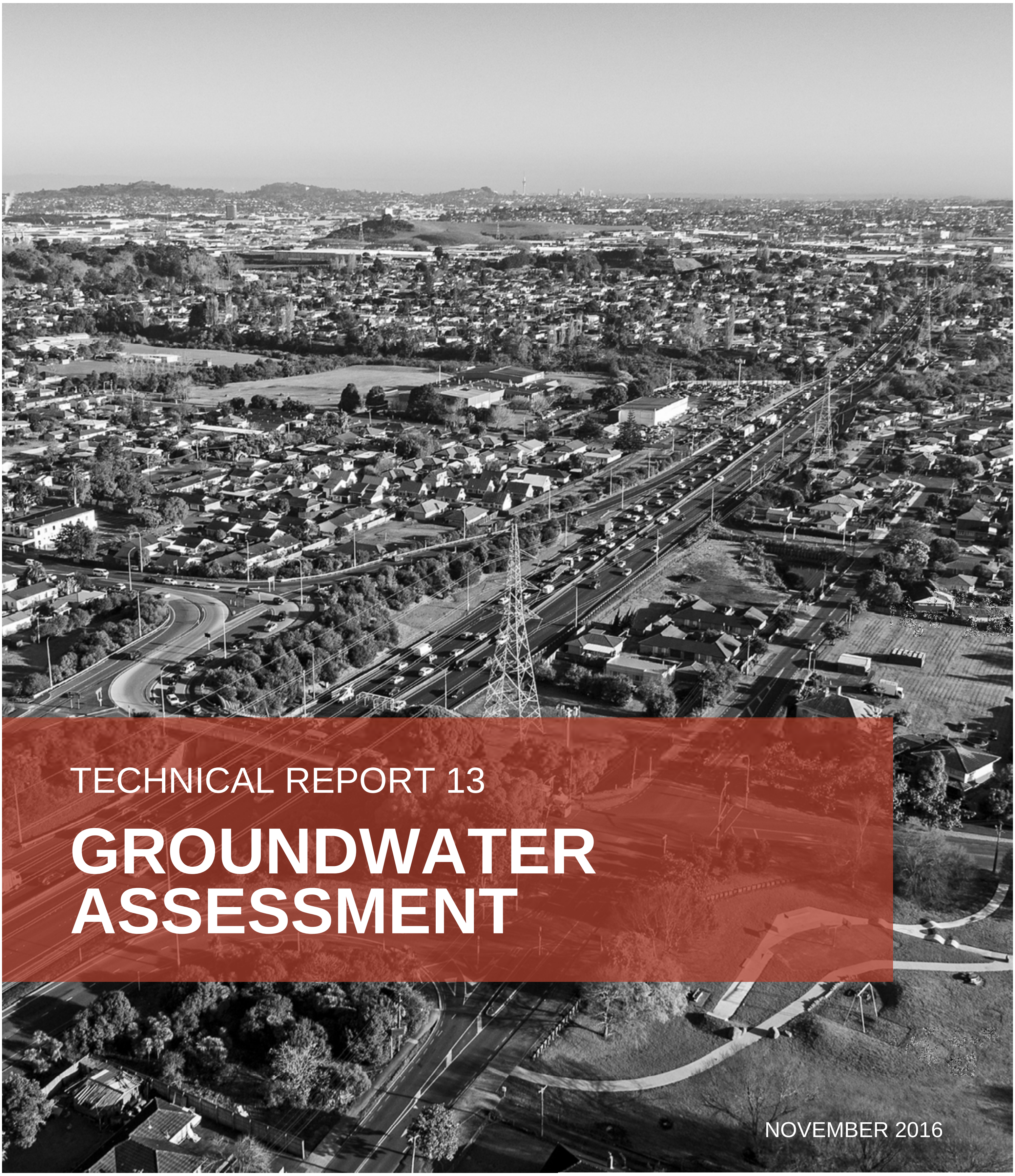

TECHNICAL REPORT 13

GROUNDWATER ASSESSMENT

NOVEMBER 2016

NZ TRANSPORT AGENCY
WAKA KOTAHI

East West Link

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0	November 2016	Final for Lodgement	Ann Williams and Theo Sarris	Gavin Alexander	Patrick Kelly

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EXECUTIVE SUMMARY

1. This report describes the potential effects of the Project on groundwater levels, flow and quality and the implications of these. It also describes how elements of the Project design have been developed to avoid or limit potential effects on groundwater.

2. The assessment was made by:
   - Developing a ground model to provide an understanding of the ground conditions in the wider Project area
   - Establishing a conceptual groundwater model
   - Undertaking subsurface investigations and groundwater level monitoring to fill gaps in understanding of the ground conditions
   - Testing groundwater quality to better understand the influences on existing water quality and how these might be altered by the project
   - Refining the conceptual groundwater model
   - Developing a 3D numerical flow model to simulate existing groundwater levels and flow conditions
   - Cutting 2D sections from the 3D numerical groundwater model to investigate groundwater movement in and around the road embankment at the foreshore
   - Simulating the completed Project in the 3D numerical groundwater model to identify the changes to groundwater that result.

Existing Environment

3. Groundwater flows from elevated ground (generally volcanoes largely comprising of basalt) and discharges to the coastal areas of the Māngere Inlet as springs at the original inlet shoreline, from basalt flow margins into Anns Creek and Ōtāhuhu Creek, and through the basalt margins offshore. Anns Creek, underlain by Tauranga Group alluvium also drains water from Mutukāroa-Hamlins Hill (Waitematā Group sandstone and mudstone). Actual flow paths may be quite sinuous according to variations in hydraulic characteristics of the lava flows and the underlying paleo-topography.

4. The Onehunga Bay and Māngere Inlet foreshore have been progressively reclaimed with landfill and engineered fill extending some 500m inland from the present foreshore. Areas of landfill directly affected by the Project and within which groundwater resides are:
   - Gloucester Reserve reclamation in the Hōpua tuff ring
   - Galway Street Landfill (includes “75 Acre Reclamation”)
   - Pikes Point East reclamation and landfill
   - Pikes Point West reclamation and landfill.

5. The main source of groundwater recharge is rainfall infiltration, both directly as rainfall and through stormwater soakage pits.

6. Saline water ingress to basalt beneath the Galway Street closed landfill and the overlying landfill material is indicated as well as in the area of Miami Stream.

7. Groundwater is lost from the system as springs, by groundwater abstraction (the largest groundwater take is on average some 11,000 m^3/day by Watercare for public water supply, peaking at 22,000 m^3/day), groundwater discharge to the harbour, and also by leachate collection from the Pikes Point closed landfills.

Assessment of Effects

8. Potential adverse effects of the Project on groundwater are:

   - Raising of the groundwater level on the upgradient side of the EWL Trench (adjacent to Onehunga Wharf) and of the road embankment where it is placed immediately adjacent to or over landfill in the Onehunga Foreshore area
   - Increased leachate generation where groundwater levels are raised in landfills
   - The potential for contamination of aquifers used for water supply during construction by mobilising fines during piling or other earthworks below groundwater level.

9. Potential positive effects are:

   - Reduction of saline ingress to existing landfills
   - Reduction of existing contaminant (leachate) discharge to the harbour
   - Improvement of the effectiveness of the Pikes Point leachate collection system and on-site treatment in new stormwater treatment wetlands.

EWL Trench

10. The EWL road level will drop to around RL 0m on the seaward side of the Hōpua tuff ring to allow an access road between Onehunga Mall and the wharf precinct to pass over the EWL. The trench will be a watertight structure which will result in a 250mm to 350mm rise of groundwater level on the upgradient side of the trench, reducing to 100mm some 250m inland.

Highway on embankment

11. From Sector 1 to just east of Waikaraka Cemetery, the foreshore embankment will be constructed adjacent to the existing seawall. This will result in lengthening in travel time of leachate through the embankment (with the improved opportunity for attenuation of contaminants) and a small rise in groundwater level inland (< 100mm). The very small magnitude of groundwater level rise will not result in adverse effects in this area.

12. However, the foreshore enhancement and lined stormwater wetland proposed in proximity to Waikaraka Cemetery might bring already elevated groundwater levels close to the ground surface, particularly in wet periods. Modification of the construction of these features such that gravel is placed against the basalt below sea-level in order to continue to allow groundwater discharge to the harbour, with construction of the low permeability promontories and wetland above, will substantially mitigate this effect.

13. East of Waikaraka Cemetery, the road embankment will be constructed in part over the existing Pikes Point West and East landfills and over the existing leachate collection system. The design of the replacement leachate collection system is such that it will cut off groundwater/ leachate flow to the area of landfill beneath the road. This means that the existing system can be used to pump remaining leachate from between the new system and the new seaward embankment face which will allow piling for the road to be undertaken without risk of leachate seepage into the underlying basalt rock (and out toward the inlet).

14. The new leachate collection system will operate under gravity and discharge leachate to the stormwater treatment wetlands through the embankment. Provision will be made for installation of pumps should monitoring indicate pumping is needed under exceptional circumstances to reduce groundwater level in the landfill.

15. The new road embankment will cause a small rise in groundwater level in Pikes Point closed landfills of the order of 50mm to 100mm within 60m to 80m of the EWL. This magnitude of groundwater level rise is not expected to result in adverse effects.

Highway elsewhere

16. Elsewhere, the highway will be constructed above groundwater level. Locally, embankments will be constructed which might result in consolidation of sediments beneath them and a small reduction in permeability, however no measurable change in groundwater level is expected to result.

Stormwater devices

17. A number of stormwater detention wetlands will be constructed in the vicinity of the alignment to treat stormwater runoff from the road.

18. Only ponds 1B, 1C and 1D, which extend below ground level and are unlined are expected to cause measurable mounding of water beneath them or upgradient. The magnitude of mounding is expected to be less than 100mm and is unlikely to result in adverse effects.

19. Stormwater treatment wetlands are proposed on the seaward side of the road where it runs adjacent to or along the foreshore. Because the toe of the road embankment is planned to be constructed from a low permeability material and the base of the treatment wetlands is also to be of low permeability in order to prevent seawater ingress, a small rise in groundwater level will occur upgradient as described above.

20. Locally, in the vicinity of Waikaraka Cemetery, the groundwater level rise will be greater and extend some distance inland of the road (250mm rise reducing some 400m inland). This rise can be controlled by adjustment of the materials used to construct the foreshore landforms and the stormwater wetland (below sea level) in this area. These changes have been incorporated into the design.

Wetlands and streams

21. The effects of the Project are largely small rises in groundwater level, rather than drawdown. Nevertheless, the extent of groundwater level rise does not reach Bycroft Reserve, Captain Springs or Anns Creek. No effect on groundwater contributions to existing wetlands and streams is therefore anticipated.

Contaminant (leachate) migration

22. The embankment will slow the movement of groundwater in the landfills towards the inlet, allowing attenuation of certain contaminants to take place, thereby reducing the concentration of contaminants entering the inlet. The flow path of contaminants mobilised in groundwater in the Galway Street landfill (leachate) will on average be slowed by 200 to 500% (depending on their location within the landfill and with respect to the stormwater treatment wetlands), allowing additional attenuation and fixing of contaminants within the mudcrete, tuff and clay liner materials, prior to discharge of the water to the inlet.

23. A new leachate collection system will be developed at the Pikes Point West and East landfills, which will allow delivery of leachate under gravity to the stormwater treatment wetlands where it will be treated together with the stormwater. This is needed because the Project will be constructed over the existing leachate collection system. The leachate will be treated with stormwater in the wetlands (refer to *Volume 3: Technical Report 12 - Surface Water Assessment).*

Coastal environment

24. Overall, the increased attenuation of contaminants that might otherwise discharge through the existing seawall or via basalt from the Galway Street landfill to the harbour will improve the quality of discharge to the inlet.

25. Use of a low permeability material on the outside and toe of the road embankment will substantially prevent sea water ingress to the Pikes Point landfills, reducing the potential for seawater ingress to generate leachate within the landfill and to transfer leachate to the coastal environment.

26. The proposed replacement leachate collection system will operate continuously and avoid the need for pumping and transfer of both leachate and (potentially) clean water abstracted from the basalt in response to pumping, for treatment off-site.

Groundwater users

27. The Project is expected to result in small rises in groundwater level locally. The extent of effects does not reach any existing groundwater take. The Project will therefore not impact groundwater users.

Mitigation

28. Potential effects on groundwater have been largely mitigated through the design process. However, there are two areas where the EWL could result in groundwater effects that might need to be mitigated. These are:

    - Where the road is taken in a watertight (tanked) trench through the future development of the Onehunga Port to allow access over the EWL and beneath the SH20 Manukau Harbour Crossing, resulting in groundwater level rise upgradient; and
    - Mounding of groundwater level beneath Waikaraka Cemetery as a result of already elevated groundwater levels and the positioning of the foreshore enhancement landforms and proposed stormwater treatment wetland.

29. It is considered unlikely that the estimated groundwater level rise resulting from the EWL Trench will be problematic because groundwater levels will remain well below ground level. A design solution has been proposed to substantially avoid the groundwater level rise at Waikaraka Cemetery.

30. Monitoring should be carried out during and following construction of Sectors 1 and 2 to:

    - Check that effects on groundwater levels do not exceed those anticipated. Higher groundwater levels may trigger the need for additional drainage;
    - Demonstrate that water levels and quality in the Pikes Point closed landfills are not exacerbated; and
    - Confirm that leachate continues to be able to be treated in the stormwater wetlands.

Conclusions

31. Potentially beneficial effects on groundwater flow have been able to be developed through the design of the Project, in particular with respect to improvements in the quality of groundwater/ leachate discharging into the inlet.

32. The Project will result in a small rise upgradient in groundwater level in Sectors 1 and 2. This could be problematic in two areas, however reasonable opportunities for remedying this rise through design adjustments are available.

33. Overall, the Project is not expected to have adverse effects on groundwater (or leachate) levels or flow.

Table of Contents

List of Figures

List of Tables

Appendices

Glossary of Technical Terms/Abbreviations

Abbreviation	Term
AEE	Assessment of Effects on the Environment
Bund	The structure designed to generally prevent inundation of the stormwater wetlands by the sea
CLCLR	Auckland Council's Closed Landfills and Contaminated Land Response Team
CMA	Coastal Marine Area
Embankment	The raised bank to carry the EWL across the CMA and existing closed landfills
EPA	Environmental Protection Authority
EWL	East West Link
EWLA	East West Link Alliance
Groundwater	Water that collects or flows beneath the ground surface
HAIL	Ministry for the Environment's hazardous activities and industries list
Hydraulic conductivity	A property of soils and rocks that describes the ease that water can move through pore spaces and fractures
Leachate	Groundwater that resides within or has travelled through landfills and therefore has the potential to contain mobilised contaminants
The NZ Transport Agency	New Zealand Transport Agency
SH(x)	State Highway (number)
Surface water	Water naturally open to the atmosphere

Glossary of Defined Terms used in this report

Term	Meaning
Auckland Council	Means the unitary authority that replaced eight councils in the Auckland Region as of 1 November 2010.
Earthworks	Means the disturbance of land surfaces by blading, contouring, ripping, moving, removing, placing or replacing soil, earth, or by excavation, or by cutting or filling operations.
Alignment	Means the route and designation footprint selected. This development involved specialist work assessing environmental, social and engineering inputs.
Motorway	Means a motorway declared as such by the Governor-General under section 138 of the PWA or under section 71 of the Government Roading Powers Act 1989.
Project	Means the East West Link Project as described in Part C: Description of the Project in the Assessment of Effects on the Environment Report contained in *Volume 1: AEE* and shown on the Drawings in *Volume 2: Drawing Set*.
State highway	Means a road, whether or not constructed or vested in the Crown, that is declared to be a State highway under section 11 of the National Roads Act 1953, section 60 of the Government Roading Powers Act 1989 (formerly known as the Transit New Zealand Act 1989), or under section 103 of the LTMA.

1 Introduction

1.1 Purpose and scope of this report

This report forms part of a suite of technical reports prepared for the NZ Transport Agency's East West Link project (the EWL or Project). Its purpose is to inform the Assessment of Effects on the Environment Report (AEE) and to support the resource consent applications, new Notice of Requirement and an alteration to existing designation required for the EWL.

This report assesses the groundwater effects of the proposed alignment of the Project as shown on the Project Drawings in *Volume 2: Drawing Set*.

The purpose of this report is to:

a. Identify and describe the existing groundwater regime;

b. Describe the potential effects of the Project on groundwater levels, flow and quality and the implications of these;

c. Describe how the Project design has been developed to avoid or limit potential adverse effects;

d. Recommend monitoring measures to check that adverse effects do not occur and identify further measures that could be implemented to mitigate potential adverse effects (including any conditions/management plan required) should monitoring indicate that these could occur; and

e. Present an overall conclusion on the level of potential effects of the Project after recommended measures are implemented.

1.2 Project description

The EWL Project involves the construction, operation and maintenance of a new four lane arterial road from State Highway 20 (SH20) at the Neilson Street Interchange in Onehunga, connecting to State Highway 1 (SH1) at Mount Wellington as well as an upgrade to SH1 between the Mount Wellington Interchange and the Princes Street Interchange at Ōtāhuhu. New local road connections are provided at Galway Street, Captain Springs Road, the port link road and Hugo Johnston Drive. Cycle and pedestrian facilities are provided along the alignment.

The primary objective of the Project is to address the current traffic congestion problems in the Onehunga, Penrose and Mount Wellington commercial areas which will improve freight efficiency and travel reliability for all road users. Improvements to public transport, cycling and walking facilities are also proposed.

For description purposes in this report, the Project has been divided into six sectors. These are:

Sector 1.	Neilson Street Interchange and Galway Street connections
Sector 2.	Foreshore works along the Māngere Inlet foreshore including dredging
Sector 3.	Anns Creek from the end of the reclamation to Great South Road
Sector 4.	Great South Road to SH1 at Mount Wellington
Sector 5.	SH1 at Mount Wellington to the Princes Street Interchange
Sector 6.	Onehunga local road works

A full description of the Project including its design, construction and operation is provided in Part C: Descrip*tion of the Project in the Assessment of Effects on the Environment Report contained in* Volume 1: AEE and shown on the Drawings in *Volume 2: Drawing Set*.

2 Experience

2.1 Expertise

Ann Williams is a Technical Fellow in the fields of Hydrogeology and Engineering Geology with the firm Beca Ltd (Beca). She is a graduate of the University of Auckland with the degrees of Bachelor of Science and Master of Science in Geology (Honours), specialising in Engineering Geology. Ann has completed post-graduate studies in Resource and Environmental Management and in Hydrogeology and has 27 years' post-graduate experience in engineering geological and hydrogeological investigations and analysis.

As technical leader of Beca's engineering geological and hydrogeological teams, Ann has had a key role in a wide range of projects that have required an understanding of the effects of infrastructure development on groundwater in a range of ground conditions. In the Auckland area, these have included the New Lynn Rail Trench, Victoria Park Tunnel and Waterview Tunnel projects as well as the technical evaluation of shortlisted options for the EWL project. She is currently providing groundwater advice to the Transport Agency's team seeking designation approvals for the Additional Waitematā Harbour Crossing. In each case these projects required assessment of the effect of different designs on groundwater flow, the potential for contaminant migration or saline intrusion, for altering base flow to adjacent watercourses, for effects on existing groundwater supplies and the development of monitoring and mitigation strategies.

Theo Sarris is an Associate Hydrogeologist at Beca Ltd. He is a graduate of the Aristotle University of Thessaloniki, Greece with the degrees of Bachelor of Science and Master of Science in Civil and Environmental Engineering (1997). He completed the degrees of Master of Science and Doctor of Philosophy in Hydrogeology at the University of South Carolina, USA, and has 15 years' professional experience in Hydrogeology. In his role at Beca Theo has developed 2D and 3D groundwater models to assess the effects of a number of roading and other linear infrastructure projects on groundwater. Examples are the Penlink Project (North Auckland), the McKays to Peka Expressway (Kāpiti Coast), SH20A Airport Access and Western Ring Route – Waterview Connection.

3 Assessment Methodology

The methodologies applied to assess existing groundwater levels and flow are set out below, together with methodologies for the assessment of the effects of the Project on groundwater, and on leachate residing within landfills adjacent to the Onehunga foreshore.

This assessment relies on data presented in the following factual reports:

a. Geotechnical Factual report, which presents the results of ground and groundwater investigations and testing

b. Preliminary Site Investigation (PSI) report, which presents the findings of a desk-based study of contaminated land in the project area and contaminants in the receiving environment.

This assessment also relies on the following technical reports:

a. Geotechnical Interpretative report;

b. Geotechnical Design;

c. Stormwater Design;

d. Embankment Section Stormwater Design;

e. Groundwater Modelling report (Appendix A to this report); and

f. Groundwater Quality Assessment (Appendix B to this report).

Models developed for the assessment of groundwater effects are listed in Table 3-1 and described in detail in Appendix A.

Table 3-1: Models developed

Model	Purpose
3D Ground model	To provide a 3D representation of the distribution of soils and rocks; input to groundwater flow model
Conceptual groundwater model	A pictorial representation of the groundwater flow system based on the available data; input to groundwater flow model
Regional 3D groundwater flow model	To evaluate the current aquifer budget (water flowing into and out of the modelled area) and assess the likely effects of the EWL on groundwater
2D Seepage modelling	To assess in more detail the effects of embankment construction adjacent to the Onehunga foreshore (sectors 1 and 2) on aquifer through-flow and groundwater levels
2D Particle tracking	To assess changes in particle travel time from areas within existing landfill to the inlet that might result from construction of the proposed EWL embankment

3.1 Ground conditions

More than 500 geotechnical investigation records dating back over 30 years were identified. Records that comprised engineering logs with soil strength data and water level records were input to a database to develop a 3-dimensional ground model using the software Leapfrog® Geo 3.1.

Additional investigations were carried out (boreholes, in-situ permeability testing and groundwater level monitoring within the boreholes, and pumping testing) to provide a more detailed understanding of ground and groundwater conditions closer to the alignment. Data obtained from these investigations was used to update the ground model.

The groundwater level records from some 139 locations were used to characterise regional flow directions and water table elevations. These include 81 monitoring locations identified in the Auckland Council (AC) geotechnical database and the AC Environmental monitoring programme (AC has 14 regularly monitored piezometers in the Onehunga area), supplemented by levels recorded in 35 geotechnical investigation boreholes, 17 groundwater monitoring bores, and 12 environmental monitoring bores, installed in April to June 2016 as part of the EWL project. The location of these monitoring points is shown in Figure 3-1.

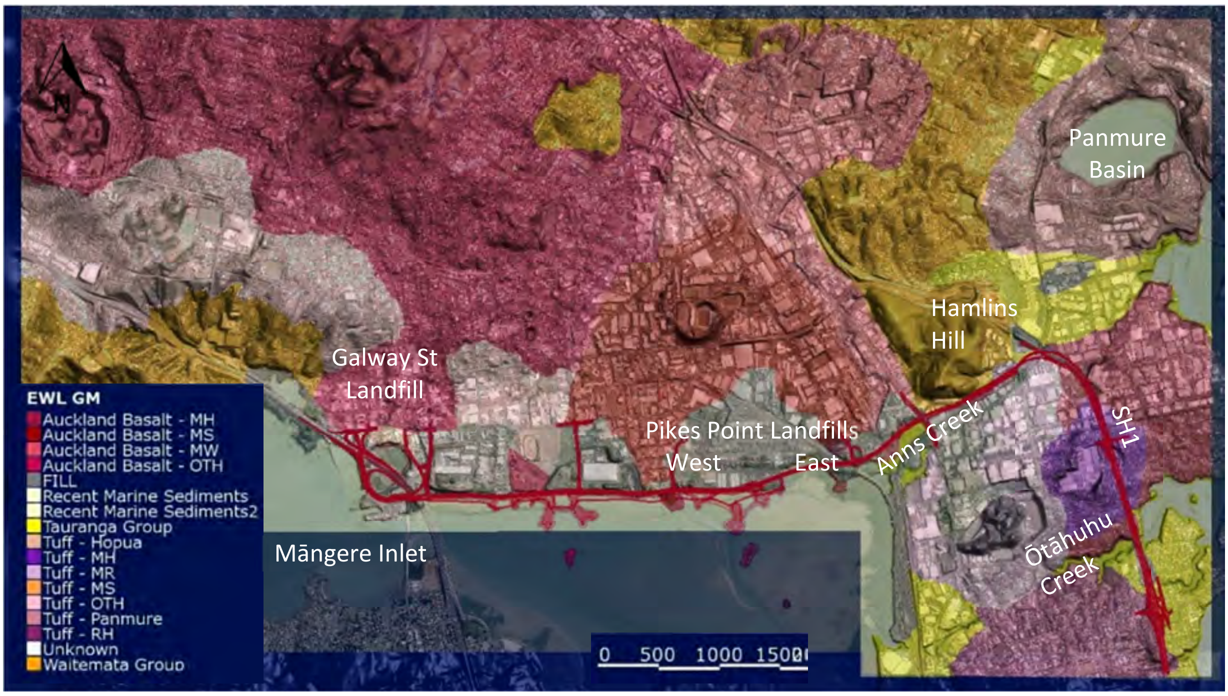
Figure 3-1: Groundwater level record locations

The ground model includes the up-catchment area north of the Project so that it could be used in analytical models to help understand groundwater recharge and flow. The extent of the ground model is shown in Figure 3-2.

3.2 Groundwater quality

Multiple groundwater samples were obtained from the groundwater and environmental monitoring bores, as well as from the Pikes Point landfill leachate collection system. Water quality test results were compared to distinguish areas influenced by seawater ingress and other contaminants (leachate) from “background” water quality (Appendices B1 and B2).

Figure 3-2: Ground model (bird’s eye view)



3.3 Conceptual groundwater model

The ground model and groundwater level data were used to develop a conceptual groundwater model. The conceptual model takes into account:

- Inputs to the system: rainfall, stormwater soakage;
- Flow through the system: ground conditions, records of reclamation and landfill construction, aquifer test results; and
- Outputs from the system: spring discharges, groundwater abstractions, leachate collection and groundwater discharge into the harbour.

It forms the basis for development of a 3D numerical groundwater flow model.

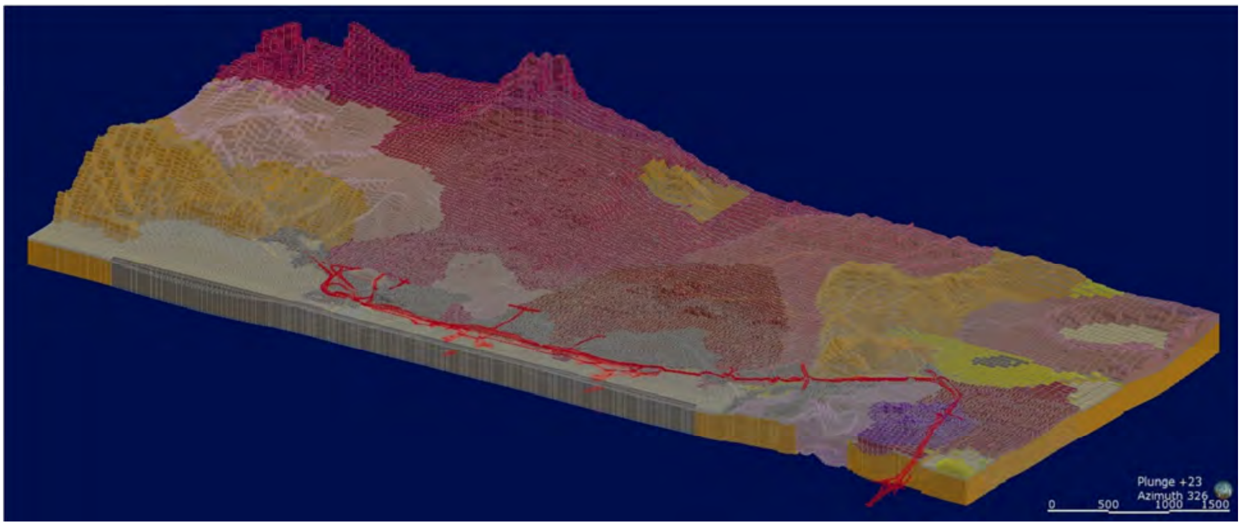
3.4 Regional 3D groundwater flow model

A 3D model has been developed to evaluate the current aquifer budget (water flowing into and out of the modelled area) and assess the likely effects of the EWL on groundwater. It also allows assessment of the fate of contaminants that might travel in groundwater.

The 3D ground model was exported from Leapfrog to Groundwater Vistas, a GIS based pre- and post-processing interface for the computer program, MODFLOW. The model area was discretized in 147 rows and 346 columns for a total of 45,465 active cells per layer that cover an active area of approximately 29km^2 (Figure 3-3). Vertically, seven layers have been used to describe the variability of ground conditions with depth.

Groundwater level records were imported into the 3D groundwater flow model and used as the basis for parameter calibration. Model parameter values were based on in-situ testing, testing of the geological formations as part of other Auckland projects, cored sample descriptions and automated model calibration. For the latter, the parameter estimation software PEST was used, in which parameters are optimised by making small adjustments to achieve the best possible reproduction of measured groundwater levels.

Figure 3-3: Groundwater flow model: numerical grid (units represented are shown in the key in Figure 3-2)



Details of model construction, parameters and calibration are set out in the *Groundwater Modelling Report* (**Appendix A**).

3.5 2D particle tracking

2D particle tracking models (MODFLOW-SURFACT) oriented perpendicular to the proposed EWL embankment (sectors 1 and 2) were used to assess changes in particle travel time from areas within existing landfill to the harbour that might result from construction of the proposed EWL embankment. This information was also used to develop the design of the embankment.

Sections were modelled at Victoria Street and Captain Springs Road to assess the benefits that might be add by road construction in front of the Galway Street Landfill.

3.6 2D seepage modelling

A series of 2D groundwater seepage models (MODFLOW-SURFACT) was developed to assess in more detail the potential effects of embankment construction adjacent to the Onehunga foreshore (sectors 1 and 2) on aquifer through-flow and groundwater levels and to consider the operation of the proposed replacement leachate collection system on the upgradient side of the embankment.

Sections were modelled at Victoria Street (embankment on foreshore adjacent to existing landfill), at Captain Springs Road and at Pikes Point West and East landfills (embankment placed over landfill). Investigation bores were drilled in transects at these locations to facilitate this analysis.

3.7 Engagement

Members of the Project's groundwater, contaminated land, design and planning teams have met with representatives of the Auckland Council's Closed Landfills and Contaminated Land Response Team (CLCLR) periodically to understand the team's key areas of concern so that these could be addressed in design, and to keep them informed of the design as it was developed.

4 Existing Environment

4.1 Ground conditions

4.1.1 Regional geology

The Project area is located within the Waitematā basin, a sedimentary basin which formed as a result of tectonic subsidence some 20 million years ago. Sediments that accumulated in the basin came from erosion of the surrounding land mass and andesitic volcanism that was occurring to the west.

Continued subsidence of the basin and thickening of the basin-filling sediments resulted in consolidation, forming the weak sandstone and siltstone rocks of the Waitematā Group. A period of uplift caused deformation of the Waitematā Group rocks which resulted in variable topography across the basin.

From about six million years ago, deposition has occurred in the Auckland area, with sediments originating from predominately terrestrial sources. The sediments are known as the Tauranga Group, and overlie the Waitematā Group across most of the Project area. The Tauranga Group comprises mainly pumiceous, terrestrial and minor estuarine deposits (silts, sands, gravels, clays, and peat).

The Project area is underlain by the Manukau Lava Field built largely of lava flows from One Tree Hill and Mt Smart (Rarotonga) volcanoes, but also from Mt Wellington volcano in the east. One Tree Hill is the oldest of these volcanoes and is understood to have erupted on a pre-existing land surface that is now well below sea-level in the mouth of a valley system. The Hōpua explosion crater (Gloucester Park) comprises an elevated tuff ring that was breached when sea-level rose; marine and organic muds were deposited within it. The breach was closed following European settlement some 70 years ago and the tuff ring was reclaimed with both urban refuse and fill.

The geology is described in more detail in the Geotechnical Interpretative report.

4.1.2 Project geology

Basalt lava and tuff overlie and are locally interbedded with a variable thickness of Tauranga Group alluvium, which comprises pumiceous silt, sand and gravel with muddy peat and non-welded and alluvially reworked ignimbrite and tephra. The basalt flows are bound to the east by an uplifted block of Waitematā Group sandstone and siltstone (Mutukāroa-Hamlins Hill), although some lava and tuff from Mt Wellington volcano have flowed around the block from the north-east in the area of Anns Creek.

Uncemented dense to vesicular sand to gravel sized basalt fragments are mapped as underlying the area between Alfred Street and Captain Springs Road and north to Patrick Street. The ash/tuff also forms a lobe between Angle and Edinburgh Streets extending into the foreshore.

Recent marine sediments (part of the latest Tauranga Group) overlie the Manukau Lava Field and older Tauranga Group soils at the coastal margin and offshore, and partially infill Hōpua crater (Gloucester Park).

The Onehunga Bay and Māngere Inlet foreshore have been progressively reclaimed with landfill and engineered fill extending some 500m inland from the present foreshore.

A description of the historic and present land uses and associated land and water quality is set out in *Volume 3: Technical Report 17- Contaminated Land Assessment*. The most significant areas of reclamation and landfill directly affected by the EWL are:

- Gloucester Reserve reclamation in the Hōpua tuff ring;
- Galway Street Landfill (includes “75 Acre Reclamation”);
- Pikes Point East reclamation and landfill; and

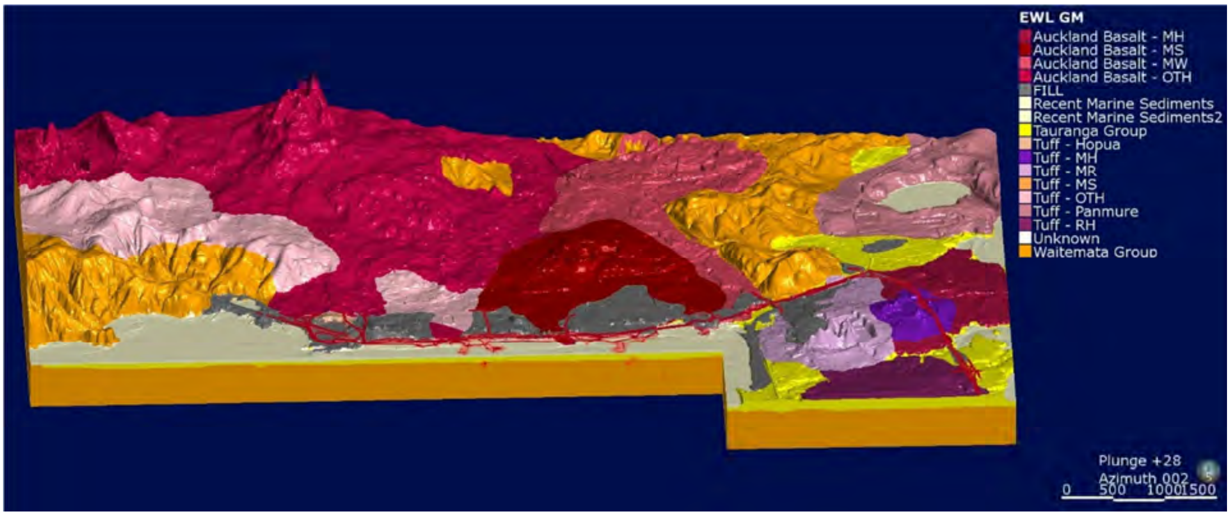
- Pikes Point West reclamation and landfill.

Waitematā Group rock underlies the north-eastern end of Anns Creek, the southern part of Great South Road and Sylvia Park Road. Lithic tuff, comprising broken up pre-volcanic materials, basalt fragments and unconsolidated ash and lapilli, is mapped as underlying the area between Abattoir Lane and Portage Road to SH1, north towards Sylvia Park Road and south to Ōtāhuhu Creek. The tuff is thought to be sourced from the Mt Richmond and McLennan Hills craters which last erupted some 30,000 years ago. Pumiceous mud, sand and gravel with muddy peat and lignite beds, non-welded ignimbrite, tephra and alluvially reworked tephra of the Puketoka Formation (also Part of the Tauranga Group) occur locally beneath part of SH1 adjacent to Sylvia Park and adjacent to Ōtāhuhu Creek.

Ground conditions specific to each sector are summarised in the Geotechnical Interpretative report. The ground model (Figure 4-1) distinguishes the following geological units:

- Fill (reclamation and landfill, including cleanfill, domestic and other waste up to 10m thick);
- Recent Marine Sediments (very soft silt and clayey silt up to 5m thick);
- Tuff (predominantly Hōpua, Mt Richmond (Ōtāhuhu) and Panmure Basin; sandy silt and silt with fine gravel beds up to 18m thick);
- Auckland Basalt (One Tree Hill (Maungakiekie), Mt Smart (Rarotonga), Mt Wellington (Maungarei) and McLennan Hills (Te Apunga o Tainui); strong variably vesicular basalt, fractured near the top and bottom of flows, up to 25m thick);
- Tauranga Group Alluvium (soft to very stiff silts with minor sand, clay and peat beds up to 20m thick); and
- Waitematā Group (extremely to very weak interbedded sandstone and siltstone).

Figure 4-1: Representation of 3D ground model



4.2 Groundwater quality

Analysis of groundwater quality indicates waters with a saline signature reside in particular in basalt and to a lesser extent fill monitoring bores located between Galway and Alfred Streets, north to Neilson Street and adjacent to the coast at Miami Parade in the vicinity of Miami Stream.

Leachate influence is indicated in many of the bores tested, but is most notable in those located within the closed Galway Street landfill. Concentrations of copper, zinc and ammoniacal nitrogen exceed the ANZECC 90% Marine Water Quality guideline values in samples from most bores tested and may exceed the guideline for cobalt and lead. The parameters recently measured in leachate pumps from Galway Street and Pikes Point landfills show that contaminant concentrations are generally within, or close to, the ANZECC 90% protection level for marine species with the exception of ammoniacal nitrogen, which is around 50 times higher than the acceptable concentrations for the 90% protection level. Stiff diagrams indicate that the cation/ anion balance of groundwater sampled upgradient of the landfills east of the Galway Street closed landfill are similar.

Overall the primary contaminants identified during groundwater investigations were nutrients, in particular ammoniacal nitrogen. Groundwater and leachate quality is described in more detail in Appendix B.

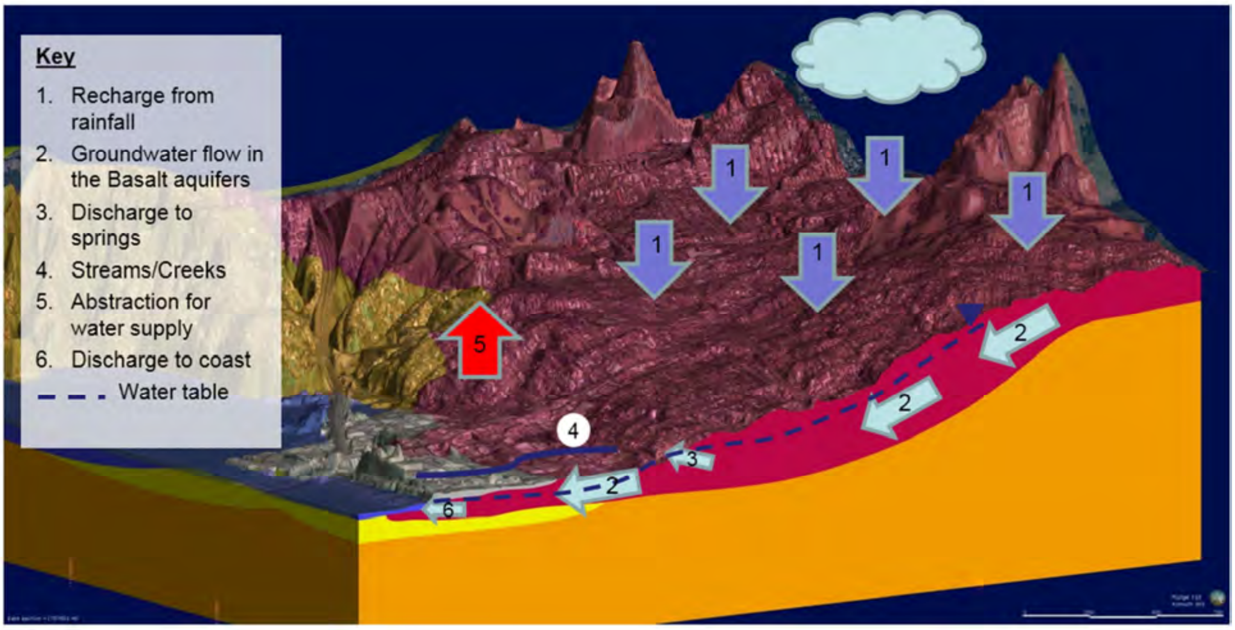
4.3 Conceptual model

Groundwater flows from elevated ground in the north and discharges to the coastal areas of the Māngere Inlet, as springs at the original shoreline, from basalt flow margins into Anns Creek (which discharges to the coast) and through the pre-reclamation basalt margins offshore. Anns Creek also drains water from Mutukāroa-Hamlins Hill. Actual flow paths may be quite sinuous according to variations in hydraulic characteristics of the lava flows and the underlying Waitematā Group paleo-topography.

The springs have for the most part been piped through the areas of landfill at the foreshore to the present coastline. Groundwater continues to flow through the basalt largely below the landfills and discharge through basalt offshore. However, a water table has established within the landfills along the Onehunga foreshore at around 2 to 2.5m bgl, except in the coastal area below Captain Springs where it is within 1m of the ground surface.

Most groundwater flow occurs within the shallow, unconfined basalt aquifers. These aquifers have moderate to very high permeability, due to fractures (shrinkage and structural) within the rock, cavities resulting from differential cooling of the flows and high porosity of associated scoriaceous or vesicular basalt. Rainfall directly infiltrates these near surface aquifers, limiting surface runoff and the formation of significant rivers or streams. The basalt aquifers are underlain by lower permeability tuff, Tauranga Group alluvial sediments and Waitematā Group sandstone and mudstone that have more limited ability to transmit groundwater. As a result, where the gradient of the basalt aquifers decreases near the coast and groundwater levels approach the surface, spring discharges occur. A schematic of the conceptual groundwater model is shown in Figure 4-2.

Figure 4-2: Conceptual ground and groundwater model schematic



4.4 Groundwater flow model

4.4.1 Hydrogeological Units

The geological units have been broadly adopted as hydrogeological units. Base case model hydraulic parameters are summarised in Table 4-1. However, hydraulic conductivity zones have been developed for the basalts according to the results of in-situ hydraulic conductivity tests carried out in boreholes, the results of pumping tests, well performance records and work carried out by others (Earthtech, 1993; PDP, 2005; Schayen, 2004). The basalt hydraulic conductivity zones are shown in Figure 4-3.

Figure 4-3: Groundwater flow model: hydraulic conductivity (K) zones within the Basalt

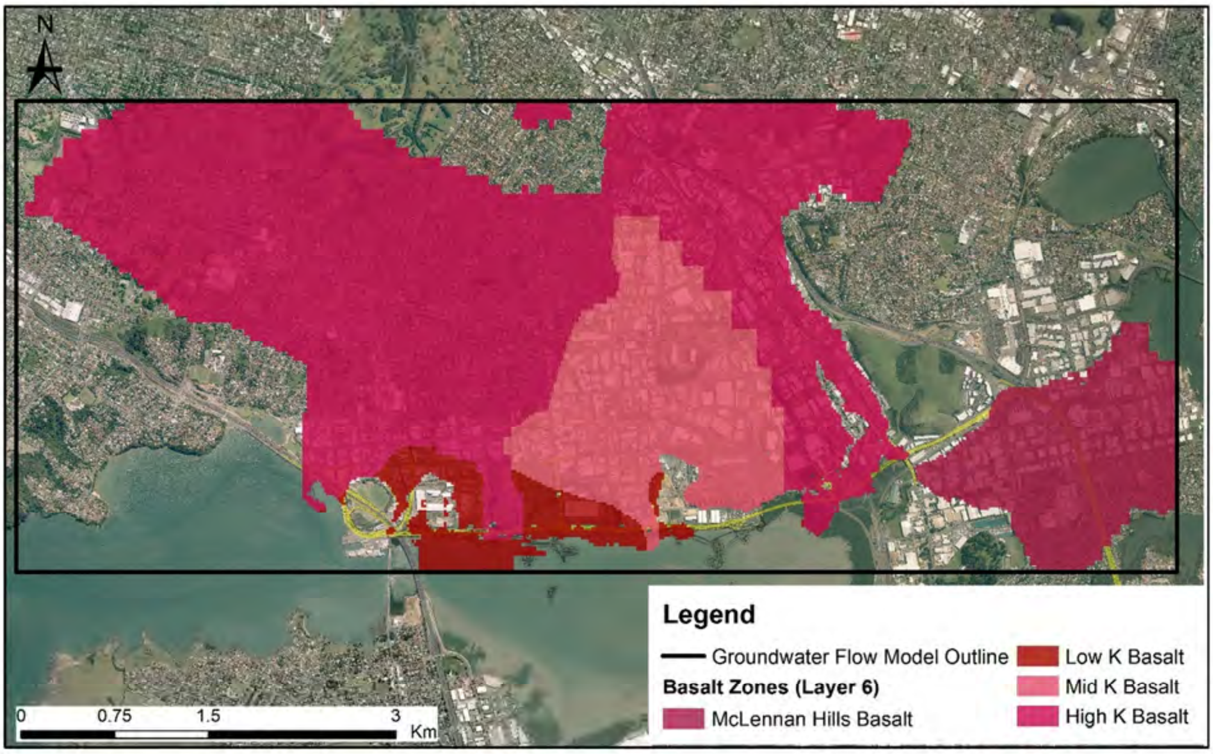


Table 4-1: Groundwater flow model: base case hydraulic conductivity values

Unit	Horizontal Hydraulic Conductivity, K_h (m/s)	Vertical Hydraulic Conductivity, K_z (m/s)
FILL	2.10E-05	2.10E-06
Recent Marine Sediments	1.00E-05	2.00E-06
Recent Consolidated Marine Sediments	1.00E-07	1.00E-08
Tuff – One Tree Hill	1.16E-05	5.80E-06
Tuff (other)*	8.00E-06	8.00E-07
Auckland Basalt – McLennan Hills (MH Figure 4.3)	3.00E-04	1.50E-04
Auckland Basalt – Low K	1.00E-04	5.00E-05
Auckland Basalt – Mid K	5.00E-04	2.50E-04
Auckland Basalt – High K	2.00E-03	1.00E-03
Tauranga Group	2.00E-07	4.00E-08
Waitematā Group	5.00E-07	5.00E-08
*parameters for different tuff rings varied in sensitivity analyses		

The fill, basalt and tuff horizontal hydraulic conductivity zones have been further refined and calibrated using the pilot point calibration technique in PEST as described in the Appendix A.

4.4.2 Groundwater recharge

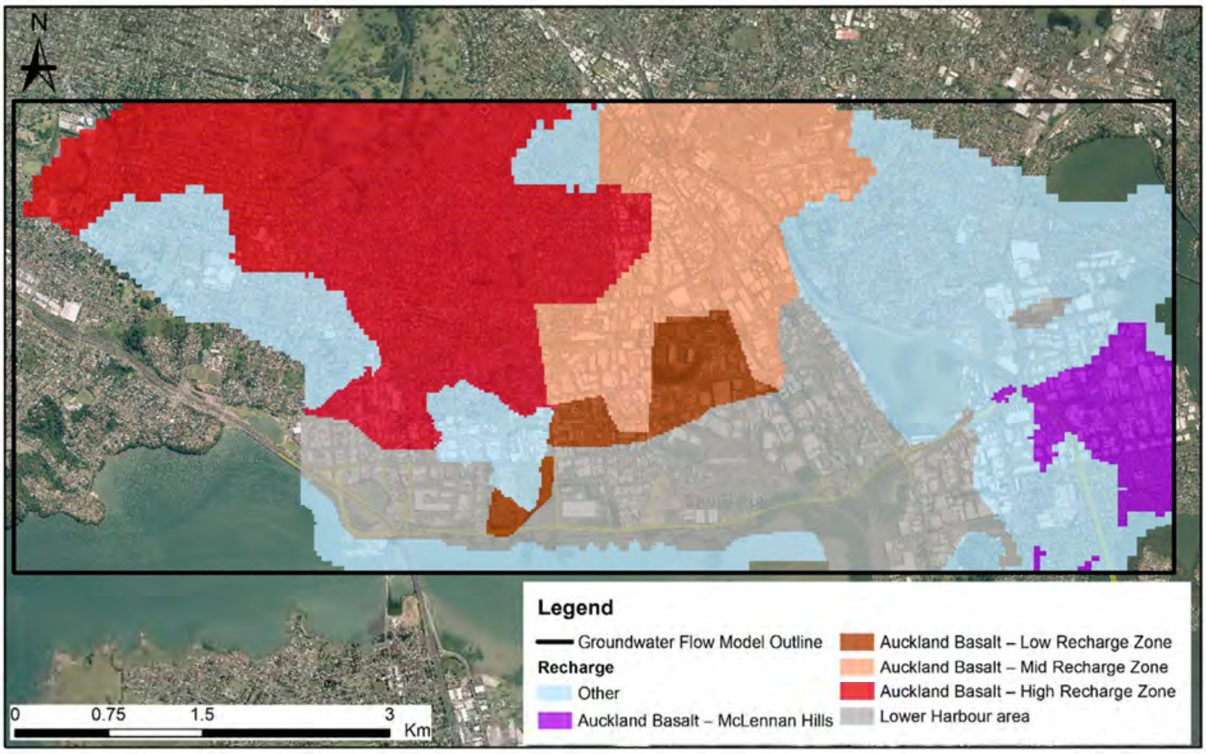
The main source of aquifer recharge is rainfall infiltration. This includes infiltration through the surface soils and through soakage pits. Measurements obtained at 15 minute intervals in 20 monitoring locations suggest that groundwater levels respond quickly to rainfall events and may rise by up to 0.5m in 8 hours.

Other contributions to groundwater include leakage from stormwater pipelines and rain water moving through backfill around water, stormwater and wastewater pipelines.

Saline water ingress occurs beneath Onehunga Harbour Road to Gloucester Park, but is not seen at Neilson Street on the inland side of Gloucester Park. Minor tidal influence is recorded in piezometers installed within the Galway Street and Pikes Point West and East landfills. This may in part be a pressure response, however chloride, sodium, pH and electrical conductivity data (Section 4.4.2 above and Appendix B) suggest some saline ingress to the Galway Street closed landfill and underlying basalt rock occurs.

Groundwater recharge from rainfall has been included in the model in the form of constant rate recharge zones. The zones have been defined based on the near surface geology, land use and cover and surface slope, in accordance with previous studies (PDP, 2005). The spatial distribution of these zones is shown in Figure 4-4.

Figure 4-4: Groundwater flow model: rainfall recharge zones (zones defined in Table 4.2)



Quarterly rainfall data obtained from Auckland Council (Onehunga station at Harbour Rd and Rowe Street station) and CliFlo (NIWA Māngere EWS station) for the period 2002 – 2016 indicates that the area receives on average 1160mm of rainfall per year. This annual average was used as the basis to calculate the zone percentage that reaches and recharges the aquifer. This compares with an average rainfall of 1179mm/year reported by PDP (2005) based on data collected from 12 rainfall stations across the Auckland Isthmus over the period 1998 – 2003.

The calibrated recharge rates used in the model are summarized in Table 4-2. The last column of this table lists the recharge rate as a percentage of the average annual rainfall.

Table 4-2: Groundwater flow model: adopted rainfall recharge rates

Zone Number	Unit	Recharge (mm/yr)	Percentage of average rainfall (%)
1	Auckland Basalt – McLennan Hills	330	28
2	Auckland Basalt – Low Recharge Zone	220	19
3	Auckland Basalt – Mid Recharge Zone	550	47
4	Auckland Basalt – High Recharge Zone	660	57
5	Lower Harbour area	33	3
6	Other	33	3

4.4.3 Groundwater discharge

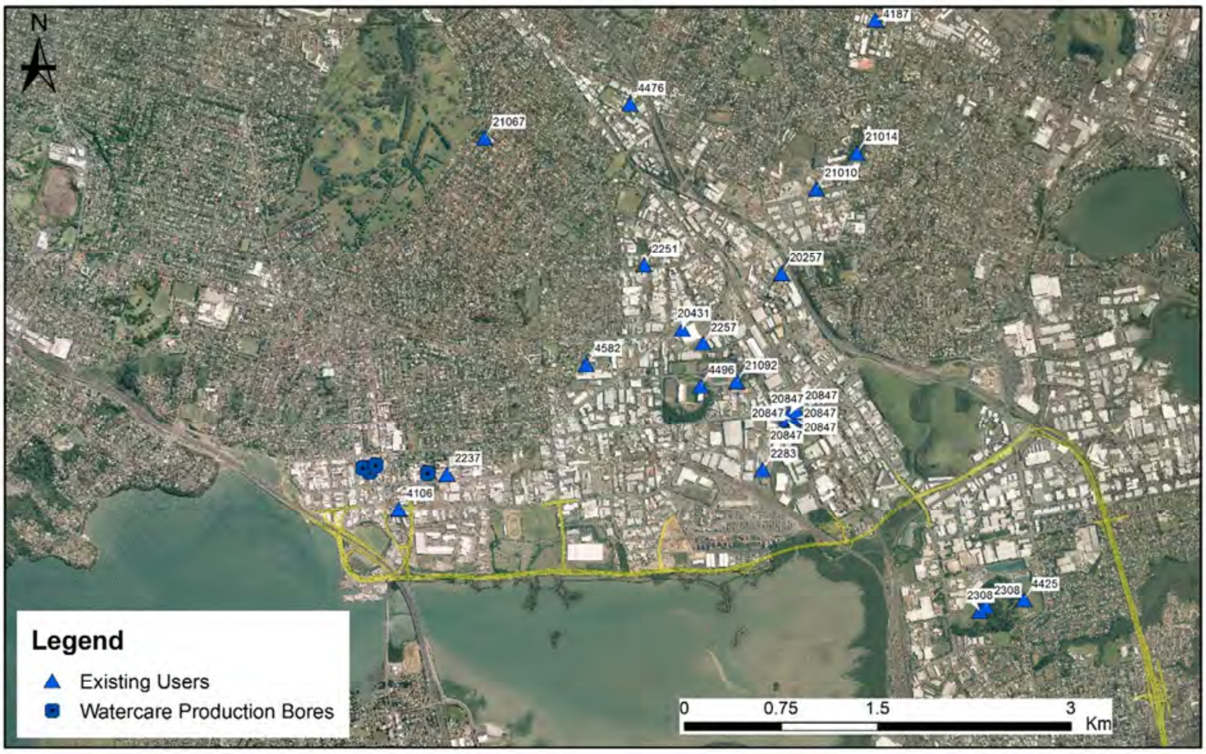
4.4.3.1 Water supply wells

The main abstraction of water from the model area is by Watercare for public water supply. Watercare has four production wells (although only two are currently operational) with a total consented maximum take of 30,000 m^3/day (8.5 Mm^3/year). Watercare has a consent condition to maintain a minimum water level in the wells of 0.5m above sea-level, however we understand that the average maximum combined daily take is just over 100 l/s (around 22,000 m^3/day) and pumping is generally maintained at around 1.8m above sea-level. The wells are located between Princes Street and Church Street north of Gloucester Park (Figure 4.5) as follows:

- Corner of Pearce Street and Upper Municipal Place (the Pearce Street well), RL 11.8m (12.3m deep)
- Within the Watercare Onehunga Treatment facility (the Rowe Street well), RL 5m (5.5m deep)
- At the back of the garage of the Onehunga Workingmen's club (the Upper Municipal Place well), RL 15.7m (14.5m deep); the well has not been operated since 2004
- On the berm, next to the pavement on Lower Municipal Place (the Lower Municipal Place well), RL 8m (blocked; depth unknown); the well has not operated since 2004.

Figure 4-5 shows the locations of all consented groundwater takes in the area; a full list is given in Appendix A (refer Appendix A6).

Figure 4-5: Consented Groundwater takes in the project area



4.4.3.2 Springs and streams

Three spring-fed streams discharging from basalt are identified:

- Miami Stream (also known as the Green Stream because of past contamination events), an open channel that runs to the coast and receives a combination of groundwater and stormwater flow
- Captain Springs, a groundwater fed spring and ecologically valuable wetland that feeds into an open unlined channel with a number of piped sections and connects to the reticulated stormwater system
- Bycroft Stream, an ecologically sensitive wetland area fed by groundwater, that runs approximately 100m before being diverted into the reticulated stormwater system.

A further stream, Anns Creek, discharges into the north-eastern corner of the Manukau Inlet. Its bed is on Tauranga Group sediments and it receives water from basalt flow margins on its western side and drains the catchment of Mutukāroa-Hamlins Hill (Waitematā Group).

The locations of the springs and streams are shown in Figure 4-6.

Figure 4-6: Springs and streams in the project area

4.4.3.3 Reclamation and landfilling

Historical aerial photographs and reports indicate that land was reclaimed by constructing an irregular network of haul roads and filling in behind them. Reports indicate that “rock bunds” exist 100m and 150m inland of the current “earth fill” or “clay core” seawalls at the foreshore of Pikes Point West and East landfills respectively and that the seaward margin of the Galway Street landfill is a rock wall.

If the haul roads are permeable and extend down to basalt, then they are a potential pathway for groundwater (and leachate) flow. If the haul roads have a low permeability and only extend down to tuff or marine sediments, then they might contain groundwater (and leachate). The distribution of monitoring bores that indicate saline ingress (Appendix B2,) suggests that the rock walls used to construct the Galway Street Closed Landfill allows seawater infiltration more readily than those at the Pikes Point Closed Landfills.

A leachate collection system was installed through landfill on the inside of the seawalls at Pikes Point West and East landfills. Concept design drawings indicate a narrow gravel trench system from which leachate is periodically pumped. Typical volumes of leachate discharged to Watercare’s trade waste from the leachate collection system at Pikes Point landfill are in the order of 50,000 m^3 to 70,000 m^3 per year[1]. This leachate is treated at the Māngere Wastewater treatment plant before being discharged to the harbour. It is considered likely that pumping draws in fresh water from the underlying basalt as well as leachate residing within the landfills. Testing of samples of leachate recovered from the collection system indicated relatively clean water (other than the high concentrations of Ammoniacal Nitrogen). No as-built records of the various bunds, seawalls and completed leachate collection systems have been sighted however.

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[1] Calculated from pump volume data supplied by Envirowaste Services Ltd

4.5 Computer groundwater modelling

4.5.1 Regional 3D groundwater flow model

A 3D groundwater flow model has been developed to simulate the existing groundwater flow system and assess the effects of different design options on groundwater. The numerical model was created in Groundwater Vistas 6.79. For groundwater flow simulations, the numerical engine MOFLOW – NWT was used. Details of the groundwater model set-up and calibration are described in Appendix A. Simulated shallow groundwater levels for the existing situation are shown in Figure 4-7 and Figure 4-8.

Figure 4-7: Simulated water table level (levels in metres RL, 5x vertically exaggerated)

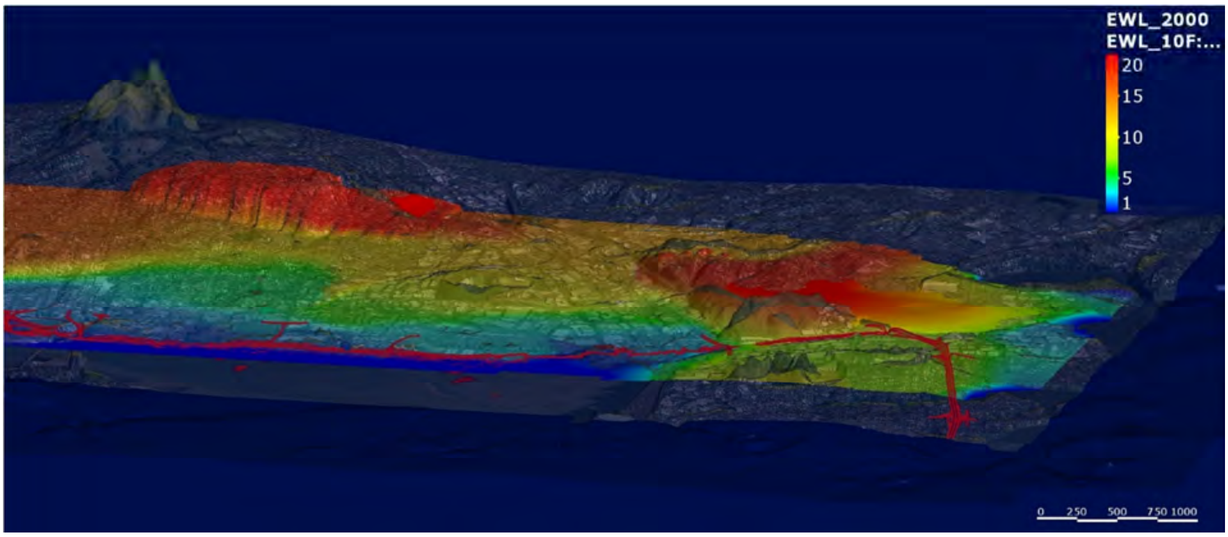


Figure 4-8: Simulated water table elevations (contours in metres RL)

5 Assessment of Potential Groundwater Effects

5.1 Potential project effects

The 3D groundwater flow model developed has been used to assess the effects of the proposed road construction on the groundwater flow system and to develop viable mitigation options through design. Key considerations are the potential for:

- Raising the groundwater level on the upgradient side of fills and lowering groundwater level on the down-gradient side;
- Lowering of groundwater level where cuts extend below groundwater level;
- Drawdown-induced ground settlement;
- Changes in groundwater level to influence ecological areas;
- Contamination of aquifers used for water supply with sediment generated during construction or by construction of fills over permeable rock (in particular basalt);
- Saline intrusion;
- Stormwater pond construction and operation to raise groundwater levels in the landfills upgradient;
- Retarding contaminant discharge to the inlet; and
- Developing a viable replacement leachate collection system.

5.1.1 Sector 1 – Neilson Street Interchange

Elements within Sector 1 that might influence groundwater are:

- Embankment fills on Hōpua tuff ring;
- Establishment of onshore stormwater wetlands;
- Lowered road (trench) through the future development of the Onehunga Port and beneath the SH20 Manukau Harbour Crossing; and
- Foreshore embankment.

5.1.2 Sector 2 - Embankment

Elements within Sector 2 that might influence groundwater are:

- Construction of the foreshore embankment adjacent to the existing seawall from Sector 1 to the eastern extent of Waikaraka Cemetery;
- Construction of offshore stormwater treatment wetlands;
- Construction of the foreshore embankment over the existing landfill and seawall from east of Waikaraka Cemetery; and
- Replacement of the leachate collection system at Pikes Point West and East landfills.

5.1.3 Sector 3 – Anns Creek

Elements within Sector 3 that might influence groundwater are:

- Embankment fill and onshore stormwater wetland 3A at Hugo Johnston Drive.

5.1.4 Sector 4 – SH1 Ramps (Tip Top Corner)

There are no elements within Sector 4 that are considered to influence groundwater.

5.1.5 Sector 5 – SH1 Ramps to Princes Street Interchange

Elements within Sector 5 that might influence groundwater are:

- Stormwater devices adjacent to Ōtāhuhu Creek; and
- SH1 bridge widening across Ōtāhuhu Creek.

5.1.6 Sector 6 - Local Roads

Elements within Sector 6 that might influence groundwater are:

- Cut through landfill refuse to form the port link road; and
- Stormwater treatment wetland within Miami Stream

5.2 Modelled effects

5.2.1 2D particle tracking

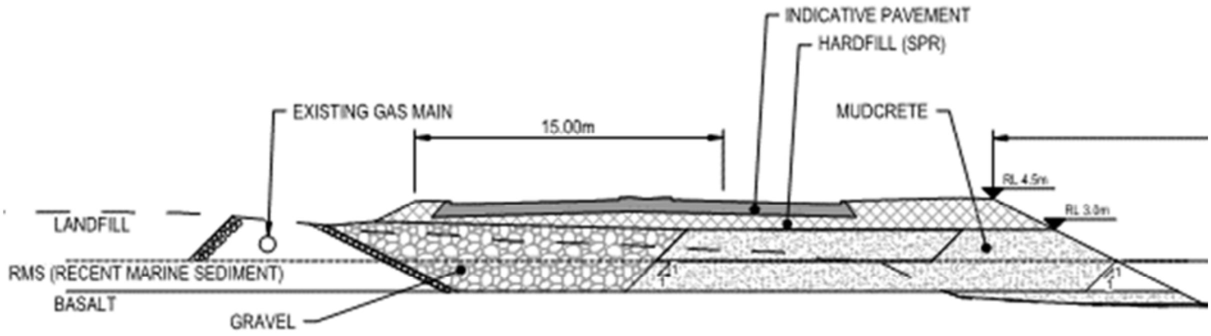
Between Galway Street and Waikaraka Cemetery (part sectors 1 and 2), the road embankment will be constructed separate from or abutted against the existing foreshore. Lined stormwater treatment wetlands will also be created on the seaward side of the embankment over much of its length. This means that there is the opportunity to develop a design that has the potential to attenuate contaminants travelling in groundwater through the landfill (leachate) that might otherwise enter the basalt beneath the landfill and discharge directly to the Inlet.

In order to investigate groundwater/leachate movement, 2D slices oriented perpendicular to the coast were taken from the 3D groundwater flow model and individual “particles” of groundwater tracked as they move naturally through the landfill and underlying ground toward the coast.

Particle movement and travel times were recorded for the present situation and compared with travel times of particles from the same range of locations with the EWL road embankment and stormwater treatment system in place. A range of embankment materials were modelled with the objective of determining the optimal construction to consistently increase the travel time of particles from different parts of the landfill such that the opportunity for attenuation of contaminants moving with groundwater is enhanced. The results of particle tracking are presented in Appendix A.

The resulting optimal embankment configuration is shown in Figure 5-1. It includes an inner granular (permeable) section and a toe down to tuff or basalt and outer section constructed from mudcrete or similar (low permeability) material. This configuration results in a result in lengthening in travel time of leachate through the embankment (with the improved opportunity for attenuation of contaminants) and a small rise in groundwater level inland (< 100mm).

Figure 5-1: Embankment configuration Galway Street to Waikaraka Cemetery



This embankment construction increases travel times of particles in the Galway Street landfill by 200% to 500% on average. Where the lined stormwater pond is constructed as (Figure 5-2), travel times are increased by up to 1000%. This means that metals that travel within the groundwater will tend to attach to sediment particles in the fill or embankment foundation rather than continuing to discharge with groundwater into the inlet.

Figure 5-2: Embankment wetland configuration typical detail

However, at times of high rainfall, groundwater levels upgradient of the embankment may rise and higher level drainage through the embankment will allow such rainfall dominated overflow to discharge either to the stormwater treatment wetlands on the seaward side of the embankment or the inlet. The lengthening of travel times would not be achieved on such occasions but treatment would be achieved in the stormwater wetlands.

Water quality testing indicates that the leachate derived from the landfills can be discharged to and treated within the wetlands.

5.2.2 2D seepage modelling

East of Waikaraka Cemetery (sector 2) the road embankment will come onshore. This means that the road embankment will sit on the Pikes Point West and East landfills and will cover the leachate collection system that exists inside the seawall at the landfills, necessitating its replacement. 2D seepage modelling was carried out to supplement the 3D regional groundwater flow modelling and allow a more detailed assessment of the operation of the current leachate collection system and design of a replacement leachate collection system.

The leachate collection system design solution is shown schematically in Figure 5-3. It comprises a trench excavated through the landfill down to the tuff or basalt and backfilled in part by low permeability material (mudcrete or compacted clay on the seaward side of the trench) and in part by gravel (landward side of the trench). The low permeability section forms a cut-off that will prevent groundwater entering the landfill beneath the road surface. The granular section will form the new leachate collection system and will include a perforated pipe that takes the leachate through the embankment and discharges it to the stormwater treatment wetlands.

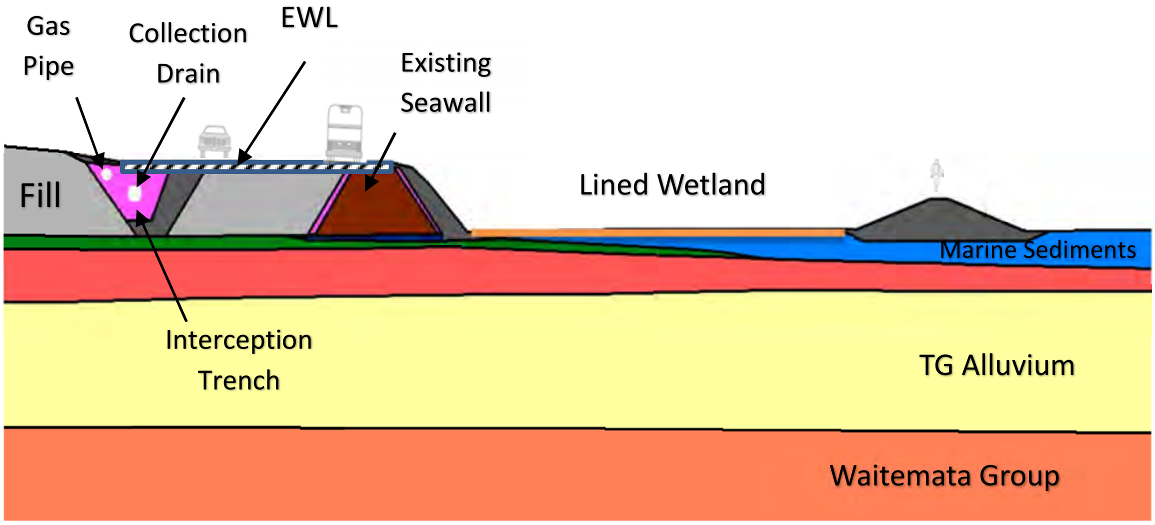
Modelling indicates an average of 140 m^3/day of leachate will be collected in total from the Pikes Point West and East landfills and discharged to the stormwater wetlands.

The design also means that the landfill remaining beneath the road will not receive any further water (as it will be essentially sealed from upgradient flow, from saline ingress and from surface ingress). This means that piles installed to support the road will not form permanent pathways for leachate travel into the basalt.

5.2.3 Leachate collection system construction effects

Local dewatering will be needed to facilitate construction of the leachate collection system. Sheetpiles or similar will be driven through the landfill on the upgradient side of the trench location to provide stability and limit groundwater/ leachate seepage into the open trench. The leachate trench will be constructed progressively and the sheetpiles moved along progressively as the trench is completed. Sheetpiles have been modelled in the 2D MODFLOW – SURFACT model as wall boundaries, with a hydraulic conductivity of 1 x 10^{-8} m/s. Modelling suggests that some 160 m^3/day of leachate will need to be discharged to trade waste from each 100m length of trench.

Figure 5-3: Embankment configuration over Pikes Point landfills

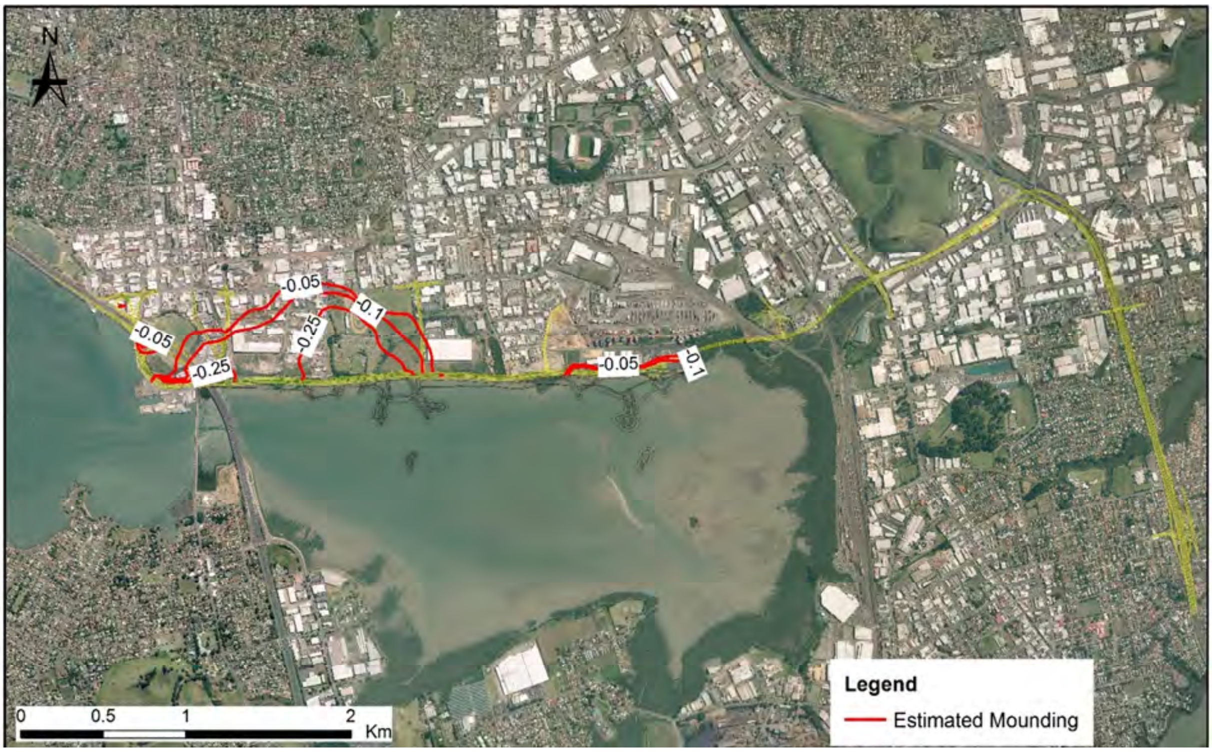


5.2.4 3D groundwater flow modelling

Figure 5-4 and Figure 5-5 show the groundwater levels expected following project completion and the change in groundwater levels from existing levels (groundwater level rise).

Figure 5-4: Modelled groundwater levels after Project construction

Figure 5-5: Change in groundwater levels as a result of the Project (unmitigated) (contours in metres)



5.3 Sector specific effects

5.3.1 Sector 1

Modelled changes to groundwater level resulting from the project in Sector 1 are shown in more detail in Figure 5-6.

5.3.1.1 Embankment fills on Hōpua Tuff Ring

The hydraulic conductivity of the tuff and marine sediments located beneath the footprint of the proposed embankment fills was reduced by an order of magnitude to simulate consolidation in those materials. This results in a small rise in groundwater level on the seaward side of the SH20 Manukau Harbour Crossing of the order of 50mm to 100mm. The very small magnitude of groundwater level rise would not result in adverse effects (groundwater level will remain below ground surface).

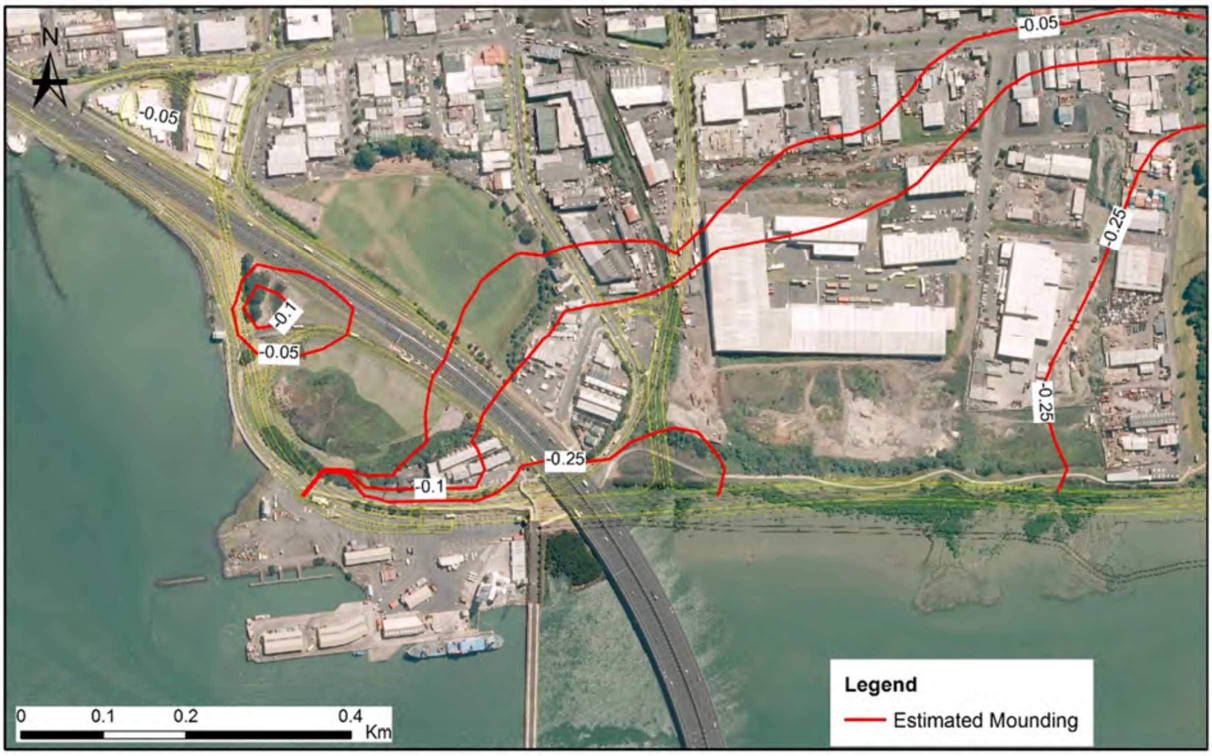
5.3.1.2 Stormwater pond construction

Ponds 1A and 1B will be unlined. Because of their locations in proximity to the coast, neither pond will have a noticeable effect on groundwater levels. Pond 1A will have no measurable effect. Pond B will result in a small rise of groundwater level beneath it that will be indistinguishable from the effect of embankment fill construction.

5.3.1.3 Stormwater ponds 1C and 1D

Ponds 1C and 1D will be formed in the area enclosed by the EWL and existing roads and will be unlined. Because of their location adjacent to the coast, the effect of the ponds is small and is not distinguishable from the mounding of groundwater level resulting from the EWL Trench. We understand that it is currently planned to pump stormwater for discharge further along the alignment.

Figure 5-6: Sector 1: Change in groundwater levels as a result of the Project (contours in metres; negative number indicates groundwater level rise)



5.3.1.4 Lowered road (trench) through Onehunga Port Land and beneath the SH20 Manukau Harbour Crossing

Road level will drop to around RL 0m (with maximum excavation depth to -5m RL) on the seaward side of the tuff ring to allow for an access road between Onehunga Mall and the wharf precinct to pass over the EWL. The trench will comprise some 280m of approach trenches and 60m of covered “box” in the central section. The trench will be constructed using secant piles and will be a watertight structure. The structure will result in a rise in groundwater level of 250 to 350mm on the upgradient side of the trench reducing to 100mm some 250m inland. The magnitude of the groundwater level rise can be accommodated below existing ground level.

5.3.1.5 Foreshore embankment

Much of the groundwater flow from the catchment occurs through the basalts underlying the Project area and this discharge will continue. However, groundwater also resides in the landfills constructed in front of the original shoreline, recharged from rainfall, stormwater and spring leakage. The Galway Street landfill has no leachate collection system and the present seawall is understood to have been constructed from rock with no low permeability core; it is therefore assumed to be permeable.

The foreshore embankment has been designed to facilitate controlled discharge of leachate with the objective of improving leachate quality before it discharges to the harbour. As a result of this, together with the EWL Trench a small rise in groundwater level (100mm extending 300 to 400m inland) is expected.

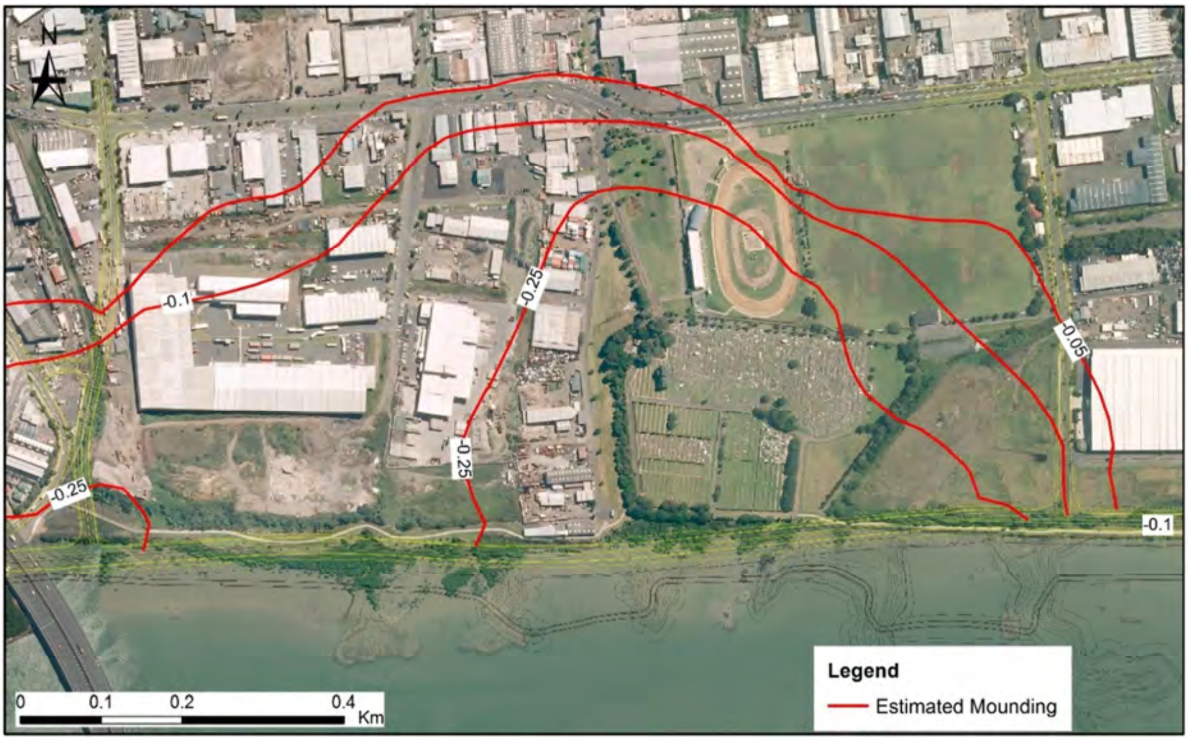
5.3.2 Sector 2

5.3.2.1 Construction of the foreshore embankment adjacent to the existing seawall

From Sector 1 to the eastern extent of Waikaraka Cemetery, the foreshore embankment will be constructed adjacent to the existing seawall as described above. However, the existing groundwater level is higher in the eastern part of Waikaraka Cemetery at < 1m bgl. This is likely to reflect discharge of Captain Springs upgradient of this area and incomplete capture of spring water in pipework.

Modelled changes to groundwater level (groundwater level rise) resulting from the Project in the western part of Sector 2 are shown in Figure 5-7.

Figure 5-7: Sector 2 West: Change in groundwater levels as a result of the Project (contours in metres; negative number indicates groundwater level rise)

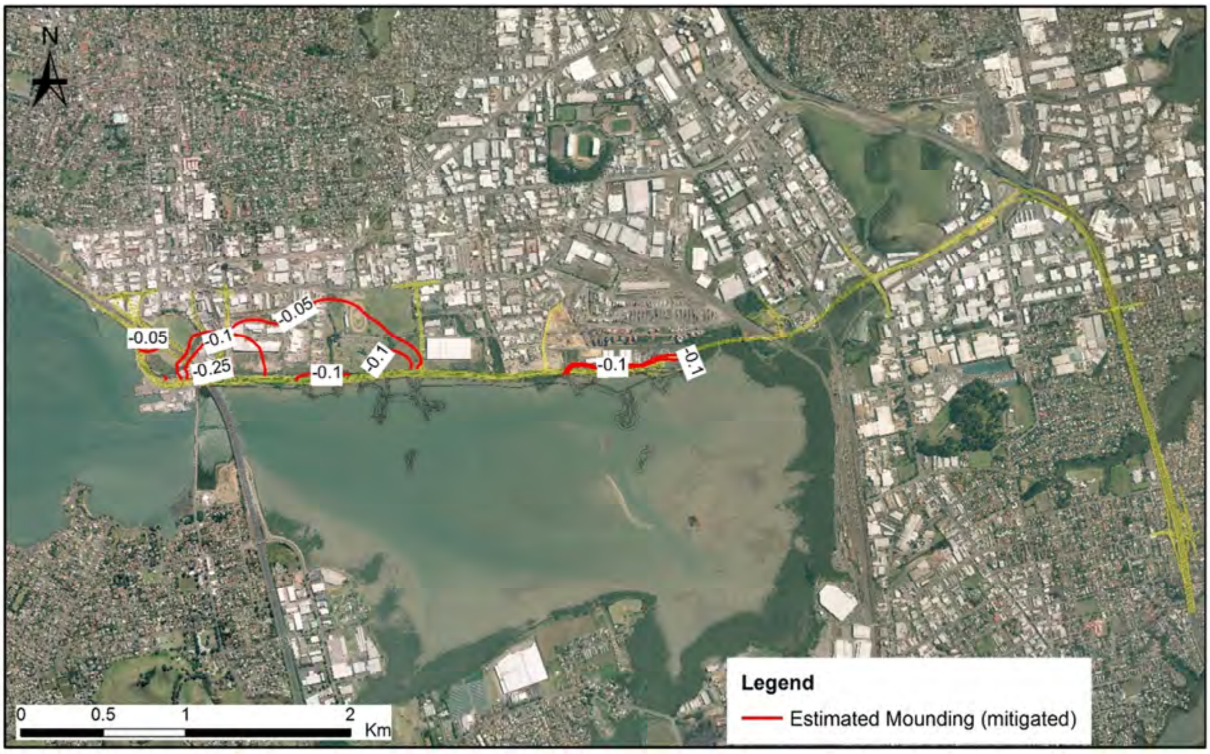


The effect of the embankment and adjacent lined stormwater wetland at this location raises the average groundwater level by 250 to 350mm within 200m to 400m of the EWL, bringing the average groundwater level close to the ground surface. The groundwater level rise reduces to 100mm 450m inland.

The leachate collection system at the Pikes Point west landfill helps to limit the extent of this groundwater level rise, however alternative designs have been considered to further limit this effect.

If marine muds cut from in front of the existing seawall to form the embankment and the foundations of the landforms in the area fronting the cemetery are replaced with gravel (or permeable equivalent) over the depth of the basalt and the landforms are constructed above the gravel, then groundwater can continue to discharge through the basalt and the magnitude of groundwater level rise can be reduced as discussed in Section 6.1 and shown in Figure 5-8.

Figure 5-8: Change in groundwater levels as a result of the Project (mitigated) (contours in metres; negative number indicates groundwater level rise)



5.3.2.2 Construction of the foreshore embankment over the existing landfill

East of Waikaraka Cemetery, the road embankment will be constructed in part over the existing Pikes Point West and East landfills, necessitating replacement of the existing leachate collection system.

Because of the highly compressible nature of landfill, the road will need to be piled where it sits on landfill. Steel H-piles are proposed which would be founded into the top of the underlying basalt rock. However, pile penetration may facilitate leachate leakage into the basalt rock, through which it might then discharge more directly to the harbour. For this reason, the design of the proposed replacement leachate trench includes a low permeability “cut-off” on its seaward side which would prevent entry of groundwater/leachate to the landfill beneath the roadway. It also ensures that leachate gathers in the gravel portion of the leachate collection trench (on the landward side) from where it will be gravity fed through the embankment to the stormwater treatment wetlands.

Modelled changes to groundwater level resulting from the project in this eastern part of Sector 2 are shown in Figure 5-9.

The effect of the road was modelled by comparing the existing situation (including pumping from the existing leachate collection system) with the completed road and new gravity leachate collection system. This results in a groundwater level rise locally of 100mm within 40m of the EWL, and 50mm at 60 to 80m inland.

Figure 5-9: Sector 2 East: Change in groundwater levels as a result of the Project (contours in metres; negative number indicates groundwater level rise)

5.3.2.3 Replacement of the leachate collection system at Pikes Point West and East landfills

It is proposed to maintain functioning of the existing leachate collection system while the new system is built. This will necessitate construction of the new system prior to covering over access to the existing system. Because the existing system is operated by pumping, and removal of the pipework is not proposed, it is expected that this can be readily achieved.

Although preliminary design indicates that a fall sufficient to achieve gravity feed to the stormwater wetlands can be achieved, if a problem were to occur (for example as a result of a prolonged period of rainfall) that resulted in higher leachate water levels then it is desirable to have the ability to pump leachate for removal from site if needed. Therefore, it is proposed to install provision for pumping as a back-up to the gravity system. The gravel portion of the new leachate collection system will be placed on top of a low permeability layer in an effort to limit the abstraction of fresher water from the underlying basalt if pumping were required.

5.3.3 Sector 3

5.3.3.1 Embankment fill and stormwater pond at Hugo Johnston Drive

The road embankment will result in consolidation of the underlying Tauranga Group sediments; however modelling indicates that this will not have a measurable effect on groundwater levels (< 50mm change).

The stormwater pond will be built up against the road embankment to, as far as possible, avoid interference with asbestos fill at this location. This means that there will be no effect on groundwater levels. The presence of asbestos will not affect groundwater quality.

5.3.4 Sector 4

There are no elements of the EWL in Sector 4 that will affect groundwater levels.

5.3.5 Sector 5

5.3.5.1 Stormwater device adjacent to Ōtāhuhu Creek

The stormwater pond will have its base 2m bgl in Tauranga Group. Because of its location close to the Ōtāhuhu Creek bank and within low permeability soils, modelling indicates that the effects on groundwater level are < 50mm and will therefore not be distinguishable from normal groundwater level variations.

5.3.5.2 Stormwater wetland Frank Grey Place

It is proposed to enlarge the existing Frank Grey Place stormwater pond and alter its function to that of a wetland; the effects on groundwater level are < 50mm and will therefore not be distinguishable from normal groundwater level variations.

5.3.5.3 SH1 bridge widening across Ōtāhuhu Creek

Cuts required to facilitate bridge widening at Ōtāhuhu Creek are less than 1m deep and well above groundwater level; no effect on groundwater is therefore anticipated.

Work at the Princes Street/ SH1 interchange will require local cut of up to 2.5 m. This cut will also be above groundwater level and therefore no effect on groundwater is anticipated.

5.3.6 Sector 6

5.3.6.1 Miami Stream stormwater wetland

The main stream flow will be through the wetland in the position of the existing stream; however there will also be a high flow bypass running parallel to the stream to discharge surface water at times of high rainfall. Modelling indicates that the wetland will have no noticeable effect (< 50mm change) on groundwater levels, as the wetland will hold permanent water and discharge to the inlet via culverts with one-way valves.

5.3.6.2 Cut through landfill refuse to form the port link road

The cut is through fill stockpiles that exist above groundwater level and will therefore not impact groundwater.

5.4 Assessment summary

5.4.1 Highway on foreshore embankment

From Sector 1 to the eastern extent of Waikaraka Cemetery, the foreshore embankment will be constructed adjacent to the existing seawall. Construction of the EWL in this location has the additional benefit of lengthening the travel time of leachate residing within the existing closed landfill in this area (with the improved opportunity for attenuation of contaminants) by forcing it to travel through the embankment materials. This is expected to substantially reduce the discharge of metals that might reside within the leachate to the inlet.

The slowing of groundwater travel through the landfill results in a small rise in groundwater level within the landfill, however the magnitude of groundwater level rise is small and is not expected to result in adverse effects, except at the Waikaraka Cemetery where already elevated groundwater levels might rise close to the ground surface, particularly in wet periods. This is exacerbated by the proposed positions of foreshore enhancement (landforms for bird habitat) adjacent to stormwater wetlands either side of the cemetery. Construction of the foreshore landforms above gravel (rather than mudcrete) would allow flow through the basalt to the inlet to continue and would mitigate this effect.

East of Waikaraka Cemetery, the road embankment will be constructed in part over the existing Pikes Point West and East landfills and over the existing leachate collection system. The design of a replacement leachate collection system is such that it will cut off groundwater/ leachate flow to the area of landfill beneath the road. This means that the existing system can be used to pump all remaining leachate from between the new system and the new seaward embankment face which will allow piling for the road to be undertaken without risk of leachate seepage into the underlying basalt rock (and on to the harbour).

The new leachate collection system will operate under gravity and discharge leachate to the stormwater treatment wetlands through the embankment. This is proposed because the quality of the leachate (Appendix B) is sufficient that it can be treated together with stormwater in the proposed wetlands (*Volume 3: Technical Report 12 - Surface Water Assessment*). Provision for removal of leachate by pumping will be made so that pumps could be installed and leachate removed if monitoring indicates pumping is needed under exceptional circumstances to reduce groundwater level in the landfill.

The new road embankment will however cause a small rise in groundwater level, of the order of 50mm to 100mm close to the embankment. This magnitude of groundwater level rise is not expected to result in adverse effects.

5.4.2 Highway elsewhere

Elsewhere the highway will be constructed above groundwater level. Locally embankments will be constructed which might result in local consolidation of sediments beneath and a small reduction in permeability, however no measurable change in groundwater level is expected to result.

5.4.3 Stormwater devices

A number of stormwater detention ponds will be constructed in the vicinity of the alignment to treat stormwater runoff from the road.

The stormwater wetland in sector 3 will be lined. Stormwater wetlands in sectors 1 and 5 will be unlined and may result in some mounding of water beneath them. Mounding is indistinguishable from the effects of the Onehunga Port trench in Sector 1 and from background groundwater level variations in Sector 5.

Locally, in the vicinity of Waikaraka Cemetery, the groundwater level rise will be greater and extend some distance inland of the road (250mm to 500mm rise reducing to 100mm some 350 to 50m inland). This rise could be managed by changing the materials used in the foreshore improvement works so that gravel (rather than mudcrete) is placed adjacent to the existing basalt, allowing continued discharge to the harbour. Mudcrete and lined stormwater wetlands can be constructed above the gravel in this area.

5.4.4 Wetlands and streams

The effects of the Project are largely small rises in groundwater level, rather than drawdown. However, the extent of groundwater level rise does not reach Bycroft Reserve or Captain Springs. No effect on groundwater contributions to existing wetlands and streams is anticipated.

5.4.5 Contaminant (leachate) migration

A benefit of construction of the EWL on the coastal side of the existing closed Galway Street landfill is that travel times of contaminants mobilised in groundwater in the Galway Street landfill (leachate) will be increased on average by 200% to 500% (depending on their location within the landfill and with respect to the stormwater treatment wetlands) and up to 1000% where stormwater wetlands are constructed, allowing additional attenuation and fixing of contaminants within the mudcrete, tuff and clay liner materials, prior to discharge of the water to the harbour.

A new leachate collection system will be developed at the Pikes Point West and East landfills which will allow delivery of leachate under gravity to the stormwater treatment wetlands (rather than pumping and removal off site) where it will be treated together with the stormwater. As discussed above, the leachate quality is sufficient that it can be treated with stormwater in the wetlands (*Volume 3: Technical Report 12 - Surface Water Assessment*).

5.4.6 Coastal environment

Overall the increased attenuation of contaminants that might otherwise discharge through the existing seawall or via basalt from the Galway Street landfill to the harbour will improve the quality of discharge to the inlet and therefore water quality in the inlet.

Use of a low permeability material on the outside and toe of the road embankment will substantially prevent sea water ingress to the Pikes Point landfills, reducing the potential for seawater ingress to generate leachate within the landfill and to transfer leachate to the coastal environment.

The proposed replacement leachate collection system will operate continuously and avoid the need for pumping and transfer of leachate and potentially, clean water that might be unintentionally abstracted from the basalt in response to pumping, for treatment off site.

5.4.7 Groundwater users

The Project is expected to result in small rises in groundwater level locally. The extent of effects does not reach any existing groundwater take. The Project will not impact groundwater users.

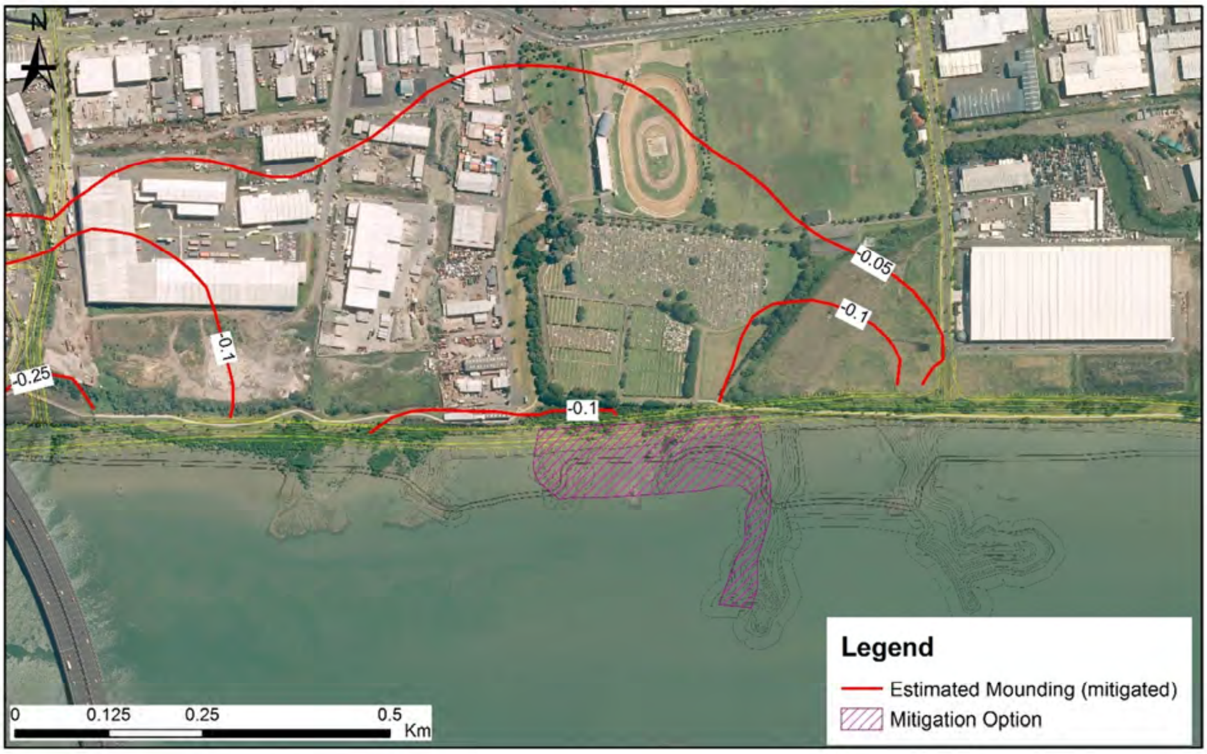
6 Recommendations

6.1 Mitigation

The proposed design is expected to improve the water quality discharging to the inlet and to increase the efficiency of the existing leachate collection system at Pikes Point (West and East). Through the design process, potential effects on groundwater have been largely mitigated. However, construction of the road embankment together with foreshore enhancement and lined stormwater wetlands could result in problematic mounding of groundwater level beneath Waikaraka Cemetery as a result of already elevated groundwater levels and the positioning and construction materials proposed.

A construction methodology for the proposed landforms that includes use of gravel adjacent to the basalt below sea-level in the area fronting the cemetery will allow groundwater flows within the basalt to continue to discharge unimpeded to the inlet and substantially avoid mounding, approximately as shown in Figure 6-1.

Figure 6-1: Sector 2 East: Mitigated change in groundwater levels as a result of the Project (contours in metres; negative number indicates groundwater level rise)



6.2 Monitoring

It is recommended that groundwater level monitoring be carried out in the vicinity of Sectors 1 and 2 to check that groundwater levels do not exceed those anticipated from modelling.

6.2.1.1 EWL Trench

Because the trench will be tanked, a rise in groundwater level will result upgradient. The magnitude of groundwater level rise is not expected to be problematic, however it is recommended that groundwater level monitoring be carried out in this area during and for a period following construction to check that groundwater levels do not rise more than anticipated, which might necessitate additional drainage.

6.2.1.2 Pikes Point closed landfills

It is proposed to replace the existing pumped leachate collection system with a gravity fed system. Provision will be made for installation of pumps and pumping to remove excess leachate, in the event that this were required at some time as a result of particular circumstances that may or may not occur in the future. However, no pumps will be installed at this stage.

It is recommended therefore that groundwater (leachate) levels and quality be recorded for a period prior to and following installation of the new leachate collection system to check that the system is performing satisfactorily.

7 Conclusions

A number of beneficial effects on groundwater flow have been able to be developed through the design of the Project, in particular with respect to increase in travel times of contaminants that might reside within groundwater in the areas of landfill through to the inlet, which is expected to result in overall improvements in water quality in the inlet.

Efficiency of the leachate collection system is also likely to be improved, removing the potential mixing of leachate with freshwater from the basalt beneath or with seawater and the need to pump and dispose of leachate offsite.

The Project will result in a small rise in groundwater level in Sectors 1 and 2. A rise in groundwater level could be problematic in the vicinity of the cemetery because groundwater levels in this area are already elevated, however this effect can be resolved through adjusting the materials used in the foundation of the wetland and recreated landforms in this area.

The extent of effects does not reach consented groundwater bores. Groundwater level rise will not affect groundwater takes in the area.

The Project will not result in groundwater lowering, and therefore consolidation settlement due to groundwater drawdown will not eventuate.

The Project will not alter existing groundwater quality onshore, but improvements to water quality discharged to the inlet are expected.

Overall the Project is not expected to have adverse effects on groundwater (or leachate) levels, flow or quality.

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Earthtech Consulting Ltd report, 1993, Groundwater Investigation scoping report: Pikes Point aftercare Auckland Regional Council

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PDP Ltd, 2005, Global Aquifer Study: Regional Groundwater Model Development Report.

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Appendix A

Groundwater Modelling Report

APPENDIX A

GROUNDWATER MODELLING REPORT

Quality Assurance Statement	
Prepared by	Theo Sarris
Reviewed by	Ann Williams
Approved for release	Patrick Kelly (EWL Alliance Manager)

Revision schedule

Rev. N^o	Description	Prepared by	Reviewed by	Approved by
0	Final for Lodgement	Theo Sarris	Ann Williams	Patrick Kelly

Table of Contents

Appendices

List of Figures

List of Tables

Glossary of Technical Terms/Abbreviations

Abbreviation	Term
AEP	Annual exceedance probability
AEE	Assessment of Effects on the Environment
AMETI	Auckland-Manukau Eastern Transport Initiative
BoI	Board of Inquiry
CMA	Coastal Marine Area
DBC	Detailed Business Case
EPA	Environmental protection authority
EWL	East West Link
EWLA	East West Link Alliance
HAIL	Ministry for the Environment’s hazardous activities and industries list
MCA	Multi Criteria Analysis process
NES	National Environmental Standard
NoR	Notice of Requirement
The NZ Transport Agency	New Zealand Transport Agency
PAUP	Proposed Auckland Unitary Plan
PPV	Peak particle velocity
RMA	Resource Management Act 1991
SEA	Significant Ecological Area
SH(x)	State Highway (number)
The Plan	The Auckland Plan
Anisotropy	Physical properties differ depending on the direction of measurement i.e. horizontal permeability being greater than vertical permeability because of the layered nature of the geological formation
Aquifer	A geological formation that contains sufficient saturated material to yield water
Aquitard	A geological formation that contains water (is saturated) but does not readily yield water
Interbedded	Describes a geological formation or unit that is comprised of multiple beds or layers of different grain size
bgl	Abbreviation for below ground level
Borehole	Hole (nominally 65 mm to 150 mm in diameter) drilled into the ground to allow assessment of characteristics of the soil and rock encountered. Returns a cylindrical soil or rock sample (known as core) to the surface for examination. Typically vertical, but can be inclined or horizontal in order to target specific depths / geological units
Calibration	A comparison between measurements or values. For the context of this report describes the comparison between observed/ tested measurements/ values and those predicted by the numerical model
Dewatering	The removal of water from the soil / rock to reduce flow rate and diminish pressure in order to allow construction to proceed in the dry. In the context of this report, refers to the allowance of water to seep into the open face, be collected in a sump and pumped out of the excavation for disposal

Abbreviation	Term
Drawdown	The lowering of groundwater level due to pumping of a well or in the context of this Project dewatering of an excavation.
GWL	Abbreviation for groundwater level
Homogeneous	Of uniform structure or composition throughout i.e. assumes that material properties such as hydraulic conductivity are constant throughout a unit. Opposite of heterogeneous
Hydraulic Conductivity	In the context of this Project refers to a unit's ability to transmit water. Given as the volume of water (cubic metres) per second, that will transmit through 1 m^2 (i.e. $m^3/s/m^2$ or m/s)
Hydrogeological	Relating to groundwater and the occurrence, movement and properties of water in the ground
Hydrogeological unit	One (or many) geological formations with a distinct set of hydrogeological properties which distinguish it from another formation
In-situ	In natural or original position / place. In the context of in-situ testing refers to testing of soil or rock as it is in the ground, as opposed to removing a sample and testing in the laboratory
Long Term	Permanent condition (post construction)
m RL	Metres Reduced Level. Refers to elevation or height above a standardised 'mean sea level' datum
Negligible	No discernible effect when compared to natural baselines
Orders of magnitude	An estimate of a size or magnitude expressed as a power of 10, used to express the comparative scale between two parameters
Perched water level	An unconfined groundwater body sitting on top of an impermeable (unsaturated) or low permeability (partially to fully saturated) formation
Permeability	The intrinsic ability of a material (natural or man-made) to transmit fluid, usually a function of grain size and pore space between grains, independent of type of fluid e.g. a gravel will more readily transmit water than a silt
Screened interval / unit	Refer to standpipe piezometer
Settlement	Gradual subsidence of the ground or a structure due to compression of the soil; in the context of this report consolidation settlement resulting from lowering of groundwater level within a soil
Slug test (hydraulic conductivity test)	A type of groundwater test undertaken "in-situ" i.e. in a borehole or piezometer. Involves the removal or addition of a "slug" (volume) of water. Observations of the recovery back to static water level allow an assessment of the hydraulic conductivity of the soil / rock exposed in the borehole or piezometer to be made
Stand pipe piezometer	A type of piezometer comprising a length of (typically, and for the purposes of this Project) narrow diameter PVC pipe installed in a bore hole. Over a limited depth the PVC is slotted (i.e. has holes) so that water from the ground can enter into the pipe from that depth / unit; this is referred to as the screen / screened interval / screened depth
Static water level	The naturally occurring level of groundwater within a borehole or piezometer

1 Introduction

1.1 Purpose and scope of this report

The East West Link (EWL) has been identified in central government's Accelerate Auckland package of accelerated transport projects, with specific recognition of the EWL as one of the government's top priority transport projects beyond the RoNS. This report is an integral part of *Technical Report 13 – Assessment of Groundwater Effects* and is prepared for the Transport Agency's East West Link project (the Project). Its purpose is to complement the Assessment of Groundwater Effects report and document the development of the numerical models used for the assessment of the project groundwater effects. The models have been used to simulate the existing groundwater flow regime, and quantify the change in groundwater level or flow that might result from the project construction. Models have also been used to develop the design.

1.2 Project Description

The EWL Project involves the construction, operation and maintenance of a new four lane arterial road from State Highway 20 (SH20) at the Neilson Street Interchange in Onehunga, connecting to State Highway 1 (SH1) at Mt Wellington as well as an upgrade to SH1 between the Mt Wellington Interchange and the Princes Street Interchange at Ōtāhuhu. New local road connections are provided at Galway Street, Captain Springs Road, the port link road and Hugo Johnston Drive. Cycle and pedestrian facilities are provided along the alignment.

The primary objective of the Project is to address the current traffic congestion problems in the Onehunga, Penrose and Mt Wellington commercial areas which will improve freight efficiency and travel reliability for all road users. Improvements to public transport, cycling and walking facilities are also proposed.

For description purposes in this report, the Project has been divided into six sectors. These are:

Sector 1.	Neilson Street Interchange and Galway Street connections
Sector 2.	Foreshore works along the Māngere Inlet foreshore including dredging
Sector 3.	Anns Creek from the end of the reclamation to Great South Road
Sector 4.	Great South Road to SH1 at Mt Wellington
Sector 5.	SH1 at Mt Wellington to the Princes Street Interchange
Sector 6.	Onehunga local road works

A full description of the Project including its design, construction and operation is provided in Part C: Description of the Project in the Assessment of Effects on the Environment Report contained in *Volume 1: AEE* and shown on the Drawings in *Volume 2: Drawing Set*.

2 Ground Conditions

2.1 Project Location

The site is located in the Auckland suburbs of Onehunga, Penrose and Ōtāhuhu approximately 10 km south of the Auckland CBD. The proposed EWL alignment stretches from SH20 at the Neilson Street Interchange, connecting to SH1 at Mt Wellington and involves widening the existing SH1 to the Princes Street Interchange. New local road connections are provided at Galway Street, Captain Springs Road, the Onehunga Wharf Access and Hugo Johnston Drive. Cycle and pedestrian facilities are also planned along the alignment.

2.2 Regional Geology

The project area is located within the Waitematā basin, a sedimentary basin which formed as a result of tectonic subsidence some 20 million years ago. Sediments from erosion of the surrounding land mass and andesitic volcanism that was occurring to the west accumulated in the basin.

Volcanism from the Auckland Volcanic Field occurred from 250,000 to 600 years ago; the field is still considered active. Volcanism generated tuff (compacted, often stratified volcanic ash and debris), and basalt lava flows.

2.3 Project Geology

Basalt lava and tuff overlie and are locally interbedded with a variable thickness of Tauranga Group alluvium, comprising pumiceous silt, sand and gravel with muddy peat and non-welded and alluvially reworked ignimbrite and tephra. The Auckland Volcanic Field basalts have been differentiated in order to guide understanding of likely preferential flow paths of groundwater through them.

The volcanics are bound to the east by an uplifted block of Waitematā Group sandstone and siltstone, although some lava and tuff from Mt Wellington volcano have flowed around the block from the north-east in the area of Anns Creek.

Recent marine sediments (part of the latest Tauranga Group) are found overlying the Auckland Volcanic Field and older Tauranga Group soils at the coastal margin and offshore, and partially infill Hōpua crater (Gloucester Park).

The Onehunga Bay and Manukau Inlet foreshore have been progressively reclaimed with landfill and engineered fill extending some 500 m inland from the present foreshore.

The 1:250,000 Geology of the Auckland Area map (Edbrooke, 2001) shows the site to be underlain by the following geological units:

- Fill: Landfill areas containing re-compacted clay- to gravel-sized materials, sometimes including demolition debris.
- Refuse landfill: Crushed and buried refuse in landfill areas.
- Recent Marine Deposits: Sand, silt mud and clay with local gravel, shell and organic beds.
- Auckland Volcanic Field Basalt: Fine grained olivine basalt or basanite lava flows.
- Auckland Volcanic Field Tuff: Lithic tuff, pre-volcanic materials, basaltic fragments, and unconsolidated ash and lapilli deposits.
- Tauranga Group: Pumiceous mud, sand and gravel with muddy peat and lignite.
- East Coast Bays Formation (Waitemata Group): Alternating sandstone and mudstone with interbedded volcaniclastic grits.

Further details on project geology as well as sector specific details are presented in the EWL Geotechnical Interpretative report.

3 Conceptualisation of Hydrogeology

This section provides a simplified conceptual understanding of the hydrogeological regime. This conceptual model forms the basis of the assumptions used for the development of the detailed numerical model.

3.1 Geological model

A 3D subsurface ground model was developed from existing and current field investigations using the software Leapfrog® Geo 3.1. The ground surface used in that model was obtained from the project's GIS team (Auckland Council LIDAR 2014/2015) and is consistent with the surface used for civil and structural design of the project. Published geological maps (Kermode, 1966; Kermode and Searle, 1966; Kermode, 1992 and Edbrooke et al, 2001) were also used to assess the geology underlying the project area. Details of the development of the subsurface ground model are provided in the Geotechnical Interpretive Report (GIR).

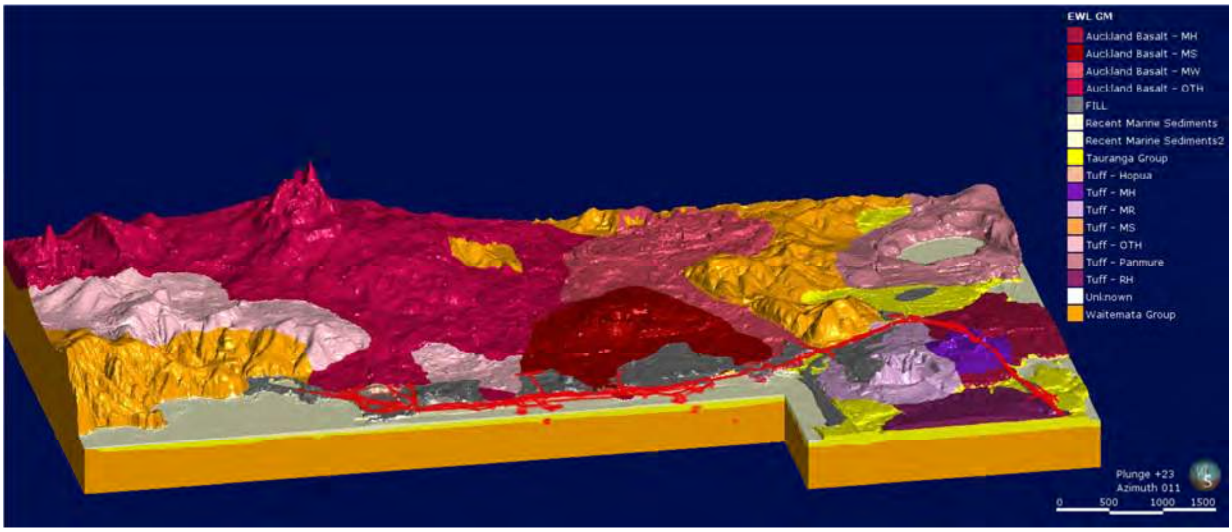
The extent of the ground model is shown in Figure 3.1.

Figure 3.1: Area covered by the ground model

The ground model (Figure 3.2) distinguishes the following geological units:

- Fill (reclamation and landfill, including cleanfill, domestic and other waste up to 10 m thick)
- Recent Marine Sediments (very soft silt and clayey silt up to 5 m thick)
- Tuff (predominantly One Tree Hill, Hōpua, Mount Richmond and Panmure Basin; sandy silt and silt with fine gravel beds up to 18 m thick)
- Auckland Basalt (One Tree Hill, Mount Smart, Mount Wellington and McLennan Hills; strong variably vesicular basalt, fractured near the top and bottom of flows, up to 25 m thick)
- Tauranga Group Alluvium (soft to very stiff silts with minor sand, clay and peat beds up to 20 m thick)
- Waitemata Group (extremely to very weak interbedded sandstone and siltstone).

Figure 3.2: Representation of 3D ground model



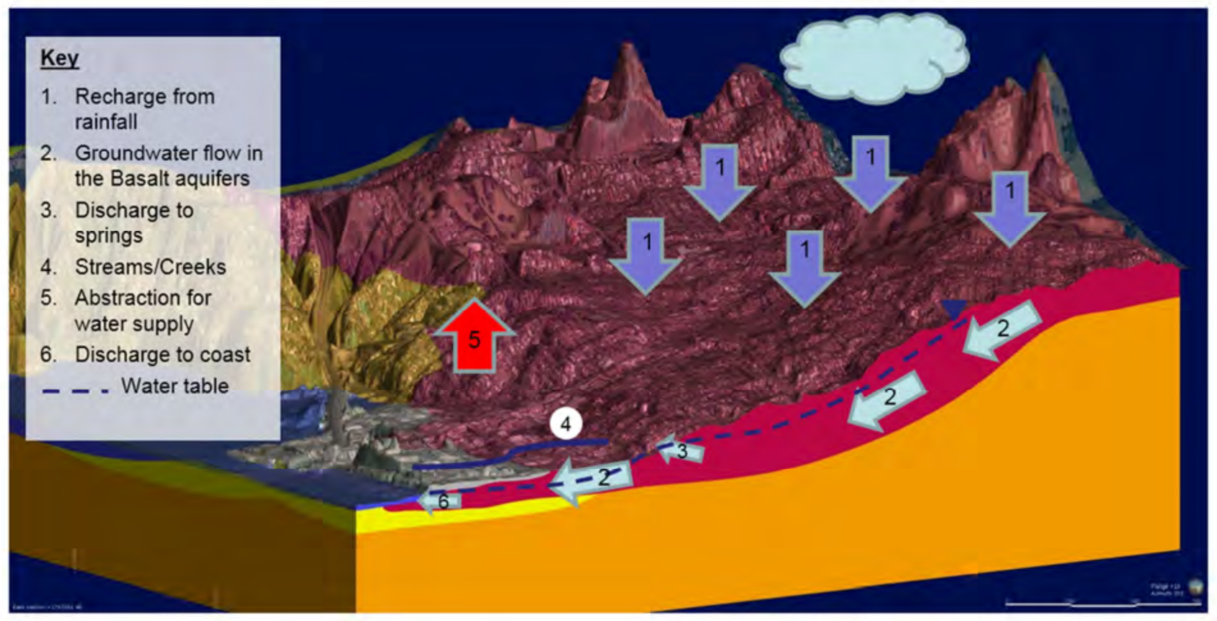
3.2 Conceptual Groundwater Flow Model

Groundwater flows from elevated ground in the north and discharges to the coastal areas of the Māngere Inlet, as springs at the original shoreline, from basalt flow margins into Anns Creek (which discharges to the coast) and through the basalt margins offshore. Anns Creek also drains water from Hamlin Hill. Actual flow paths may be quite sinuous according to variations in hydraulic characteristics of the lava flows and the underlying paleo-topography.

The springs have been largely piped through the areas of landfill at the foreshore to the present coastline. Groundwater continues to flow through the basalt largely below the landfills and discharge through basalt offshore. However a water table has established within the landfills along the Onehunga foreshore at around 2.5 m bgl, except in the coastal area below Captain Springs where it is within 1 m of the ground surface.

Most groundwater flow occurs within the shallow, unconfined to semi confined basalt aquifers. These aquifers have moderate to very high permeability, due to shrinkage (and structural) fractures of the rock, cavities resulting from differential cooling of the flows and high porosity of associated scoriaceous or vesicular basalt. Rainfall directly infiltrates these near surface aquifers, limiting surface runoff and the formation of significant rivers or streams. The basalt aquifers are underlain by lower permeability Tauranga Group alluvial sediments and Waitemata Group sandstone and mudstone that have more limited ability to transmit groundwater. As a result, where the gradient of the basalt aquifers decreases near the coast and groundwater levels approach the surface, spring discharges occur. A schematic of the area's conceptual groundwater model is shown in Figure 3.3.

Figure 3.3: Conceptual groundwater model schematic



3.3 Hydrogeological Units

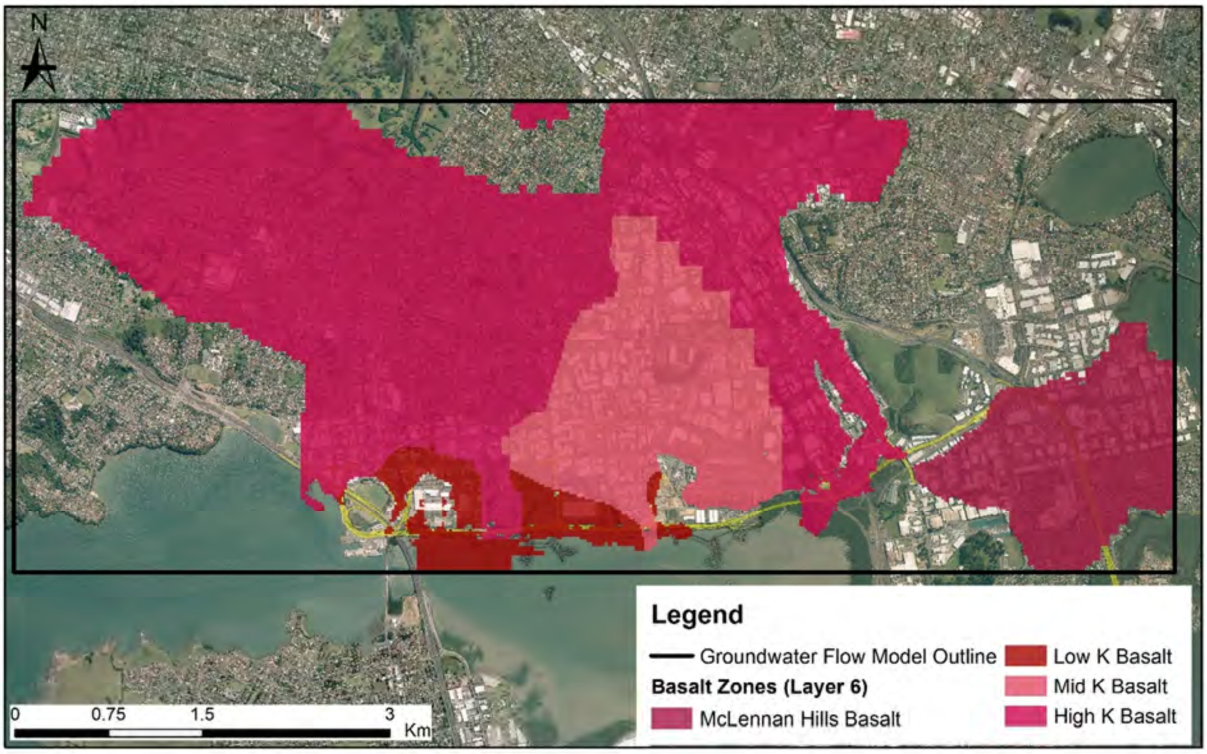
The geological units have been broadly adopted as hydrogeological units. However, hydraulic conductivity zones have been developed for the basalts according to the results of in-situ hydraulic conductivity tests carried out in boreholes, the results of pumping tests and well performance records and work carried out previously by others (Earthtech, 1993; PDP, 2005; Schayen, 2004). Generally lower permeability basalts are encountered beneath the western and eastern parts of the reclaimed areas. In these areas fines may have entered fractures in the shallow basalt and reduced the ability of the basalt to transmit groundwater. However long unbroken cores of dense basalt with few vesicles were also recovered from a number of the boreholes indicating a lower than typical hydraulic conductivity in these materials. Table 3.1 summarizes the project hydrogeological units and their properties.

Table 3.1: Hydrogeological Units and typical properties

Hydrogeological Units	Typical Properties
Fill	Variable, ranging from low to high permeability
Recent Marine Sediments	Loose silty sediments, expected to be moderately permeable
Recent Consolidated Marine Sediments	Consolidated silts and clayey silts, aquitard
Tuff	Varies from sandy silt to gravel beds; moderate to low permeability
Auckland Volcanic Field Basalts	Variable vesicular fractured basalt to dense unfractured basalt: very high permeability to moderate permeability aquifer
Tauranga Group	Soft to stiff silts, moderately low permeability aquifer
Waitemata Group	Extremely weak to weak sandstone and siltstone, moderately low permeability

The adopted basalt hydraulic conductivity zones used in the groundwater flow models are shown in Figure 3.4.

Figure 3.4: Conceptual Groundwater Flow Model: basalt hydraulic conductivity zones



4 Groundwater Level Monitoring and Hydraulic Conductivity Testing

The groundwater level records from some 139 locations were used to characterise regional flow directions and water table elevation. These include 81 monitoring locations identified in the Auckland Council (AC) geotechnical database and the AC Environmental monitoring programme (AC has 14 regularly monitored piezometers in the Onehunga area). These records were supplemented by levels recorded in 35 geotechnical investigation boreholes, 17 groundwater monitoring bores, and 12 environmental monitoring bores, installed in April to June 2016 as part of the project. The location of these monitoring points is shown in Figure 4.1. Project piezometers are labelled in Appendix A1.

Figure 4.1: Overview of groundwater level record locations

Standpipe piezometers were installed in all on-land machine boreholes, with the exception of BH2028a, to allow measurement of short and long-term fluctuations in groundwater level and to better define flow directions. Piezometer installation details are provided on each borehole log in the Geotechnical and Geoenvironmental Factual Report.

The standpipe piezometer installations consist of nominally 50 mm diameter uPVC pipe with a slotted screen section located in the response zone of interest. Screened sections are backfilled with 2 mm K2 gravel which extends above and below the screen. A bentonite plug has been placed above and below each screened section to confine the targeted area.

Data loggers (leveloggers) were installed in 20 of the standpipe piezometers recording groundwater levels at 15 minute intervals. These measurements allow response to rainfall and tidal movement to be distinguished. A manual barometric compensation to the level data was undertaken using the Barologger recordings, installed on site in borehole BH4001.

The results of groundwater level monitoring are presented in Appendix A2. The monitoring results indicate variable groundwater responses to rainfall. Piezometers BH4006 and BH4007 (both screened in basalt) recorded a rise in groundwater level of approximately 700 mm over a 15 hour period in response to rainfall on 26 June 2016. During and immediately after the same rainfall event, groundwater levels in other piezometers increased by as little as 150 mm. Piezometers located near the Watercare production bores (i.e. BH4002, BH4003 and BH4003A) indicate an initial increase followed by rapid groundwater level decline, most likely in response to pumping commencing after the detection of increased groundwater table. A tidal response of around 0.01 – 0.06 m was also evident in some piezometers (typically < 0.01 – 0.02 m).

4.1 Permeability Testing

In-situ permeability testing was undertaken in 16 project boreholes, to provide an understanding of the hydrogeological characteristics of the soils in the project vicinity. The permeability test locations are shown in Figure 4.2.

Figure 4.2: Permeability testing locations

4.1.1.1 Falling Head Tests

Falling head (slug) permeability tests were conducted in three piezometers screened in the Waitemata Group rock. The bores were developed and static water level was recorded before a prescribed volume of water was added to the piezometers. Water level recovery was then recorded until it reached the pre-test level, or until there was no level change for 5 consecutive readings. Results from the falling head tests are presented in Appendix A3 and summarised in Table 4.1.

Table 4.1: Falling head test summary

BH ID	Top of Screened interval (m bgl)	Bottom of Screened interval (m bgl)	Permeability (m/s)
BH4003	22.3	25.3	7.13E-08
BH4004	22.5	25.5	1.07E-07
BH4012	15.5	18.5	8.86E-07

4.1.1.2 Packer Permeability Testing

Eleven packer permeability tests, using a single packer, were undertaken in selected groundwater machine boreholes. These tests targeted the Auckland Volcanic Field Basalts and were undertaken during drilling. The test data and analysis is included in Appendix A4 with Lugeon values reported on the relevant logs and the results summarised in Table 4.2.

Table 4.2: Packer test summary

BH ID	Top of Screened interval (m bgl)	Bottom of Screened interval (m bgl)	Permeability (m/s)
BH4001	6.0	10.5	1.0E07
BH4002	5.5	10.5	3.0E-06
BH4003	5.0	10.5	8.7E-06
BH4004	5.75	12.5	3.4E-06
BH4005	8.5	15.0	2.7E-05
BH4006	3.5	8.25	1.8E-05
BH4007	3.75	9.0	2.5E-06
BH4008	5	9.75	1.8E-05
BH4009	5.5	10.5	1.3E-05
BH4010	6.5	10.5	1.0E-05
BH4011	2.5	5.0	4.3E-05

4.1.1.3 Pumping Tests

Stepped rate and constant rate pumping tests were undertaken in two boreholes (BH5005-Pump and BH5008-Pump) to determine hydraulic properties of the basalt and to determine whether changes in groundwater level in the basalt would affect groundwater levels in the overlying fill. Both bores were developed following completion of well installation. Groundwater levels were monitored in the tested wells and monitoring bores for 24 hours prior to testing.

A stepped rate test comprising four steps each of one hour duration was undertaken in each bore. The discharge rates for each step and bores used for monitoring groundwater levels during each test are summarised in Table 4.3. Groundwater levels were monitored continuously during each test and for 24 hours following the end of pumping to confirm groundwater level recovery to antecedent conditions.

A pumping rate of 1.3 l/s was selected for the constant rate pumping test carried out in bore BH5005-Pump based on the stepped rate test results and was maintained for 2.5 days, when pump failure interrupted the test. Groundwater recovery was monitored in all monitored bores (Table 4.3) for the test, for 2.5 days after pumping ceased.

The second constant rate pumping test was undertaken in bore BH5008-Pump. The bore was pumped for 4 days at a constant rate of 1.0 l/s, while groundwater levels were monitored in 5 project piezometers (Table 4.3). On cessation of pumping groundwater recovery was monitored for 3 days.

Table 4.3: Pumping test summary (all tests carried out in basalt)

BH ID	Screen Depth (m bgl)	Stepped Rate Discharge (l/s)	Constant Rate Discharge (l/s)	Monitoring Bores
BH5005_PUMP	7.0 – 10.0	0.4, 0.7, 1.0, 1.3	1.3	BH5005, BH5005a (Fill), BH5006, BH2032
BH5008_PUMP	8.5 - 11.5	0.4, 0.7, 1.0, 1.3	1.0	BH5008, BH5008a (Fill), BH2023, BH4009, BH4010a

The analysis of the pumping test data was undertaken using AQTESOLV Pro 4.0 and outputs are presented in Appendix A5. Results from the step rate tests analysis, for both boreholes, show a better fit for the recovery data than pumping data. Estimating aquifer properties from recovery data has the benefit of removing influence due to pump rate variation.

A summary of the estimated range of the hydraulic properties is presented in Table 4.4.

Table 4.4: Pumping test results summary

BH ID	Screened Material	Hydraulic conductivity (m/s)	Transmissivity (m^2/d)	Storativity
BH5005_PUMP	Basalt	1.7E-5 – 7.0E-4	11 – 53	6.5E-4 – 1.2E-3
BH5008_PUMP	Basalt	2.1E-5 – 1.1E-4	31 – 57	1.2E-4 – 2.7E-3

5 2D Groundwater Flow Modelling

A series of 2-D groundwater models were created to investigate travel times of leachate (contaminants travelling in groundwater) through the Galway Street and Pikes Point West and East Landfills to the coast currently and compare them with travel times assuming different EWL configurations and construction materials.

5.1 Model Development

5.1.1 Model Code

The numerical model was created in Visual Modflow Pro 4.6, developed by Schlumberger Water Services. Visual Modflow Pro is a pre- and post- processing software that was used for input file generation and output manipulation and visualization. For the groundwater flow simulation, the numerical engine MODFLOW – SURFACT v.4 from HGL was used. The main advantage of MODFLOW – SURFACT is the ability to simulate unsaturated flow conditions.

Particle tracking was undertaken with MODPATH v.3 (Pollock, D.W., 1994)[1], a particle tracking post processing program designed to work with MODFLOW flow simulations. In MODPATH output from steady-state or transient MODFLOW simulations is used to compute paths for “particles” of water moving through the simulated groundwater system.

5.1.2 Model Extent and Boundaries

Two locations were selected as representative of the ground conditions: the first was along Victoria Street (Sector 1 through Galway Street Landfill), and the second along Captain Springs Road (Sector 2 through Pikes Point West Landfill)[2]. Along Victoria Street the fill overlies consolidated marine sediments and tuff, while along Captain Springs Road the fill was placed on tuff. Each model was 2.1 km long, extending 800 m into the harbour to allow consideration of the proposed lined stormwater treatment wetland and coastal bund. The geological profile of each model was obtained from the 3D ground model for the project.

The model area was discretized by 656 columns and 45 layers. Grid cells have dimensions of 0.3 m x 0.2 m (H x V) in the vicinity of the shorefront, widening gradually at the outer model boundaries (Figure 5.1).

Constant head boundaries were applied to the upgradient model boundary and on the top of the marine sediment layer in the harbour. The constant head values were selected to reproduce the average water levels recorded along the cross-section. On the model surface rainfall recharge was applied in accordance with the regional 3D model. Furthermore the hydraulic conductivity values used were those obtained from the first stage calibration of the regional model as set out in Table 6.2.

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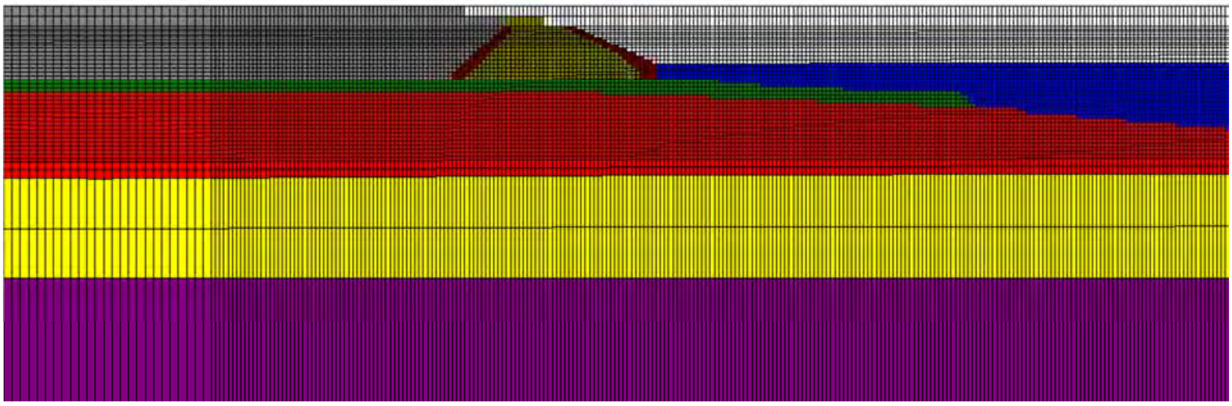
[1] Pollock, D.W., 1994, Source Code and Ancillary Data Files for the MODPATH Particle Tracking Package of the Ground-Water Flow Model MODFLOW -- Version 3, Release 1: U.S. Geological Survey Open-File Report 94-463.

[2] Additional cross-sections have been considered during earlier stages of the project, before the proposed design was finalized; these results are not presented here as they are not relevant to the proposed design.

Figure 5.1: Cut out of the 2D model grid on Captain Springs Road



5.1.3 Particle Tracking Results

Particle movement and travel times were recorded for the present situation and compared with travel times of particles from the same range of locations with the EWL road embankment and stormwater treatment system in place. A range of embankment materials were modelled with the objective of determining the optimal embankment construction configuration to consistently increase the travel time of particles from different parts of the landfill such that the opportunity for attenuation of contaminants moving with groundwater is enhanced.

Embankment materials considered included sand, gravel (permeable hardfill) and mudcrete. Configurations that have been investigated included various thicknesses of permeable core, ranging from 5 m to 20 m, with an outer mudcrete shell. For every core configuration two options for toe construction were considered: solid mudcrete toe, and split toe consisting partly of the same permeable core material and partly of mudcrete.

A graphical representation (not to scale) of the considered construction material configurations is shown in Figure 5.2.

Figure 5.2: Cut out of the 2D model grid on Captain Springs Road

Four and five particles for the Victoria St and Captain Springs Rd cross-sections respectively have been considered at distances ranging from 25 m to 130 m from the existing shorefront. The particle tracking results are shown in Figures 5.3 through 5.6. The graphs show calculated travel time in days, from particle generation to discharge in the harbour. Particles are labelled P1 through P5 and different colour bars correspond to different construction materials and configuration. Figures 5.3 and 5.4 (Victoria St cross-sections) have been truncated to maximum travel time of 2,000 days, even though modelling indicated values up to 8,000 days. This is done in order to better quantify average improvements over the existing conditions, which more closely represent the anticipated benefits.

Figure 5.3: Victoria Street section: travel times results for gravel core

Figure 5.4: Victoria Street section: travel times results for sand core

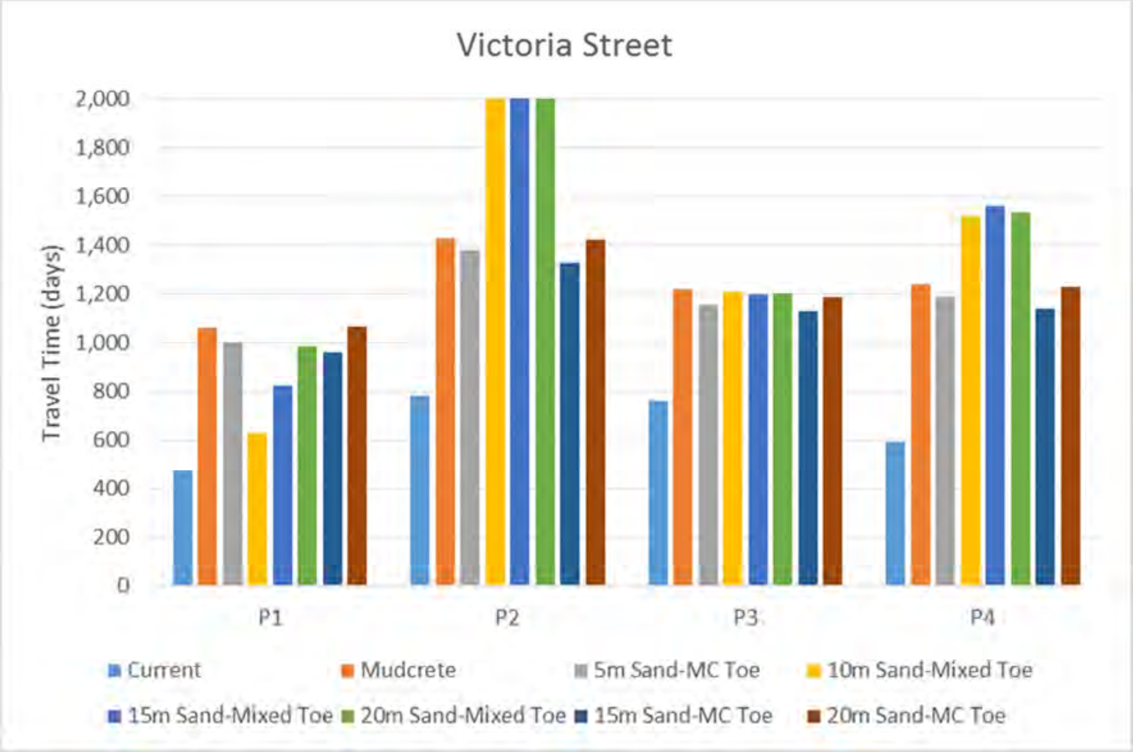


Figure 5.5: Captain Springs Rd section: travel times results for gravel core

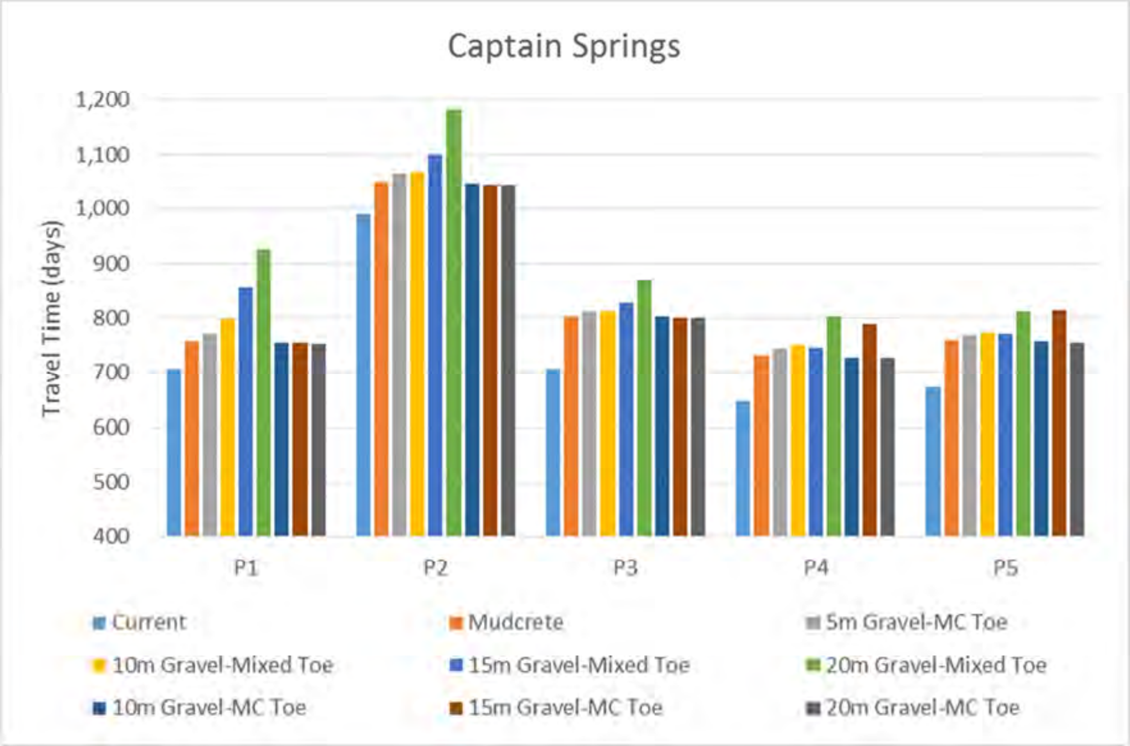
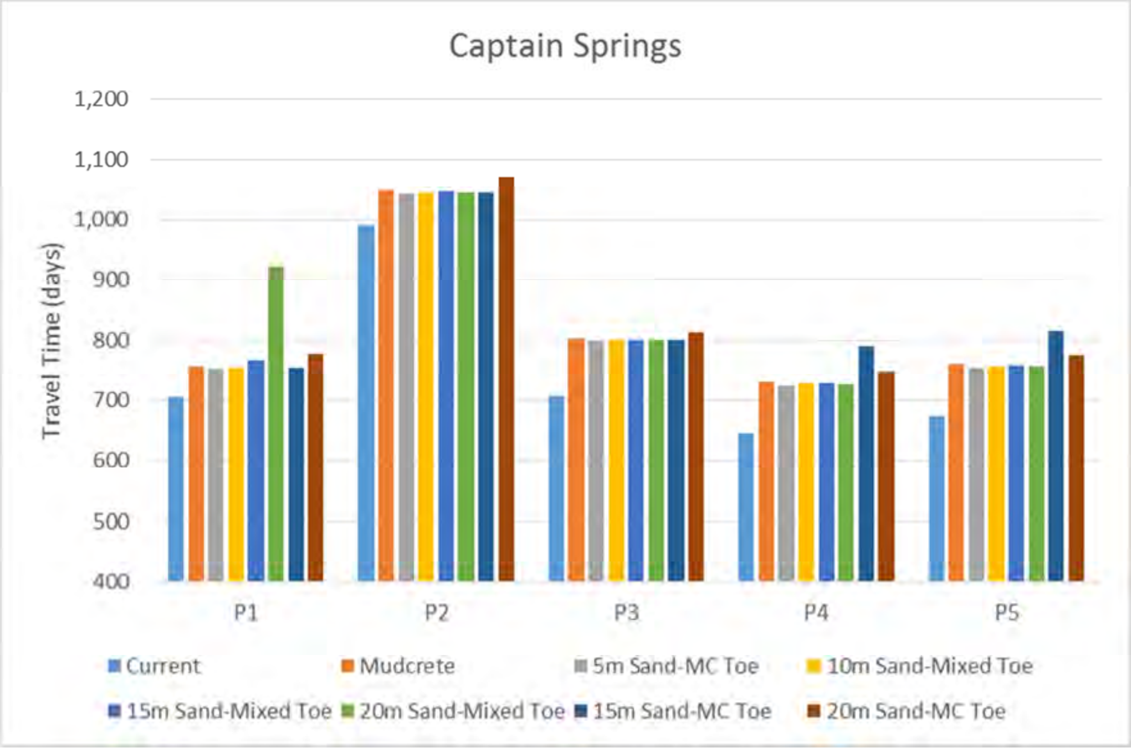


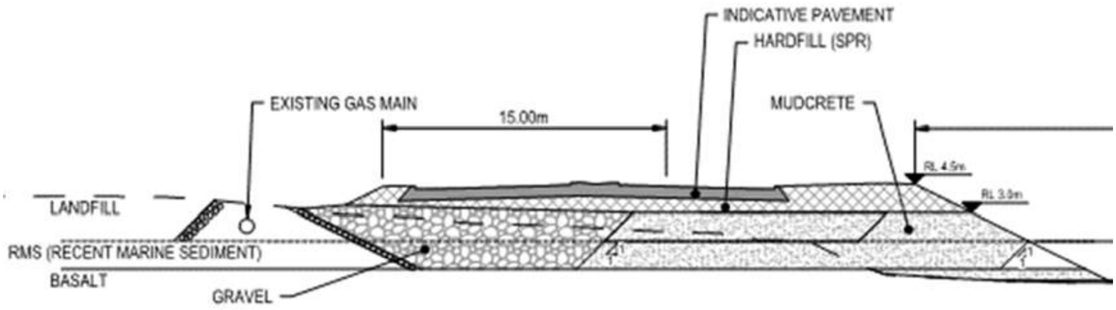
Figure 5.6: Captain Springs Rd section: travel times results for sand core



Simulation results suggest that all considered options would increase travel times, some by up to 1000 % (i.e. Victoria St cross-section with 15 m gravel core and mudcrete toe). Improvement magnitude is affected by the existing seawall in the vicinity of Captain Springs Rd and Miami Parade. In this area, assuming the wall is constructed with a lower permeability core (not able to be confirmed during ground investigations), some attenuation has already been achieved and therefore the potential for improvement is smaller.

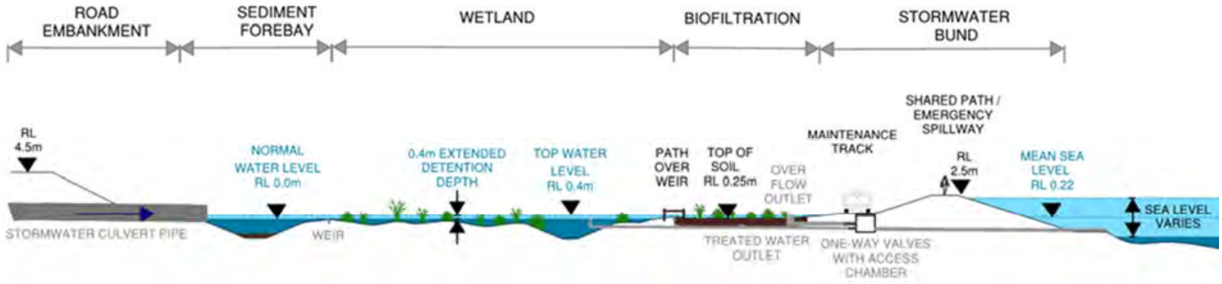
The resulting optimal embankment configuration is shown in Figure 5.7. It includes an inner granular (permeable) section, and an outer section constructed from mudcrete or similar (low permeability) material. This embankment construction increases travel times by 200 % on average (100% for the areas closest to the shorefront).

Figure 5.7: Embankment configuration Galway St to Waikaraka Cemetery



Where the lined stormwater pond is constructed as shown in Figure 5.8, travel times are expected to increase further due to the longer travel path before contaminants moving with groundwater are released to the inlet. Total travel time is expected to increase by 500 % on average and by 200 % for the areas closest to the existing shore.

Figure 5.8: Embankment wetland configuration typical detail



5.2 2D Seepage modelling

5.2.1 Waikaraka Cemetery

A two-dimensional model was developed to give a preliminary indication of groundwater effects in Waikaraka Cemetery. The model was developed in SEEP/W and geology geometry was exported from the 3D Leapfrog model. Parameters and boundary conditions used were the same as those in the 3D regional model. 2D results indicate that embankment construction might result in a long term increase in groundwater levels of 250 mm adjacent to the embankment, reducing to 200 mm some 150 m from the existing shorefront. Not surprisingly, this rise is slightly greater than anticipated by 3D modelling because it assumes an infinite 2D section.

5.2.2 Leachate Collection System

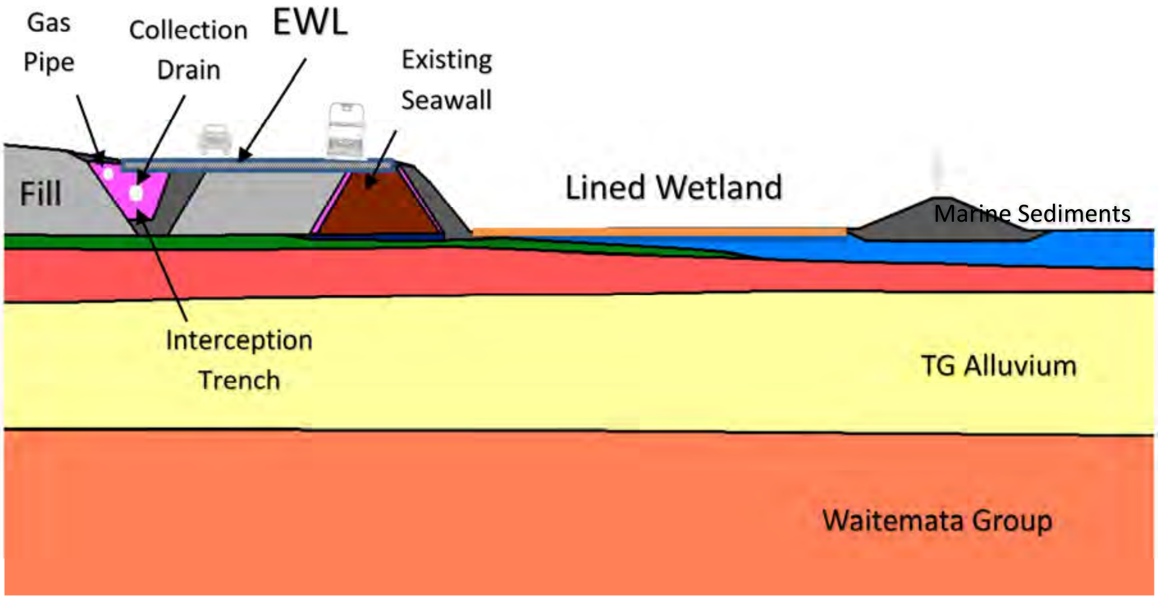
In Sector 2, East of Waikaraka Cemetery where the road embankment will come onshore, the existing leachate collection system will be covered and will need to be replaced. 2D seepage modelling was carried out to supplement the 3D regional groundwater flow modelling and allow a more detailed assessment of the operation of the current leachate collection system and design of a replacement leachate collection system. This assessment focused on identifying drainage configurations that would maximize leachate interception from groundwater originating or traveling through fill and landfills, while minimizing abstraction of fresher water travelling through the underlying basalts.

The drainage pipe was simulated using the MODFLOW-SURFACT drain boundary condition, while the onshore road pavement was assumed impermeable, thus not allowing water to infiltrate in the underlying soils. Numerical results suggest that depending on the soils that separate the basalts and the fill there is potential for the drain to take groundwater from the basalt. This is likely to occur with the current system.

Several alternative interception system scenarios have been modelled. The preferred leachate interception system design solution is shown schematically in Figure 5.9. It comprises a trench excavated through the landfill down to the tuff or basalt backfilled in part by low permeability material (mudcrete or compacted clay over its base and on the seaward side of the trench) and in part by gravel (landward side of the trench). The low permeability section forms a cut-off that will prevent groundwater entering the landfill beneath the road surface and limit take from the basalt. The granular section will form the new leachate collection system and will include a perforated pipe that takes the leachate through the embankment and discharges it to the stormwater treatment wetlands.

2D modelling indicates a maximum of 140 m^3/day of leachate will be collected from the Pikes Point West and East landfills and discharged to the lined stormwater treatment wetlands in the Inlet. This is a conservative estimate as it does not account for the varying groundwater level along the shorefront, tidal effects (although monitoring of boreholes installed in this area indicates negligible tidal influence in this area), and the varying invert level of the collection drain that is necessary to achieve gravity driven discharge.

Figure 5.9: Embankment configuration over Pikes Point landfills



The design also means that the landfill remaining beneath the road will not receive any further water (as it will be essentially sealed from upgradient flow, from saline ingress and from surface ingress). This means that piles installed to support the road will not form permanent pathways for leachate travel into the basalt.

Ongoing breakdown of refuse may generate a small amount of liquid. Inclined drains through the base of the embankment would be used to discharge any such liquid to the stormwater wetland.

5.2.3 Construction effects

Local dewatering will be needed to facilitate construction of the leachate collection system. Sheetpiles or similar will be driven through the landfill on the upgradient side of the trench location to provide stability and limit groundwater/ leachate seepage into the open trench. The leachate trench will be constructed progressively and the sheetpiles moved along progressively as the trench is completed. Sheetpiles have been modelled in the 2D MODFLOW – SURFACT model as wall boundaries, with a hydraulic conductivity of 1×10^{-8} m/s. Modelling suggests that some 160 m^3/day of leachate will need to be discharged from each 100 m length of trench.

6 Regional 3D Groundwater Flow Model

The purpose of the 3-dimensional groundwater flow model was to provide an understanding of how the proposed EWL will affect groundwater flow in the aquifers underlying the greater project area, to allow quantification of this interaction and to investigate the potential benefit of various mitigation options. The model conservatively assumes steady state conditions; that is that boundary conditions (rainfall and harbour water levels) remain constant at their average values. As actual conditions will vary, so will actual effects, however steady state modelled effects will be greater than those estimated by a transient model. This is because effects take time to develop and therefore in the naturally changing environment the extremes of the variability will naturally counter (mitigate) one another.

6.1 Model Development

6.1.1 Model Code

The numerical model was created in Groundwater Vistas 6.79, developed by Environmental Simulations Inc. Groundwater Vistas is a pre- and post- processing software that has been used for input file generation and output manipulation and visualization. For the groundwater flow simulation, the numerical engine MOFLOW – NWT from the US Geological Survey (Niswonger, R.G., Panday, Sorab and Ibaraki, Motomu, 2011) was used.

The parameter estimation software PEST 13, developed by Watermark Numerical Computing Inc., was used for model calibration. PEST is an automated process to optimize model parameter values. During model calibration small adjustments to model parameters are used to check the model response. The model was then updated using the parameters that maximized the accuracy of simulation results.

6.1.2 Model Extent and Boundaries

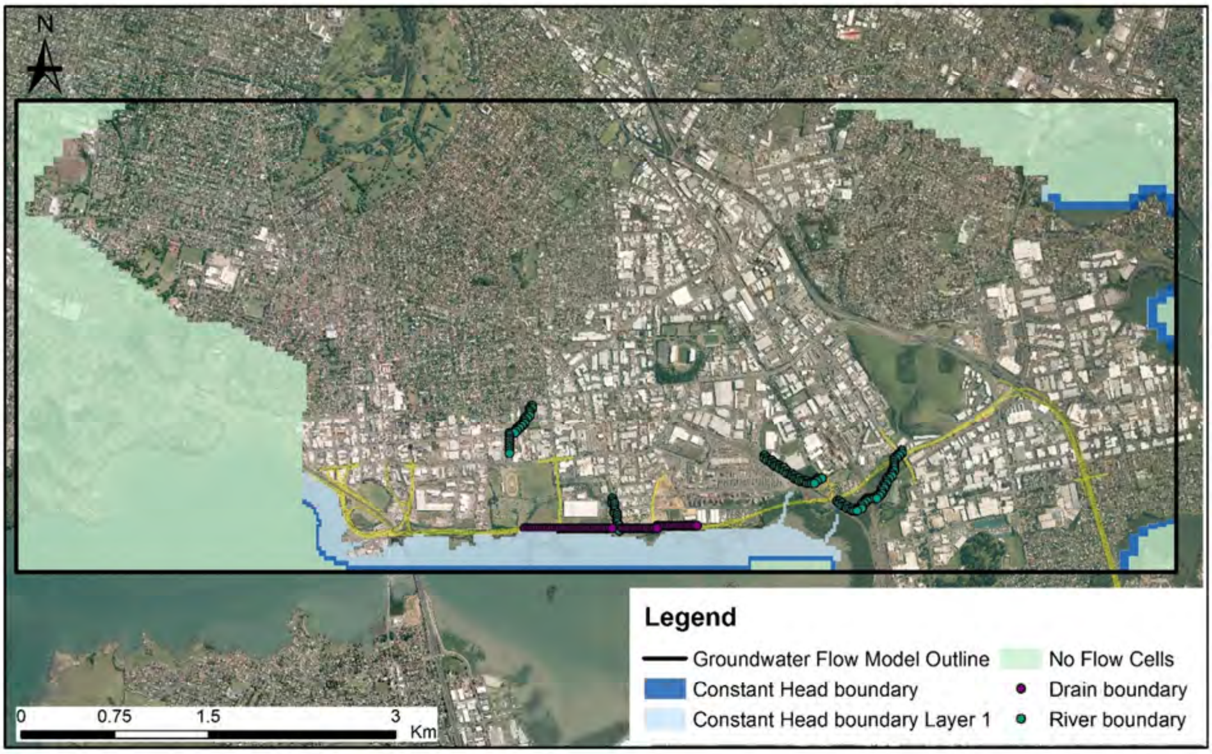
The model covers an area of approximately 35 km^2 (9.2 x 3.8 km) from Māngere Harbour, to One Tree Hill in the north and to Panmure Basin and Ōtāhuhu Creek in the east. The model area extent is shown in Figure 6.1

Constant head boundary conditions were applied to the coastal boundaries of the Māngere harbour, Ōtāhuhu Creek and Panmure Basin. Anns Creek and Miami Stream have been simulated as a combination of constant head and river boundaries.

The spring that feeds Bycroft Stream, that runs approximately 100 m before being diverted via the reticulated stormwater system has been simulated as a sink and incorporated into the model as a pumping well abstracting groundwater at a constant rate of 30 m^3/d, which is the minimum residual flow in the wetland.

All other model boundaries were assigned as no-flow (i.e. flow occurs only parallel to the boundary) that coincides with naturally occurring groundwater divides (northern, eastern and south-eastern model boundaries), and along boundaries with low permeability outcropping Waitemata rocks (south-western boundary). Assigned model boundary conditions are shown in Figure 6.1.

Figure 6.1: Groundwater flow model: Boundary conditions



6.1.3 Model Grid and Cell Size

The 3-dimensional ground model created using the geological modelling software Leapfrog Geo 3.1 developed by ARANZ Geo Ltd was discretised in a 115 x 346 cell grid with 7 vertical layers. The top of the Waitemata group rock (where it does not outcrop at the ground surface) was used as the top of layer 7. The remaining layers were assigned the hydrogeological properties of the corresponding formation. Grid cells have dimensions of 25 m x 25 m in the vicinity of the alignment[3], widening gradually to 75 m x 75 m at the outer model boundaries. A 3-dimensional representation of the model grid five times vertically exaggerated is shown in Figure 6.2.

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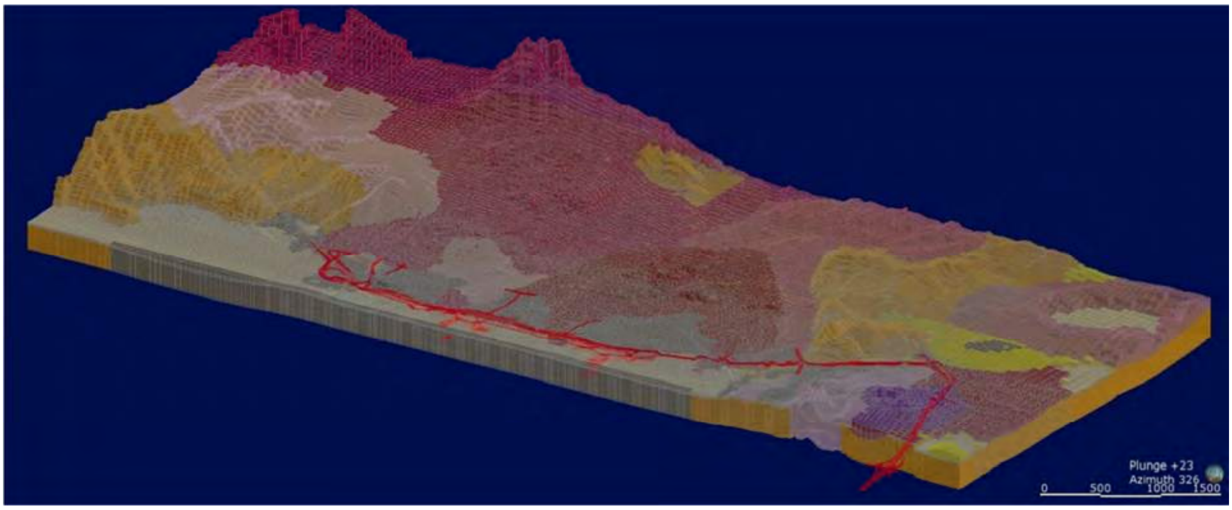
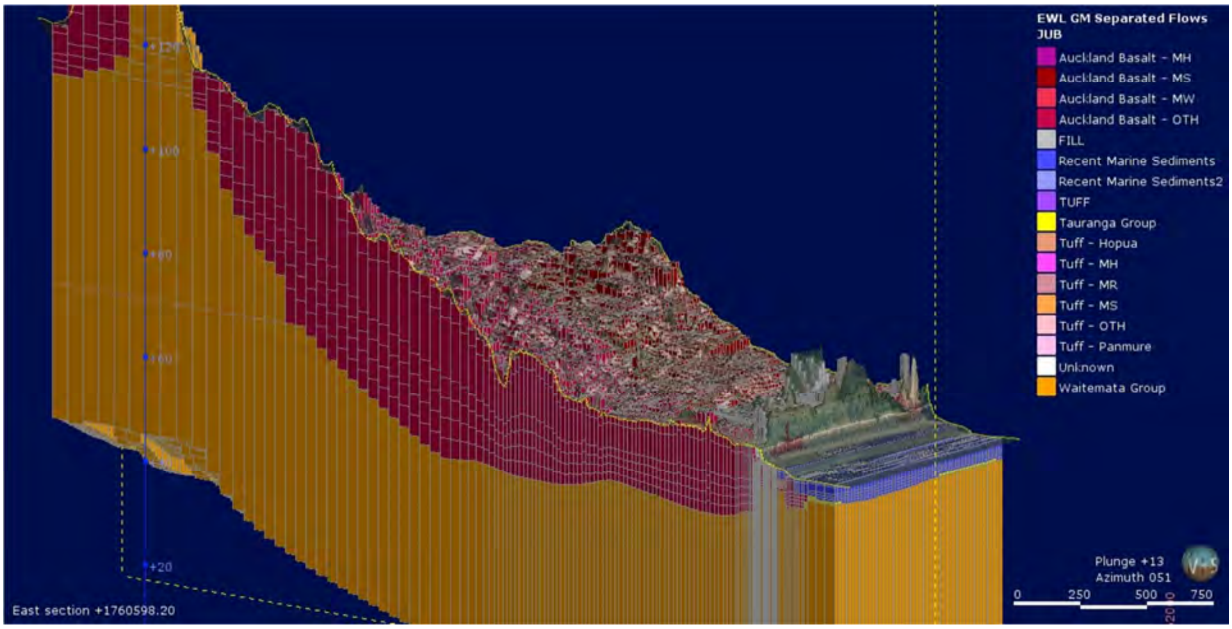
[3] The grid was further refined near the shorefront for the predictive simulations as discussed in the next section.

Figure 6.2: Groundwater flow model: numerical grid



A typical North-South cross-section of the model grid (20 times vertically exaggerated) is shown in Figure 6.3.

Figure 6.3: Groundwater flow model: numerical grid cross section

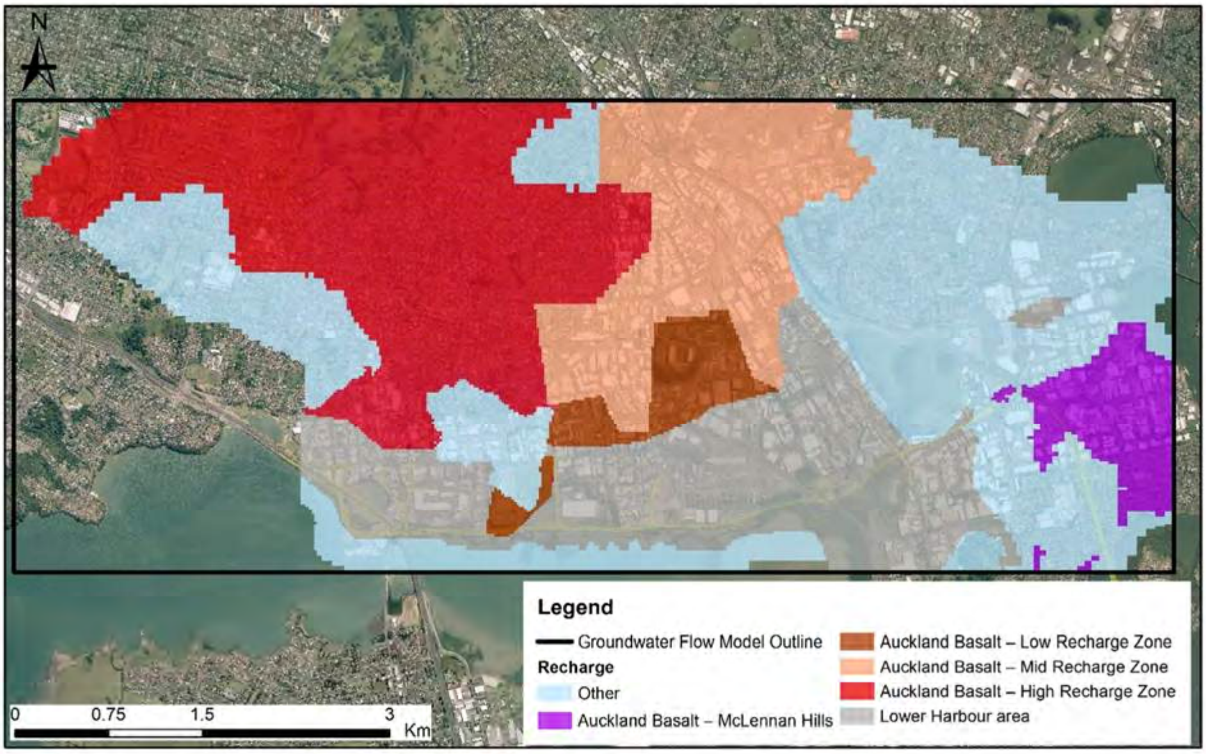


6.1.4 Recharge

The main source of aquifer recharge is rainfall infiltration. This includes infiltration through the surface soils and through soakage pits. Measurements obtained at 15 minute intervals in 20 monitoring locations suggest that groundwater levels respond quickly to rainfall events and may rise by up to 0.5 m in 8 hours.

Rainfall recharge has been applied to the uppermost layer of the model through the MODFLOW Recharge package as constant rate recharge zones. The zones have been defined based on the near surface geology, land use and cover and surface slope, in accordance with previous studies (PDP, 2005). The spatial distribution of these zones is shown in Figure 6.4.

Figure 6.4: Groundwater flow model: rainfall recharge zones

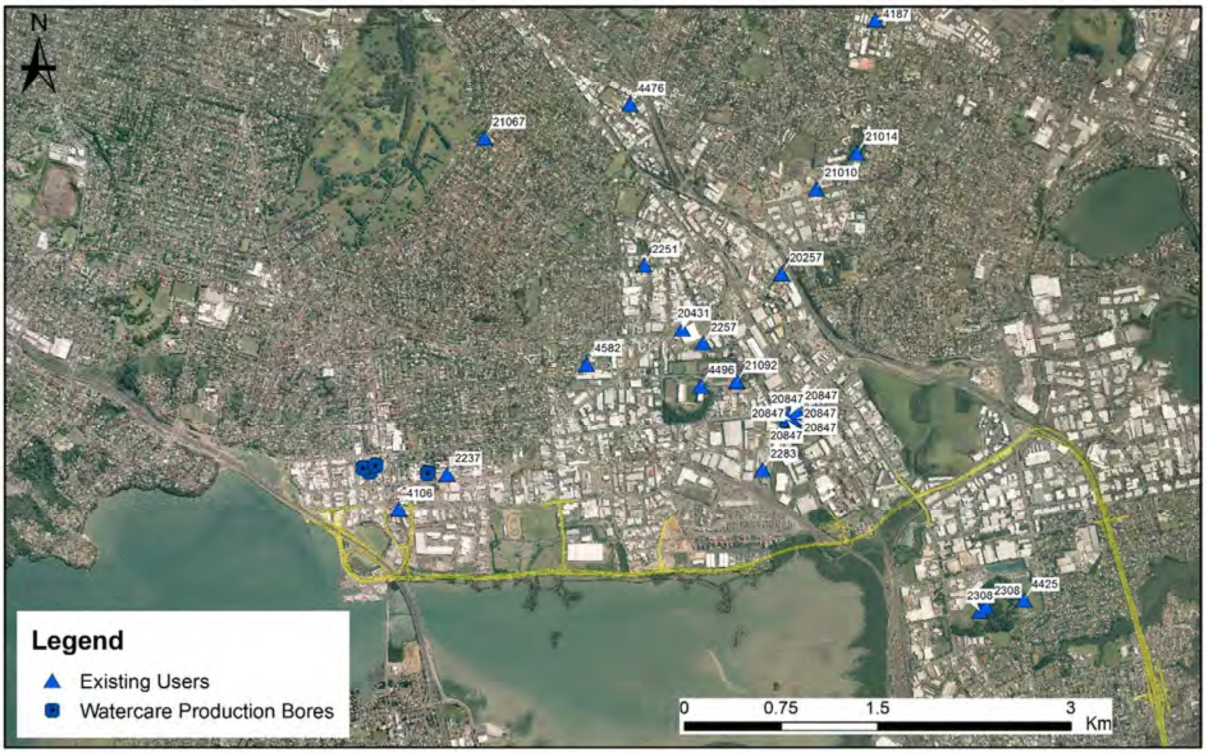


Quarterly rainfall data obtained from Auckland Council (Onehunga station at Harbour Rd and Rowe St station) and CliFlo (NIWA Māngere Ews station) for the period 2002 – 2016 indicates that the area receives on average 1160 mm of rainfall per year. This annual average was used as the basis to calculate the zone percentage that reaches and recharges the aquifer. It compares with an average rainfall of 1179 mm/year reported by PDP (2005) based on data collected from 12 rainfall stations across the Auckland Isthmus over the period 1998 – 2003.

6.1.5 Public Water Supply Wells

The main abstraction of water from the model area is by Watercare for public water supply. The wells are located between Princes Street and Church Street north of Gloucester Park. Figure 6.5 shows the locations of all consented groundwater takes in the area; the takes are summarised in Appendix A6.

Figure 6.5: Consented Groundwater takes in the project area



Watercare has four production wells (although only two are currently operational) with a total consented maximum take of 30,000 m3/day (8.5 Mm3/year). Watercare has a consent condition to maintain a minimum water level in the wells of 0.5 m above sea-level, however we understand that to date the maximum combined daily take is just over 100 l/s (around 22,000 m^3/day) and during pumping groundwater levels are generally maintained at 2 m above sea-level.

It is our understanding that accrual pumping rates are highly seasonal ranging from the maximum combined daily of 22,000 m^3/d to a minimum of 7,000 to 8,000 m^3/d during summer. This take represents a very significant part of the area's water balance (more than 50 % of the modelled area's water inflows are abstracted by Watercare). Therefore, these abstractions have been included in the steady state model as four pumping wells with a combined abstraction rate of 11,230 m^3/d, representing an annual average of the actual take. All other takes in the area have not been included in the model as pumped wells for the following reasons:

- They represent only a very small fraction of the model area water balance
- They are private takes and it is very difficult to determine actual, long term take; they may be used intermittently or not at all.

6.1.6 Model Calibration

A two stage model calibration approach has been used, using the parameter estimation software PEST. The first stage involved calibration of hydraulic conductivity properties (horizontal and vertical) and recharge rates for the zones depicted in Figure 6.4. During model calibration small adjustments to zone model parameters (a single value for each parameter was assigned to each zone) were used to check the model response. The model was then updated using the parameter values that provided the best reproduction of measured water levels.

For the second calibration stage the methodology included in PEST using Pilot Points and Single Value Decomposition (Doherty and Hunt, 2010)[4] was used. During this stage the distribution of horizontal hydraulic conductivity for the basalt and fill zones was defined by a set of pilot points (at 100 m to 400 m spacings). Calibrated horizontal conductivity values were estimated at each of these points and spatially interpolated between the points using kriging, effectively assigning a different horizontal hydraulic conductivity value in each model grid cell.

6.1.7 Calibration Targets

Average water level data from 104 locations has been used for model calibration. These locations included:

- 52 No. project boreholes fitted with piezometers
- 13 No. bores regularly monitored by Auckland Council as part of the Council Environmental monitoring program; and
- 39 No. groundwater level records (usually one time measurements) obtained from the Auckland Council Geotechnical Database.

These records are summarized in Appendix A7. Water levels from the Auckland Council Geotechnical Database were considered to have a lower level of reliability because:

- The water level records were obtained at different times;
- Most were recorded during drilling and not from a properly installed and developed piezometer; and
- Ground level is not always surveyed, resulting in significant uncertainty as to the sampled level and aquifer.

6.1.8 Calibration measures

The model response to the observed values can be associated with the correlation coefficient. The Correlation Coefficient (CoC) is defined as the covariance between the observed and modelled water levels divided by the product of their standard deviations. The correlation coefficient is calculated using the following equation:

$$CoC = \frac{Cov(h_o, h_m)}{\sigma_o \sigma_m}$$

The covariance between the observed and the modelled water levels is given by:

$$Cov(h_o, h_m) = \frac{1}{n}\sum_{i=1}^{n}(h_o - \mu_o)_i\,(h_m - \mu_m)_i$$

where: n is the number of measurements

ho is the observed water level

hm is the modelled water level

μo is the mean observed water level

μm is the mean modelled water level

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[4] Doherty, J.E., and Hunt, R.J., 2010, Approaches to highly parameterized inversion—A guide to using PEST for groundwater-model calibration: U.S. Geological Survey Scientific Investigations Report 2010–5169, 59 p.

σ_o is the standard deviation of observed water levels

σ_m is the standard deviation of modelled water levels

The correlation coefficient ranges between -1 and 1. It provides an indication of whether two ranges of data move together - i.e. whether large values of one data set are associated with large values of the other data set (positive correlation), whether small values of one data set are associated with large values of the other data set (negative correlation), or whether values in both sets are unrelated (correlation near zero). The closer CoC is to 1 the stronger the response of the model to measured water levels.

The performance of model calibration is associated with the difference between measured and modelled water levels. This measure is quantified through the normalized root mean square (nRMS) error, defined as:

$$nRMS = \frac{100}{\Delta H} RMS = \frac{100}{\Delta H} \sqrt{\frac{1}{n} \sum_{i=1}^{n} (h_o - h_m)_i^2}$$

where: n is the number of measurements

ho is the observed water level

hm is the modelled water level

ΔH is the range of measured water levels

The normalized RMS is expressed as a percentage, and is a more representative measure of the fit than the standard RMS, as it accounts for the scale of the potential range of data values. Therefore if the ratio of the RMS error to the total head change is small, the error is only a small part of the overall model response.

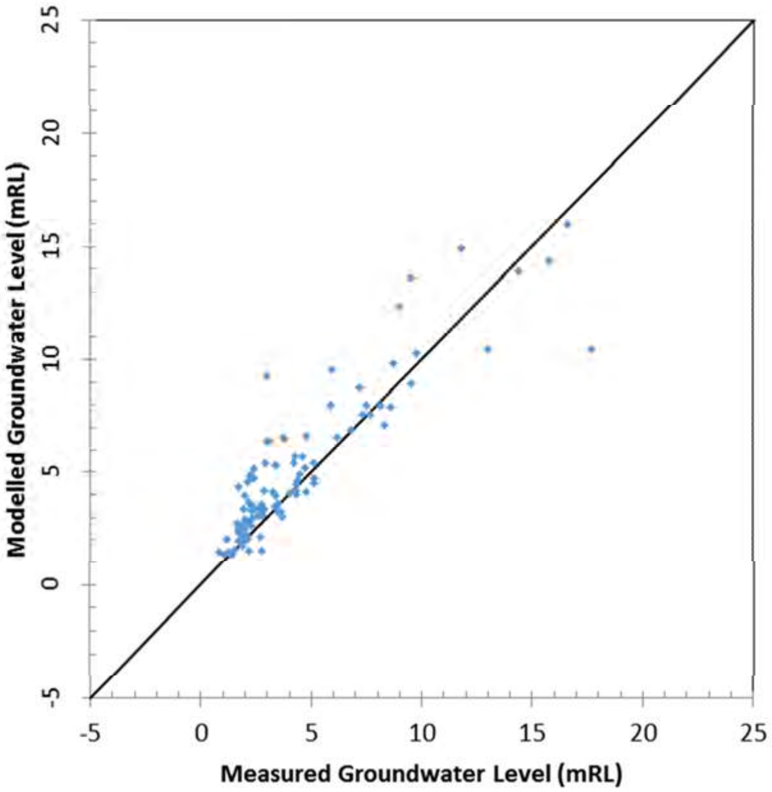
6.1.9 First Stage Calibration

6.1.9.1 Calibration Results

Comparison between measured and modelled groundwater levels is shown in the form of a scatter plot in Figure 6.6. The black line represents the “modelled = measured” groundwater levels and ideally all the points should fall on this line. In this first stage calibration the correlation coefficient of the scatter plot data is 0.91, indicating an excellent comparison.

The average absolute residual (RMS) between the observed and simulated groundwater levels was 1.66 m. Typically the maximum acceptable value for the calibration criterion depends on the magnitude of the change in heads over the model domain. If the ratio of the RMS error to the total head change is small, known as the normalized RMS (nRMS), the errors are only a small part of the overall model response (Anderson and Woessner, 1992). The ratio of RMS (1.66 m) to the total head change across the calibration points (16.86 m) indicates a nRMS value of 9.8%.

Figure 6.6: Steady state modelled vs. measured groundwater levels



6.1.9.2 Model Water Balance

The mass balance error or the difference between calculated model inflows and outflows, at the completion of the first stage calibration, expressed as a percentage of discrepancy, was -0.0015 %, indicating an excellent accuracy of the numerical solution and overall stability of the model. Table 6.1 summarizes the steady state model water budget.

Table 6.1: Stage One Calibration: Water Budget

Parameter	Flux In (m^3/d)	Flux Out (m^3/d)
Recharge	20845.57	0
CH	0	-2969.80
Well	0	-11230.00
River	608.35	-7220.44
Drain	0	-33.68
Error	-3.35E-03	
Percent Error	-0.0015 %	

6.1.9.3 Calibrated Hydraulic Parameters

The calibrated model hydraulic conductivity parameters are shown in Tables 6.2 and 6.3 respectively. The adopted values compare well with those used for modelling work on other projects in the greater Auckland area.

Table 6.2: Groundwater flow model: base case hydraulic conductivity values

Unit	Kh (m/s)	Kz (m/s)
FILL	2.10E-05	2.10E-06
Recent Marine Sediments	1.00E-05	2.00E-06
Recent Consolidated Marine Sediments	1.00E-07	1.00E-08
Tuff – One Tree Hill	1.16E-05	5.80E-06
Tuff (other)*	8.00E-06	8.00E-07
Auckland Basalt – McLennan Hills	3.00E-04	1.50E-04
Auckland Basalt – Low K	1.00E-04	5.00E-05
Auckland Basalt – Mid K	5.00E-04	2.50E-04
Auckland Basalt – High K	2.00E-03	1.00E-03
Tauranga Group	2.00E-07	4.00E-08
Waitemata Group	5.00E-07	5.00E-08
*parameters for different tuff rings varied in sensitivity analyses		

Table 6.3: Groundwater flow model: adopted rainfall recharge rates

Zone Number	Unit	Recharge (mm/yr)	Percentage of average rainfall (%)
1	Auckland Basalt – McLennan Hills	330	28
2	Auckland Basalt – Low Recharge Zone	220	19
3	Auckland Basalt – Mid Recharge Zone	550	47
4	Auckland Basalt – High Recharge Zone	660	57
5	Lower Harbour area	33	3
6	Other	33	3

6.1.9.4 Sensitivity Analysis

Sensitivity analysis was undertaken to evaluate whether the model calibration and predictions are sensitive to any input parameters. The statistic used to assess the relative model sensitivity of input parameters given the set of head observations was the sum of squared residuals and the total flux to the constant head boundary cells representing the Māngere inlet.

For this analysis, the following multipliers to calibrated values were used:

- Zone hydraulic conductivity: 0.1, 0.5, 2.0, 10.0; and
- Zone recharge rate: 0.6, 0.8, 1.2, 1.4

Figures 6.7 and 6.8 show sensitivity analysis results for the considered hydraulic conductivity (Kh and Kv) and recharge rate multipliers. Figure 6.7 shows the model calibration sensitivity, while figure 6.8 shows the modelled flux to the Inlet sensitivity to parameter variability. In both figures the horizontal axis is the parameter zone number listed in Tables 6.4 (hydraulic conductivity) and 6.3 (recharge), the vertical axis is the calculated statistic (relative value, dimensionless) and the five colour coded series represents the different applied multipliers.

These results suggest that model estimates are relatively sensitive to large changes (by an order of magnitude) of the high hydraulic conductivity (K) basalt zone hydraulic conductivity value and moderately sensitive to one order of magnitude decrease of the mid K basalt hydraulic conductivity. Model estimates are not sensitive to changes in recharge rates.

Figure 6.7: Sensitivity analysis results against calibration sum of squared residuals

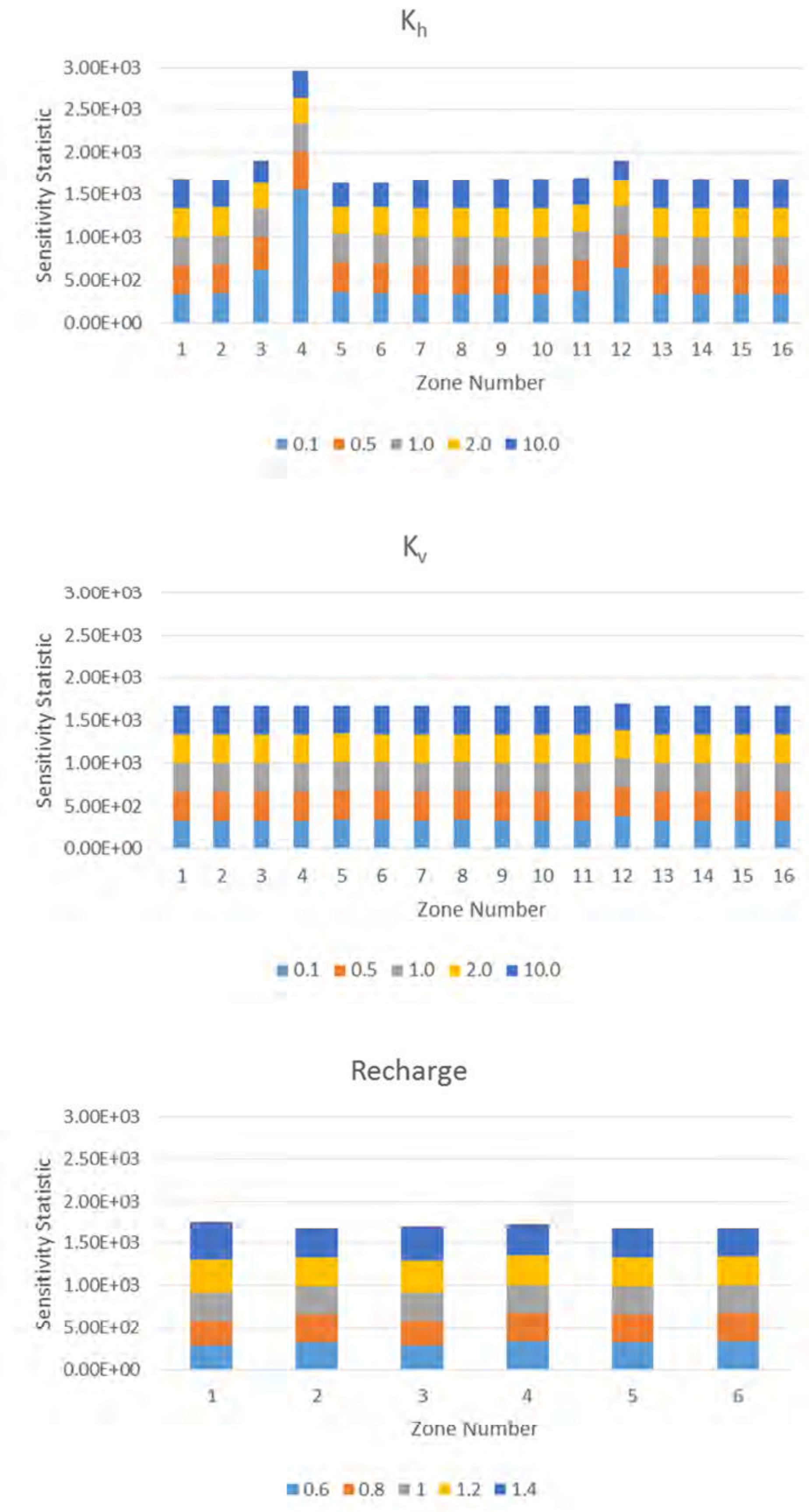


Figure 6.8: Sensitivity analysis results against flow to Māngere Inlet

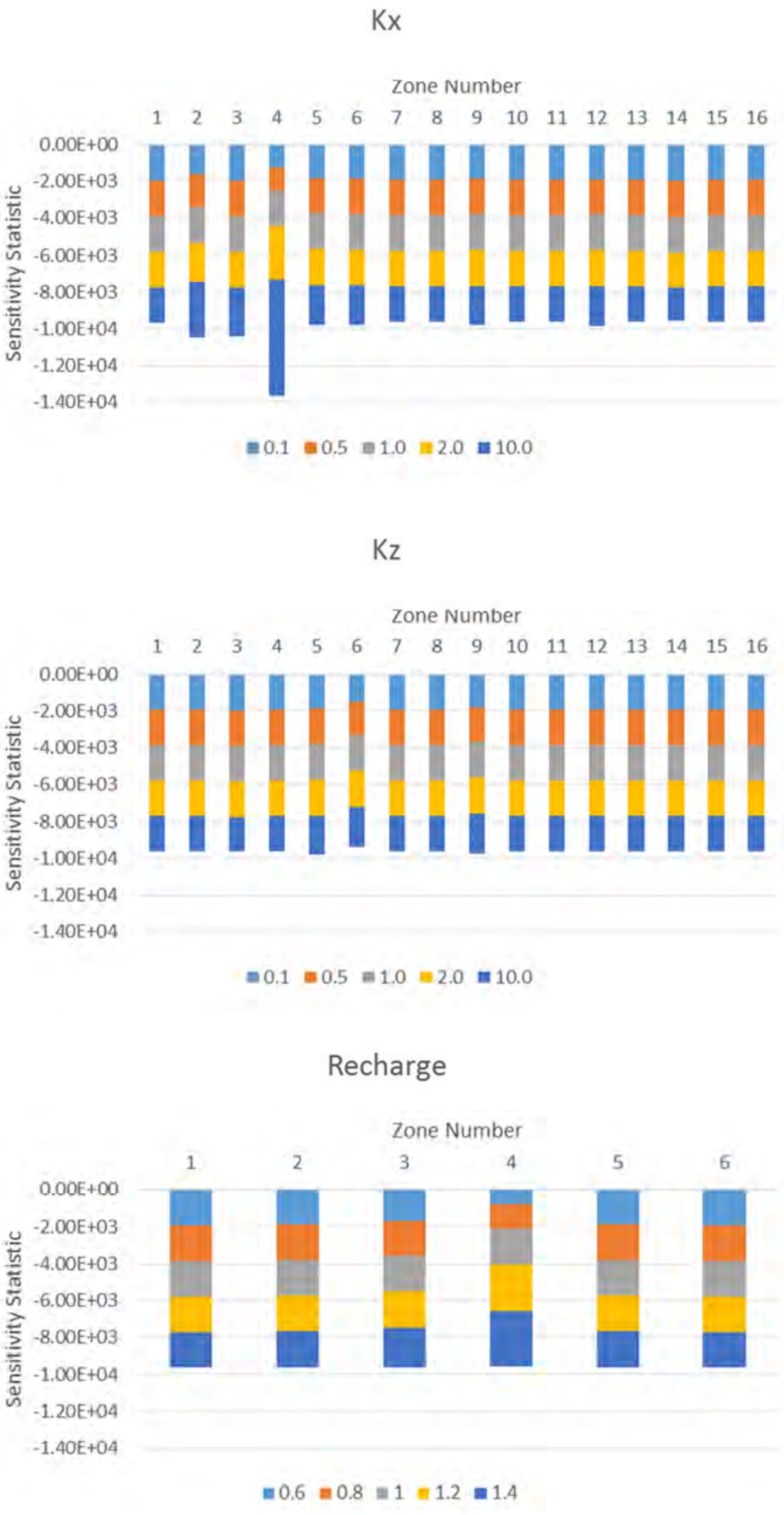


Table 6.4: Groundwater flow model: base case hydraulic conductivity values

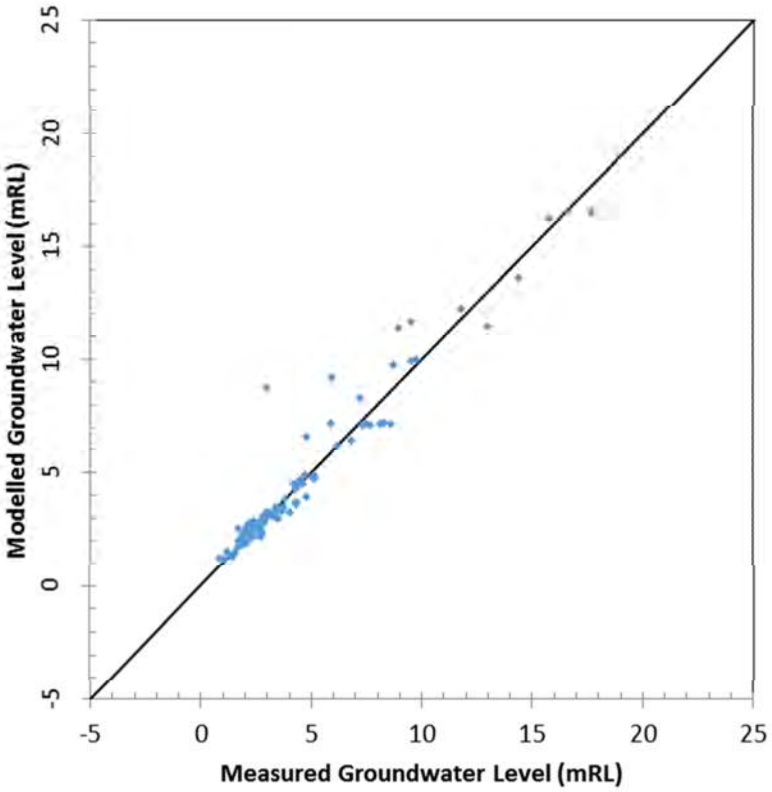
Unit	Hydraulic Conductivity Zone
FILL	5
Recent Marine Sediments	6
Recent Consolidated Marine Sediments	7
Tuff – One Tree Hill	14
Tuff (other)	9, 10, 11, 13, 15, 16
Auckland Basalt – McLennan Hills	1
Auckland Basalt – Low K	2
Auckland Basalt – Mid K	3
Auckland Basalt – High K	4
Tauranga Group	8
Waitemata Group	12

6.1.10 Second Stage Calibration

6.1.10.1 Calibration Results

Comparison between measured and modelled groundwater levels is shown in the form of a scatter plot in Figure 6.9. In the second stage calibration the correlation coefficient of the scatter plot data increased from 0.91 to 0.97, indicating an excellent comparison. The average absolute residual (RMS) between the observed and simulated groundwater levels was decreased to 0.87 m (from 1.66 m during the first stage calibration). The ratio of RMS (0.87 m) to the total head change across the calibration points (16.86 m) indicates an RMS value of 5.1%.

Figure 6.9: Second stage steady state modelled vs. measured groundwater levels



Simulated shallow groundwater levels for the existing situation are shown in Figure 6.10. Figures 6.11 and 6.12 show the log transformed calibrated (in stage two) horizontal hydraulic conductivity distribution near the surface and at depth respectively.

Figure 6.10: Simulated groundwater levels in metres RL

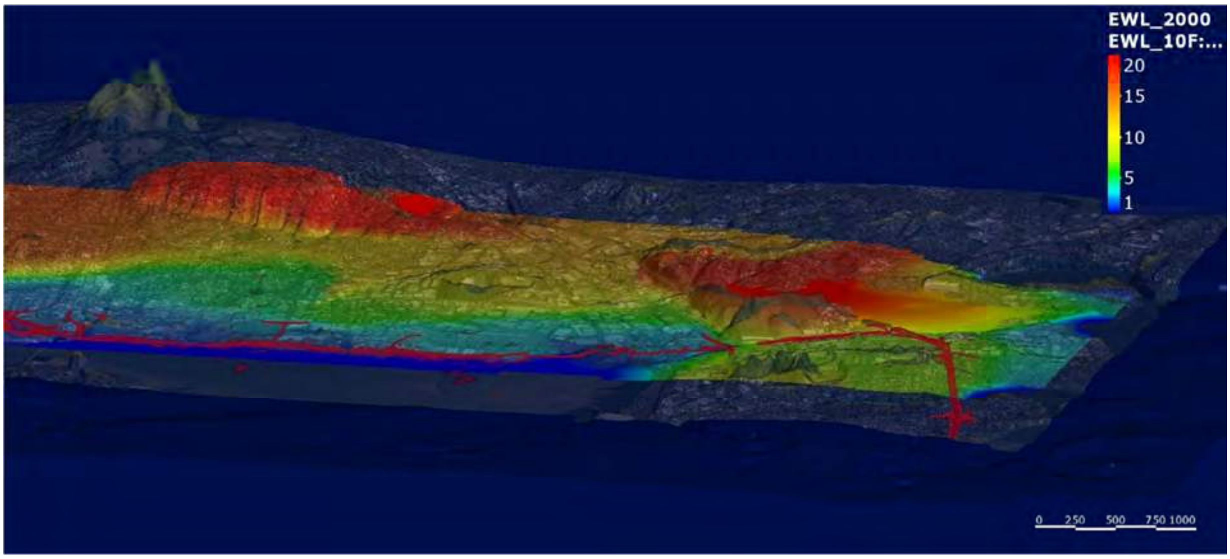


Figure 6.11: Calibrated log transformed Kh values (in log-m/s) near the surface (model layer 1)

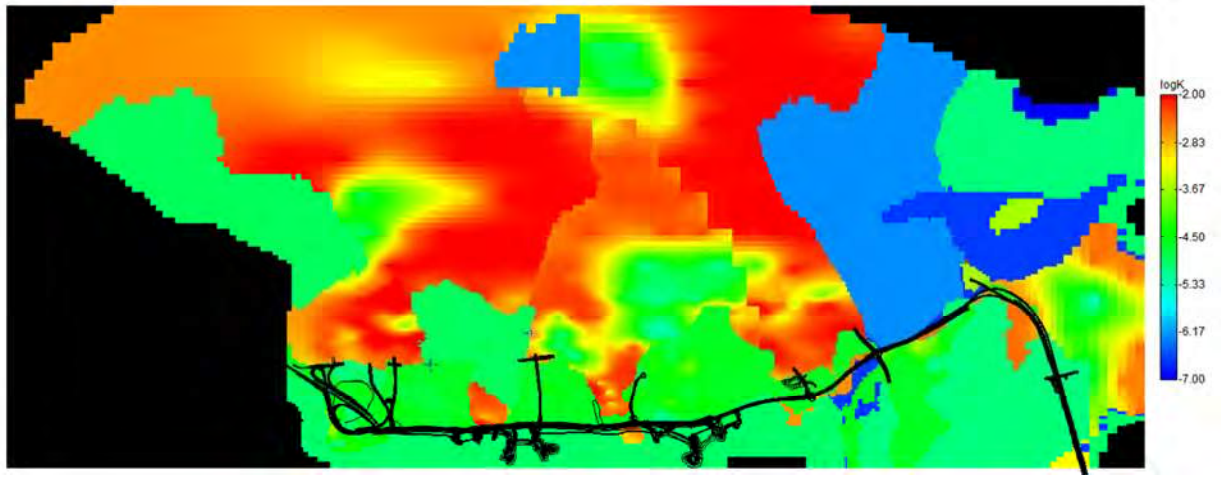
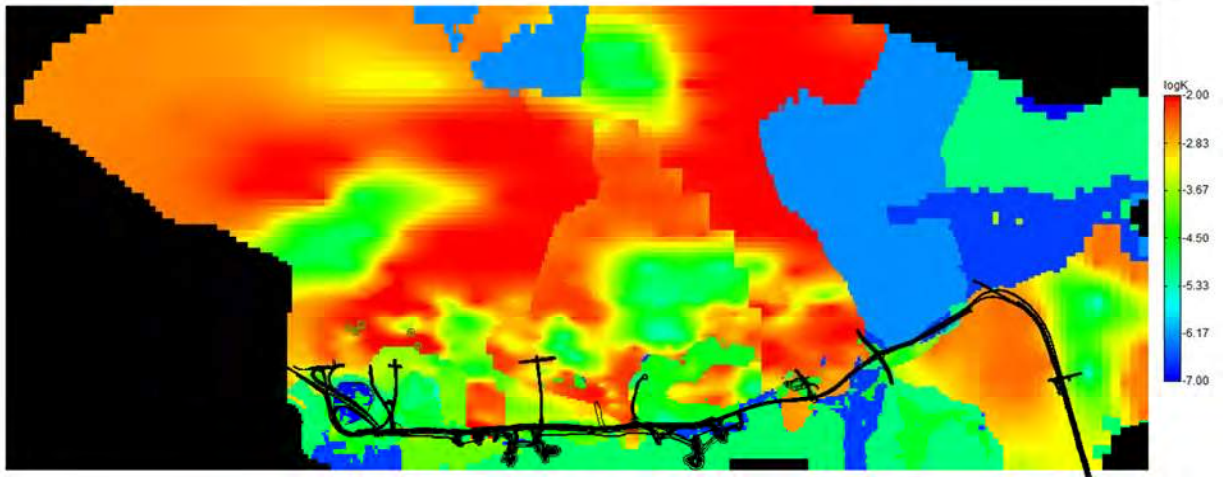


Figure 6.12: Calibrated log transformed Kh values (in log-m/s) in model layer 4



6.1.10.2 Model Water Balance

The mass balance error or the difference between calculated model inflows and outflows, at the completion of the second stage calibration, expressed as a percentage of discrepancy, was -0.001 %, indicating an excellent accuracy of the numerical solution and overall stability of the model. Table 6.5 summarizes the steady state model water budget.

Table 6.5: Stage Two Calibration: Water Budget

Parameter	Flux In (m3/d)	Flux Out (m3/d)
Recharge	20845.57	0
CH	0	- 3043.37
Well	0	-11230
River	295.69	-6860.41
Drain	0	-7.47
Error	2.1E-03	
Percent Error	1E-3 %	

7 Predictive Simulations

The 3D groundwater flow model has been used to assess the effects of the proposed road construction on the groundwater flow system and to develop viable mitigation options through design. Key construction elements introduced in the regional groundwater flow model include:

- Embankment construction adjacent to the shorefront
- Onshore embankment construction
- Onehunga Port trench
- Onshore stormwater wetlands
- Offshore stormwater wetlands
- Cuts required for construction that extend below the groundwater table
- Embankment construction on compressible soils
- Offshore basalt features

For the assessment of project effects the numerical grid of the calibrated model was further refined to allow a more accurate representation of the project construction activities. Grid spacing in the north south direction was reduced to 5 m near the alignment, resulting in total 147 model rows and a total of 318,255 active grid cells.

The steady state outputs of the model can be conservatively applied to average, low and high groundwater levels, while the natural range between minimum and maximum level should not be expected to change.

7.1 Assessment of project effects

The construction elements described above have been incorporated numerically in the model. The embankment construction has been introduced as new materials (low permeability mudcrete or similar and permeable hardfill) in accordance with the construction details set out in the Geotechnical Design and the Constructability methodology and as shown on the Drawings in *Volume 2* of the AEE. The hydraulic conductivities of the construction materials are summarized in Table 7.1.

Table 7.1: Hydraulic properties of construction materials

Unit	K_h (m/s)	K_z (m/s)
Mudcrete	1.00E-08	1.00E-08
Hardfill	5.00E-04	1.00E-04

The Sector 1 trench has been introduced in the model as no-flow cells, simulating a water tight longitudinal trench.

Onshore stormwater wetlands have been included in the predictive simulations as river cells recharging the underlying aquifers, while maintaining a permanent water level of 50 mm. Offshore stormwater wetlands have been introduced as lined surface features and by removal of the surface constant head boundary under their footprint.

Embankment construction on compressible fill and alluvial soils, has been introduced by lowering the hydraulic conductivity of the top model layer by an order of magnitude, simulating the potential consolidation of these materials. As no cuts below the water table are proposed this effect was not considered in the modelling simulations. Finally the offshore basalt features proposed in the inlet, adjacent to the stormwater wetlands, have been simulated by replacing the material under the feature footprint with mudcrete to the top of basalt, while removing the near surface constant head boundaries to simulate the proposed reclamation.

The measurable increase of average groundwater levels is presented in Figure 7.1 through 7.4. Some minor drawdown should be expected south of the Onehunga Port trench, which will form a cut off wall potentially blocking the normal groundwater flow towards the inlet, but the proximity to the coastal boundary and ability of flow to move around the trench through the permeable basalt is expected to substantially mitigate this drawdown, which according to the numerical results is less than 50 mm.

Figure 7.1: Change in groundwater levels as a result of the Project Unmitigated) (contours in meters)

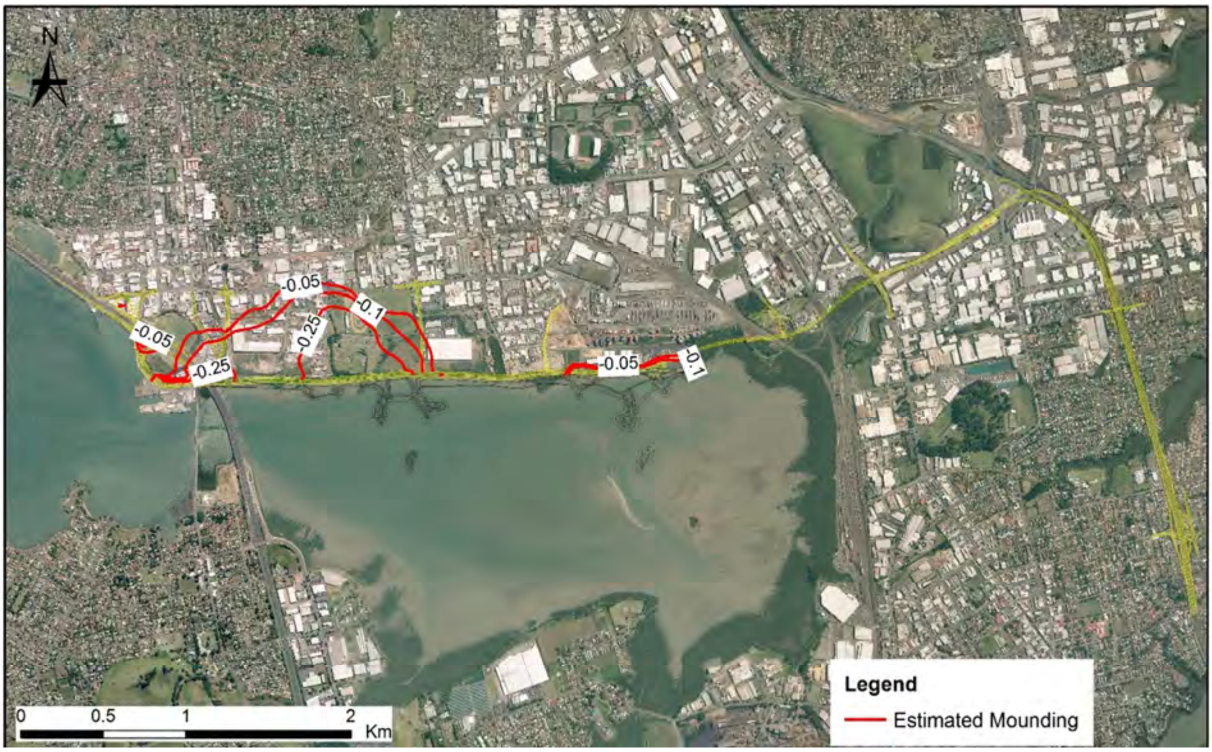


Figure 7.2: Sector 1: Change in groundwater levels as a result of the Project (contours in metres; negative number indicates groundwater level rise)

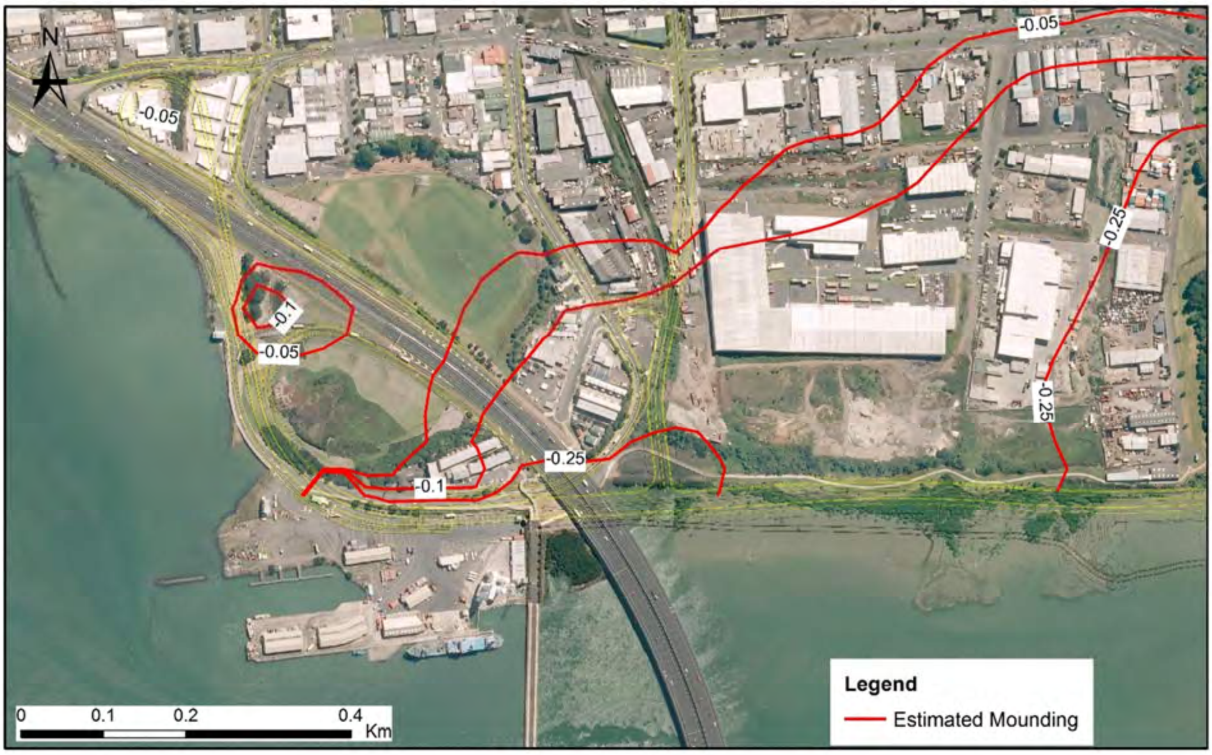


Figure 7.3: Sector 2 West: Change in groundwater levels as a result of the Project (contours in metres; negative number indicates groundwater level rise)

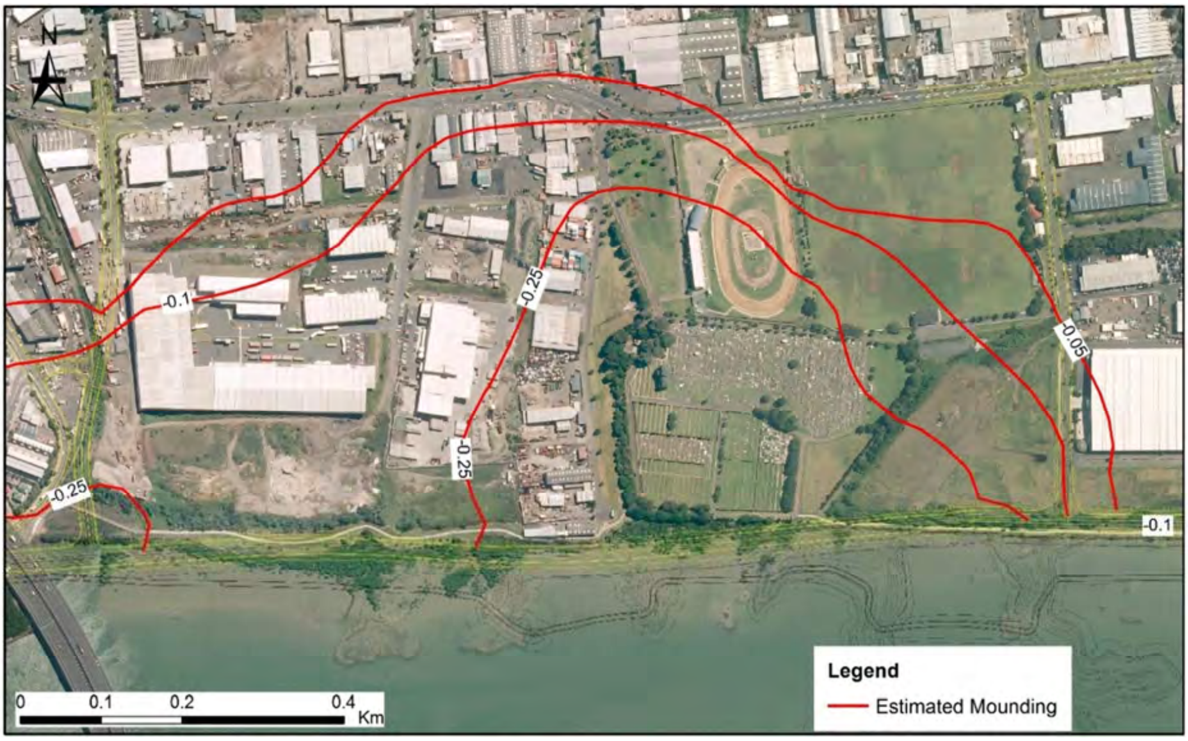


Figure 7.4: Sector 2 East: Change in groundwater levels as a result of the Project (contours in metres; negative number indicates groundwater level rise)

7.2 Predicted performance of design solution

The anticipated effects from the project are considered minor with the exception of the mounding beneath Waikaraka Cemetery, where groundwater levels are already elevated. The anticipated mounding in this area is mainly the result of the positioning of the proposed offshore stormwater treatment wetland and the construction materials proposed (i.e. use of mudcrete for the foreshore reconstruction features).

These elevated groundwater levels can be largely avoided by placing a more permeable hardfill layer extending to -3.0 mRL beneath the wetland liner and/or beneath the foreshore reconstruction features in the shaded area shown in Figure 7.5. This would also allow expansion of the proposed wetland and provide more volume for stormwater treatment and storage if it was needed. This design option was considered in the numerical assessment of effects. The resulting simulated increase in average groundwater levels is shown in Figure 7.6.

Figure 7.5: Outline of the proposed hardfill placement area

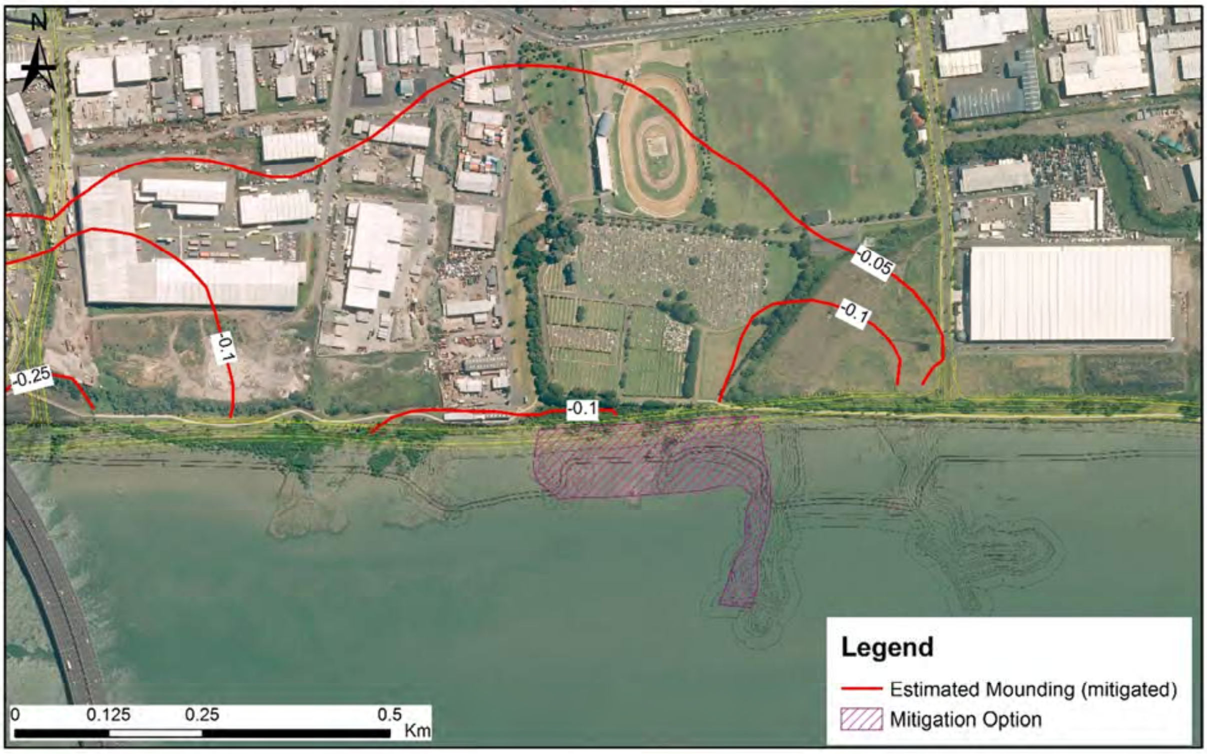


Figure 7.6: Change in groundwater levels as a result of the Project (mitigated) (contours in metres; negative number indicates groundwater level rise)

A more permeable layer has also been introduced to the 2D SEEP/W model. The introduction of this layer in the model resulted in a modelled mounding reduction of 50 and up to 100 mm across the modelled cross-section. The smaller mitigation effects in the 2D model are expected considering the three dimensional nature of the flow conditions.

8 Summary and Conclusions

Both 2D and regional 3D modelling have been undertaken to facilitate design and assess project effects on the existing groundwater flow regime. Various 2D models have been considered in the north south direction perpendicular to the shorefront to assess whether the project can have a beneficial effect by reducing the discharge of contaminants to the inlet, in particular through the Galway Street closed landfill. Particle movement and travel times were recorded for the present situation and compared with travel times of particles from the same range of locations with the EWL in place. A range of embankment materials were modelled with the objective of determining placement of construction materials to consistently increase the travel time of particles from different parts of the landfill such that the opportunity for attenuation of contaminants moving with groundwater is enhanced.

2D seepage models were used to assess the functioning of the existing leachate interception system and the potential effects of a new replacement system within the Pikes Point West and East closed landfills.

The steady state regional 3D groundwater flow model was developed to simulate average groundwater levels and flow directions as determined from measurements obtained at 104 locations. An excellent agreement between modelled and recorded groundwater levels has been achieved through calibration, suggesting that the model is able to reasonably simulate potential effects of the project on the groundwater flow regime.

A small rise of average groundwater levels can be expected to result from the project upgradient of Sectors 1 and 2. These elevated groundwater levels can be largely avoided by selection of the construction materials used.

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Appendix A1

Groundwater Level Monitoring Locations

Figure A8.1: Project piezometers (sector 1)

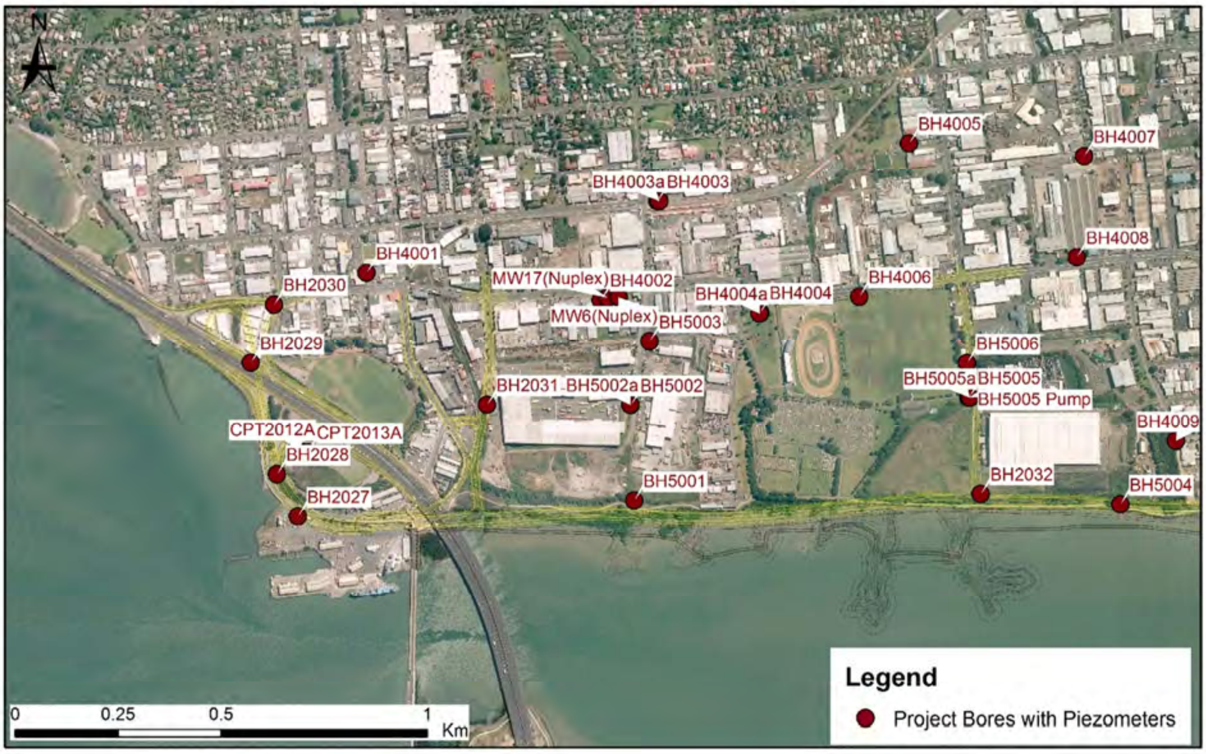

Figure A8.2: Project piezometers (Sectors 2 to 3 and 6)

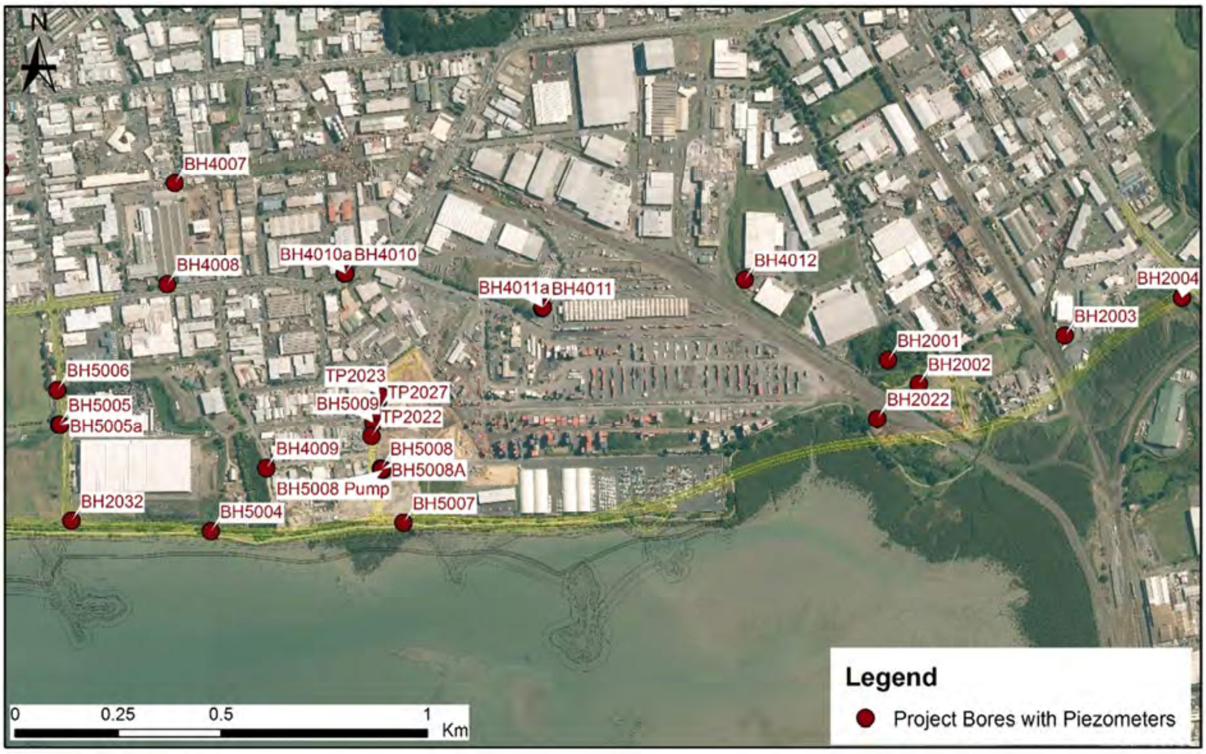

Figure A8.3: Project piezometers (Sectors 4 and 5)

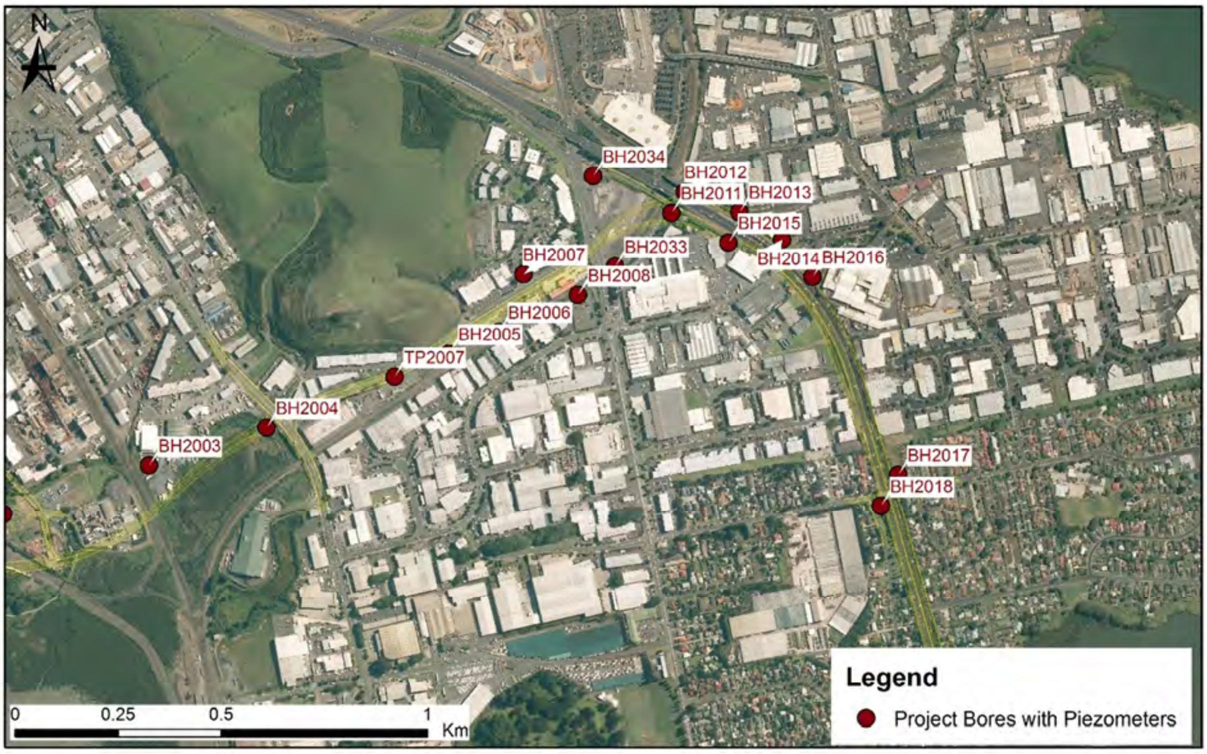

Figure A8.4: Project piezometers (Sector 5)