IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of Resource Consents and Notices of Requirement for the Central Interceptor main project works under the Auckland Council District Plan (Auckland City Isthmus and Manukau Sections), the Auckland Council Regional Plans: Air, Land and Water; Sediment Control; and Coastal, and the National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health

STATEMENT OF EVIDENCE OF GRAEME RICHARD TWOSE ON BEHALF OF WATERCARE SERVICES LIMITED

GROUNDWATER AND SURFACE SETTLEMENT

1. INTRODUCTION

1.1 My name is Graeme Richard Twose. I am a senior Geotechnical Engineer in the geotechnical group of Tonkin & Taylor Limited. I have 16 years post graduate experience in geotechnical engineering, including site investigation, soil and rock mechanics, groundwater and settlement analyses and natural hazard assessments, and geotechnical risk assessments.

1.2 I hold the qualification of Bachelor of Engineering (Civil) from the University of Auckland, and a New Zealand Certificate of Engineering (Civil).

1.3 From 1991 - 1992 I was employed by Babbage Consultants, and from 1992 - 1999 I was employed by Manukau Consultants Limited (now GHD Limited) as a design engineer working on local authority infrastructure projects, including sewer reticulation, stormwater upgrades and sanitary landfill design. Between 1999 and 2000 I was employed by the University of Auckland, undertaking research into the settlement of shallow foundations on residual and volcanic soil in Auckland.

1.4 Since joining Tonkin & Taylor Limited in 2000, I have provided specialist geotechnical and hydro-geological design and consenting inputs for a number of groundwater and tunnelling projects. These include the Three Kings Quarry dewatering project, the Hobson Bay sewer tunnel project ("**Project Hobson**"), the North Shore sewer tunnel project ("**Rosedale Project**"), and the Northern Gateway Johnsons Hill twin tunnel design. I have also acted as technical peer reviewer on groundwater assessments for the New Lynn Rail trench project, and the Waterview tunnel project, and undertook a detailed study of the completed Vector Tunnel ("**Vector**"), measuring groundwater inflows along the tunnel and correlating it to geology.

Involvement in the Central Interceptor Project

1.5 I have been involved with the assessment of groundwater conditions and effects for the Central Interceptor Project ("**Project**") since 2011. My Project role has been to lead the assessment of tunnelling and shaft construction effects on groundwater flow and surface settlement, with personnel from Tonkin & Taylor Limited working under my direction completing modelling work. I am the principal author of the Tonkin & Taylor Technical Report titled "Central Interceptor Project Effects of Tunnels on Groundwater and Surface Settlement" ("**Groundwater and Surface Settlement Report**") which was included as Technical Report J of Part D of the Central Interceptor Main Project Works Assessment of Effects on the Environment submitted to the Council in August 2012 ("**AEE**").

Executive Summary

1.6 Tunnels of similar configuration, and through similar areas and geology, have been completed successfully in Auckland in recent history.

1.7 As Mr Cooper has described, the Project intends to use tunnel and shaft construction methodologies that have proven successful on the Rosedale Project and Project Hobson.

1.8 The settlement arising from tunnel and shaft construction measured on each of these projects was well within the consent limits, with the limits set to protect buildings from damage associated with surface settlement.

1.9 From my own knowledge and from talking with people who were directly involved in the construction phases of those projects, including Mr Cooper, there was no damage to buildings or structures on those projects associated with the groundwater effects or surface settlement resulting from tunnel or shaft construction.

1.10 Geological investigations undertaken specifically for this Project have identified the ground and groundwater conditions that construction activities will expect to encounter, and construction methodologies have been developed for these specific conditions, and for potential local variations in conditions that may be encountered during construction.

1.11 Analyses have been undertaken to assess the potential settlement hazard as a result of tunnelling in the various ground conditions identified, and have assessed the capacity of the proposed construction methodologies to mitigate the potential settlement.

1.12 Based on the results of those analyses, and considering experience from the similar Project Hobson and the Rosedale Project, it is my conclusion that the Project tunnels and shafts can be constructed without resulting in unacceptable settlement or damage to buildings and structures.

1.13 Consent conditions will require monitoring and contingency plans to develop monitoring networks to track the development of effects during construction to confirm that the settlement effects are being adequately managed, and to provide additional construction controls in the event that effects start to develop away from those expected.

Code of Conduct

1.14 I have been provided with a copy of the Code of Conduct for Expert Witnesses contained in the Environment Court's Updated Practice Note 2011 which took effect on 1 November 2011. I have read and agree to comply with that Code. This evidence is within my area of expertise, except where I state that I am relying upon the specified evidence of another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Scope of evidence

1.15 My evidence is based on work I undertook or directed relating to surface settlement due to groundwater drawdown as presented in detail in the Groundwater and Surface Settlement Report. That report also summarises work undertaken by Watercare's Principal Engineering Advisors (undertaken or directed by Mr Cooper) related to the potential for "mechanical settlement" and I include reference to that work in my evidence and summarise its findings.

1.16 The purpose of my evidence is to outline:

(a) the findings of geotechnical and groundwater investigations;

(b) an assessment of the potential for groundwater effects;

(c) the potential for ground settlement arising from the groundwater effects and as a result of tunnel and shaft construction; and

(d) the magnitude of the settlement effects and the mitigation measures that will be employed to control the effects to levels acceptable to buildings and structures.

1.17 The groundwater and surface settlement associated with tunnelling activities depends on a number of variables, such as the geological and groundwater conditions, the type of tunnelling to be undertaken and the proposed construction methodology, controls and mitigation. For that reason, before assessing the potential effects of the tunnels and shafts on groundwater and surface settlement, the existing geological and hydrological environment must be considered. My evidence is therefore structured as follows:

(a) Section 1: Executive Summary;

(b) Section 2: Background;

(c) Section 3: Geology;

(d) Section 4: Groundwater;

(e) Section 5: Effects of Tunnels and Shafts on Groundwater and Surface Settlement;

(f) Section 6: Monitoring and Contingency;

(g) Section 7: Response to submissions;

(h) Section 8: Response to Council Pre-hearing Report;

(i) Section 9: Watercare's Proposed Conditions; and

(j) Section 10: Conclusions.

2. BACKGROUND

2.1 The Project overview by Mr Munro and the Project concept design and construction briefs of evidence presented by Mr Cantrell and Mr Cooper have set out the Project in detail. I have therefore included only some additional technical details that are of particular relevance to the ground conditions and settlement aspect of the Project. Elsewhere I rely on information presented in the briefs of evidence referred to.

2.2 As illustrated on **Figure A1** in **Appendix A** to my evidence (from Appendix A of the Groundwater and Surface Settlement Report) the tunnel alignment passes through built up urban areas, public open space, beneath roadways and rail corridors (both existing and future), and the Manukau Harbour.

2.3 Tunnels of similar configuration, and through similar areas, have been completed successfully in Auckland in recent history.

2.4 These include the 3m diameter Vector tunnel from Penrose to Hobson Street in the CBD, the 2.8m diameter Rosedale tunnel from the Rosedale wastewater treatment plant to Mairangi Bay and the 3.4m Project Hobson tunnel which passes under Hobson Bay and the Orakei Ridge line.

2.5 Each of these projects traversed a range of geological and groundwater conditions similar to that expected on much of the Project, and in the case of the Rosedale Project and Project Hobson, tunnels were constructed using tunnelling methodologies similar to those proposed for the Project.

2.6 With the exception of the short section of tunnel from the Kiwi Esplanade site on the southern side of the Manukau Harbour to Mangere Wastewater Treatment Plant ("**Mangere WWTP**") where the geological conditions are expected to be different, these projects provide direct examples of the magnitude of surface settlement effects that could be associated with construction of the Project.

2.7 I have been directly involved in each of these projects. For the Rosedale Project and Project Hobson I undertook the assessments of potential groundwater effects and surface settlement effects during the consenting stage of the projects. I have undertaken a study of the Vector tunnel after it was constructed assessing the long term groundwater inflow to the completed tunnel and the groundwater effects associated with the inflow. As part of the work undertaken for this Project, I have reviewed construction monitoring data for each of these projects.

2.8 In summary, the Vector tunnel monitoring data showed that construction of the tunnel resulted in very small levels of measured surface settlement, averaging less than 10mm, and typically less than 20mm, but with one outlier measurement of approximately 40mm. This was directly above the tunnel construction where the tunnel liner was not installed for some 12 – 18 months after excavation, where significant groundwater inflows were observed into the excavated tunnel and where the tunnel passed beneath settlement prone materials.

2.9 The Project Hobson and Rosedale Project tunnels were constructed using methodologies very similar to that proposed for the Project, in that, unlike Vector, the tunnels were lined very soon after excavation. Average surface settlement measured during construction above those tunnels was in each case less than 10mm (on the Rosedale Project settlement was typically less than 10mm, but with one outlier measurement of approximately 40mm).

2.10 The settlement measured on each of these projects was well within the consent limits, with the limits set to protect buildings from damage associated with surface settlement.

2.11 From my own knowledge and from talking with people who were directly involved in the construction, including Mr Cooper, there was no damage to buildings or structures above the tunnels that was associated with the groundwater effects or surface settlement resulting from tunnel or shaft construction.

2.12 Given the similar geological and groundwater conditions, and the similar construction methodology and monitoring proposed, I am confident that this Project can also be constructed in a way that does not create unacceptable surface settlement effects, based on my own experience and from talking with the people who were directly involved in the construction stage of these earlier projects.

2.13 The following sections of my evidence present a summary of the technical work that has been carried out to confirm design details and construction methodologies that are required so that the Project is constructed in a way that does not create unacceptable settlement effects.

2.14 My evidence relates to the proposed construction of the main tunnel and Link Sewers 1, 2 and 3 and their associated shafts. As Mr Cooper explained in his evidence, Link Sewer 4 will be constructed by shallow (1 – 3 m deep) open excavations above groundwater level. As such there is no potential for groundwater effects and Link Sewer 4 will not be discussed further in my evidence.

3. GEOLOGY

3.1 Regionally, the Auckland Isthmus is dominated by sandstones and siltstones of the Waitemata Group, in particular the East Coast Bays Formation ("**ECBF**"). Overlying Tauranga Group alluvium deposits are typically present within present day and paleo-drainage channels. The various deposits of the Auckland Volcanic Field ("**AVF**") occur over a wide area, but are largely limited to basalt flows or a mantling of tuff and ash associated with specific volcanic centres.

3.2 The geological structure of Auckland consists of a broadly rectangular patchwork of fault generated blocks. The Manukau Harbour and adjacent Manukau Lowlands are part of a regional-scale down-thrown block relative to the Auckland Isthmus.

3.3 The area has been further disrupted by episodes of volcanic activity, with the volcanic centres of Mt Albert, Mt Roskill, Mt Mangere and the Mangere Lagoon lying close to the tunnel alignment.

3.4 In the initial stages of the Project, existing ground investigation data, including that from the State Highway 16 / State Highway 20 Waterview Connection project, the State Highway 20 motorway extension project and the upgrade project of Mangere WWTP, known as Project Manukau, were inspected, along with published geological maps. These were used to create a conceptual geological model for the Project.

3.5 Some further 34 geological investigation boreholes have since been drilled within the proposed tunnel corridor to investigate ground conditions specifically for the Project. The boreholes were located to specifically address key uncertainties in the conceptual geological model along the tunnel alignment.

3.6 Piezometers (devices to measure groundwater levels) were permanently installed in some of the investigation boreholes to measure groundwater levels during the investigation phase and to allow development of a database of long term groundwater level fluctuations.

3.7 The details of the site investigations completed to date, including borehole logs, groundwater level monitoring and test data, are set out in the Groundwater and Surface Settlement Report and this detail is not duplicated here.

3.8 These boreholes, in combination with the historic investigation data for the wider area, were used to refine the geology models for the Project and create a conceptual geological model of the range of ground conditions that can be expected and their distribution along the route. This is a key requirement for designing the Project and forms the basis for managing the risks associated with construction. **Figures A3 – A9** from Appendix A of the Groundwater and Surface Settlement Report are set out in **Appendix A** to this evidence and present a geological map and longitudinal sections of the tunnel alignment.

3.9 In summary, three zones of distinct geological conditions, relevant to groundwater flow and surface settlement effects, have been identified from the conceptual model, and form the basis for assessing Project effects and for managing risks associated with construction:

3.10 A Northern Zone: (Western Springs to Mt Roskill) with ECBF at tunnel level and surface geology dominated by AVF basalt and volcanic tuff. Depending upon the pre-eruptive topography, the AVF deposits either directly overlie the ECBF rocks or Tauranga Group alluvium. The tunnels are excavated entirely within the ECBF. This is shown on **Figures A5, A7** and **A8**.

3.11 A Central Zone: (Mt Roskill to Hillsborough / northern shore of the Manukau Harbour) with the tunnel excavated entirely within ECBF and outcropping ECBF rocks and minor Tauranga Group alluvium cover at the surface. This is shown on **Figure A5**.

3.12 A Southern Zone: (Manukau Harbour and Mangere) with the tunnel excavated in ECBF, as well as Kaawa and Puketoka Formation deposits, and surface geology dominated by AVF eruptive centres. This is shown in detail on **Figure A6**.

3.13 Within each of these three zones, cross sections of the tunnel alignment were developed that identified geological conditions at key locations along the tunnel alignments. The location of the sections is identified on **Figure A1**, with the sections collectively representing the range of geological conditions that are expected in tunnel construction. The sections represent the material that the tunnel is expected to be excavated through, as well as the overlying material that may consequentially be influenced by groundwater effects from tunnel excavation and construction. These sections form the basis for computer modelling discussed later in my evidence, carried out to assess groundwater and settlement effects associated with tunnel construction and are included in the Groundwater and Surface Settlement Report.

3.14 Further sections were similarly developed at specific shaft locations to provide the basis for modelling work carried out to assess groundwater and settlement effects associated with shaft construction, and are included in the Groundwater and Surface Settlement Report.

3.15 The AEE identifies a horizontal and vertical corridor for tunnel construction. The horizontal corridor is 40m wide, and the vertical corridor is 20m deep. The assessment of the range of geological conditions that might be encountered on the Project is not sensitive to the location of the tunnel within the corridor. Further ground investigation boreholes will, however, be necessary to support detailed design of the Project in the future and to refine the geological models.

3.16 Within the vertical corridor the materials expected at tunnel level in this assessment are based on the shallowest tunnel possible within the corridor, as this provides the highest potential effects at the ground surface (i.e. deeper tunnels would be expected to have less effects at the surface). The deeper tunnel would also result in deeper shafts.

3.17 In shaft construction, it is excavation through the near surface deposits that is most likely to contribute to surface settlement. Excavations deep in the ECBF rock at tunnel level would not be expected to contribute significantly to surface settlement. As such, while deeper shafts would not be expected to result in lesser effects, nor would they be expected to result in greater effects. On this basis, the shaft analyses carried out for the shallowest tunnel alignment presented in my evidence can be considered representative of those for the deeper alignment also.

3.18 In the Northern and Central Zones a deeper tunnel would encounter the same material at tunnel level as the shallower ECBF.

3.19 In the Southern Zone, deep tunnels might be excavated entirely within the ECBF, and potentially not encounter Kaawa Formation or Puketoka Formation materials at tunnel level. The shallow tunnel provides the highest potential effects in this zone as in addition to my comment in 3.11, a tunnel excavated in Kaawa and/or Puketoka Formation material is expected to have higher surface effects than one in ECBF.

3.20 The detailed characteristics of the materials present along the Project alignment and represented on the tunnel and shaft cross sections are set out in full in the Groundwater and Surface Settlement Report, along with explanations of how they have been derived. I will now present a summary of the materials and their hydrogeological characteristics to illustrate how they have been used in the assessment of effects associated with the Project.

Hydro-geological units

3.21 A hydro-geological unit is a strata or group of materials that have similar hydrological characteristics. The materials identified by the geological investigations described above have been grouped into eight hydrogeological units for the purposes of the assessments of effects. These eight units are:

(a) AVF Basalt;

(b) AVF Tuff;

(c) Estuarine Sediments;

(d) Tauranga Group Alluvium incorporating the upper Puketoka Formation;

(e) the Lower Puketoka Formation;

(f) Kaawa Formation;

(g) Residual to Highly Weathered ECBF; and

(h) ECBF Rock (including Parnell Grits).

3.22 The engineering and hydrogeological properties of these units are an essential input into modelling the existing groundwater conditions and for assessing the effects of constructing the Project tunnels and shafts on groundwater and surface settlement.

3.23 The most important engineering properties for the assessment are the ones that describe how permeable the material is and how compressible the material is.

3.24 The permeability of the material describes how easily groundwater can flow through it. A highly permeable material provides little resistance to groundwater flow compared to a low permeability material.

3.25 The compressibility of a material describes how much settlement might result from groundwater level changes in the material. When groundwater levels drop, a high compressibility material will contribute to surface settlement much more than a low compressibility material of the same thickness.

3.26 The overall effect of the various permeability and compressibility on surface settlement depends on the distribution and extent of the materials in the vicinity of the tunnel and shaft works, as is identified on the longitudinal and cross sections developed to represent the conditions along the alignment.

3.27 A summary of the eight hydrogeological units and their relative permeability and compressibility is set out as follows:

(a) The *AVF Basalt* consists of hard rock lava flows. The basalt is typically well jointed and is therefore highly permeable but has very low compressibility so, even if affected by significant groundwater level changes, is not expected to contribute significantly to surface settlement. The basalt overlies extensive reaches of the tunnel alignment in the Northern and Southern Zones (**Figure A5**), up to 30m in thickness.

(b) *AVF Tuff* comprises clayey to sandy silts with some gravels through to silty gravels. Tuff typically has moderate to high permeability and moderate compressibility. If affected by significant groundwater level changes, it would be expected to compress and to contribute to surface settlement. Tuff has been identified along the tunnel to thicknesses in the order of 5m in the Northern Zone near Mt Roskill, and in the Southern Zone (**Figure A5**).

(c) *Estuarine sediments* are found in and around the Manukau Harbour (in the Southern Zone – **Figure A5**) and consist typically of silts and sands with variable shell, gravel and organic content. Typically these deposits have moderately low permeability (although some layers in the deposit can have locally high permeability) and very high compressibility. If affected by significant groundwater level changes these materials are expected to contribute significantly to surface settlement. Typically these materials are in tidal areas so buildings are not likely to be exposed to the settlement.

(d) *Tauranga Group Deposits* and the *Upper Puketoka Formation* have been grouped together as they are expected to behave similarly. They have moderately low permeability and moderately high compressibility, and are found predominantly in the Northern and Southern Zones. Significant groundwater level changes in these materials would be expected to result in surface settlement. It was groundwater level changes in these materials that resulted in the highest measured settlement on the Vector tunnel project discussed earlier. (**Figures A5, A7, A8, A9**).

(e) The *Lower (predominantly sand) Puketoka formation* is considered a separate unit as it is expected to be more permeable and have lower compressibility than the Upper Puketoka Formation. It is identified only in the Southern Zone (**Figure A6**), with potential for short sections of the tunnel excavation to be directly in this material.

(f) The *Kaawa Formation* deposits consist of poorly cemented sandstone and sands in thicknesses of up to 15m. The Kaawa has moderate permeability, low compressibility and is found in the Southern Zone (**Figure A6**). From Kiwi Esplanade to the Mangere WWTP short sections of the tunnel are excavated in Kaawa formation so these materials will be directly affected by tunnel excavations.

(g) *Residual to Highly Weathered ECBF* is present along the entire route (**Figure A5**). The upper surface of the ECBF has a variable weathering profile along the route, with typically up to 5 m of residually to highly weathered ECBF. This weathered material typically has a moderately low permeability and moderate compressibility. As this material is in direct contact with the ECBF rock, groundwater effects within the ECBF would propagate into this material first, before extending into other overlying materials.

(h) The *ECBF Rock* identified in the investigations is typical of this material elsewhere in the Auckland Region. On a geological scale it is typically described as extremely weak to weak rock. It comprises inter-bedded siltstones and muddy sandstones. The tunnels are excavated entirely in this material except for the short section from the Kiwi Esplanade site to the Mangere WWTP in the Southern Zone. Groundwater flows are typically concentrated along the sandstone beds, with rock fractures and faults providing interconnection between the beds through the siltstone. Along the sandstone beds (nominally horizontal) it has a moderate permeability, while between beds (nominally vertical) permeability is low. ECBF rock is considered to have a low compressibility. It is not expected to contribute significantly to surface settlement even when affected by significant groundwater level changes. An occasional local variation of the ECBF is Parnell Grit which is typically much stronger than native ECBF.

3.28 From our investigations and the analysis undertaken it is expected that the excavation at tunnel level will predominantly encounter ECBF rock as identified on **Figure A1**. The ECBF is therefore the unit that will be most directly affected by tunnelling and associated effects. Owing to its low compressibility, however, even if affected by significant groundwater level changes, it is not expected to contribute to significant surface settlement. Significant surface settlement would only arise in areas if the groundwater effects propagate from the ECBF into the overlying, more compressible material such as the Tauranga Group material described above. The ECBF typically has a low vertical permeability, and this has the effect of slowing the propagation of groundwater effects into overlying materials, such that effects in the overlying material can take some months to develop. Monitoring undertaken for the Vector tunnel project in particular identified that even 18 months after tunnel excavation, during which time groundwater was able to freely flow into the tunnel, groundwater levels in the near surface deposits, such as the Basalt material, were still unaffected.

3.29 The ECBF is expected to primarily have the characteristics as described above. However:

(a) The SH16/SH20 Waterview Connection investigations (near the tunnel alignment) encountered zones of Parnell Grit, an occasional local variation of the ECBF that occasionally had a much higher permeability owing to large open fractures. It is possible that tunnel construction could encounter high permeability Parnell Grit material, although investigations to date have not encountered it. The permeability of this material could be similar to that of Basalt. If this material was encountered by the tunnel excavation it could result in higher than normal groundwater inflows into the tunnel excavation, and the groundwater effects in the ECBF propagating more rapidly into overlying materials, increasing the risk of surface settlement arising from effects that develop in those materials.

(b) ECBF adjacent to explosion craters elsewhere within the AVF has been found to be more significantly fractured than material distant from the craters. Experience from dewatering of the Three Kings Volcanic Complex has indicated that disturbance in the ECBF around volcanic vents may extend as much as 800 m to 1,000 m from the volcanic crater and that the disturbed rock is much more permeable. It is possible that tunnel construction could encounter such high permeability ECBF, although investigations to date have not encountered it. If this material was encountered by the tunnel excavation, the effects would be the same as described in (a) above.

3.30 Given that there are examples of other hydrogeological units being unexpectedly encountered, the potential for higher permeability ECBF zones being encountered by tunnel excavations cannot be entirely discounted by the investigations. Sensitivity studies considering the potential effects of tunnelling through this material have modelled it with a high permeability consistent with findings from the Three Kings Volcanic complex. As described by Mr Cooper, the proposed tunnel construction methodology includes specific capability to respond to such circumstances during construction operations, and to provide specific control over the magnitude of groundwater effects and surface settlement.

3.31 Overall, the investigations that have been undertaken identified the range of geological conditions that can be expected along the Project alignment. They identified the materials that are expected at tunnel level and those above the tunnel that might be affected by groundwater effects associated with tunnelling, and directly through shaft excavation. The distribution of these materials has been represented on sections at key locations along the tunnel alignments that represent the range of conditions that are expected for tunnel and shaft construction. The permeability and compressibility of the material present within these sections has been assessed as part of the investigations as key inputs into computer models used to assess groundwater effects and settlement effects. This has provided a basis for planning appropriate tunnel and shaft excavation and construction methodologies as described by Mr Cooper.

3.32 Based on information and experience from past projects, it is recognised that there remains a chance that other materials may be encountered at tunnel level, or above the tunnel, and that this could result in a higher risk of settlement. The further investigations that will be required for detailed design will reduce the chance of this occurring unexpectedly, but it will always remain a possibility as it is not possible to investigate the full tunnel length.

3.33 The method of construction selected for the Project and described by Mr Cooper has been specifically chosen to address the identified ground and groundwater conditions and the assessed potential settlement effects arising from tunnelling. As described by Mr Cooper, it also provides the capacity to respond to a range of ground conditions to actively control settlement effects associated with potentially unexpected ground conditions. The contractors will be required to be able to respond to changing ground conditions.

3.34 For shafts, while there is also a chance that other materials may be encountered by shaft excavation, this can be significantly reduced by the further investigations required for detailed design, and borehole investigations can be carried out at the specific location of each shaft. This will provide an accurate assessment of the material that will be encountered as the shaft is excavated. The specific methodologies developed during detailed design can address the specific conditions identified.

4. GROUNDWATER

4.1 Along with the existing geological conditions and the properties of the materials, the existing groundwater conditions along the alignment of the Project must also be assessed. This is because the response of the existing groundwater flow regime to the tunnelling and shaft construction activities will greatly influence the degree to which surface settlement might occur.

4.2 To help assess the groundwater conditions, piezometers were installed in some of the investigation boreholes to allow measurement of groundwater levels. In-situ testing was also undertaken in selected boreholes to assess the permeability of the ground. This testing, along with data from projects in similar geological environments in Auckland

and full discussion of the groundwater conditions along the alignment, is presented in full in the Groundwater and Surface Settlement Report.

Groundwater Conditions

4.3 Regionally the Auckland Isthmus is characterised by groundwater levels that fluctuate in response to rainfall within near surface deposits and a deeper more stable (regional) groundwater level. The regional groundwater level is typically a subdued reflection of surface topography; with higher levels beneath the ridges, and with levels generally falling towards the coast where it ultimately merges with sea level.

4.4 Piezometers indicate that in the Northern Zone, from Western Springs to Mt Albert Road, basal material in paleo-valleys (typically Tauranga Group materials) are recharged with groundwater flow from ECBF in the sides and base of the valley. The tunnel level is relatively shallow beneath the known paleo-valley bases so in these locations there is a risk of groundwater effects that develop in the ECBF as a result of tunnelling directly affecting the compressible Tauranga Group materials and contributing to surface settlement.

4.5 In this same area, a number of groundwater users have consent to take groundwater from the Basalt for irrigation (Auckland Council, Kings Plant Barn and Akarana Golf Club), and for general use at the Auckland Zoo (Auckland Council). These takes are between 90m and 280m from the tunnel alignment. Experience and monitoring from past projects, specifically Vector tunnel, indicate that the availability of groundwater in the Basalt aquifers is unlikely to be affected by tunnelling in the underlying ECBF. Vector tunnel groundwater monitoring showed that even when large groundwater effects were measured in the ECBF near tunnel level, the groundwater level in Basalt immediately above the tunnel alignment was not affected. This indicates that groundwater level changes in the ECBF associated with tunnelling are not likely to affect users of groundwater sourced from the Basalt aquifers.

4.6 The Western Springs flow from Basalt in this zone forming the man-made Western Springs Lake. This observation indicates that the source flows of the lake are not likely to be affected by tunnel excavations.

4.7 Shafts excavated through the Basalt will however need to address groundwater control specifically to ensure lake source flows are not affected. In the vicinity of the lake, piezometers identify that the regional groundwater level is below the bottom of the lake indicating downward seepage of lake water to the regional groundwater below. This indicates that groundwater level changes in the ECBF below the lake (potentially as a result of tunnelling) are not likely to result in any increased drainage out of the lake.

4.8 In the Northern Zone, from Mt Albert Road to Mt Roskill Road, piezometers indicate similar hydro-geological conditions, with the tunnel significantly below the known paleo-valley bases. In these locations there is a lower risk of any groundwater effects that develop in the ECBF as a result of tunnel excavation directly affecting the overlying compressible Tauranaga Group materials and resulting in surface settlement.

4.9 Within the Central Zone, in the Hillsborough Road ridge, the regional groundwater level is expected to rise from sea level at the coast, at a grade of between 2% and 5% inland, consistent with observations elsewhere in the Auckland Isthmus (although Project specific investigations have not been undertaken to confirm this). This has been assumed for the purposes of groundwater assessments here, and results in an assumed regional groundwater level in this part of the alignment close to ground surface. This is expected to be a conservative assumption (it results in higher assessments of effects than assuming a deeper groundwater level). Further investigations at detailed design stage could identify a lower regional groundwater level, but are unlikely to identify a higher one.

4.10 The Manukau Lowlands in the Southern Zone are characterised by complex inter-bedded sequences of deposits, most below sea level. The interconnectivity of groundwater in these sequences is expected to be complex, reflecting deposition of disparate materials. Piezometers show that groundwater levels in the materials broadly match sea level. The potential presence of major faults within the ECBF in this area raises the possibility of compartmentalised groundwater systems however, monitoring to date does not identify any significant head differential across the potential fault zone. The location of these faults is speculative. The Kaawa Formation forms a locally significant aquifer in this area. Watercare are the only known users in this vicinity, drawing groundwater from this aquifer from its bores at the Mangere WWTP some 1km from the alignment. The construction methodologies developed for the Project specifically consider the groundwater use from this aquifer to minimise the potential for any effect on supply during construction.

4.11 In summary, our investigations have confirmed that the tunnel excavation will be below regional groundwater level along the entire length of the main tunnel and Link Sewers 1, 2 and 3. For the assessments presented here, and described in detail in the Groundwater and Surface Settlement Report, the groundwater systems in the ECBF and overlaying materials are assumed to be directly connected with groundwater level close to surface level. This means that groundwater effects that occur in the ECBF as a result of tunnelling are assumed to propagate over time into the overlying materials to varying extents depending on the distribution of the material at any location and its properties.

4.12 It is the magnitude of groundwater effects that propagate into the materials overlying the ECBF that are most likely to contribute to the development of surface settlement. In the following sections I describe how computer modelling was carried out to assess the extent that the effects might propagate into the overlying materials, and the settlement that might arise as a result.

5. EFFECT OF TUNNELS AND SHAFTS ON GROUNDWATER AND SURFACE SETTLEMENT

Introduction

5.1 Settlement can be caused by drawdown of the local groundwater level resulting in consolidation of soils and rock (settlement caused by groundwater levels "dropping"), or by the relaxation of the ground around the tunnel and shafts in response to the excavation process (called "mechanical settlement").

5.2 The following sections discuss how modelling was carried out to assess the range of potential groundwater responses along the Project alignment. Mechanical settlement is addressed later in this section.

5.3 The potential effect of tunnel and shaft construction on groundwater and surface settlement has been estimated with computer modelling taking into account the range of ground and groundwater conditions expected along the alignment as described above.

5.4 The modelling work has been guided by experience gained through similar modelling work that I undertook for Project Hobson and the Rosedale Project. The approach to modelling has been to adopt two dimensional seepage models using the software package SEEP/W.[1] The results from the seepage modelling were then used directly to assess the potential settlement associated with the groundwater changes using the software package SIGMA/W.[2] The models were set up to represent the various representative geological cross-sections that are discussed earlier in my evidence.

5.5 The models were first used to investigate the potential effects of tunnel construction when using methodologies that do not provide for any specific measures to control groundwater effects. The groundwater response and resulting settlement estimates obtained in these models represent the basic settlement hazard that exists due to the combination of geology, material properties, groundwater conditions and tunnel size and depth characteristics. The settlement estimates obtained in these analyses are termed "unmitigated settlements."

5.6 The models were then used to assess the settlements that might arise when the construction methodology proposed by Watercare is implemented, to provide a basis for assessing the extent to which the methodology addresses the settlement hazards associated with the geology and groundwater combinations identified in the unmitigated settlement assessment. The settlement estimates obtained in the analyses that assume the intended construction methodology are termed "mitigated settlements."

5.7 In each case, sensitivity analyses were also carried out to investigate localised variability away from the expected geological conditions so that construction methodologies and contingency plans can consider these potential effects. As an example, models specifically considered the

1 GeoSlope International Ltd, 1991 – 2012.
2 GeoSlope International Ltd, 1991 – 2012.

potential effects associated with encountering high permeability Parnell Grit in the tunnel excavation.

5.8 The unmitigated and mitigated settlement estimates were compared to typically acceptable settlement limits (described in the next section of my evidence) to identify where the mitigation measures included in the proposed construction methodology were necessary to control effects to acceptable levels.

5.9 The locations and conditions that require the mitigation measures to control effects to acceptable levels identify zones where construction monitoring is required to confirm that the mitigation measures are effective and that they have controlled settlement to acceptable levels. Outside of those areas, in the areas where the unmitigated settlements are within acceptable levels, construction monitoring is required to confirm that effects remain within acceptable levels during construction, or to identify where additional mitigation measures (such as use of the Earth Pressure Balance ("**EPB")** capability of the Tunnel Boring Machine ("**TBM"**) are required to control effects that are developing away from pre-construction expectations.

Surface Settlement Summary

5.10 In Auckland, structures and buildings founded on the ground surface (such as residential buildings) are often subject to ground movement arising from seasonal soil moisture changes. Measurements of 20mm of vertical movement between seasons are not uncommon in much of Auckland. AS 2870: 2011 "Residential Slabs and Footing" provides guidance for allowance for ground movements in design of foundations for residential buildings. For Tauranga Group soils, and Residual ECBF soils, such as those found on parts of the tunnel alignment, AS 2870: 2011 indicates that surface movements of up to 70mm should be considered in design.

5.11 In addition to these seasonal movements, some limited additional settlement of the ground surface is expected as a direct result of groundwater level changes about the tunnel and shafts during construction. The magnitude and extent of settlement is directly related to the magnitude and extent of groundwater effects induced and to the characteristics of the geology affected. Based on experience on Vector tunnel, Rosedale and Project Hobson, settlement is expected to be of a similar magnitude to ground movement associated with seasonal soil moisture changes.

5.12 The nature of the construction induced settlement may be:

(a) Imperceptible (i.e. settlement is within measurement error for survey methods or is masked by seasonal surface movements due to near surface soil moisture changes);

(b) Measureable, but uniform over large areas (where the effects of groundwater changes are spread over a wide area within uniform geology); or

(c) Measureable, but locally variable (where changes in groundwater response occur over short distances, or where locally highly variable geology is affected by groundwater changes).

5.13 From experience and monitoring on the Vector, Rosedale Project and Project Hobson tunnels, it is clear that the magnitude of settlement that typically occurs is of a similar magnitude to that occurring seasonally as a result of soil moisture changes, with settlement typically manifesting as type (a).

5.14 In all cases, the potential for surface settlement to result in damage to structures depends primarily on the differential settlement (type (c) settlement), rather than the total settlement, and the form of the buildings construction. For example, brick buildings will be more sensitive to ground settlement than timber structures, and a building that settles at a different amount across its footprint will be more affected than a building that settles a larger, but an equal amount across its footprint.

5.15 Damage occurs to structures only when surface settlement results in distortion of the structure. The greatest distortion hazard from settlement arising from groundwater level change is at the points of maximum trough curvature in the case of both tunnels and shafts. Elsewhere settlements may result in tilting rather than distortion with lower potential for structural damage (although excessive tilting can result in loss of serviceability) as shown in **Figure 1** below.

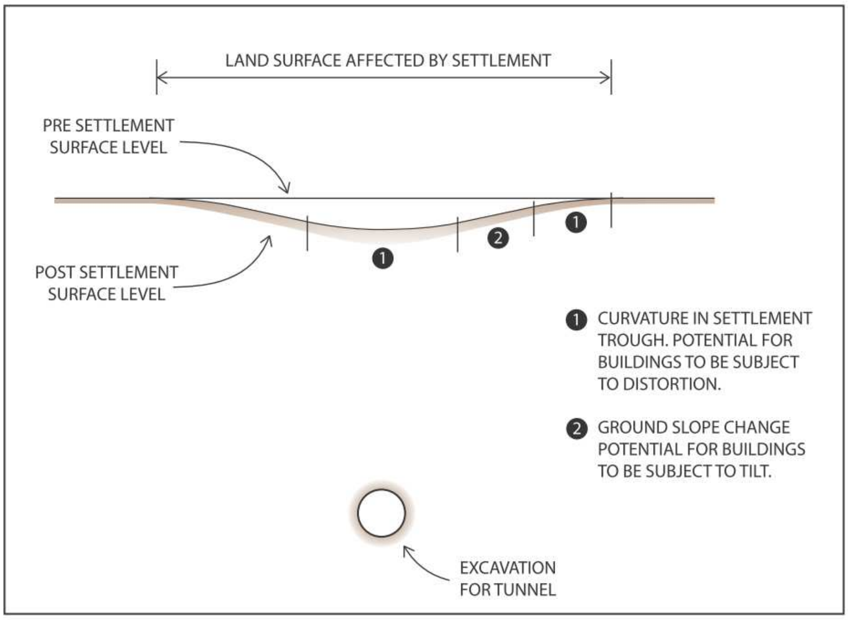

Figure 1 - Typical shape of any settlement trough above tunnel excavations. Note that the figure is not to scale, and the settlement trough is exaggerated for clarity.

5.16 Guidance on settlement tolerances for buildings in general is provided in the NZ building code in Appendix B B1/VM4, clause B1.0.2. This clause states that "Foundation design should limit the probable maximum differential settlement over a horizontal distance of 6m to no more than 25mm…..unless the structure is specifically designed to prevent damage under a greater settlement". This effectively sets a guidance limit of approximately 1:240 differential settlements.

5.17 Further guidance on the tolerance of specific building types and/or uses to differential settlement suggests that to protect against aesthetic damage to some residential buildings, and to ensure functionality of machinery in an industrial situation, differential settlements should be limited to 1:500 – 1:750.[3]

5.18 It is noted that lesser levels of differential settlement may affect some sensitive structures or less well constructed structures that have undergone some distortion already, potentially as a result of seasonal movements. A differential settlement limit of 1:1,000 (combined with a maximum total settlement limit of 50mm) has been successfully applied in a wide range of projects as a conservative basis for limiting the potential

[3] Bjerrum, L., "Allowable settlement of structures." Proc. 3rd European Conference on Soil Mechanics & Foundation Engineering, 1963.".

for damage to structures, and this approach is taken in Watercare's Proposed Conditions.

5.19 The details of the modelling work undertaken are presented in the Groundwater and Surface Settlement Report. In the following sections I summarise the key information presented in that report and the key findings of the modelling work.

Settlement associated with construction of tunnels

5.20 Settlement can be caused by drawdown of the local groundwater level resulting in consolidation of soils and rock (settlement caused by groundwater levels "dropping"), or by the relaxation of the ground around the tunnel and shafts in response to the excavation process (called "mechanical settlement"). The results of the analyses that estimate settlement associated with these two causes are considered below.

During Construction

<u>Settlement associated with ground loss</u>

5.21 Watercare's Principal Engineering Advisors assessed the potential for ground loss, or mechanical settlement, as a result of tunnel excavation. This settlement arises as the size of the hole excavated for the tunnel is often slightly larger than the tunnel lining, and as a result of the ground around the excavation relaxing into the tunnel void, until it contacts the liner.

5.22 Where the tunnel is excavated in ECBF (the majority of the alignment), the potential component of surface settlement arising from mechanical settlement was assessed by Watercare's Principal Engineering Advisors to be 1 – 6mm.

5.23 For excavation in the Kaawa Formation (the Southern Zone, from the Kiwi Esplanade site to Mangere WWTP) the assessment of mechanical settlement was up to 10mm – 20mm.

<u>Settlement associated with groundwater effects</u>

5.24 Tunnel excavation reduces groundwater pressures in the material immediately surrounding the excavation. This reduction in groundwater pressure leads to groundwater flow towards the excavation and an associated redistribution of groundwater pressures in the surrounding rock-mass. Initially this effect is limited to the rock-mass close to the excavation face. With time this effect radiates out from the excavation until an equilibrium steady state is achieved. The volume of flow to the tunnel and the extent and rate of drawdown of groundwater level in the rock is a function of hydrogeological conditions, the rock mass properties, the availability of groundwater to recharge the rock mass and the time taken for the liner to be installed. Where compressible material overlies the rock mass and is affected by the groundwater level changes, compression results and ultimately some surface settlement may result. Settlement estimates prepared for these conditions are the unmitigated settlements.

5.25 Construction methodology and construction activities subsequent to excavation influence the extent of groundwater level effects and the associated potential for surface settlement. Construction of a very low permeability tunnel lining significantly reduces (essentially halts) the groundwater flow into the tunnel void. As the tunnel face advances, groundwater pressures around the lined section of the tunnel behind the excavation will begin to recover and groundwater levels will also begin to recover. A consideration for tunnel construction is determining an acceptable delay between excavation and installation of the liner. This is a key issue and mitigation measure for construction planning, particularly in areas where geology is susceptible to settlement.

5.26 As set out in the evidence of Mr Cantrell and Mr Cooper, the Central Interceptor tunnel and Link Sewer 3 will be constructed using an EPB TBM. The TBM combines the activities of excavation, spoil removal, and placement of tunnel liner into one continuous operation to provide significant control in surface settlement as was demonstrated on the Rosedale Project and Project Hobson discussed earlier.

5.27 This methodology provides direct mitigation of groundwater effects because it:

(a) constructs a substantially water tight lining soon after tunnel excavation limiting the magnitude of groundwater effects that develop and allowing the groundwater to recover rapidly after excavation; and

(b) provides the capacity for pressure to be applied to the excavated face of the tunnel to balance ground and or groundwater pressures during excavation to reduce the magnitude of groundwater effects and mechanical settlement.

5.28 The TBM supports the ground until the permanent liner can be installed. The potential for groundwater effects to develop is chiefly, then for the short period as the TBM passes. Typically there is approximately a 1 – 2 day period between excavation at the face at the front of the machine, the installation of the tunnel liner at the rear of the machine and grouting up around the liner to form a substantially watertight tunnel. Once the tunnel is substantially watertight, the potential for groundwater effects reduces significantly and groundwater levels typically start to recover. This type of equipment has been successfully employed on the Rosedale Project and Project Hobson. On these projects, the observed groundwater effects as a result of tunnel excavations in the ECBF rock were as expected. Settlement of the surface as a result of these groundwater effects was however very small as highlighted earlier in my evidence.

5.29 Face pressure can be applied by the TBM to stabilise the excavation face in soft ground, or in cohesionless ground that has the potential to flow due to presence of groundwater. As explained by Mr Cooper, this is the purpose of the EPB capability of the TBM. This face pressure allows the TBM to directly reduce the potential surface settlement associated with mechanical settlement. Face pressure can also be applied to balance or partially balance groundwater level to prevent or reduce groundwater flows into the excavated face and to minimise surface settlement that could result from groundwater effects. As described in Mr Cooper's evidence, when face pressure is applied during tunnelling, operations are usually slower, more stressful on the machine, and use more soil conditioners. Settlement estimates were therefore prepared on assumption that the EPB capability would generally not be employed and instead only allowed only for the rapid lining capability. These are the mitigated settlements. Consideration of the EPB capability is only made when it is identified as necessary by the mitigated settlement estimates and as a contingency measure during construction to respond to settlement that is developing at a rate and a magnitude above that expected.

5.30 Mr Cooper has described the micro tunnelling operations that will be used to construct the much shorter Link Sewers 1 and 2. This method differs from that of the main tunnel and Link Sewer 3 in that the lining and advance of the machine is achieved using precast pipe units inserted from the launch shaft behind the machine. The methodology will provide a similar capacity to rapidly line the tunnel after excavation, to provide positive support to counter groundwater inflow and to control mechanical settlement effects when required. In the rest of my evidence I do not differentiate between the technical details of the equipment.

5.31 For much of the route (the Northern and Central Zones) the tunnel will be excavated in ECBF Rock. Experience from previous tunnelling projects in Auckland, and modelling carried out for this Project, indicates that when excavated in ECBF rock, it takes some time for groundwater effects to propagate out of the ECBF and into overlying materials, and little effect is expected on overall near surface groundwater levels after one month to a year of excavation. Observations from Vector tunnel in particular and modelling indicate that groundwater levels in Basalt surface aquifers are not impacted by tunnel excavation in the ECBF, even when tunnel lining is delayed by over a year (as it was for the Vector tunnel). Estimates of unmitigated settlement in these zones from modelling work indicate that a maximum of 30mm of unmitigated settlement could be expected one month after excavation and up to 70mm after one year. When the intended construction methodology is considered and the lining of the tunnel within 1 - 2 days is included in analyses, a maximum mitigated settlement of less than 20mm is estimated in these two zones. Watercare's Principal Engineering Advisors estimate that mechanical settlement of an additional 1 - 6 mm could occur in these areas. In both unmitigated and mitigated cases, low differential settlement is estimated. In these zones construction of the tunnel lining within 1-2 days is not necessary to control settlement effects to within normally acceptable levels. As the construction methodology provides this in any case, there is a high level of control on groundwater and settlement effects.

5.32 In the Southern Zone, and where the tunnel is excavated in Kaawa formation, groundwater level effects are expected to develop more rapidly than in the Northern and Central Zones, with the potential for significant groundwater level drawdown in surface deposits to develop within a month if a lining is not installed. Estimates of unmitigated settlement in these conditions indicate that some 70mm of settlement could be expected within a month of excavation. When the intended construction methodology is considered, and the lining of the tunnel within 1-2 days is included in analyses, a maximum mitigated settlement of less than 50mm is estimated. Watercare's Principal Engineering Advisors estimate that mechanical settlement of an additional 10-20mm could occur in this area. Clearly the maximum unmitigated and mitigated settlement exceeds acceptable levels in this zone.

5.33 Mr Cooper has described, however, that the TBM would use its EPB capability through this section, and as a result, settlement arising from groundwater effects is expected to be controlled in practice to less than 10 - 20mm and mechanical settlement to 10mm or less (and to very low differential settlement). With this level of mitigation, maximum settlements are expected to be controlled to within acceptable levels in this zone.

5.34 The combined mitigation measure of tunnel lining within 1-2 days and use of EPB face pressure is also expected to be sufficient to limit groundwater level effects so that users of groundwater from the Kaawa aquifer identified earlier in my evidence are also not expected to be affected.

5.35 In those areas where rapid tunnel lining is not necessary to control groundwater and settlement effects, alternatives to the EPB TBM are theoretically possible methodologies. This was demonstrated on the Vector tunnel where no adverse effects were associated with measured groundwater response to tunnel excavation, and construction of the tunnel liner was delayed in some sections by 12 – 18 months. While this is not the current intention of Watercare overall, short sections of connecting tunnels may not be lined immediately, unless required. Flexibility is recommended in the Proposed Consent Conditions to enable the contractor to determine the most appropriate construction methodology or methodologies while managing risk.

Following Construction

5.36 If a leaky liner is constructed, seepage into the completed tunnel may result in on-going groundwater level reduction of the material around the tunnel, which in turn could result in long term development of surface settlement. The modelling carried out and long term monitoring data from the Vector tunnel project shows that the very low permeability liner proposed for the tunnel will mitigate this potential.

5.37 In the operating tunnel, and in typical flow situations (tunnel flowing partially full), internal tunnel pressure will be at or near to local atmospheric pressure, significantly lower than external groundwater pressure. While the tunnel liner will be engineered to reduce seepage to an absolute minimum, if there is any seepage it will be groundwater leaking into the tunnel, not effluent leaking out. In these conditions it is very unlikely that the quality of groundwater surrounding the tunnel would be influenced by the flows in the tunnel.

Settlement associated with groundwater response to shafts

During Construction

5.38 The Project shafts are of varying size and depth, and will be excavated in variable ground conditions:

(a) A shaft of approximately 35m diameter and some 30m to 50m deep will be constructed at the proposed Mangere Pump Station.

(b) Shafts of approximately 25m diameter are proposed at May Road and at Western Springs, with the shaft in the order of 70m to 85m deep at May Road and 27m to 42m deep at Western Springs.

(c) More typically, there will be a number of shaft excavations in the order of 10m diameter or less along the alignment. The completed shaft diameters (permanent lined shafts) in these cases are generally smaller than the initial excavation, with the larger excavation backfilled.

5.39 As a result, no single construction methodology is proposed for shaft construction, but a number of potential techniques are available. These construction techniques have varying degrees of water tightness during construction, and hence varying effects on groundwater drawdown.

5.40 Similar to the approach for tunnels, analyses were carried out to estimate the potential settlement effects of constructing the shafts in the absence of any specific groundwater control measures. These are reported in detail in the Groundwater and Surface Settlement Report. The analyses indicated that control measures were likely to be required for the construction of shafts to minimise potential surface effects.

5.41 Mr Cooper has described the various shaft sinking methods and a detailed discussion of the technical options available is provided in the Groundwater and Surface Settlement Report. At this point it is worthwhile commenting on techniques to control groundwater effects as a brief summary of these two sources of information.

5.42 The construction techniques most effective at controlling groundwater drawdown are secant piling and diaphragm walling. In both techniques piles or diaphragm wall panels are installed prior to excavation, in an interlocking pattern to form a continuous low permeability barrier. Excavation is then undertaken inside the barrier. **Figure 2** identifies secant piling using sheet piles for construction of a shaft on the Rosedale Project.

Figure 2 - Sheet piled shaft excavation during construction for the Rosedale sewer tunnel, source - TunnelTalk.com.

5.43 Alternatively, open caisson shafts can be sunk with an open bottom and top during construction. They are usually made of reinforced concrete, or steel. This technique is similar to secant pile/diaphragm walls in so far as groundwater is excluded from the sides of the excavation as excavation proceeds.

5.44 Where shafts encounter Basalt, these methodologies are less feasible, and grout curtains could be employed to control groundwater flow into the excavations, possibly with secant piles or caissons used once excavations extend through the Basalt.

5.45 A permanent substantially watertight shaft liner will be installed after excavation, irrespective of construction methodology, to minimise groundwater inflow into the shafts and to limit groundwater level reduction in the long term.

5.46 As part of responses to section 92 information requests from the Council, specific modelling was undertaken to confirm that these construction methodologies were sufficient to control surface settlement at two key sites; Mount Albert War Memorial Reserve and Whitney Street. For shafts, the analyses included assessment of mechanical settlement, so that does not need to be added in separately – as it was for tunnels.

5.47 These sites were selected as the available geotechnical information indicated the presence of compressible materials and the risk of surface settlement, and because both are currently proposed in close proximity to surrounding buildings and so provide a good basis for assessing potential effects of settlement on buildings. The methodology used in the modelling was provided by Mr Cooper, and reflects the most likely construction methodology for these particular shafts.

5.48 The specific modelling analyses provided estimates of surface settlement resulting from shaft construction, and reflect settlement from both groundwater drawdown and from mechanical settlement during excavation.

5.49 In general terms, the maximum settlement magnitude may be expected immediately adjacent to the shaft, with settlement reducing away from the shaft. The specific modelling analyses for the two sites indicated that settlement resulting from shaft and tunnel construction will be significantly less than the levels which might cause structural damage to buildings:

(a) At the Mount Albert War Memorial Reserve site, the maximum total settlement estimated at the nearest structure was 40mm with associated differential settlement of approximately 1:2,000. This applies regardless of whether the shaft is sunk in its original location on the Reserve site or the alternative location on the Car Park site.

(b) At Whitney Street, the maximum total settlement estimated at the nearest building was 25mm with an associated differential of approximately 1:2,000.

(c) In both cases the estimates are significantly below (better than) the 1:1,000 limit for differential settlement that has historically been set on similar projects to limit the potential for damage to structures, as described in 5.3 above.

5.50 Details of the modelling set up, the specific construction stages and the analysis cases carried out are provided in the section 92 response submitted to the Council, dated March 2013.

Following Construction

5.51 The analyses indicated that the provision of a very low permeability liner in the completed shaft was sufficient to control long term groundwater effects and surface settlement (these effects are included in the above settlement estimates).

5.52 Models indicate that settlement differentials for all cases (construction cases and long term operation) are typically 1:2,000, or flatter where buildings are present above the tunnel. This is significantly flatter than the 1:1,000 limit for differential settlement that has historically been set on similar projects to limit the potential for damage to structures, as described above.

Conclusions on Settlement

5.53 In Auckland, structures and buildings founded on the ground surface (such as residential buildings) are often subject to ground movement arising from seasonal soil moisture changes.

5.54 In addition to these seasonal movements, some limited additional settlement of the ground surface is expected as a direct result of groundwater level changes about the tunnel and shafts during construction. The magnitude and extent of settlement is directly related to the magnitude and extent of groundwater effects induced, and to the characteristics of the geology affected.

5.55 For tunnel construction, analyses have identified that ground and groundwater conditions in the Southern Zone in particular have the potential to result in unacceptable surface settlements from tunnelling activities if specific construction methodologies are not employed to control them. In the Northern and Central Zone, conditions are much more favourable, and specific control measures are not as necessary.

5.56 As set out in the evidence of Mr Cantrell and Mr Cooper, the Central Interceptor tunnel will be constructed using an EPB TBM. The TBM combines the activities of excavation, spoil removal and placement of tunnel liner into one continuous operation and provides the control on groundwater effects that is required to control settlements in the Southern Zone. The equipment would be employed on the entire route, and therefore provides significant control on settlement in all zones. As a result the tunnel excavations are expected to be completed with surface settlements in all areas within acceptable levels, as was achieved with similar construction methodologies on the Rosedale Project and Project Hobson tunnels.

5.57 While a single methodology will be employed for tunnels, the Project shafts are of varying size and depth, and will be excavated in variable ground conditions. As a result, no single construction methodology is proposed for shaft construction. A number of potential techniques are available.

5.58 Similar to the approach for tunnels, analyses were carried out to estimate the potential settlement effects of constructing the shafts in the absence of any specific groundwater control measures. The analyses indicated that control measures were likely to be required for the construction of shafts to minimise potential surface effects.

5.59 Mr Cooper has described the various shaft sinking methods and provided a detailed discussion of the technical options available. Models reflecting these methodologies provide estimates of potential surface settlement at two of the shaft sites, selected as they had ground conditions that were prone to settlement, and had buildings nearby.

5.60 The models confirmed that construction methodologies are available that provide sufficient control on surface settlements effects such that nearby buildings are not subject to unacceptable surface settlements.

5.61 The results of the settlement analyses provide a high degree of confidence, backed up by recent experience on the Rosedale Project and Project Hobson, that the Project can be constructed in a way that does not create unacceptable surface settlement effects.

6. MONITORING AND CONTINGENCY PLANNING

6.1 The hydrogeological modelling and settlement assessment identifies that the tunnel and shafts can be constructed in a manner such that surface settlement would not be expected to result in damage to buildings. However, in projects of this type there always remains a level of variability in ground conditions and resulting behaviour. It is never possible to carry out sufficient ground investigations or construction planning to completely address this uncertainty. A carefully planned and executed programme of monitoring and contingent actions is required to respond to unexpected results should they be observed.

6.2 This uncertainty was managed on the Rosedale Project and Project Hobson by monitoring and contingency planning that tracked effects as they developed during construction. The same approach is intended to be adopted for this Project.

6.3 The purpose of the monitoring programme is to provide advance warning of the potential for settlement levels to vary from those estimated in pre-construction assessments. The advanced warning provides the basis for construction activities to be modified to take account of the variation, and limit further settlement to within the consented limits. An example of how construction activities could be modified would be to move to operating the TBM in EPB mode as an additional control on settlement.

6.4 While both groundwater and surface levels should be subjects of the monitoring programme, it is changes in surface levels (settlement) that is of most importance for protecting public and private property from potential adverse effects associated with construction.

6.5 Construction groundwater responses may vary significantly from those estimated by pre-construction models, but provided the settlement resulting is within tolerable (and consented) limits then this variance is not necessarily a reason to interrupt construction. As noted earlier in this evidence, it can take a significant amount of time for groundwater changes within ECBF to propagate into overlying materials and then for settlement to occur.

6.6 The recommended approach for monitoring and responding to groundwater and surface level changes is to set in place a programme for monitoring groundwater and surface settlement around the works coupled with action trigger levels. The monitoring programme is linked to the construction programme and the estimated settlement hazard associated with construction. In areas where the settlement hazard is estimated to be low (such as in low compressibility geology like ECBF) monitoring locations would be more widely spaced than in areas where settlement hazard is estimated to be higher, (such as where tunnelling passes beneath compressible deposits). Similarly, monitoring networks would be denser in built up areas, and more dispersed in undeveloped areas, such as Ambury Park. The timing of recording will vary to match the progress of the works in that area.

6.7 Triggers would be set such that additional monitoring (frequency and/or locations) might be required in the event that alert levels (levels set to reflect expected behaviour) are approached. In the event such alert levels were reached, additional modelling/estimates would be prepared to confirm that alarm levels (levels set to reflect Proposed Consent Conditions) are not expected to be threatened despite variance from expected behaviour. Mitigation measures would be provided that could be implemented in the event that alarm levels were threatened. Other controls, such as changing the construction methodology, can also be implemented to keep effects within agreed limits. This approach has been successfully applied on many other tunnelling projects and groundwater drawdown projects in Auckland.

6.8 For groundwater and surface level monitoring, a clear understanding of background seasonal behaviour and survey repeatability is of key importance in interpreting the response of monitoring installations during the construction period. This can be achieved from baseline monitoring records that extend for at least 12 months, and preferably 24 months, prior to commencement of construction activities. The piezometers installed during the investigation phases for this Project have already provided some of this baseline data.

6.9 The detail of how the monitoring layout is to be designed, installed and managed would be set out in a monitoring plan developed prior to works commencing and updated as the works are progressed. This would be combined with a contingency plan, which details the processes of data and predictive model review, as well as outlining actions to be undertaken in the event that corrective action is required.

6.10 The monitoring and contingency plan will enable the settlement risks associated with tunnelling and shaft excavation to be managed and ensure that any effects are not more than minor. Further, the plan would be subject to regular review and updating as required following analysis of the monitoring results.

6.11 It is my opinion that Watercare's Proposed Conditions, discussed below, describing the plan, are appropriate to achieve these objectives.

7. RESPONSE TO SUBMISSIONS

7.1 I address concerns raised by submitters where they are relevant to my area of expertise and evidence. These are addressed by topic, where the concern is shared by more than one submitter, or by submitter.

7.2 A key issue for many submitters is the potential for the shaft and tunnel construction works to result in damage to houses and buildings through ground surface settlement[4] and the locations associated with these submissions are identified in **Appendix B**.

7.3 In Section 6 I noted that in the Northern and Central Zones there is a negligible risk of damage to buildings and structures as a result of tunnel and shaft construction and long term operation, based on experience from past tunnel construction projects (Vector tunnel, the Rosedale Project tunnel and the Project Hobson tunnel) and from analyses specifically carried out for this Project. The groundwater control measures that will be implemented during construction (installation of the tunnel liner typically within 1 - 2 days of excavation) provide a high level

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[4] This is the case for; Anne and Robin Boyd of 15 Wairere Avenue, Melanie Sannum as secretary for the Body Corporate of 63 Asquith Avenue, Toby Curnow and Helen Hume of 25 Wairere Avenue, St Lukes Gardens Apartments Body Corporate at Morning Star Place (all within the Northern Zone of the alignment,) Foodstuffs Auckland Limited at Roma Road and May Road, Moi Moi Ong for 51 Marion Avenue (both near the boundary between the Northern and Central Zones) Paula and Maria Puertollano of 47a Arundel Street (within the Central Zone), St Lukes Environmental Protection Society and St Lukes Garden Apartments Progressive Society Incorporated.

of control on potential surface settlement effects. The additional control measure (EPB capability) ensures that a high level of control is available, if it is required, to mitigate unexpected settlement if it develops during excavation.

7.4 In Section 5 I outlined some of the potential methodologies that could be employed for shaft construction, and discussed specific analyses undertaken to confirm the settlement effects associated with these methodologies. The analyses confirmed that the shafts can be expected to be constructed without damage to nearby buildings and structures associated with surface settlement effects.

7.5 In Section 6 I noted that, in projects of this type, there always remains a level of variability in ground conditions and resulting behaviour. It is never possible to carry out sufficient ground investigations or construction planning to address all uncertainty. A carefully planned and executed programme of monitoring and contingent actions is required to respond to unexpected results should they be observed.

7.6 As discussed in Section 9 below, Watercare's Proposed Conditions provide for such a plan and set limits on settlement at a maximum settlement of 50mm, and differential of 1:1,000. These limits have been demonstrated to be sufficient to protect buildings from damage in past tunnel construction projects (Vector tunnel, the Rosedale Project and Project Hobson).

7.7 Based on the work I have undertaken, and considering Watercare's Proposed Conditions, I believe that the effects of tunnel and shaft construction can be managed such that there is a negligible risk of damage to buildings arising from surface settlement effects.

Transpower

7.8 Transpower lodged a submission in respect of their regionally important power supply infrastructure located near the alignment. In particular, Transpower is concerned about the potential effects on the structural integrity of the support structures resulting from excavations, and Watercare's ability to undertake construction in accordance with the NZECP 34:2001 New Zealand Code of Practice for Electrical Safe Distances and the National Policy Statement on Electricity Transmission.

7.9 We have carried out some additional specific work to respond to this submission. Transpower were provided with estimates of surface settlement associated with tunnel and shaft construction for each of its assets in close vicinity to the Project works. The estimates identified that 10-25mm of settlement could be expected at towers close to the alignment, and up to 20mm at two substation buildings. The settlement could impose an additional differential across the tower and structure foundations of approximately 1:5,000.

7.10 Mr Cooper has advised that construction works can be undertaken in accordance with the NZECP 34:2001 New Zealand Code of Practice for Electrical Safe Distances, and can be managed through the Construction Management Plans ("**CMP**") to ensure the design and works are undertaken in accordance with best practice.

7.11 On this basis, I am satisfied that the potential effects of construction on Transpower's assets can be appropriately managed and/or mitigated.

St Lukes Environmental Protection Society

7.12 A potential issue identified by St Lukes Environmental Protection Society is that groundwater effects associated with the Project may lead to reduced base flow in watercourses.

7.13 In parts of a watercourse, stream base flow is supported by seepage of groundwater from near surface materials into the stream. If groundwater levels near the stream were temporarily or permanently lowered, this seepage could be affected.

7.14 Experience from the Vector tunnel, the Rosedale Project and Project Hobson and the results of modelling for this Project indicate that near groundwater in the near surface soils is not likely to be affected by the construction of the tunnel. On this basis, any stream base flow supported from groundwater seepage from near surface groundwater is also not likely to be affected.

7.15 The construction of shafts has the potential to directly impact groundwater levels in the surface deposits as it requires excavation through them.

7.16 Construction methodologies for shaft construction will be required to be designed to minimise groundwater seepage to negligible levels to control surface settlement to acceptable levels. These controls however have the secondary effect that by reducing groundwater inflows to the shaft to negligible levels, the effect on groundwater levels in surface deposits near the shaft are also negligible.

7.17 On this basis, I consider that there is a very low risk of any impact on stream base flows associated with groundwater effects arising from shaft and tunnel construction by methodologies described in my evidence.

8. RESPONSE TO COUNCIL PRE-HEARING REPORT

8.1 I have reviewed the Council Pre-hearing Report as it relates to groundwater and settlement issues, and am satisfied that Council's assessments are appropriate.

8.2 In relation to the tunnel alignment itself, the Pre-hearing Report agrees with my conclusion that the tunnel is able to be constructed without resulting in adverse groundwater or land settlement effects.[5]

8.3 In terms of the construction sites, I am largely satisfied with the conditions proposed in the Pre-hearing Report, subject to the amendments I set out below.

8.4 I concur with the conclusion of the Council's reviewers, Mr Hazard and Mr Nelson that, provided the works are undertaken in accordance with the conditions proposed, and subject to the amendments I have recommended below, the potential adverse effects of the activity in relation to groundwater and surface settlement are considered to be no more than minor.[6] The Pre-hearing Report concludes that:[7]

> The operation of the take and divert permit will not have any detrimental effects on any other groundwater users or on the groundwater resource as a whole. Potential settlement induced by groundwater level drawdown will be managed within acceptable limits and is therefore not likely to cause any damage to surrounding buildings, structures and services. Overall any

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5 Hearing Report for Notices of Requirement under Section 168 of the Resource Management Act 1991 and Applications for Resource Consent under Section 88 by Watercare Services Limited - Central Interceptor Project, Auckland (27 June 2013) ("**Pre-hearing Report**"), Page 75.

6 Pre-hearing Report, Page 107.

7 Pre-hearing Report, Page 107.

> adverse effects of the proposed works in terms of groundwater and settlement are considered to be no more than minor.

8.5 In terms of the general approach proposed, I would also like to highlight the conclusion of the Pre-hearing Report that:[8]

> In terms of those sites notes as being subject to potential instability a more detailed design stage following the grant of consent is considered generally appropriate, having regard to the successful implementation of three other significant tunnelling projects within the Isthmus.

8.6 I agree.

9. PROPOSED CONDITIONS

9.1 In general, I am largely satisfied with the conditions proposed in the Pre-hearing Report, subject to the amendments I set out below.

Monitoring and Contingency Plan.

9.2 The requirement to prepare a Monitoring and Contingency Plan ("**M&CP**") before commencement of shaft sinking or tunnelling, as well as the contents of the M&CP, is set out in Proposed Consent Conditions 4.5 to 4.8.

9.3 Proposed Consent Condition 4.6 requires the Manager to approve the M&CP at least 10 days prior to Commencement of Dewatering. I support this requirement. However, I consider that the following further addition could usefully be made to the condition:

> <u>Aspects of the M&CP dealing with pre-construction monitoring shall be submitted to the Manager for written approval (such approval not to be unreasonably withheld) at least 12 months prior to the Commencement of Dewatering for shaft sinking or tunnelling.</u>

9.4 I recommend that Proposed Consent Condition 4.6 be amended to include the statement above, so that the details of groundwater and surface settlement monitoring networks can be approved by the Manager in advance of the 12 month period of baseline monitoring required by the Proposed Consent Conditions (4.20 and 4.28).

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8 Pre-hearing Report, Page 106.

Pre-construction Condition Survey

9.5 The Council has proposed a condition (Proposed Consent Condition 4.12) that I do not consider to be necessary. The proposed condition reads:

> Where neighbouring building/property owners indicate the presence of particularly sensitive structures (examples include old or brittle structures, vibration sensitive equipment, unusually heavy loads or settlement sensitive machinery) a full engineering assessment shall be undertaken to determine what, if any, additional avoidance, design, remedial or monitoring works are required in this vicinity. The Consent Holder shall use best endeavours to complete work to the satisfaction of the building owner.

9.6 In my view this is appropriately covered off in Proposed Consent Conditions 4.2 and 4.11 in relation to settlement.

9.7 For a tunnel project, the concept of "neighbouring building/property owners" is difficult to define, and provides the opportunity for the consent holder to be required to undertake full engineering assessments on an undefined number of properties at the behest of the property owner, resulting in potential for considerable additional cost to the Project.

9.8 The requirement of a full engineering assessment as the only method of addressing the owner's issues limits the opportunity to remedy the potential issues in other ways, such as through agreements to make good if damage actually does occur and ultimately through the processes defined in Proposed Consent Condition 4.17.

9.9 That uncertainty aside, the intention of Proposed Consent Condition 4.12 is already embedded in Proposed Consent Condition 4.11, which requires the consent holder to consult with the owners of existing buildings as part of the risk assessment process and to undertake a building inspection to assist in assessing the allowable magnitude of ground settlement effects. The risk assessment process is defined in Proposed Consent Condition 4.9 and requires the consent holder to undertake a risk assessment to identify existing buildings and structures at risk of damage due to settlement caused by shaft sinking or tunnelling activities.

9.10 Proposed Consent Condition 4.2 requires the Consent Holder to ensure that the works are designed and constructed so as to avoid as far as practicable any damage to existing buildings, structures and services, and this includes those buildings identified in the risk assessment.

9.11 In my opinion, the combination of Proposed Consent Conditions 4.2, 4.9 and 4.11 appropriately addresses the intention of Proposed Consent Condition 4.12, and the separate vibration issues will be addressed through the Construction Noise and Vibration Management Plan. I therefore recommend the deletion of Proposed Consent Condition 4.12.

Post-construction Condition Surveys

9.12 I support the inclusion of the proposed advisory note clarifying what the "Completion of Dewatering" means in relation to the operation of the conditions. I do, however, consider that the advisory note would benefit from further amendment, as follows (additions in underline, deletions in ~~strikethrough~~):

> Note: 'Completion of Dewatering' means when all the shaft lining, base slab and walls are complete and the tunnel lining is complete ~~essentially watertight, the structures internal support mechanisms have been completed~~ and effectively no further groundwater is being taken for the construction of the shaft/tunnel.

9.13 The original text defines "Completion of Dewatering" as occurring when all the tunnel and shaft linings are "essentially watertight". The degree to which, in particular, the lining of all shafts are required to be "essentially watertight" will be the subject of more detailed design stages following grant of consent. That stage may identify that different degrees of water tightness are required at each of the shaft sites to sufficiently control effects. The wording above has been proposed to reflect this, and allow for this in the consent so that all shaft linings are not arbitrarily required to be "essentially watertight". I recommend this advice note be amended as shown above.

Groundwater Monitoring

9.14 The requirements for groundwater monitoring are set out in Proposed Consent Conditions 4.18 to 4.25. On the whole, I am supportive of the intent of the conditions.

9.15 The wording in Proposed Consent Condition 4.18 regarding new monitoring bores is acceptable, although I consider that "drilled" should be amended to "installed" as a minor change for technical correctness. A hole is drilled, into which the monitoring equipment is installed.

9.16 The Council has proposed Consent Condition 4.25 as follows:

> Construction methodology shall ensure that following the Completion of Dewatering groundwater levels will not significantly change from pre-construction groundwater levels or exceed trigger levels established as part of this consent.

9.17 I do not agree that this condition is necessary. In my view Proposed Consent Condition 4.2 already adequately covers this.

9.18 The wording of 4.25 requires that, once construction is complete, groundwater levels shall not change from those measured prior to construction. This statement overrides the findings of the technical study described in my evidence. The technical study was undertaken to identify to what extent groundwater level changes need to be controlled to ensure that effects are less than minor. That work, and the experience from the Rosedale Project, Project Hobson and the Vector project show that groundwater levels can change significantly without resulting in significant surface settlement effects or in effects on groundwater users. On this basis, Proposed Consent Condition 4.25 imposes a control that is significantly above that required to ensure that effects are less than minor, and I recommend that it be deleted.

Settlement Monitoring

9.19 Proposed Consent Condition 4.26 relates to the location of the Ground Settlement Monitoring Works. While this reflects an earlier condition Watercare suggested to Council, I have reflected on this further and consider that the following wording is more appropriate for (a) and (b) of this condition:

> The Ground Settlement Monitoring Marks shall be located generally as follows:
>
> (a) At least one mark within 5m of each of the groundwater monitoring boreholes described in Condition 4.18

(b) At locations along the alignment of the tunnels, and around each of the shafts, such that:

- The marks are more closely spaced in areas of higher settlement risk, and more widely spaced in areas of low settlement risk, these areas being identified in the risk assessment carried out under Condition 4.9;

- The marks are of sufficient number and are located such that they provide a reliable basis for assessing, monitoring and responding to settlement risk during shaft sinking and tunnelling construction work and for confirming compliance with the limits set out in Condition 4.33.

9.20 When reflecting on the consent conditions originally proposed by Watercare, it became apparent that alternative interpretations of the wording were possible that could allow for very limited settlement monitoring to be required. Such an interpretation would not be consistent with the intent of the settlement monitoring discussed in the Groundwater and Settlement Report. The wording above is proposed to ensure that the intent is captured, while allowing for the detail of the network to be defined in the CMP.

9.21 Part (c) of Proposed Consent Condition 4.26 relates to temporary shaft retaining walls. I support the requirement to install inclinometers in temporary retaining walls to measure retaining wall deformation. However, I recommend Proposed Consent Condition 4.26(c) be amended slightly as follows:

(c) At shaft locations identified in the risk assessment under Condition 4.9 as being in an area of high settlement risk, ~~S~~sufficient inclinometers shall be installed, in accordance with industry best practice, in temporary shaft retaining walls to measure retaining wall deformation. Measurement accuracy shall be to best practice.

9.22 The amendment targets the additional monitoring in those areas where risk assessments required under Condition 4.9 identify that additional surface settlement that might arise from lateral wall deflection has the potential to affect structures. The additional monitoring provides an additional opportunity to control the construction methodology to manage the effects that arise so that they are less than minor. In those areas where there are no structures that would be affected by additional settlement the amendment removes the requirement for the additional monitoring.

Summary

9.23 In general, I am largely satisfied with the conditions proposed in the Pre-hearing Report. However, there are a number of minor amendments that I recommend should be made:

(a) The following statement should be added to Proposed Consent Condition 4.6:

> Aspects of the M&CP dealing with pre-construction monitoring shall be submitted to the Manager for written approval (such approval not to be unreasonably withheld) at least 12 months prior to the Commencement of Dewatering for shaft sinking or tunnelling.

(b) Proposed Consent Condition 4.12 should be deleted.

(c) The advisory note to Proposed Condition 4.14 should be amended as follows:

> Note: 'Completion of Dewatering' means when all the shaft lining, base slab and walls are complete and the tunnel lining is complete ~~essentially watertight, the structures internal support mechanisms have been completed~~ and effectively no further groundwater is being taken for the construction of the shaft/tunnel.

(d) In Proposed Consent Condition 4.18, "drilled" should be replaced with "installed".

(e) Proposed Consent Condition 4.25 should be deleted.

(f) Proposed Consent Condition 4.26(a) and (b) should read:

> The Ground Settlement Monitoring Marks shall be located generally as follows:
>
> (a) At least one mark within 5m of each of the groundwater monitoring boreholes described in Condition 4.18;
>
> (b) At locations along the alignment of the tunnels, and around each of the shafts, such that:

- The marks are more closely spaced in areas of higher settlement risk, and more widely spaced in areas of low settlement risk, these areas being identified in the risk assessment carried out under Condition 4.9;
- The marks are of sufficient number and are located such that they provide a reliable basis for assessing, monitoring and responding to settlement risk during shaft sinking and tunnelling construction work and for confirming compliance with the limits set out in Condition 4.33.

(g) Proposed Consent Condition 4.26(c) should read:

(c) At shaft locations identified in the risk assessment under Condition 4.9 as being in an area of high settlement risk, ~~S~~sufficient inclinometers shall be installed, in accordance with industry best practice, in temporary shaft retaining walls to measure retaining wall deformation. Measurement accuracy shall be to best practice.

9.24 These amendments are included in Watercare's Proposed Conditions, as attached to the evidence of Ms Petersen.

10. OTHER MATTERS

10.1 Lastly, I'd like to draw the Commissioner's attention to a minor error in the Auckland Council document "Technical Memo – Natural Resources & Specialist Unit, 14 June 2013", provided with the Pre-hearing Report, which I now correct for the record.

10.2 In Section 2.5 "Hydrogeology", this document refers to the section 92 response submitted to the Council, dated March 2013 and states that "Total settlement, including combined effects of tunnel settlement, has be estimated at up to 60mm at the nearest house." The 60mm is incorrect. This document actually identifies that total settlement, including combined effects of tunnelling was estimated at up to 40mm at the nearest house.

11. CONCLUSIONS

11.1 Some settlement of the ground surface is expected as a direct result of groundwater level changes and mechanical settlement effects about the tunnel and shafts during construction. The magnitude and extent of settlement that might occur is directly related to the magnitude and extent of groundwater effects induced, to the characteristics of the geology affected and the construction methodology used.

11.2 Analyses have been undertaken to estimate potential groundwater effects and surface settlement effects of the tunnels and shafts based on a range of geological and hydro-geological conditions and for a range of potential construction techniques.

11.3 The analyses can be considered as relatively conservative (over) estimates of settlement, by comparison with observed performance of tunnelling and other relevant projects in Auckland.

11.4 The assessments consider the shallowest tunnel alignment possible within the corridor for which consent is sought. The shallowest alignment would be expected to provide higher surface effects associated with tunnels than a deeper alignment and to be representative of effects for deeper shafts. The assessments of settlement undertaken are not expected to be sensitive to the final location of the tunnel within the tunnel corridor.

11.5 The upper bound for potential surface settlement along the route has been estimated by considering routine construction methodologies (for shafts and tunnels) that do not specifically control groundwater effects. This unmitigated settlement hazard varies along the route, depending on the local hydro-geological conditions, and is estimated to be generally up to approximately 70mm, but locally higher. The design and construction methodology for shafts and tunnels will need to specifically consider this hazard, and ensure that measures provide for control of the settlement to acceptable levels.

11.6 Experience from past projects (Vector tunnel, Project Hobson and the Rosedale Project) indicates that there are practical construction methodologies available that have been used successfully to address similar issues.

11.7 As set out in the evidence of Mr Cantrell and Mr Cooper, Watercare intends to construct the main tunnel and Link Sewer 3 with an EPB capable TBM (as successfully used on the recent Project Hobson and Rosedale). Link Sewers 1 and 2 could be constructed using an EPB capable machine or a slurry machine, as has been successfully used on the South Western interceptor in 2011 and Hunua 4 under SH1 in 2013.

11.8 Modelling indicates that for the intended tunnel construction methodology, maximum surface settlement from groundwater drawdown and mechanical settlement is expected to be in the order of 15-25mm in most geology, and differential settlement is expected to be typically flatter than 1:2,000, and primarily controlled to these levels by the installation of the tunnel liner immediately behind the TBM equipment. In the Southern Zone in particular, the TBM is expected to also employ its EPB capability to limit maximum settlement to in the order of 30mm.

11.9 Analyses of shafts indicate they can be constructed without damage to nearby buildings or structures. Expected maximum settlement is in the order of 40mm, with maximum differential settlement in the order of 1:2,000.

11.10 Seepage outflows from the tunnel to surrounding groundwater are not expected, due to the high external groundwater pressure and the low permeability tunnel liner.

11.11 Construction of the tunnel using the intended methodology, and the shafts with the available appropriate methodologies are not expected to impact groundwater availability to users of groundwater from the high capacity basalt aquifers in the Northern Zone, or in the Kaawa Aquifer in the Southern Zone.

11.12 The method of construction selected for the Project and described by Mr Cooper has been specifically chosen to address the identified ground and groundwater conditions and the assessed potential settlement effects arising from tunnelling. As described by Mr Cooper, it also provides the capacity to respond to a range of ground conditions to actively control settlement effects associated with potentially unexpected ground conditions. The contractors will be required to be able to respond to changing ground conditions.

11.13 The construction methodologies set out in Mr Cooper's evidence are expected to adequately control groundwater and surface settlement effects on this Project. I have concluded that it is possible to design and construct the tunnels and shafts for the Project such that:

(a) Surface settlements due to dewatering above the tunnel alignment and in the vicinity of shafts are limited to less than 50 mm with a low risk of exceedance.

(b) Differential settlements above the tunnel and in the vicinity of shafts are limited to less than 1:1000 with a low risk of exceedance.

(c) There is negligible risk of structural damage to buildings and services as a result of tunnel and shaft excavation and long term operation.

(d) There is a low risk of measurable changes in groundwater quality immediately about the tunnel and negligible risk of any adverse effect on regional groundwater quality.

(e) There is negligible risk of tunnel and shaft construction having an effect on groundwater users in the vicinity.

11.14 I believe that Watercare's Proposed Conditions, as attached to the evidence of Ms Petersen, appropriately address the technical issues in relation to groundwater and settlement and will ensure that the effects of tunnel and shaft construction can be managed and will be no more than minor.

Graeme Twose

12 July 2013