

Before the Board of Inquiry  
Waterview Connection Project

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*in the matter of:* the Resource Management Act 1991

*and*

*in the matter of:* a Board of Inquiry appointed under s 149J of the Resource Management Act 1991 to decide notices of requirement and resource consent applications by the NZ Transport Agency for the Waterview Connection Project

Statement of evidence of Ann Williams (Groundwater) on behalf of the  
**NZ Transport Agency**

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Dated: 8 November 2010

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REFERENCE: Suzanne Janissen (suzanne.janissen@chapmantripp.com)  
Cameron Law (cameron.law@chapmantripp.com)

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## **STATEMENT OF EVIDENCE OF ANN WILLIAMS ON BEHALF OF THE NZ TRANSPORT AGENCY**

### **INTRODUCTION**

- 1 My full name is Ann Louisa Williams. I am a Technical Director in the fields of Hydrogeology and Engineering Geology with the firm Beca Infrastructure Ltd (*Beca*).
- 2 I am a graduate of the University of Auckland with the degrees of Bachelor of Science and Master of Science in Geology (Honours), specialising in Engineering Geology. I have completed post-graduate studies in Resource and Environmental Management and in Hydrogeology. I have 21 years post-graduate experience in engineering geological and hydrogeological investigations and analysis.
- 3 I am the immediate past Chair of the New Zealand Geotechnical Society and have been elected Vice-President representing Australasia on the Executive of the International Association for Engineering Geology and the Environment (*IAEG*) for the period 2011 to 2014. I am a Fellow of the Geological Society of London (*FGS*) and member of the International Association of Hydrogeologists (*IAH*), and an associate editor of the international journal, Quarterly Journal of Engineering Geology and Hydrogeology (*QJEGH*).
- 4 As leader of Beca's geological and hydrogeological teams, I have had a key role in a wide range of projects that have required an understanding of the interaction of water and soil and effects of seepage and ground movement. Of particular relevance to the Waterview Connection Project (*Project*) are the following:
  - 4.1 Evaluation of the effect of deep basement excavation as part of the Sky City and Sky Tower development in central Auckland on groundwater levels and existing neighbouring structures and overview of engineering geological mapping of excavations;
  - 4.2 Two-dimensional modelling of seepage from a sludge landfill into the existing groundwater regime and harbour as part of the upgrade of the Manukau Wastewater Treatment Plant in Auckland;
  - 4.3 Assessment of the nature, strength and piezometric variation within the 'mudcrete' (cement-stabilised marine silt) backfill used in the construction of Fisherman's Wharf at the Viaduct Basin, Auckland, including 2-dimensional modelling of seepage flows through the wharf;

- 4.4 Review of technical evidence addressing the reasons for differences between the predicted and observed effects of dewatering of the 3 Kings Quarry located in a residential part of Auckland on behalf of Housing New Zealand and most recently, review of the potential effects on groundwater of the proposed filling of the quarry for WaterCare;
- 4.5 Direction of investigations for and 2- and 3-dimensional groundwater modelling of a 1200 m long underground railway station (including a 720 m long "Rail Trench") at New Lynn, central Auckland (recently completed). The station was constructed beneath the groundwater table in Tauranga Group alluvial deposits overlying Waitemata Group sandstone/ mudstone at variable depth (which also occur at the Waterview Project site). Modelling was used to assess likely groundwater drawdown, associated settlement effects, excavation inflows, uplift pressures beneath the trench, potential damming of groundwater upgradient of the box and monitoring requirements during construction and in the long-term. I reviewed monitoring data through construction;
- 4.6 Investigation and 2- and 3-dimensional groundwater modelling of a new trunk watermain to distribute water from Auckland's southern water sources to central Auckland (Hunua 4), that will comprise a pipeline of 1.3 to 1.9 m diameter with a length of some 30 km including pipe bridges and trenchless crossings;
- 4.7 Investigation and development of 2- and 3-dimensional groundwater models for a 3-lane motorway tunnel being built by cut and cover techniques beneath Victoria Park (Victoria Park Tunnel), central Auckland (under construction). This included assessment of likely groundwater drawdown and inflows associated with tunnel construction, assessment of the impact of different tunnel designs on regional groundwater flow and the potential for contaminant migration and saline intrusion. I am the in-team reviewer for groundwater aspects of the design-build phase of the project;
- 4.8 Preliminary investigation, 2-dimensional groundwater modelling and identification of construction and cost risks (in particular the potential extent of groundwater drawdown induced settlements) for a Rail Loop between Britomart Station and Newton which will comprise some 3.5 km of tunnel and 6 stations in the Central Business District of Auckland (currently in the notice of requirement phase);
- 4.9 Eden Park playing fields are estimated to flood during a 1:2 year or greater rainfall event, due for the most part to the rise of groundwater to the surface. Auckland City is required

to manage a 1:10 year event to meet criteria for the Rugby World Cup hosting. I have managed the design and direction of investigations, analyses and 3-dimensional groundwater modelling for feasibility stage design of a system to allow drawdown of the complex basaltic aquifer sufficient that Eden Park will assimilate a 10 year rainfall event; and

- 4.10 Guidance of desk-based assessment of groundwater issues associated with an alternative crossing of the Waitemata Harbour – bridge and tunnel (this project is currently in the option selection phase).
- 5 In each case these underground projects required assessment of the effect of different designs on regional and perched groundwater flow, the potential for contaminant migration or saline intrusion and for dewatering adjacent watercourses and affecting existing groundwater supplies.
- 6 In addition I have directed investigation and development of deep groundwater as a strategy for meeting NZ Drinking Water Standards for municipal, commercial and industrial supplies in centres throughout New Zealand. I have also had the role of technical expert addressing the potential effects of the proposed Waitahora Wind Farm (Manawatu) to be constructed in part on karstic limestone, on groundwater and water supplies, in the Environment Court.
- 7 My evidence is given in support of notices of requirement and applications for resource consents lodged with the Environmental Protection Authority (*EPA*) by the NZ Transport Agency (*NZTA*) on 20 August 2010 in relation to the Project. The Project comprises works previously investigated and developed as two separate projects, being:
  - 7.1 The State Highway 16 (*SH16*) Causeway Project; and
  - 7.2 The State Highway 20 (*SH20*) Waterview Connection Project.
- 8 I am familiar with the area that the Project covers, and the State highway and roading network in the vicinity of the Project.
- 9 I have read the Code of Conduct for Expert Witnesses as contained in the Environment Court Consolidated Practice Note (2006), and agree to comply with it. In preparing my evidence, I have not omitted to consider material facts known to me that might alter or detract from my opinions expressed.

## **SCOPE OF EVIDENCE**

- 10 My evidence will deal with the following:
  - 10.1 Executive summary;
  - 10.2 Background and role;
  - 10.3 Summary of methodology;
  - 10.4 Summary of assessment of groundwater effects;
  - 10.5 Post-lodgement events;
  - 10.6 Comments on submissions;
  - 10.7 Comments on Reports to the Board; and
  - 10.8 Proposed Groundwater conditions.

## **EXECUTIVE SUMMARY**

- 11 Two and three dimensional numerical groundwater modelling has been undertaken, under my direction, to assess the effects of the proposed cut-and-cover tunnels, driven tunnel, portals and approaches on the existing groundwater regime.
- 12 The models are based on data from 305 boreholes, 231 piezometers, 171 in-situ permeability tests, 7 pumping tests and water level monitoring undertaken over the periods 2001 to 2003 and 2006 to 2010.
- 13 The geology of the area has been grouped into seven units that each respond in a different way to changes in groundwater.
- 14 Water level monitoring indicates a north to northwesterly gradient on the regional water table towards the coast. The gradient within the 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 and have a seasonal variation of +/- 1.5 m.
- 15 Base case modelling assumes that the driven twin tunnels will be progressed with a 50 m lag between the northbound and southbound tunnels and that the tunnels are excavated in two sections: the upper half being excavated and shotcreted first, followed by the lower half. The cut-and-cover tunnels are assumed to be drained, whereas the driven tunnels will be undrained (sealed) once the lining is in place.

- 16 Modelling suggests that the northern portals and approaches can 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.
- 17 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 tunnels are 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 tunnel length.
- 18 In the long term, the tunnels will be sealed to limit the inflow of groundwater. A maximum drawdown of 3 m immediately adjacent to the tunnels is anticipated with measureable drawdown extending less than 100 m from the tunnels.
- 19 At the southern portal a permanent drain in the basalt to relieve pressure on retaining walls is proposed. In this case the greatest magnitude and extent of drawdown occurs in the long term. 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.
- 20 Monitoring of boreholes screened in the Phyllis Street Reserve through the summer of 2009/2010 and winter of 2010 suggest there is almost no water residing within the fill. The potential to spread contaminants through the underlying low permeability soils in response to the predicted drawdown is therefore almost nil.
- 21 Analyses suggest a reduction of Oakley Creek baseflow by 6 % over the length of the approaches to the southern portal, reducing to 2 % over the length of the driven tunnel and northern cut-and-cover tunnel.
- 22 I therefore consider the adverse effects of the Project on groundwater overall to be minor.
- 23 A monitoring programme has been proposed to record groundwater levels prior to, through and following construction. This will allow actual changes in groundwater levels to be checked against those predicted and appropriate responses to be implemented, if needed.

## BACKGROUND AND ROLE

- 24 The NZTA retained Beca as part of a consortia team to assist with the investigation, engineering and planning of the Project and to prepare the assessment of the groundwater effects of the Project. Ms Sian France (Senior Hydrogeologist) and Ms Erica Cammack (Engineering Geologist), both of whom work in my team at Beca, undertook field investigations and testing, data analysis, 2- and 3-dimensional groundwater modelling and prepared an Assessment of Groundwater Effects (the *Report*) under my direction, and with my review and input.
- 25 The Report has been peer reviewed by Graeme Twose (Senior Geotechnical Engineer) of Tonkin & Taylor Ltd and by Brett Sinclair (Senior Hydrogeologist) of Golder Associates Ltd.
- 26 The Report was lodged with the EPA on 20 August 2010 as part of the overall Assessment of Environmental Effects (AEE) (specifically, Part G, Technical Report G.7).
- 27 The Report was supported by Geotechnical Factual Reports, also lodged with the AEE (see Part G), being:
  - 27.1 Report G.28 (500 series), Volumes One to Three; and
  - 27.2 Report G.29 (700 series), Volumes One to Three.
- 28 The Report was informed by, relies upon, and informs other technical reports lodged with the EPA in support of the Project, those reports being primarily:
  - 28.1 Geotechnical Interpretive Report (Technical Report G.24);
  - 28.2 Assessment of Land and Groundwater Contamination (Technical Report G.9); and
  - 28.3 Assessment of Ground Settlement Effects (Technical Report G.13).<sup>1</sup>
- 29 The 2- and 3- dimensional groundwater modelling and assessment of groundwater effects uses, as a base, the geological data and model developed with Tonkin & Taylor Ltd and described in the Geotechnical Interpretive and Factual Reports (being Technical Reports G.24, G.28 and G.29).
- 30 Details of contaminants that presently reside in groundwater at different locations along the proposed alignment are described in Technical Report G.9 *Assessment of Land and Groundwater Contamination*.

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<sup>1</sup> All contained within the AEE, Part G.



- 31 The 2- and 3- dimensional groundwater modelling provides the expected groundwater drawdown profiles that have been used to assess groundwater drawdown-induced ground settlement described in Technical Report G.13 *Assessment of Ground Settlement Effects*.

### **SUMMARY OF METHODOLOGY**

- 32 My evidence considers the interaction of the construction phase and long term operation of the tunnels with groundwater. Some of the interactions inform tunnel design and some allow identification and, if necessary, mitigation of potential effects on the environment.
- 33 Issues investigated that inform tunnel design include the:
- 33.1 Rate of inflow of groundwater to the tunnels, portals and excavations during construction and in the long term;
  - 33.2 Uplift pressures beneath portal and tunnel floors, and groundwater pressures on tunnel lining; and
  - 33.3 Efficacy of limiting these effects by wall and tunnel design elements and construction sequencing.
- 34 Issues investigated that are important to understand because of their potential to impact on the environment include the:
- 34.1 Potential to cause groundwater drawdown that might result in ground settlement and affect existing structures;
  - 34.2 Potential to affect Oakley Creek base flows and flow regime by altering groundwater flow in the vicinity of the tunnels, in particular during construction;
  - 34.3 Potential to spread contaminants residing in areas of past landfilling by drawing groundwater down toward the tunnel excavations where they pass beneath such areas;
  - 34.4 Potential to affect yield or quality of water at existing abstraction bores or springs by altering groundwater flow patterns; and
  - 34.5 Opportunities to mitigate potential environmental effects through design and construction sequencing.

### **Investigations**

- 35 In order to understand the groundwater systems, an understanding of the geology of the Project area is needed.

- 36 Subsurface investigations, local field mapping, in-situ testing and laboratory testing have been carried out for earlier alignments and the finally proposed alignment.<sup>2</sup> Field investigations included:
- 36.1 305 machine drilled boreholes to depths of less than 10 to more than 100 metres;
  - 36.2 231 piezometer installations;
  - 36.3 171 in-situ permeability tests (lugeon tests and rising head tests); and
  - 36.4 7 pumping tests.
- 37 The locations of investigation sites are shown in drawings presented in Appendix A of the Geotechnical Interpretive Report, Technical Report G.24.
- 38 The data obtained from the above investigations was used to develop a 3-dimensional geological model that could be used to take off long-sections and cross-sections for both geotechnical and groundwater analysis.
- 39 I understand that further data is now available following installation of a suite of the proposed monitoring bores. This data will be considered in detailed design.

#### **Construction assumptions modelled<sup>3</sup>**

- 40 Key construction method assumptions made in the assessment of the groundwater effects are:
- 40.1 Construction of the cut-and-cover section of the tunnel at the northern end will commence prior to work on the driven tunnel.
  - 40.2 The floor of the northern and southern cut-and-cover sections of the tunnel are unsealed (drained) in the long term.
  - 40.3 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 contractor 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.

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<sup>2</sup> See Technical Reports G.24, G.28, G.29 (AEE, Part G).

<sup>3</sup> See section 3, pages 5-10 of Technical Report G.7.

- 40.4 The tunnels will be excavated in 50 m lengths.
  - 40.5 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.
  - 40.6 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.
  - 40.7 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) or could commence following completion of both driven tunnels (up to 2 years later, considered as an alternative modelling scenario).
- 41 Due to the higher groundwater table within the basalt, a grout curtain will be constructed adjacent to the Southern portal 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.

#### **Approach to modelling<sup>4</sup>**

- 42 Both 2-dimensional (2D) and 3-dimensional (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.
- 43 The 3D model was developed to consider overall groundwater flow trends and broad scale effects resulting from tunnel construction. 3D groundwater flow modelling was carried out using the computer software Visual MODFLOW Pro v4.3 (Schlumberger, Canada).
- 44 Because of the complex geology and 3D nature of flow, the 3D model is used for assessment of:
  - 44.1 Effects on water balance and groundwater flows into and from Oakley Creek;

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<sup>4</sup> See section 3.3, pages 7-8 of Technical Report G.7.

- 44.2 Magnitude of drawdown at more than 100 m from the tunnel centreline (in combination with the outputs from the 2D modelling);
  - 44.3 The extent of drawdown; and
  - 44.4 Effects of dual tunnel construction sequencing.
- 45 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 close to the tunnel (100 m either side). However, as regional groundwater flow is roughly perpendicular to the 2D sections (along the length of the tunnel), this modelling cannot be used to assess effects on Oakley Creek. The 2D model is used for assessment of:
- 45.1 The rate of groundwater seepage into the tunnels, both during construction and in the long term;
  - 45.2 Uplift pressures beneath the tunnel floor;
  - 45.3 The influence of pile depth on drawdown and uplift pressures;
  - 45.4 The amount of drawdown and how it varies along and within 100 m either side of the tunnels; and
  - 45.5 The effects of constructing cross-passages between the dual tunnels.

### **SUMMARY OF ASSESSMENT OF GROUNDWATER EFFECTS**

- 46 In this section of my evidence, I discuss the Groundwater Report and my conclusions on groundwater effects associated with the Project.

#### **Purpose of groundwater assessment<sup>5</sup>**

- 47 The potential effects of the Project on groundwater are:
- 47.1 The potential to affect Oakley Creek Base Flows. Drawdown of groundwater in the vicinity of Oakley Creek to facilitate tunnel construction might reduce the amount of groundwater that naturally flows towards Oakley Creek; it might also increase the volume of water that naturally discharges

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<sup>5</sup> See section 4, pages 8-9 of Technical Report G.7.

through the bed of the Creek to recharge the underlying groundwater system;

- 47.2 The potential to spread contaminants from landfill areas. 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; and
- 47.3 The potential to draw down (or lower) groundwater to the extent that it results in ground settlement that causes 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.
- 48 I 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. Accordingly, while my evidence addresses drawdown, the potential effects of drawdown (e.g. on ground settlement and contaminants) will be covered by other technical witnesses (respectively, Gavin Alexander and Terry Widdowson).

#### **Geological model<sup>6</sup>**

- 49 The tunnels are to be located in the western-central suburbs of Auckland, within a stream valley (in part occupied by Oakley Creek), between Mt Albert Volcano and the Great North Road / Blockhouse Bay Road ridge. The ridge is made up of East Coast Bays Formation (ECBF) sandstone and siltstone that forms the bedrock of the area. The ECBF rocks include lenses of volcanoclastic sandstone (Parnell Grit) found to occur in the Phyllis Reserve and Waterview Downs area. Younger Tauranga Group alluvial sediments were deposited in low lying areas, in particular in the Oakley Creek paleo-valley. Mt Albert (also known as Owairaka Volcano) erupted through and over a now buried ridge and cliff line of ECBF rocks more than 30,000 years ago with basalt lava and ash filling the valley.
- 50 A geological map of the tunnel area is included as Figure 3 in the Report. The soils and rocks encountered in investigations have been

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<sup>6</sup> See section 5, pages 11-15 of Technical Report G.7.

grouped into hydrogeological units (that is, units that behave in a similar way with respect to storage and transmission of groundwater). This is important because the different units will respond differently to drawdown of groundwater levels as some are compressible, but others are not. Seven hydrogeological units are recognised and the broad distribution of these units is shown in Figure 3 and in long-section in **Annexure A**. The units are:

- 50.1 Fill - variable in nature and thickness (including some pockets of industrial waste);
  - 50.2 Auckland Volcanic Field (AVF) - high permeability, variably jointed basalt lava flows;
  - 50.3 Tauranga Group Alluvium (TGA) - low permeability, compressible clays, silts and sands;
  - 50.4 Weathered East Coast Bays Formation (WECBF) - low permeability silts, sands and clays;
  - 50.5 Weathered Parnell Grit (WPG) - soft to firm sensitive low permeability silts and clays;
  - 50.6 East Coast Bays Formation (ECBF) - moderately permeable interbedded sandstone and siltstone; and
  - 50.7 Parnell Grit (PG) - high permeability, coarse volcanoclastic sandstone.
- 51 Groundwater levels within the ECBF and Parnell Grit are similar to the water level in Oakley Creek and indicate a northerly gradient of 3 % to 4 % falling to close to sea-level at the coast, with a small local component of flow toward Oakley Creek. These water levels are considered to represent the regional groundwater system, which is semi-confined.
- 52 Water levels in the basalt, Tauranga Group and weathered ECBF and weathered Parnell Grit respond directly to rainfall events and represent perched water levels that exist because of the contrast in permeability between these units. That is, water resides in higher permeability layers (such as the basalt or sand lenses within the Tauranga Group) and is 'hung up' on top of lower permeability layers. Water 'leaks' more slowly through these lower permeability layers, which can be described as aquitards because they slow the rate of groundwater flow.
- 53 Groundwater drawdown will be greatest in the ECBF and Parnell Grit as the tunnel is, for the most part, driven through these units. However, the effect of the drawdown (in terms of resultant ground

settlement) will be greatest in the Tauranga Group and weathered Parnell Grit because these soils are compressible.

- 54 In the next section of my evidence, I will describe the key points of the Report.

### **Conclusions in my assessment<sup>7</sup>**

- 55 Numerical groundwater modelling has been undertaken to provide an assessment of effects on the existing groundwater regime associated with the short term construction and long term operation of the driven and cut-and-cover tunnels, the portals and the tunnel approaches. The results are summarised in Table 8.1 of the Report (a copy of which is attached as **Annexure B** to my evidence.)

### **Portals**

- 56 For the northern tunnel portals and approaches, maximum inflows of groundwater occur during excavation of the tunnel floor because the walls will have been installed prior to excavation and the water table resides just above floor level at the northernmost end, deepening to the south. Modelling indicates a peak groundwater inflow of 0.02 to 2.0 m<sup>3</sup>/d/m length of tunnel, depending on the depth and width of cut and cover excavation and geology; a total inflow of 280 m<sup>3</sup>/d (3.2 litres/second) of groundwater to the 400 m length of fully drained cut and cover tunnel is expected.
- 57 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.
- 58 The settlement effects associated with this amount of drawdown are reported in Technical Report G.13 *Assessment of Ground Settlement Effects* (AEE, Part G) and discussed in the evidence in chief (EIC) of Mr Gavin Alexander.
- 59 In the long-term steady state condition (that is, once the tunnels are completed and groundwater levels are allowed to stabilise) the drained portals and tunnel approaches will have resulted in up to 10 m of drawdown, with measureable drawdown extending up to 300 m from the tunnels. Associated ground settlement effects are expected to be minor.<sup>8</sup>

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<sup>7</sup> See pages 26 and 17 of Technical Report G.7.

<sup>8</sup> See Technical Report G.13 *Assessment of Ground Settlement Effects* and Mr Alexander's evidence in chief.

### ***Tunnels***

- 60 Construction of the 'undrained'<sup>9</sup> 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. Peak groundwater inflows to the tunnels during construction are expected to range from 1.5 to 5.3 m<sup>3</sup>/d/m length of tunnel in ECBF up to 120 m<sup>3</sup>/d/m length of tunnel in ungrouted Parnell Grit. Measureable drawdown is predicted to typically extend less than 100 m from the tunnels. Where the tunnel is driven through more permeable fractured Parnell Grit, generally in the vicinity of the Phyllis Reserve, a greater magnitude and extent of drawdown is predicted to occur. However, this could be mitigated by pre-grouting<sup>10</sup>, adopting shorter construction to lining time-frames through this section of the tunnels and managing the open drained tunnel length. Such mitigative construction techniques are most likely to be adopted as there are associated risks to the tunnelling process with high groundwater inflow.
- 61 The driven tunnels will be sealed to limit the inflow of groundwater either progressively (base case modelled) or up to 2 years following completion of the tunnels. The long term effects of tunnel construction (i.e. some 3 years following completion of the tunnels when groundwater levels will have stabilised) are expected to be up to 3 m of drawdown immediately adjacent to the tunnels, with measureable drawdown extending generally less than 100 m from the tunnels.
- 62 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 minor.

### ***Southern Portal***

- 63 A permanent drain in the basalt to relieve pressure on the retaining walls is proposed at the Southern Portal. Modelling suggests the average inflow during construction will range from 0.2 to 1.7 m<sup>3</sup>/d/m length of tunnel (peak inflows of up to 75 m<sup>3</sup>/d/m length of tunnel in basalt), reducing to less than 0.5 m<sup>3</sup>/d/m length of tunnel in the long term.
- 64 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

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<sup>9</sup> The cut and cover sections of tunnel at the northern and southern portals are likely to be 'drained', such that the groundwater can freely drain into the excavation. Once drainage is complete and the permanent concrete lining/segments have been installed, the driven tunnels will be essentially watertight, that is they will be 'undrained'.

<sup>10</sup> This means injecting grout through the excavation face from centres in a radial pattern ahead of excavating the higher permeability Parnell Grit.



dewatering are described in Technical Report G.13 *Assessment of Ground Settlement Effects* and the EIC of Mr Alexander, and are considered to be minor.

### ***Spread of contaminants***

- 65 Areas of landfill exist in the Phyllis Reserve area. In this area the tunnels will be driven through more permeable Parnell Grit at depth. During construction, a significant increase in the vertical component of groundwater flow will be induced by drawdown, potentially allowing some vertical migration of mobile contaminants. However a 7 m to 21 m thick layer of low permeability soil derived from weathering of the Parnell Grit (Weathered Parnell Grit, *WPG*) separates the fill from the more permeable unweathered Parnell Grit (PG) and will act as an aquitard (as described in para 40) and dissuade such groundwater movement.
- 66 Because the period for maximum vertical flow is limited to the time of breakout and shotcreting of the tunnels, the potential for contaminants to travel with groundwater into the excavation or deeper rock aquifers is very low. Furthermore, monitoring of water levels in piezometers screened in the landfill over the summer of 2009/2010 suggests there is almost no water residing within the fill and therefore the potential for contaminant spread is almost nil.

### ***Groundwater users***

- 67 The Auckland Regional Council (ARC) well database identifies 5 existing water wells within the wider Project area. Four of the 5 wells have expired consents and no information is available for the remaining well. The fifth well has co-ordinates some 1.5 km south of the tunnel and should it exist, is located beyond the extent of predicted drawdown. No effects on well users are therefore anticipated.
- 68 Groundwater springs emerge from basalt in the Unitec grounds. Limited data is available on the springs, which are likely to have been modified over time and currently discharge to a small pond. No effect on spring flows is anticipated because modelling indicates that no drawdown within the basalt in this area will occur.

### ***Oakley Creek***

- 69 Long-term continuous flow monitoring of Oakley Creek indicates that the Creek can be described as a flashy stream with significant flow variations and a low base flow component.<sup>11</sup> This means that most of the water is sourced from quick flow (rainfall runoff, stormwater discharges etc). About one third of the stream flow is sourced from stored sources such as in-stream flow from upgradient, upgradient and local groundwater recharge. As groundwater recharge along the length of the alignment comprises

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<sup>11</sup> See Appendix D of Technical Report G.7.

only a small portion of all flows, the effect of the potential reduction in contribution from groundwater, estimated to be between less than 2 % and 6 % (at the southern portal) of baseflow contribution, would be less than minor, as described in the evidence of Dr Eddie Sides.

### **Monitoring and mitigation**

- 70 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 of the groundwater is different to that predicted. As groundwater drawdown in the relatively incompressible ECBF occurs in advance of drawdown and drawdown induced settlement in the Tauranga Group soils, groundwater monitoring can also serve as a trigger to initiate more settlement monitoring and or implement mitigation measures in a particular area.
- 71 A monitoring programme will be established well before construction commencing to record natural variations in groundwater levels and seasonal ground settlement. A draft monitoring programme has been prepared as part of Technical Report G.21, the Construction Environmental Management Plan (*CEMP*) described in the evidence of Mr Hugh Leersnyder.
- 72 Overall, the adverse effects of the Project on groundwater are considered to be minor, with a large number of potential mitigation options available to manage unexpected effects, should these occur.

### **POST-LODGE MENT EVENTS**

- 73 Since the Project application was lodged, a Technical Addendum Report (*Addendum*) has been completed and lodged by the NZTA.<sup>12</sup> The section of the Addendum that is relevant to my Report provides further comments on the interpretation of groundwater systems (perched and regional) within the Waitemata Group (ECBF) Richardson Road ridge, and the associated model calibration on the western side of the tunnel alignment.<sup>13</sup>
- 74 In the Project area, a cascading series of perched water tables is recorded within the Waitemata Group soils and rocks, as occurs throughout the Waitemata Group rocks in the Auckland Region. Infiltrating groundwater is held up on lower permeability layers, slowly discharging through fractures and the rock mass to the underlying higher permeability layers until again being “caught” above a further low permeability layer.

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<sup>12</sup> See Technical Addendum Report G.31 (September 2010).

<sup>13</sup> Appendix 4, Technical Addendum Report G.31 (copy provided in **Annexure C** to my evidence).

- 75 The head of water on each successive water table is only a fraction of the total head between the regional (lowest recorded) water table and the uppermost (near-surface) water table. This is the case even where the hydrostatic levels in successive groundwater lenses overlap. This means that when deep excavations are made in Waitemata Group rock, these local perched water tables discharge without inducing wider ground settlement. (Examples I am familiar with include the 23 m deep Sky City excavation, the 8 m deep New Lynn Rail Trench excavation and the Maoro Street interchange, which is itself a part of the Richardson Road ridge).
- 76 A similar situation arises on the Waterview Project. For this reason the 2D and 3D groundwater models have been calibrated to representative water levels recorded within groups of piezometers at particular locations. This does not mean that the models are poorly calibrated, but simply that the recorded water levels apply to different cascading groundwater levels and cannot all be used for calibrating to one water level.
- 77 The Addendum also includes an updated Figure 3 from Technical Report G.7, to show the revised geology as determined from the 2010 investigations. See Figure F1 in **Annexure C**.

#### **COMMENTS ON SUBMISSIONS**

- 78 I have read submissions lodged on the Project that raise groundwater or related issues relevant to my area of expertise. In this section of my evidence I will address these submissions to the extent that they raise issues not already addressed in my evidence or the groundwater assessment report.

#### **Oakley Creek**

- 79 A number of submitters have identified concerns that the Project will affect Oakley Creek and its environment.<sup>14</sup>
- 80 The flow within Oakley Creek is made up of base flow and quick flow. Quick flow is the portion of stream flow from rainfall runoff, stormwater discharges and water discharges from the near surface unsaturated soils. Base flow is the portion of stream flow received from groundwater discharge and delayed shallow near surface flow. In the case of Oakley Creek, quick flow makes up about two thirds of Creek flow and base flow makes up about one third.
- 81 The portion of stream flow that can be influenced by tunnel construction is base flow. Modelling indicates that the effect on base flow is likely to be of the order of <2 % to 4 % along the length of the northern portal and driven tunnels (<2 % in the long term), and up to 6 % at the southern portal. This is a very small

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<sup>14</sup> Submitter Nos. 02, 017, 181, 185, 206 and 166.

effect and will not be noticeable, given the natural variability in stream flows (two thirds of flow varies in response to rainfall). The greatest change in base flow is likely at the southern portal. As described in the evidence of Dr Eddie Sides, this change, a reduction of base flow by about 6 %, would not deleteriously impact the ecology of the Creek. Essentially, this means that the Project will not cause the drying up of Oakley Creek.

- 82 As identified in the proposed Groundwater Management Plan<sup>15</sup>, I have recommended that a series of flow gauges be established along the length of Oakley Creek to allow Creek flows to be monitored for a period of at least 12 months prior to commencement of construction. Monitoring of Creek flows will allow two things: first, the calibration of the groundwater modelling carried out as part of detailed design to actual flow changes, which will refine predictions of effects on Creek flows; and second, actual changes in Creek flows can be monitored and mitigation measures implemented, should flow losses exceed those expected.

#### **Groundwater level changes**

- 83 Submissions made by the North Western Community Association and Friends of Oakley Creek – Te Auaunga identify general concerns about changes to groundwater levels and seek that the effects of these changes be further assessed and mitigated accordingly.<sup>16</sup>
- 84 As described in the Report, and summarised in my evidence, both 2D and 3D computer groundwater modelling have been carried out. The models were developed from data gathered over several years from a large number of investigation sites to provide our best understanding of the potential effects of the Project on groundwater levels. Further investigations are planned to support detailed design. A comprehensive suite of monitoring sites is being installed (along Oakley Creek, within the area of predicted drawdown effects, and beyond) to allow modelled water levels to be compared with actual water levels and mitigative action to be taken in advance of effects being realised, should potentially deleterious differences between modelled and actual levels be recorded.
- 85 As there are no operational wells known to exist in the vicinity of the tunnels, lowering of water levels is not expected to impact well users.
- 86 As I describe in my evidence above, the effect of groundwater lowering on Oakley Creek is expected to be less than minor.

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<sup>15</sup> See page 15, Appendix H of Technical Report G.7.

<sup>16</sup> Submission Nos. 185 and 179.

- 87 Ground settlement resulting from groundwater drawdown and monitoring and mitigation of this are described in the evidence of Mr Gavin Alexander.
- 88 I therefore consider that changes in groundwater level have been adequately assessed as part of this application and confirm that this assessment will be updated as part of detailed design, as will design of any further mitigation, should this be required.

**Submission by Auckland Regional Council<sup>17</sup>**  
***Phyllis Street Reserve***

- 89 The Auckland Regional Council (ARC) is concerned that ground settlement at the Phyllis Street Reserve, which is a closed refuse landfill, might result in cracking of the landfill cap which would allow more rainfall to infiltrate the fill, potentially generating further leachate which could then contaminate groundwater.<sup>18</sup>
- 90 As described in my evidence and in more detail in the Report, the Phyllis Street Reserve is underlain by some 7 m to 21 m of low permeability residual soils and Tauranga Group sediments. These soils behave as an aquitard, significantly reducing the risk of contaminants moving downward towards the tunnel excavation or migrating into the deeper rock aquifer.
- 91 Groundwater modelling indicates 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 periods of maximum drawdown. Leachate travelling at this rate would take some 650 days to reach the base of the soils, with the average travel time being some 1800 days. As the period of maximum vertical flow is limited to the time taken to breakout and shotcrete each tunnel, the potential for leachate to travel with groundwater into the rock below the landfill or into the tunnel excavation is very low. Therefore, even if leachate were to be generated within the landfill, it is unlikely that the Project would exacerbate the spread of contaminants.
- 92 Nevertheless, it is agreed that it is preferable to avoid the potential for generation of additional leachate, and as described in the Groundwater Management Plan,<sup>19</sup> the recording of water levels in and around the Phyllis Street Reserve is proposed.
- 93 In order to address this concern, it is proposed that a trigger level be established such that should water levels recorded in the shallow piezometers installed within the Phyllis Street landfill rise above the trigger, then an inspection of the surface of the landfill will be made

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<sup>17</sup> Submission No. 207.

<sup>18</sup> Paragraphs 4.8.6 and 4.8.7 in Submission No. 207.

<sup>19</sup> See section 6, pages 10-16 of Groundwater Management Plan, Appendix H, Technical Report G.7.

and the surface re-levelled in areas where cracking of the cap or ponding of water on the surface is indicated (other than exists prior to commencement of the works).

***Groundwater and ground settlement***

- 94 The ARC identifies that groundwater drawdown will result in ground settlement and that limits need to be set to provide warning of potential problems with sufficient time for implementation of remedial works.<sup>20</sup>
- 95 I agree, and have for this reason set out in Appendix A of the Groundwater Management Plan a comprehensive suite of existing and proposed monitoring locations. In section 6.1.7 of the Plan Alert and Alarm levels are identified that have been derived from the groundwater modelling performed.
- 96 Because groundwater drawdown occurs in advance of ground settlement associated with the drawdown, monitoring of water levels provides the necessary warning needed to initiate mitigative works if drawdowns exceed those anticipated. Alert and alarm trigger responses are set out in the Groundwater Management Plan. Mitigation options are outlined in the Report.<sup>21</sup>
- 97 The ARC expresses concern that settlements have been calculated along representative cross-sections, and that the geology between sections might vary and therefore result in a different settlement profile.<sup>22</sup> While this aspect is addressed more fully in the evidence of Mr Gavin Alexander, it is important to understand that while 2D cross-sections are used to facilitate calculation of settlements, the sections modelled were taken from 3D geological and ground models and the drawdown profiles used are comparable or more conservative than those derived from the 3D groundwater modelling work. I therefore consider that an appropriately conservative approach has been adopted.
- 98 The monitoring details requested at parts a, b and c of point 4.8.18 of the ARC submission are set out in the Groundwater Management Plan. Details of settlement monitoring are described by Mr Gavin Alexander and are set out in the Settlement Effects Management Plan.<sup>23</sup>
- 99 The ARC submission suggests "*that some of the proposed consent conditions will not address matters in rules of the Proposed Auckland Regional Plan: Air, Land, Water, such as rules 6.4.47,*

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<sup>20</sup> Paragraphs 4.8.13 and 4.8.18 in Submission No. 207.

<sup>21</sup> See section 7, pages 23-24 of Technical Report G.7.

<sup>22</sup> Paragraph 4.8.16 in Submission No. 207.

<sup>23</sup> See Appendix H of Technical Report G.13.

6.5.68 and 6.5.69.”<sup>24</sup> I disagree. These rules deal with Diverting Groundwater and require that the life supporting capacity of water bodies is provided for (addressed in my evidence and that of Dr Eddie Sides), that existing lawful groundwater users are not adversely affected (addressed in my evidence), that ground settlement will be avoided, remedied or mitigated (addressed in the evidence of Mr Gavin Alexander), that flooding will not be exacerbated (addressed in the evidence of Mr Tim Fisher), that adverse effects of groundwater discharge are avoided (addressed in the evidence of Mr Graeme Ridley), that adverse effects on ecosystem habitats are avoided, remedied or mitigated (addressed in the evidence of Dr Eddie Sides) and that monitoring, including recording of water levels and pressures and recording of the movement of ground, building and other structures takes place (addressed in my evidence and that of Mr Gavin Alexander).

- 100 It is therefore my view that the rules and policies of the Auckland Regional Plan: Air, Land, Water that relate to the diversion of groundwater have been considered in this application and will be complied with.

**Submission by Auckland City Council<sup>25</sup>**

- 101 Auckland City Council’s concerns with respect to groundwater relate to the potential for contaminants held in existing landfills (in particular Phyllis Street Reserve, but also Alan Wood Reserve) to be mobilised by both short term and long term groundwater drawdown.<sup>26</sup>

***Phyllis Street Landfill***

- 102 Details of investigations of contaminants and contamination levels are described in the evidence of Mr Terry Widdowson. I note that ‘water’ levels within the Phyllis Street landfill are so low that it was difficult to obtain samples for testing.
- 103 This is not surprising because the area of the Phyllis Street landfill is understood to have originally been underlain by basalt that overlay low permeability Tauranga Group sediments and weathered East Coast Bays Formation soils. The landfill is formed adjacent to Oakley Creek and the base of the basalt was above the level of Oakley Creek. The basalt was quarried, and the space that was left was filled with refuse. This means that much of the leachate that developed over time is likely to have drained into Oakley Creek, but some would have been retained in the upper part of the underlying sediments.

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<sup>24</sup> Paragraph 4.8.10 in Submission No. 207.

<sup>25</sup> Submitter No. 111.

<sup>26</sup> Points 340, 394 and 398 in Submission No. 111.

- 104 Our assessment of the potential for spread of contaminants as a result of the strong vertical hydraulic gradient induced during tunnel construction utilised the groundwater models established and tracked the time taken for a 'particle' of water located just above the base of the landfill to travel through the soils underlying the landfill. As I describe above, the model indicates a minimum travel time of 650 days, well in excess of the time in which a 50 m section of tunnel below the landfill will have been broken out and shotcreted. I note also that this is the travel time of water and that many contaminants travel more slowly than water.
- 105 I therefore consider that the assessment of the potential for spread of contaminants from the Phyllis Street landfill and the monitoring identified in the Groundwater Management Plan are appropriate.

#### ***Alan Wood Reserve***

- 106 Assessments of the extent of landfilling at Alan Wood Reserve have shown that contaminated fill is localised and will be removed and replaced with inert fill where it is encountered as described in the evidence of Mr Terry Widdowson.

#### **COMMENTS ON REPORTS TO THE BOARD**

- 107 The ARC, in its s149G Key Issues Report suggests that "*the interpretation of site characterisation and irregularities in groundwater model calibration has resulted in a less conservative estimate of groundwater drawdown effects to the west of the tunnel alignment.*" This is responded to in Appendix 4 of the Addendum (attached in **Annexure C**) and paragraphs 73 to 77 of my evidence.
- 108 The ARC identifies that if the ground is fully saturated from near the ground surface in the Waitemata Group ridge to the west of the alignment, then the drawdown will be larger than predicted and extend further than predicted. If this were the case, then the amount and extent of ground settlement would be greater than predicted.
- 109 However, the collective data demonstrate that the groundwater profile in the Waitemata Group ridge is not a single fully saturated soil mass but is a cascading series of perched water tables with lower separated water lenses occurring within the Waitemata Group soils and rocks. This has been shown to occur elsewhere in the Waitemata Group in Auckland, and at cuts as part of the Maioro Street interchange work close by.
- 110 I therefore conclude that the modelled drawdowns represent our best estimate of what will occur in response to tunnelling.
- 111 The models have been calibrated to a representative groundwater level profile recorded within one horizon. There are no irregularities



in model calibration. This approach is equally representative of the other perched water tables that exist at each location.

### **PROPOSED GROUNDWATER CONDITIONS**

- 112 In the documentation lodged with the AEE, the NZTA included a set of Proposed Consent Conditions (see Part E, Appendix E.1). This included proposed groundwater conditions which I recommended would be appropriate to attach as conditions to the designations sought. A copy of the proposed conditions is contained in **Annexure D** to my evidence.
- 113 I consider that those conditions are still appropriate with some minor modifications as marked in **Annexure D** to my evidence.



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**Ann Williams**  
**November 2010**

Annexures:

Annexure A – Distribution of Hydrogeological Units

Annexure B – Summary of Predicted Effects (Table 8.1)

Annexure C – Addendum to Technical Report G.7

Annexure D – Amended Proposed Groundwater Conditions

**ANNEXURE A: DISTRIBUTION OF HYDROGEOLOGICAL UNITS**



**ANNEXURE B: TABLE 8.1 OF THE REPORT - SUMMARY OF  
PREDICTED EFFECTS<sup>27</sup>**

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<sup>27</sup> See page 28 of Technical Report G.7.

Table 8.1 Summary of Predicted Effects

Northern Cut and Cover Tunnels (Sealed)	Effect	Lower Bound		Upper Bound	
		Construction Maximum	Long Term Maximum	Construction Maximum	Long Term Maximum
	Inflow to Tunnel	0.02 to 1 m <sup>3</sup> /day/m of tunnel	0.02 m <sup>3</sup> /day/m of tunnel	0.5 to 2 m <sup>3</sup> /day/m of tunnel	1.0 m <sup>3</sup> /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 <sup>1</sup>	< 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 <sup>1</sup>	30 m	100 m	180 m	300 m
	Oakley Creek Leakage	~2 % reduction throughout			

Driven Tunnel	Effect	Lower Bound		Upper Bound	
		Construction Maximum	Long Term Maximum	Construction Maximum	Long Term Maximum
	Inflows	2 m <sup>3</sup> /day/m of tunnel	0.07 m <sup>3</sup> /day/m of tunnel	118 m <sup>3</sup> /day/m of tunnel (8 to 20 m <sup>3</sup> /day/m of tunnel if pre-grouted)	0.02 m <sup>3</sup> /day/m of tunnel (0.02 m <sup>3</sup> /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 <sup>1</sup>	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 <sup>1</sup>	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

Southern Portal and Approaches	Effect	Lower Bound		Upper Bound	
		Construction Maximum	Long Term Maximum	Construction Maximum	Long Term Maximum
	Inflows	0.2 m <sup>3</sup> /day/m of tunnel	<0.2 m <sup>3</sup> /day/m of tunnel	73 m <sup>3</sup> /day/m of tunnel	0.5 m <sup>3</sup> /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 <sup>1</sup>	< 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 <sup>1</sup>	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.

<sup>1</sup> 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

**ANNEXURE C: ADDENDUM TO REPORT G.7<sup>28</sup>**

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<sup>28</sup> Appendix 4, Technical Report G.31.

**Technical Assessment: G.7 Assessment of Groundwater Effects****Respondent:** Ann Williams, Beca

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This Addendum is prepared to provide further clarity on the interpretation of groundwater systems (perched and regional) within the Waitemata Group (ECBF) ridge, and the associated model calibration on the western side of the tunnel alignment.

**The Model**

As occurs throughout the Waitemata Group rocks in the Auckland Region, a cascading series of perched water tables occurs within the Waitemata Group. Water “hangs up” on lower permeability layers, slowly discharging through fractures and the rock mass to the underlying higher permeability layers until again being “caught” above a further low permeability layer. The head of water on each successive water table is only a fraction of the total head between the regional (lowest recorded) water table and the uppermost near-surface water table. This is correct *even where the successive water table heads overlap*. Therefore when deep excavations are made in Waitemata Group rock, these local upper perched water tables discharge without inducing noticeable ground settlement.

Head differences of 5 m are commonly observed between successive water tables. In some areas the difference is less pronounced. The model calibration plot shows all piezometer readings (except the uppermost levels from BH512 and BH508). However the model has not been calibrated to the perched water tables as this is clearly not appropriate and would be incorrect. In model calibration, consideration has been given to those piezometers in close proximity to the alignment, which are also generally closer to the regional water level because the alignment runs for the most part beneath lower elevation ground associated with Oakley Creek.

Figure F1 presented in the report G.7 Assessment of Groundwater Effects has been updated. The rainfall recharge zones modelled are shown in the Figure F1 attached in Appendix A.

**2D Analyses**

In places the water table modelled is just below that recorded in piezometers. Check analyses were carried out at CH 2750 m and CH 3400 m to consider the effect of a water table just above water levels recorded in piezometer suites.

It was suggested that this be attempted by increasing the anisotropy (lowering the vertical hydraulic conductivity) and by increasing recharge.

Adjusting the vertical anisotropy to values very much lower than found in testing or elsewhere in Auckland is needed to raise the water table beneath the ridge, however with such low vertical hydraulic conductivity the extent and amount of drawdown is small (less than in the original base case modelling).

Applying 3 % rainfall to the 2D models (as already applied in 3D modelling) does increase the modelled water table to a reasonable level, just above the lowest recorded water levels (Figures A, B and C in Appendix A). The models were then run with the modified water table.

### Settlement

The outputs from the models with these changes in water level were then used to check the effect on the settlement estimates. At Ch2750 m the maximum consolidation settlement value increased by a factor of around 1.6 compared to the current results (74 mm vs 48 mm)(refer report G.13 Assessment of Ground Settlement Effects). In terms of total settlement this results in an increase from 98 mm to 124 mm (26 % increase). This increase is due to a combination of both a higher initial groundwater level (thereby increasing the thickness of compressible material included in the analyses) and a greater total drawdown. There was very little difference in the extent of the estimated settlements, with the zero settlement extent remaining the same as the base case modeled and previously presented.

At Ch3400 m the consolidation settlement values were typically within 5 % of the current results, but the maximum value *decreased* by around 10 %. In terms of total settlement the differences are even less. There was no discernable difference in the extent of the settlement at this chainage.

### Conclusions

These results do not alter the conclusions or recommended mitigation as described in report G.7 Assessment of Groundwater Effects.

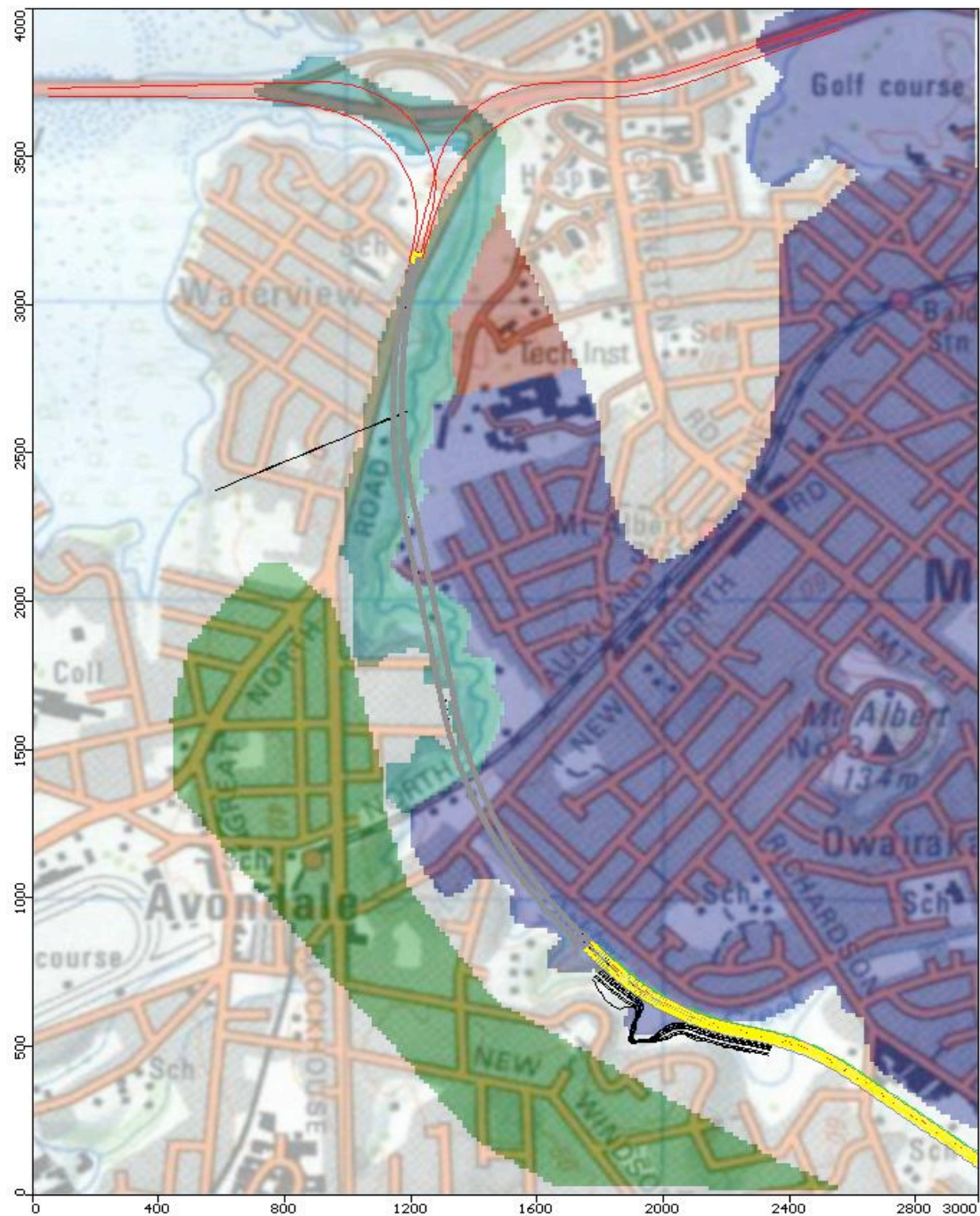
### Additional Figure

The distribution of existing wells in the area is shown in Figure D attached in Appendix A.



## Appendix A

**Figure F1 Addendum**



Zone	Recharge (mm / yr)	% Rainfall	Comments
1	27	2%	"Typical" background ECBF, at lower end of typically accepted range (2 - 10%) due to urbanisation.
2	0	0%	Steep banks > 30 degrees therefore most rainfall will run off into creek so negligible recharge.
3	0	0%	Groundwater springs / artesian conditions therefore negligible downward recharge likely.
4	38	3%	"Typical" background ECBF, higher % to encourage elevated GWLs as recorded through this zone.
5	91	7%	Areas of basalt or thick (and coarse) tephra deposits therefore greater recharge, as demonstrated by monitoring records.

Based on average rainfall 1350 mm/yr

**Figure A**

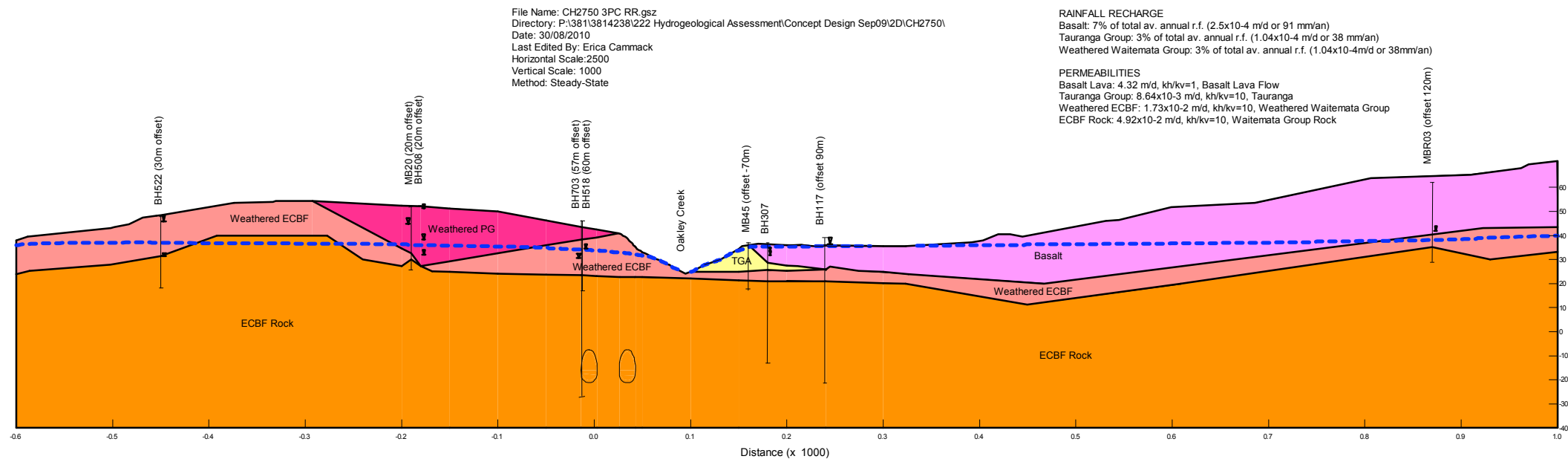


Figure B

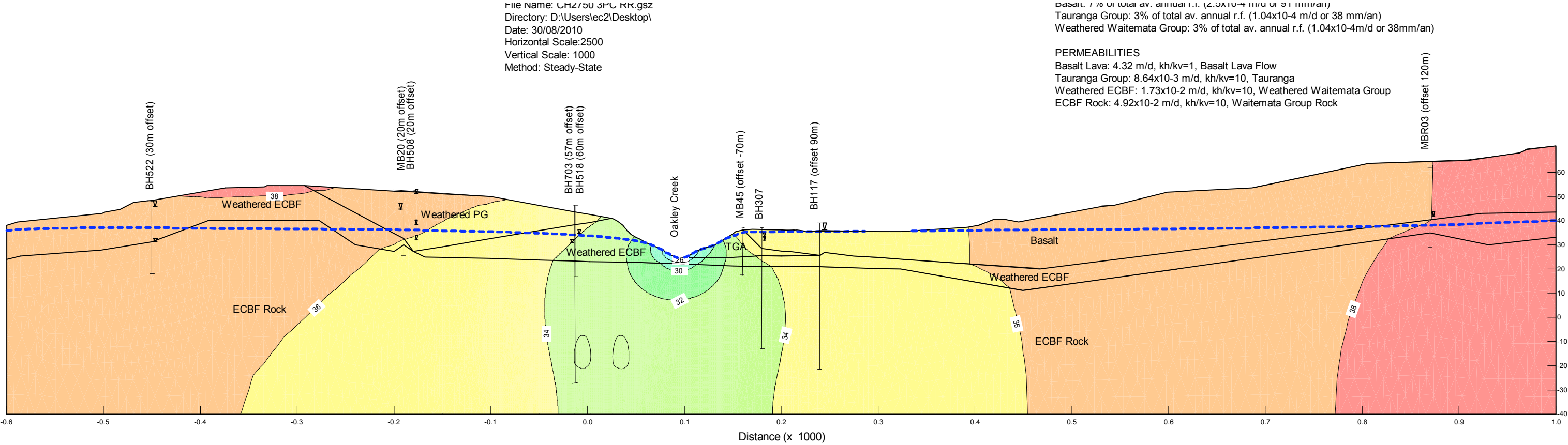


Figure C

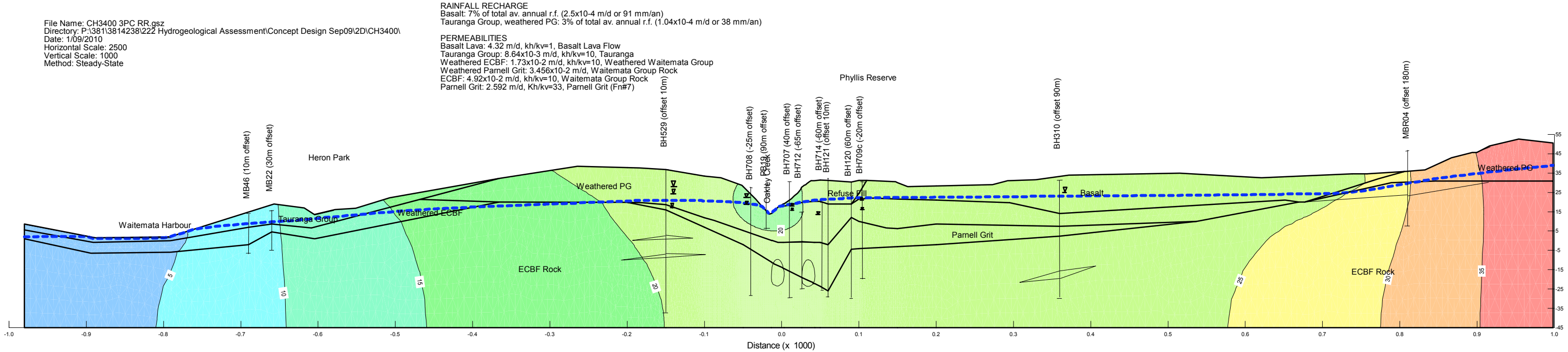
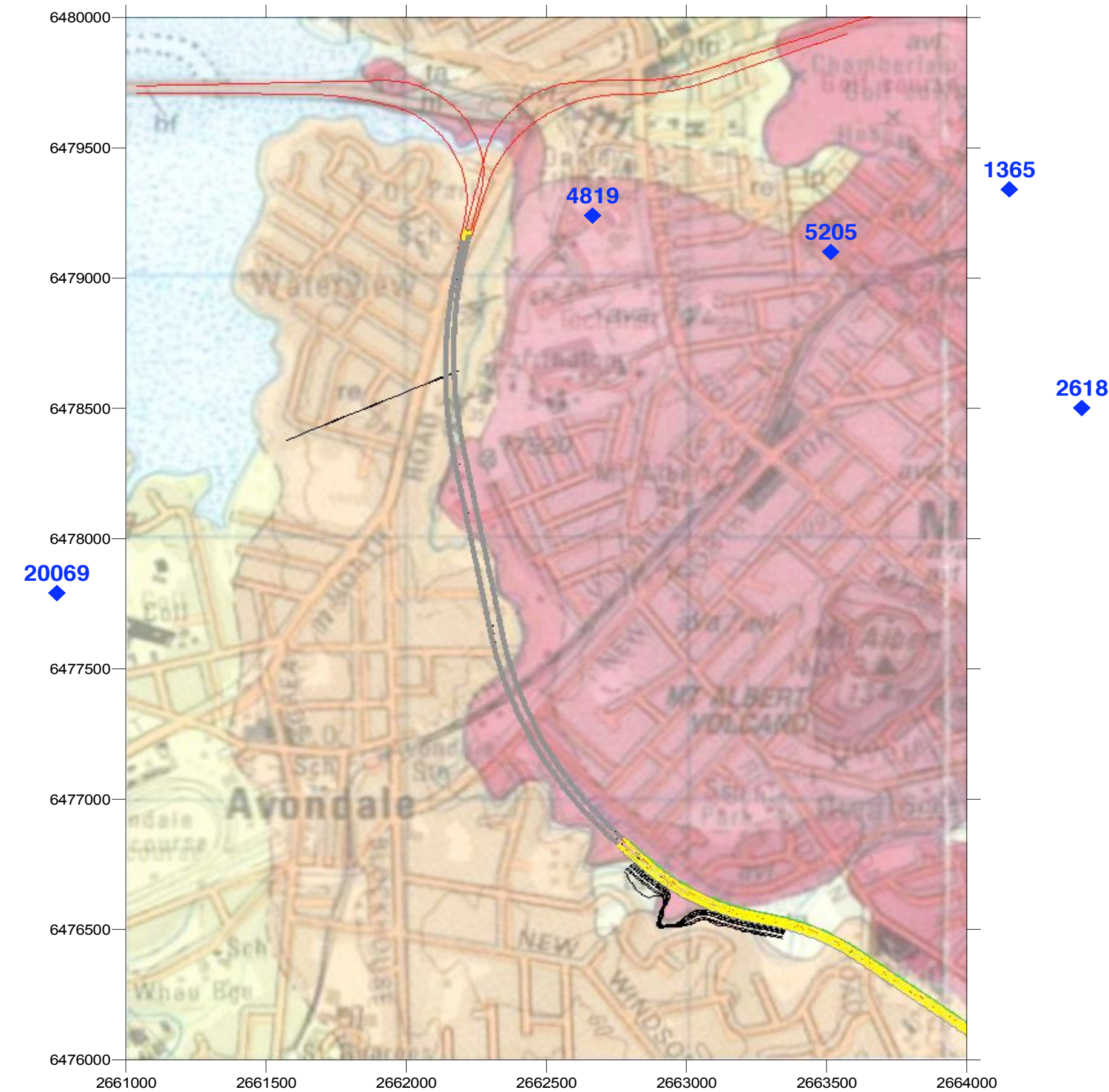




Figure D Addendum

Rec	BORE ID	FILE REFERENCE	CONSENT HOLDER	EXPIRY DATE	CONSENT STATUS	PURPOSE	EASTING	NORTHING	LOCATION	DIAMETER	SCREEN FROM	SCREEN TO	STATIC WATER LEVEL
22		C512-12-2094	Fulton Hogan Limited	19981208	Expired	Irrigation supply	1750330	5916080	203 Rosebank Rd, Avondale College	100	91.4	300	11
23		C512-12-1724*	Auckland City Council	19970222	Expired	Stock / domestic supply	1753100	5917400	Roadside berm, Cnr Leone Terrace & Martin Terrace	65			
39		No information					1754000	5916800	No information				
40		C512-12-1285	Kings Plant Barn Limited	19950623	Expired	Irrigation supply	1753738	5917642	118 Asquith Ave	100	15	30	10
42		C512-12-1574	LAYTONS LINEN HIRE LTD	19960508	Expired	Industrial use	1752246	5917538	Star Laundry, 1A Carrington Road	100	91	300	2

Map Showing Location of Private Wells (relative to modelled area)



## **ANNEXURE D: AMENDED PROPOSED GROUNDWATER CONDITIONS<sup>29</sup>**

G.1	<p>The NZTA shall finalise, and implement through the CEMP, the Groundwater Management Plan (GWMP), submitted with this application and provide it to the [Auckland Council] prior to commencement of tunnelling. The GWMP shall include, but not be limited to:</p> <ul style="list-style-type: none"> <li>(a) The location of the groundwater monitoring bores;</li> <li>(b) The location of the continuous monitoring stations on Oakley Creek;</li> <li>(c) The methods and frequency for groundwater monitoring;</li> <li>(d) The groundwater trigger levels;</li> <li>(e) Procedures to follow in the event of trigger levels being exceeded;</li> <li>(f) Reporting requirements;</li> </ul>
G.2	<p>The NZTA shall install and maintain the groundwater monitoring boreholes shown in Appendix A of the GWMP, for the period of monitoring specified in this Consent.</p>
G.3	<p>The NZTA shall monitor groundwater levels in the groundwater monitoring boreholes shown in Appendix A of the GWMP and keep records of the water level measurement and corresponding date in accordance with the GWMP. These records shall be compiled and submitted to the [Auckland Council] at three monthly intervals.</p>
G.4	<p>The NZTA shall monitor groundwater levels monthly in existing boreholes and in newly installed monitoring boreholes shown in Appendix A of the GWMP (required as part of this consent, as far as practicable) for a period of at least 12 months before the commencement of tunnelling. The variability in groundwater levels over this period, together with the monitoring trends obtained during the investigation and detailed design phases, will be used to establish seasonal groundwater level variability and establish trigger levels.</p>
G.5	<p>Prior to the commencement of tunnelling, and then at 3 monthly intervals while tunnelling, the NZTA shall review the results of monitoring as compared with expected effects on groundwater levels due to tunnelling. This review will consider the final tunnel alignment construction methodology and progress at the time of the review.</p> <p>The output of the first review shall be used to define the expected range of groundwater levels at each borehole during tunnelling activities and check the potential for damage to structures due to ground settlement. A factor for natural seasonal variability shall be allowed for in this review based on the monitoring completed under Condition G.4.</p>

<sup>29</sup> Contained in AEE, Appendix E.1, pages 45 - 47. Underlined text indicates amended or new conditions.

G.6	<p>From commencement of tunnelling, the NZTA shall monitor groundwater levels in each borehole at a minimum of monthly intervals and records shall be kept of each monitoring date and the corresponding water level in each borehole. In addition, all boreholes located within 100 metres of the tunnel excavation face shall be monitored for groundwater level at least twice weekly. These records shall be compiled and submitted to the [Auckland Council] at three monthly intervals.</p>
G.7	<p><u>From commencement of tunnelling, the NZTA shall monitor groundwater level in boreholes established in the Phyllis Street Reserve. Should water levels rise more than 0.6 m above the highest recorded pre-construction water level in the period where tunnelling is taking place within 100 m of the Reserve, then an inspection of the surface of the landfill will be made and the surface re-levelled in areas where cracking of the cap or ponding of water on the surface is indicated (other than exists prior to commencement of the works).</u></p>
G.8	<p>All monitoring data obtained pursuant to Condition G.6 shall be compared to the predicted groundwater levels for each borehole. Where groundwater levels are exceeded the appropriate actions as set out in the GWMP shall be undertaken and the [Auckland Council] shall be notified, forthwith, advising of the exceedance, the risk of settlement that might cause damage to structures or adverse effects in Oakley Creek, and details of the actions undertaken.</p>
G.9	<p>The NZTA shall continue to monitor groundwater levels in each borehole at monthly intervals for a period of up to 12 months following completion of tunnelling, then 3 monthly thereafter for a further 24 months, or for a lesser period if groundwater levels in any particular borehole show either:</p> <ul style="list-style-type: none"> <li>(a) Recovery of the groundwater level to within 2 metres of the pre-tunnelling groundwater level as recorded in accordance with Condition G.5; or,</li> <li>(b) A trend of increasing groundwater level in at least 3 consecutive monthly measurements; or,</li> <li>(c) An equilibrium in the groundwater level, allowing for the seasonal variation, has been reached,</li> </ul> <p>In which case monitoring at that borehole may cease, subject to the written approval of the [Auckland Council].</p>



G.10	<p>The NZTA shall establish continuous flow monitoring stations at the following approximate locations within Oakley Creek:</p> <ul style="list-style-type: none"> <li>(a) Chainage <u>1800 -</u> 1900 (Waterview Connection Operational Plan, Drawing No: 20.1.11-3-D-C-910-117);</li> <li>(b) Chainage <u>2200</u> (Waterview Connection Operational Plan, Drawing No: 20.1.11-3-D-C-910-116);</li> <li>(c) Chainage 3500 (Waterview Connection Operational Plan, Drawing No: 20.1.11-3-D-C-910-114); and</li> <li>(d) Between Chainage 3900 to 4200 ((Waterview Connection Operational Plan, Drawing No: 20.1.11-3-D-C-910-113).</li> </ul> <p><u>The NZTA shall establish a continuous flow monitoring station at the upstream major tributary at Chainage 1000.</u></p> <p>The NZTA shall continue to monitor the flow monitoring station installed at CH2900 (Waterview Connection Operational Plan, Drawing No: 20.1.11-3-D-C-910-116).</p> <p>The exact location of the gauges shall be determined based on stream bed conditions such that they record the full range of flows <u>as far as practical</u>, with the locations detailed in the GWMP.</p>
G.11	<p>The continuous monitoring required by Condition G.9, shall record in-stream flows, at 15 minute intervals, for a period of:</p> <ul style="list-style-type: none"> <li>(a) At least 12 months prior to tunnelling commencing;</li> <li>(b) During tunnelling; and</li> <li>(c) Up to 12 months following completion of tunnelling, or a shorter period if no effects on base flows are recorded.</li> </ul>
G.12	<p>The continuous monitoring results shall be reviewed on a monthly basis to determine if there is any effect of the tunnelling on base flows in Oakley Creek. The results shall be included in the 3 monthly groundwater reports, and provided to the [Auckland Council].</p>
G.13	<p>The NZTA shall, within 10 working days of completion of tunnelling, advise the Manager [Auckland Council], in writing, of the date of completion.</p>