

6. Effects Assessment: Construction Activities and Operation

This section discusses the outputs of groundwater modelling in terms of effects on Oakley Creek, the extent and magnitude of drawdown, the potential for spread of contaminants from areas of landfill and the anticipated volume of water that would need to be discharged via drainage in the short (construction) and long (operation) terms.

Details of model set-up, including areal extent, grid size, boundary conditions, recharge, calibration, model sensitivity and methodology for modelling construction sequencing are described in Appendix F and G, for the 3D and 2D models respectively.

The 3D modelling has been used (in conjunction with the 2D modelling) to assess:

- Effects on groundwater inflows to Oakley Creek and drawdown-induced losses from Oakley Creek;
- The overall magnitude of drawdown resulting during tunnel construction in the long-term; and
- The extent of drawdown and differences in effects resulting from construction sequencing.

The 2D modelling has been used to assess:

- The volume of groundwater seepage into the tunnels;
- Assessment of uplift pressures on the base slab, assessment of the amount of drawdown within 100 m of the tunnels; and
- The effects of cross-passages between the tunnels.

Plots of pore pressure change output from the 2D modelling have been used for assessment of settlement effects in the Technical Report G.13 *Assessment of Ground Settlement Effects*.

The discussion below provides a summary of the predicted effects associated with the proposed "base case" construction method and timing, as outlined in Section 3.2. This discussion incorporates the results of both the 3D and 2D modelling (which were generally comparable).

For both 3D and 2D numerical modelling, a number of scenarios and sensitivity checks have been considered to assess the effects of varying hydrogeological parameters, varying dewatering timeframes and alternative construction methodologies. These results, including discussions on model sensitivity are given in Appendix F (3D modelling) and Appendix G (2D modelling).

6.1 Changes in Groundwater Level

As the driven tunnel will be fully sealed in the long term, the largest changes in groundwater level will result from the short-term dewatering during tunnelling. As the northern and southern portals will be partially or fully drained, the greatest changes in groundwater level in these areas will occur in the long term when steady state conditions have been achieved.

6.1.1 Northern Cut and Cover Tunnel

As a minimum, the northern portal needs to be drained short term to facilitate construction. However modelling, supported by experience from previous projects in similar materials, suggests that some 50 to 70 % of steady state drawdown[1] could occur within the construction dewatering period. The difference in drawdown between short term and permanent drainage at the northern portal is relatively small, and no significant advantage is gained by permanently sealing the base slab.

With the northern portal drained permanently, a maximum long-term drawdown of 5 m – 10 m is anticipated in compressible soils immediately adjacent to the tunnel walls, reducing to less than 5 m at a distance of 50 m. Measurable drawdown would extend some 200 m from the cut-and-cover tunnel walls.

6.1.2 Driven Tunnel

As the driven tunnels are to be lined in the long term, the maximum drawdown immediately adjacent to the tunnels will occur during the construction phase. Modelling suggests that when the tunnel is driven through ECBF sandstones and siltstones, maximum drawdown expected in the TGA will be between 0.5 m and 8 m adjacent to the tunnels. When the tunnel is driven through, or in close proximity to the fractured PG, the maximum drawdown in the TGA will be much greater (because of the higher hydraulic conductivity of the Parnell Grit) at between 15 m and 32 m[2]. Fractured PG has been identified in a group of boreholes in the vicinity of Phyllis Reserve and its extent is being further investigated at present. The extent assumed in 3D modelling is shown in Appendix F.

Drawdown within the TGA rapidly reduces to less than 4 m within 50 m to 100 m of the tunnels. Measurable drawdown (0.5 m) is predicted to extend no more than 90 m from the tunnels within the TGA; the exception being where the tunnels are driven through PG. In areas of PG, measurable drawdown in the overlying WPG is predicted to reach some 250 m from the tunnels.

In the long term the modelling suggests a negligible drawdown in the TGA and WPG immediately adjacent to the tunnels (< 0.5 m) with measurable drawdown extending no more than 80 m from the tunnels.

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[1] The maximum drawdown that could be expected in the long term should the portal be fully drained.

[2] Note the 3D modelling suggests a lesser peak drawdown, of between 8 m to 10 m for this scenario. The 2D modelling is considered to over-estimate drawdown because it cannot consider flow parallel to the tunnel alignment, which in this case is the dominant regional groundwater flow.

6.1.2.1 Southern Portals

The base case option assumes the base slab at the Southern approaches and portals are fully drained long term and the greatest drawdown will occur when long term steady state conditions are achieved.

2D and 3D modelling suggests a drawdown of up to 2 m to 15 m immediately adjacent to the walls if the portals are drained, with measurable drawdown extending no more than 100 m. The magnitude and extent of drawdown is a function of the basalt permeability which will vary with the degree of fracturing and connectivity between fractures. Hence there may be locations where drawdown could extend a lesser or further distance.

6.1.3 Damming

Modelling suggests that as the tunnel is oriented generally parallel to the dominant groundwater flow direction, it is unlikely to cause an elevation of up-gradient groundwater levels once construction is complete. Buoyancy effects that can occur if groundwater levels become elevated above normally occurring levels (such as upward movement of services or structures) are therefore not anticipated.

6.2 Groundwater Inflow to the Tunnels

Modelled seepage inflow to the tunnels in the short and long term is described in Appendix G. Seepage has been plotted as ‘outflows’ from the model, which therefore have a negative notation. Estimates of seepage are primarily sourced from the 2D models, which compare well to those predicted by 3D modelling. As the actual inflow into the **tunnel** will be primarily a factor of the length of open tunnel face, construction inflows are discussed in terms of cubic metres of water per day (m^3/d) per metre of open tunnel (/m).

6.2.1 Cut and Cover Tunnel and Northern Portal

Maximum inflows to the northern end cut-and-cover section occur during excavation of the floor as the walls will have been placed prior to excavation and the water table resides just above floor level at the northernmost end, deepening to the south. The modelling suggests a peak inflow of 0.02 to 2.0 m^3/d/m length of tunnel depending on the depth and width of the cut and cover excavation, and geology.

In the transition zone of some 150 m in length, where the northern alignment will be a driven tunnel, but the southern alignment will be cut and cover, the peak inflow of the order of 0.5 to 0.9 m^3/d/m length of tunnel, will be generated during excavation of the driven tunnel.

Assuming the northern portal is permanently drained, a total inflow of 280 m^3/d (3.2 l/s) is expected (from 3D modelling) to the 400 m length of cut and cover tunnel.

6.2.2 Driven Tunnel

The maximum groundwater inflow to the driven tunnels occurs during the initial breakout of the tunnels. Depending on the tunnel location and geological profile, the models suggest an initial peak inflow in the order of 1 to 120 m^3/d/m length of tunnel. Where the tunnel is driven through ECBF sandstones and siltstones the peak inflows range from 1.5 to 5.3 m^3/d/m length of tunnel; where the tunnel is driven through high permeability PG, the peak inflows reach the maximum of about 120 m^3/d/m length of tunnel.

The average inflows during the construction phase of the tunnel (once shotcreted) range from 0.3 to 5.3 m^3/d/m length of tunnel. Once the tunnels are sealed the inflow rate reduces to less than 0.1 m^3/d/m length of tunnel.

Long term inflow rates of 0.007 to 0.02 m^3/d/m length of tunnel are considered likely. When these rates are pro-rated over the full length of the driven tunnel alignment (2000 m), this equates to 40 m^3/d (or 0.5 l/s), a very small volume of water.

6.2.3 Southern Portal and Approaches

The maximum groundwater inflow to the southern portal occurs during excavation of the basalt, or if basalt is not present, on completion of excavation to floor level. The model suggests peak inflows of around 0.2 m^3/d/m length of alignment if the road alignment is not through basalt and peak inflows of 10 to 75 m^3/d/m length of tunnel when the road level is within or below basalt. The highest predicted peak inflow occurs where the level of the road is below the basalt. This peak drops off to 2.5 m^3/d/m length of tunnel within 30 days.

Modelling suggests the average inflow during construction will range from 0.2 to 1.7 m^3/d/m length of alignment reducing to 0.15 to 0.45 m^3/d/m length of tunnel in the long term. When these rates are pro-rated over the representative length of the alignment (1000 m), this equates to 150 to 450 m^3/d (2 to 4 l/s).

Long term inflows of around 240 m^3/d (2.8 l/s) can be expected for a permanently drained base slab (with a basalt drain).

6.3 Potential for Contaminant Migration

Areas of landfill have been identified between CH3000 and CH3500. In this area the tunnel is at least partially driven through the more permeable PG, which could under-drain the fill (and the TGA that underlies it), resulting in downward movement of groundwater and contaminant migration.

During the construction phase a significant increase in vertical flow would be induced by drawdown, potentially allowing for some vertical migration of mobile contaminants. However a 7 m to 21 m thick layer of low permeability residual soil derived from the weathering of the PG (WPG) separates the fill from the unweathered PG. This material will behave as an aquitard, reducing the risk of contaminants reaching the tunnel excavation or migrating into the deeper rock aquifer.

Modelling shows that the vertical velocity of groundwater within the layers underlying the fill is likely to be in the order of 0.02 m/d during the periods of maximum drawdown; water travelling at this velocity would take a minimum of 650 days to reach the base of the weathered materials, with the average travel time being more like 1800 days. As the period of maximum vertical flow is limited to the time for the breakout and shotcreting of each tunnel, the potential for contaminants to travel with groundwater into the tunnel or deeper rock aquifers is considered to be very low. This is consistent with the results of 3D modelling, which suggest only negligible drawdown in the fill due to the presence of low permeability TGA and WPG.

Monitoring of water levels in boreholes screened within the fill through the summer of 2009/2010 and ongoing investigations in the winter of 2010 suggests that there is almost no water residing within the fill in this area. Therefore the potential spread of contaminants is approximately nil.

6.4 Potential Impacts on Surface Water

For a drained northern portal, modelling suggests that the effects on Oakley Creek, both in the short and long term are less than minor, with groundwater base flows to Oakley Creek reducing by around 2 %.

For the short term construction dewatering and long term operation of the driven tunnels, effects on Oakley Creek will be less than minor. During construction dewatering, base flows to Oakley Creek are typically unaffected, though where the tunnel is driven through higher permeability Parnell Grit they may be reduced by about 4 %. Long term the sealed tunnels would result in a reduction to in-stream base flow of < 2 %.

For the southern portal and approaches, permanent drainage associated with the retaining walls and base slab is predicted to reduce base flow by around 6 %.

6.5 Sensitivity Analyses

A number of alternative scenarios (sensitivity checks) were undertaken to assess the potential range of effects under differing natural and engineering design conditions. A full description of the results is given in Appendix F and G and a summary is provided below.

6.5.1 Variations in Hydraulic Conductivity

The models were found to be relatively insensitive to changes in **basalt** hydraulic conductivity (even over the wide range indicated by in-situ field testing) where significant thicknesses of alluvial and residual soils limit the connection between the tunnel and basalt. Where the TGA / WECBF profile is thin, altering basalt hydraulic conductivity can reduce or increase predicted drawdown by 20 %.

Reducing the hydraulic conductivity of the TGA or WPG has a comparable effect reducing or increasing drawdown by 20 %, depending on the situation.

Reducing the anisotropy in the ECBF (from 0.1 to 0.5) results in changes in drawdown of the order of ± 20 % but in some cases up to 50 % (i.e. increasing drawdown at some locations from 8 m to almost 12 m).

The model is most sensitive to changes in the PG hydraulic conductivity. The base case model conservatively assumes that the higher field test values (3×10^{-5} m/s) are widespread and not restricted to a fracture zone of finite length, however where the lower hydraulic conductivity (1×10^{-6} m/s) is assumed, predicted inflow to the tunnel is significantly less (by 2 orders of magnitude) and construction related drawdown in the TGA is also reduced, by around 20 % to 40 %.

In all cases, sensitivity analyses indicate that the Project will have only a small effect on Oakley Creek base flows and groundwater drawdown away from the tunnels. The groundwater modelling undertaken has demonstrated that for all expected conditions the Project will result in negligible or less than minor adverse effects on the environment.

6.5.2 Variations in Design and Construction

Pre-grouting of the PG (in a radial pattern about the excavation face) could result in significant reductions in peak inflows and reductions in drawdown within the TGA. A small rise in the groundwater level (damming) is predicted to occur as a result of the grouting, however this would have a negligible effect on the groundwater regime because the regional groundwater flow is approximately parallel to the alignment.

Modelling suggests that if the hydraulic conductivity of the tunnel lining is one order of magnitude lower than anticipated, the long term inflow to the tunnel may also be reduced by an order of magnitude. This would reduce the reported drawdown effects and inflows to the tunnel.

A small amount of relaxation of the rock mass immediately around the tunnel excavation might occur, and although this could result in a short term increase in the peak inflow, modelling suggests that the average construction and long term inflows remain unchanged.

The construction of 5 m high cross-passages is unlikely to change the expected peak inflow, but long term inflows could be 25 % greater (the magnitude of inflow remains small however, i.e. an increase of 0.005 $m^3/d/m$) at these locations. Cross-passage construction is also likely to result in 30 to 35 % more construction drawdown at those locations during construction, but has a negligible effect on long term drawdown.

Should the partially drained period be extended from 4 months to 2 years, a small increase in the magnitude and extent of drawdown (within the compressible soils) is predicted at distance from the tunnels. The magnitude of drawdown is predicted to increase by no more than 1 m and measurable drawdown might extend a further 30 m.

The numerical modelling indicates that for all considered variations in design and construction, the Project will result in negligible or less than minor adverse effects on the environment.

6.6 Long-term Damming Effects

Modelling suggests that as the tunnel is oriented generally parallel to the dominant groundwater flow direction, noticeable elevation of up-gradient groundwater levels is unlikely. Buoyancy effects such as upward movement of services or structures are therefore not anticipated.

6.7 Long-term Settlement Effects

Although modelling suggests that the TGA will never be completely dewatered, some long term drawdown resulting in a reduction in pore pressure can be expected. The reduction in pore pressure will result in an increase in the effective stress on the soil layer. This increase in effective stress, if large enough, can result in settlement of compressible soils such as the TGA.

Assessment of the total magnitude and extent of settlement resulting from drawdown of groundwater during construction and in the long term is presented in the Technical Report G.13 *Assessment of Ground Settlement Effects*. This report also provides an evaluation of differential settlement and angular distortion, and the cumulative effect of settlement due to groundwater lowering, tunnel volume loss and wall deflection (at the portals).

7. Mitigation of Effects and Monitoring

Groundwater drawdown in itself is not an environmental effect, but the potential effects of groundwater drawdown are:

- Changes in pore-pressure resulting in ground settlement;
- Changes in the balance of groundwater flow into and discharge from Oakley Creek; and
- Changes in groundwater flow direction and gradient that might alter existing contaminant distribution.

Monitoring of groundwater levels, ground surface elevations (settlement) and surface water flows will be undertaken to confirm the results of predictive modelling and to refine models if early monitoring indicates that actual behaviour is different to that predicted. As groundwater drawdown in the ECBF occurs in advance of drawdown and resultant settlement in the TGA, groundwater monitoring will also serve as a trigger to initiate more comprehensive settlement monitoring and / or implementation of mitigation measures if necessary. Monitoring is described in Section 7.2.

7.1 Mitigation

The following strategies have been used in tunnel design to mitigate potential effects on groundwater:

- Construction of a grout curtain within the basalt at the southern portal, to restrict the volume of water reaching the excavation, leading to lower peak inflows;
- Consideration of variation of pile depth which will increase the length of the flow path of water entering an excavation and lessen drawdown;
- Construction of an undrained driven tunnel which limits the potential effects on groundwater to the construction period, after which the tunnel is sealed allowing groundwater levels to return to close to pre-construction levels;
- A 3-step excavation sequence followed by shotcreting of each excavated portion within 3 days to rapidly limit the volume of groundwater inflow to the tunnel at that location and therefore the extent of drawdown that will occur;
- Proposal to grout ahead of tunnel excavation where the tunnel passes through the high hydraulic conductivity (fractured) Parnell Grit, which will slow groundwater flow through the in-situ rock and therefore limit groundwater inflow to the tunnel at that location and therefore the extent of drawdown that will occur.

The following strategies are commonly used during the construction phase of excavations, and one (or a combination) of these options could be considered to reduce the amount of drawdown and associated effects should maximum consented drawdowns be exceeded:

1. Monitor groundwater elevation, flow and quality and respond appropriately;

2. Alter the cross-passage construction methodology to reduce the period of time that the passages are drained (i.e. reduce the dewatering period and seal the passages as quickly as possible following boring);

3. Construct cross-passages in critical locations during winter, when the effects on Oakley Creek flows will be less significant;

4. Should loss of water flow from Oakley Creek be of concern, a 'liner' or cut-off wall within or adjacent to the Creek could be constructed (a slurry wall is currently proposed at the southern portal in the basalt); or

5. Grout fractures (natural and construction related) to cut off groundwater flow. This would reduce groundwater drawdown; and

6. Recharge groundwater to limit the amount of drawdown. In principle this would require injecting a comparable volume of water to that being drained from the tunnel back into the ECBF (using deep injection wells). This may not be efficient or cost effective, given the low hydraulic conductivity of the TGA and ECBF, and a field trial to confirm feasibility would be needed to confirm the appropriateness of this approach.

Appropriate mitigation method(s) would be selected by the Contractor at the time that an issue arose.

7.2 Monitoring

A monitoring programme will be required to record groundwater effects and trigger appropriate responses. A draft monitoring programme has been prepared as part of the Technical Report G.21 *Construction Environmental Management Plan (CEMP)* and will include a combination of the following:

- Multi-level piezometer arrays in proximity and at distance from the tunnels to monitor changes in groundwater levels;

- Baseline monitoring data taken in advance of works to obtain seasonal and annual variations (this has been underway since July 2001 and it is recommended that this should continue in the existing and new installations until construction begins);

- Flow meters at collection sumps, drainage locations and discharge points to measure inflows;

- Flow meters or continuous flow monitoring of Oakley Creek at key localities;

- Monitoring of key indicators of mobile contaminants in selected bores down gradient and below land fills;
- Initial and on-going condition surveys of potentially affected structures including level monitoring;
- Ground and building settlement monitoring pins in proximity and at distance from the tunnels;
- Regular readings throughout the works and post-construction to monitor residual/ on-going responses;
- Establishment of various trigger levels (e.g. advisory, alert and alarm) with appropriate remedial action plans; and
- A system of review to determine at what stage after construction monitoring can be reduced or cease.

8. Summary and Conclusions

Numerical groundwater modelling has been undertaken in order to provide an assessment of effects on the existing groundwater regime associated with the short term construction and long term operation of the driven tunnels, portals and approaches. The results are summarised in Table 8.1.

8.1 Portals

For the northern portals and approaches, the short term dewatering associated with construction is expected to result in drawdown of up to 6 m immediately adjacent to the structural walls, with measureable drawdown extending no more than 130 m and a negligible effect on Oakley Creek base flows. As such the potential effects on Oakley Creek associated with the construction and ***short term*** dewatering are considered to be ***less than minor***. The settlement effects associated with this amount of drawdown are reported in the Technical Report G.13 *Assessment of Ground Settlement Effects*.

In the long term steady state condition, the drained portals and approaches will result in up to 10 m of drawdown with measureable drawdown extending up to 300 m from the tunnels. Associated settlements (see the Technical Report G.13 *Assessment of Ground Settlement Effects*) are expected to be ***minor***.

8.2 Tunnels

Construction of the 'undrained' driven tunnels is expected to result in short term drawdown of 8 m to 15 m immediately adjacent to the tunnel, which rapidly reduces with distance from the tunnels. Measureable drawdown is predicted to typically extend less than 100 m from the tunnels. Where the tunnel is driven through more permeable PG, a greater magnitude and extent of drawdown is predicted to occur, however this could be mitigated by pre-grouting, adopting shorter construction to lining time-frames through this section and managing the open drained tunnel length.

In the long term the driven tunnels will be sealed to limit the inflow of groundwater. The long term effects are expected to be up to 3 m of drawdown immediately adjacent to the tunnels, with measureable drawdown extending for typically less than 100 m.

The potential effects on the groundwater regime associated with the short term construction and long term operation of the driven tunnels are therefore considered to be ***less than minor***.

8.3 Southern Portal

A permanent drain in the basalt to relieve pressure on retaining walls is proposed. Some 2 m to 13 m of drawdown is expected in the compressible soils immediately adjacent to retaining walls, with measureable drawdown typically extending for less than 50 m (and no more than 100 m) beyond them. The potential effects associated with this dewatering are described in the Technical Report G.13 *Assessment of Ground Settlement Effects* and are considered to be ***less than minor***.

8.4 Monitoring and Mitigation

A monitoring programme will be established well prior to construction to record natural variations in groundwater levels and seasonal ground settlement. This monitoring will allow appropriate responses to be triggered should actual effects differ from those predicted. Overall the effects of the proposal are considered to be less than minor, with a large number of potential mitigation options available to manage unexpected effects, should these occur.

Table 8.1 Summary of Predicted Effects

Section	Effect	Lower Bound		Upper Bound	
		Construction Maximum	**Long Term Maximum**	**Construction Maximum**	**Long Term Maximum**
Northern Cut and Cover Tunnels (Sealed)	**Inflow to Tunnel**	0.02 to 1 m^3/day/m of tunnel	0.02 m^3/day/m of tunnel	0.5 to 2 m^3/day/m of tunnel	1.0 m^3/day/m of tunnel
	Drawdown magnitude at base TGA/ WPG	< 0.5 m to 2 m	3.0 m	2 m to 8 m	5.0 m
	Drawdown extent at base TGA/ WPG[1]	< 25 m	< 25 m	30 m to 180 m	150 m
	Drawdown magnitude at top of Rock	0.6 m to 1 m	5.0 m	10 m to 20 m	15 m
	Drawdown extent at top of Rock[1]	30 m	100 m	180 m	300 m
	Oakley Creek Leakage	~2 % reduction throughout			

Section	Effect	Lower Bound		Upper Bound	
		Construction Maximum	**Long Term Maximum**	**Construction Maximum**	**Long Term Maximum**
Driven Tunnel	**Inflows**	2 m^3/day/m of tunnel	0.07 m^3/day/m of tunnel	118 m^3/day/m of tunnel *(8 to 20 m^3/day/m of tunnel if pre-grouted)*	0.02 m^3/day/m of tunnel *(0.02 m^3/day/m of tunnel if pre-grouted)*
	Drawdown magnitude at base TGA/ WPG	0.5 m to 4.5 m	0.2 m	15 m to 32 m *(8m to 15 m if pre-grouted)*	0.65 m *(3m if pre-grouted)*
	Drawdown extent at base TGA/ WPG[1]	50 m to 100 m	< 50 m	400 m *(250 m if pre-grouted)*	300 m *(<50m if pre-grouted)*
	Drawdown magnitude at top of Rock	7 m to 15 m	0.2 m	35 m *(31 m if pre-grouted)*	0.3 m to 1 m *(<0.5m if pre-grouted)*
	Drawdown extent at top of Rock[1]	150 m	< 50 m	350 m *(280 m if pre-grouted)*	< 50 m
	Oakley Creek Leakage	0 % Reduction	0 % Reduction	5 % Reduction *(2.5 – 3.5 % if pre-grouted)*	3.5 % Reduction

Section	Effect	Lower Bound		Upper Bound	
		Construction Maximum	**Long Term Maximum**	**Construction Maximum**	**Long Term Maximum**
Southern Portal and Approaches	**Inflows**	0.2 m^3/day/m of tunnel	<0.2 m^3/day/m of tunnel	73 m^3/day/m of tunnel	0.5 m^3/day/m of tunnel
	Drawdown magnitude at base TGA/ WPG	1.8 m	1.8 m	12.8 m	13.4 m
	Drawdown extent at base TGA/ WPG[1]	< 30 m	< 30 m	60 m	60 m
	Drawdown magnitude at top of Rock	2.5 m	3 m	25 m	25 m
	Drawdown extent at top of Rock[1]	50 m to 100 m throughout			
	Oakley Creek Leakage	7 % reduction throughout			

Results from 2D and 3D modelling combined. As a rule, the lower bound is where the tunnel is driven through ECBF, and the upper bound is where the tunnel is driven through PG, actual magnitude encountered at any specific location will range between the two end values and is dependent on geological profile. Refer to, Appendices F and G.

[1] Maximum extent of drawdown taken as the distance where drawdown = < 0.5m

PG = Parnell Grit, ECBF = East Coast Bays Formation, TGA = Tauranga Group, WPG = Weathered Parnell Grit

9. References

9.1 2010 Assessment of Environmental Effects

9.1.1 Technical Assessment Reports

G.9 Assessment of Land and Groundwater Contamination, Beca, 2010

G.13 Assessment of Ground Settlement Effects, Beca, 2010

G.22 Erosion and Sediment Control Plan (ESCP), Ridley Dunphy Environmental, 2010

9.1.2 Technical Supporting Documents

G.24 Geotechnical Interpretive Report, Tonkin and Taylor, 2010

G.28 Geotechnical Factual Report – 500 Series, Beca, 2010

G.29 Geotechnical Factual Report – 700 Series, Beca, 2010

9.2 Historical Waterview Reports

Beca, 2001: Geotechnical Factual Report, prepared for Transit New Zealand – December 2001

Beca, 2002: Geotechnical Interpretive Report, prepared for Transit New Zealand – December 2002

Beca, 2003: Geotechnical Factual Report – Stage 3, prepared for Transit New Zealand – May 2003

Beca, 2003: Geotechnical Interpretive Report – Stage 3, prepared for Transit New Zealand – May 2003

Beca, 2006: Vic Park Tunnel Project - Hydrogeological and Engineering Assessments Report, prepared for Transit New Zealand - March 2006

Beca 2008: New Lynn Rail Trench –Assessment of Groundwater Effects Addendum Report, prepared for FCC - March 2008

Connell Wagner, 2007: Draft Geotechnical Factual Data Report SH20Waterview Connection Driven Tunnel Concept, prepared for Transit New Zealand – March 2007

9.3 Other References

Brown, E.J. and Bardsley, E., 2002: A Model Based Evaluation of Horizontal Wells for Improving Functionality of an Urban Reservoir System, Natural Resources Research Vol. 11, No. 3, September 2002

Crowcroft, G and Smail, A. 2001: "Regional Groundwater Summary: Auckland" In *Groundwaters of New Zealand*. New Zealand Hydrological Society

10. Glossary

Where given *italic text* provides an example of the term in the context of the Project.

a.s.l	Refers to height of a particular point, usually in metres or as specified, above (mean) sea level.
Anisotropy	Having variations in physical properties that differ dependent on the direction of measurement, i.e. *horizontal permeability being greater than vertical permeability*. Opposite of isotropy.
Aquifer	A geologic formation that contains sufficient saturated material to yield water *i.e. East Coast Bays Formation (ECBF) or Basalt (AVF)*
Aquitard	A geologic formation that contains water (is saturated) but does not readily yield water. An aquitard may transmit appreciable water to or from adjacent aquifers i.e. *Tauranga Group Alluvium (TGA)*.
Bedded units	Describes a geological formation or unit that is comprised of multiple beds or layers, *i.e. East Coast Bays Formation which typically comprises alternating beds of higher permeability sandstone and lower permeability siltstone.*
Borehole	Hole (nominally 65 mm to 150 mm in diameter) drilled into the ground to allow assessment to be made of characteristics of the soil and rock encountered. Returns a cylindrical soil or rock sample (known as core) to the surface for examination. Typically vertical, but can be inclined or horizontal in order to target specific depths / units.
Breakthrough	*For this Project describes the process where a section of driven tunnel that already has been fully lined with the permanent concrete segments is drilled (or broken through) to allow drilling of the cross-passages which connect the tunnels.*

Calibration	A comparison between measurements or values. *For the context of this report describes the comparison between observed/ tested measurements/values and those predicted by the numerical modelling.*
Compressible soil	A geological unit whose volume and/or structure can change in response to changes in applied pressure (due to additional load at surface or reduction in groundwater level) *i.e. TGA whose structure settles and compresses due to drawdown (reduction in pore water pressure).*
Constant head test	A type of in-situ hydraulic conductivity test (or slug test) whereby water is applied to a borehole (at a known discharge rate) and by recording the change in groundwater level, an assessment of the hydraulic conductivity of the soil / rock can be made.
Core logs	A specific technical report describing the observed geological properties of drill core retrieved from a borehole. Can also report results of in-situ strength or groundwater tests.
Dewatering	The removal of water from the soil / rock to reduce flow rate and diminish pressure in order to allow construction to proceed in the dry. *In the context of this report, refers to the allowance of water to seep in to the open face, be collected in a sump and pumped out of the excavation for disposal.*
Diaphragm wall	An underground structural element, typically a panel, used to retain earth behind an excavation. Typically constructed of a low permeability concrete / grout (to restrict groundwater flow) with structural reinforcing to resist earth pressures. Because of the low permeability, these also act as cut-off walls forcing groundwater to take a longer flow path around the panel hence reducing inflows and drawdown.
Discontinuous lens	A geological unit of limited thickness and extent i.e. the thickness varies considerably over small distances and / or the unit cannot be traced over large distances.
Drawdown	The lowering of groundwater level due to pumping of a well *or in the context of this Project dewatering of an excavation.*
Flow gauging	The measurement of the total (from all sources) volume of water flowing in a river channel
Fully drained tunnel (unsealed or unlined tunnel)	*For this Project describes the stage of the driven tunnel excavation where the tunnel shape has been bored and the rock face is fully exposed with no form of lining or water proofing, such that the groundwater can freely drain into the excavation.*
Grout	A low permeability construction material (typically comprising water, sand and cement, occasionally fine gravel) used to inhibit the flow of water by infilling fractures and pore-space to reduce permeability. Applied as a thick liquid which hardens with time. Similar to concrete.
Grout curtain	A low permeability barrier used to inhibit groundwater flow, constructed by drilling multiple boreholes at close spacing and filling

	the boreholes with grout to locally reduce the permeability of the surrounding ground.
Homogeneous	Of uniform structure or composition throughout *i.e. assumes that material properties such as hydraulic conductivity are constant throughout a unit*. Opposite of heterogeneous.
Hydraulic Conductivity	The measure of a soil or rocks ability to transmit a specific fluid. Unlike permeability this value **is dependent** on fluid viscosity and density. *For the context of this Project refers to a unit's ability to transmit water*. Given as the cubic metres of water per second, that will transmit through 1 m^2 (i.e. $m^3/s/m^2$ or m/s)
Hydraulic Conductivity test	refer to **slug test**
Hydrogeological	Relating to groundwater and the occurrence, movement and properties of water in the ground.
Hydrogeological unit	One (or many) geological formations with a distinct set of hydrogeological properties (i.e. hydraulic conductivity, storativity) which distinguish it from another formation.
In-situ	In natural or original position / place. *In the context of in-situ testing refers to testing of soil or rock as it is in the ground, as opposed to removing a sample and testing in the laboratory.*
Jointing	Discrete brittle fractures in rock, often with open spaces between the two rock-faces which may allow the transmittal of fluid.
Leaky tunnel	*For this Project refers to the long term scenario where the tunnel is fully and permanently drained, allowing ongoing seepage of groundwater into the excavation.*
Lining	The permanent concrete segments that support the tunnel excavation and limit groundwater seepage
Lined tunnel	Refer to **Undrained tunnel.**
Lugeon test	refer to **Packer test**
Orders of magnitude	An estimate of a size or magnitude expressed as a power of 10, used to express the comparative scale between two parameters. *For example the hydraulic conductivity of the PG (at K = $2x10^{-6}$ m/s) is one order of magnitude (or almost 10 x greater) than the typical hydraulic conductivity of the ECBF (at K =$3x10^{-7}$ m/s)*
Packer test (Lugeon test)	A test used to assess the hydraulic conductivity of a rock by assessing the volume of water that can be injected into a segment of a borehole under a known pressure.
Partially drained tunnel	*For this Project describes the stage of the driven tunnel excavation where the tunnel shape has been bored and a lining of shotcrete has been applied to the rock face, such that the groundwater is*

	somewhat restricted from entering the excavation. Some discharge though fractures etc can be expected.
Perched water level	An unconfined ground water body sitting on top of an impermeable (unsaturated) or poorly permeable (partially to fully saturated) formation. *For the context of this project used to describe water levels in the basalt (AVF), TGA and residual soils, and also some water levels in the ECBF.*
Permanently	*For this Project refers to the long term, final condition or structure, i.e. post construction, operational etc.*
Permeability	The intrinsic ability of a material (natural or man-made) to transmit fluid, usually a function of grain size and pore space between grains, independent of type of fluid *i.e. a coarse grained rock (e.g. PG) will more readily transmit any type of fluid then a dense, compacted silt (e.g. TGA).*
Piezometer	A permanent hole / installation in the ground designed to measure the groundwater level. Typically designed to allow the water to only enter from a particular depth or unit (not the full length of the hole).
Pore water pressure	The pressure exerted on a soil or rock by the water held in its pore spaces.
Pumping test	A test that is undertaken to determine aquifer (hydraulic conductivity, transmissivity and storativity) or well characteristics (well efficiency), by extracting water from a bore hole or well at a know rate and observing the changes in static water level in the pumped bore hole and other adjacent boreholes.
Rising head test	A type of in-situ hydraulic conductivity test (or slug test) whereby water is removed from a borehole and the recovery of the water level back to static water level is observed allowing an assessment of the hydraulic conductivity of the soil / rock to be made.
Scoria	A particular type of basalt characterised by (typically within the Auckland area) loose, rubbly gravels with large vesicles (void spaces within the rock), which readily transmits water (i.e. high permeability).
Screened interval / unit	Refer to **standpipe piezometer**.

Sealed tunnel	Refer to **Undrained tunnel.**
Secant pile wall	A retaining wall built by drilling and constructing overlapping reinforced piles (large diameter holes filled with concrete and steel) typically embedded into rock. The steel reinforcing and embedment into rock help the wall resist earth pressures whilst the low permeability of the concrete helps to restrict groundwater flow i.e. acts as cut-off similar to diaphragm wall.
Settlement	Gradual subsidence of the ground or a structure due to compression of the soil.
Shotcrete	A type of concrete often reinforced with fibres that is sprayed onto the face of an excavation to form a protective lining (preventing soft / weak material from falling into excavation or limiting groundwater inflow).
Slug test (hydraulic conductivity test)	A type of groundwater test undertaken "in-situ" i.e. in a borehole or piezometer. Involves the removal or addition of a "slug" (volume) of water. Observations of the recovery back to static water level allow an assessment of the hydraulic conductivity of the soil / rock exposed in the borehole or piezometer to be made.
Stand pipe piezometer	A type of piezometer comprising a length of (typically, and for the purposes of this Project) narrow diameter PVC pipe installed in a bore hole. Over a limited depth the PVC is slotted (i.e. has holes) so that water from the ground can enter into the pipe from that depth / unit; this is referred to as the screen / screened interval / screened depth.
Static water level	The naturally occurring level of groundwater within a borehole or piezometer.
Storativity	The volume of water an aquifer releases from (or takes into storage) for a particular area and change in water level i.e. a measure of how readily a formation will dewater. A dimensionless ratio, always less than 1.0.
Temporarily	*For this Project refers to the short term (< 5 year) construction condition.*
Transmissivity	The rate at which water is transmitted through a unit width of aquifer under a given hydraulic gradient. Given as cubic metres of water per day transmitted through a <u>vertical section</u> of aquifer 1 m wide (i.e. m^2/d). To convert to hydraulic conductivity, divide by the thickness of

	the aquifer.
Undrained tunnel (sealed or lined tunnel)	*For this Project describes the stage of the driven tunnel excavation where the tunnel shape has been bored and the permanent concrete lining / segments have been installed such that, to the full extent possible, groundwater is restricted from entering the excavation.*
Unlined tunnel	Refer to **fully drained tunnel**
Unsealed tunnel	Refer to **fully drained tunnel**
Vibrating wire piezometer	A type of piezometer which records very small changes in pore pressures (which can then be converted to groundwater level). The pore pressures are recorded at a specific depth often referred to as the "tip".
"Wished in place"	A phrase used to describe a modelling assumption where by something happens instantaneously without consideration of timing or stages. *For the context of this Project used to describe the process whereby the 3D numerical groundwater model assumes that the excavations will occur (to full depth and over the full extent) instantaneously without consideration of the many days time, or construction staging it will in take to actually excavate to the full depth required over a wide area.*

FIGURES

APPENDIX A – Geological Long Section

APPENDIX B – Groundwater Level Data

APPENDIX C – In-Situ Hydraulic Conductivity and Pumping Test Data

APPENDIX D – Oakley Creek Flow Data

APPENDIX E – Hydrogeological Setting, Conceptual Groundwater Model & Approach to Numerical Modelling

APPENDIX F – Visual MODFLOW 3D Groundwater Model

APPENDIX G – SEEP/W 2D Groundwater Model

APPENDIX H – Groundwater Management Plan