Wellington Water Limited

Wellington Harbour Exploration Bores Project

Hydrogeological Analysis of SP1a Exploration Phase: Abstraction Feasibility Assessment & Recommendations

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Table of Contents

Appendices Volume:

APPENDIX 1:	Geological and geophysical summary
APPENDIX 2:	Field investigation methodology
APPENDIX 3:	Data analysis methodology
APPENDIX 4:	Groundwater monitoring hydrographs
APPENDIX 5:	Pumping test results
APPENDIX 6:	Water quality laboratory test results
APPENDIX 7:	Hydrochemistry assessment (GNS)
APPENDIX 8:	Age dating results (GNS)
APPENDIX 9:	Site photographs
APPENDIX 10:	Additional GNS modelling: Calibration/uncertainty analysis and hypothesis testing

1. Introduction

1.1 Background and report purpose

A major source component of the public water supply system for the greater Wellington area is the artesian Waiwhetu Aquifer which is located beneath the Lower Hutt Valley and parts of Wellington Harbour. There is also a deeper aquifer – the Moera Aquifer – which may be a potential source of potable water.

Wellington Water Ltd (WWL) has undertaken an exploration drilling project in Wellington Harbour to ascertain whether the sub-harbour extension of the Waiwhetu Aquifer can provide an alternative resilient drinking water supply for central Wellington.

Exploration drilling activities undertaken for the project (SP1a stage) have confirmed the existence of a sub-sea freshwater resource and have addressed some of the significant information gaps regarding the geological and hydrogeological nature of the offshore fresh groundwater environment. Information obtained from the drilling activities provides a basis for enabling an initial assessment of the potential for the sub-harbour aquifers to provide a secure supplementary water source whilst avoiding risks such as saltwater contamination.

Regardless of whether the project is successful in identifying an alternative water source, the information obtained from the drilling and analyses activities will also significantly improve management of the onshore Waiwhetu Aquifer. The information obtained from the project will enable an improved understanding of saline intrusion risks and will contribute to future review of the sustainable yield.

The completed (SP1a) exploration phase of the project included a number of geophysical exploration surveys, geological analysis and conceptual modelling, the drilling and testing of two exploration bores in the harbour, and a new groundwater modelling analyses. A diverse team of scientists from research organisations (NIWA, GNS Science) and specialist consultancies (Earth in Mind and Pattle Delamore Partners) have closely collaborated throughout the technical implementation of field activities and the subsequent analysis of information. Peer reviews have been undertaken by the University of Canterbury and Pattle Delamore Partners Ltd.

This report presents a revised hydrogeological analysis of the groundwater environment beneath Wellington Harbour and a feasibility assessment of offshore groundwater abstraction. Its main purpose is to identify whether there are any obvious or potential ‘fatal flaws’ in the proposal to abstraction groundwater from beneath the harbour floor and to identify further work necessary to reduce uncertainty. This information is intended to assist WWL in determining whether to commit to investing in a second exploration phase – ‘SP2’ – which would entail the construction of a test production bore accompanied by extensive testing and monitoring of the sub-harbour groundwater resource.

1.2 Report structure

The SP1a phase investigations and technical analyses are comprehensively documented in this report and the accompanying appendices. In particular, this report documents the development of a numerical model (HAM4) for the offshore aquifer system designed to meet the requirements and objectives of this project.

This report provides a complete technical documentation of the SP1a investigation programme. The report has the following structure:

Chapter 2: Introduces the physical geological setting of Wellington Harbour and previous work;

Chapter 3: Provides a background to the geophysical exploration programme and interpretations;

Chapter 4: Describes the exploration drilling activities, bore siting rationale and summarises the findings from the two bores;

Chapter 5: Documents the hydrogeology the sub harbour aquifer groundwater environment and the conceptual groundwater model used as basis for then numerical model;

Chapter 6: Provides a discussion of saline intrusion risks which are central to evaluating the feasibility of abstraction;

Chapter 7: Documents the development, calibration and use of the new HAM4 numerical model which has been used to assess abstraction feasibility through simulation of a number of scenarios, and to identify any ‘fatal flaws’ from a hydrogeological perspective;

Chapter 8: Describes an alternative model comparison;

Chapter 9: Introduces some further calibration uncertainty modelling carried out by GNS Science;

Chapter 10: Provides a summary and discussion of the current modelling work, and recommendations for future exploration and analysis work.

2. Hydrogeological Context

2.1 Previous work

The Lower Hutt groundwater environment, of which the sub-harbour groundwater system is a part, has an extensive history of geological and hydrogeological investigation over the past half a century. Some of the principal geological and hydrogeological resources that have informed the present study are:

- Stevens (1956a, b) –the first interpretation of the geological history of the Hutt Valley and the artesian aquifer system.
- Donaldson and Campbell (1977) produced a seminal hydrogeological study entitled *Groundwaters of the Hutt Valley – Port Nicholson Alluvial Basin* which represented the most complete compilation and analysis of information at the time. It also presented a conceptual hydrogeological model which, with adaptations, remains valid.
- The 1:50 000 Geological map of the Wellington Area including memoir (Begg and Mazengarb, 1996).
- Recent geological modelling of the Hutt Valley in: It's our Fault – Geological and Geotechnical Characterisation and Site Class Revision of the Lower Hutt Valley (Boon et al., 2010).
- Wellington Regional Council (1995) – Hydrology of the Hutt Catchment, vol. 2: Groundwater
- Earth in Mind Limited (2014) – Development of the Hutt Aquifer Model (HAM3) and revised sustainable yield assessment.

The geophysical study of Wellington Harbour by Wood and Davey (1992) is an invaluable source of information relating to the interpretation of offshore geology and the extension of the Waiwhetu gravels into the harbour. In relation to the offshore hydrogeology, an insightful and unique study of the submarine spring discharges in Wellington Harbour was undertaken during a master's programme at Victoria University of Wellington by Harding (2000). This work has provided helpful information on the offshore discharge from the Waiwhetu Aquifer.

Several phases of groundwater modelling work have focussed on the terrestrial aquifer system for resource management purposes. The most recent modelling was undertaken by Earth in Mind Limited (EIM, 2014) which resulted in the HAM3 (Hutt Aquifer Model 3). The HAM3 model represents the most comprehensive modelling investigation undertaken to date and is currently used for management of the onshore Waiwhetu Aquifer by Wellington Water Limited and the Greater Wellington Regional Council. The offshore part of the HAM3 was revised in 2015 on the basis of the new geophysical investigation carried out by NIWA to assist in determining the feasibility of the current project.

There have always been acknowledged data gaps concerning the offshore extension of the Lower Hutt Groundwater Zone beneath Wellington Harbour. Geophysics has been of limited assistance in the absence of substantial direct physical data in the form of drill hole logs which extend through the aquifer and aquitard sequence. The current drilling project has helped to fill critical information gaps concerning the geology beneath Wellington harbour, aquifer water quality and aquifer pressures, which have enabled a more informed hydrogeological conceptualisation and analysis to be formulated.

2.2 Geological and hydrogeological overview

The Hutt Valley – Port Nicholson (Wellington Harbour) alluvial basin is the southernmost and largest of a series of structurally-controlled Quaternary age sedimentary basins associated with the major Wellington Fault. It has a broadly wedge-shaped morphology tapering from its widest extent, inferred to be around 9.5km across the harbour, to about 5km wide at the Petone foreshore and then narrowing to only a few hundred metres in width at Taita Gorge (Figure 2.1). The basin hosts the 'Lower Hutt Groundwater Zone' (LHGZ) which encompasses the floodplain of the Hutt River downstream of Taita Gorge and extends under Wellington harbour out as far as the harbour entrance (or 'harbour heads') - a distance of about 23km.

The western and deepest side of the basin is controlled by Wellington Fault where subsidence has created a sub-vertical basin margin, thought to be more than 300m deep in places. It is probable that the Wellington Fault has disrupted and displaced the basin fill sediments adjacent to the fault. The Somes Island ridge is a notable basement high which is an active fault-bounded horst structure that traverses the basin obliquely and displaces younger sediments (Begg et al., 2008). This structure is of particular importance in terms of influencing the alluvial deposition of the aquifer sequence.

The Hutt River fluvial system is responsible for infilling the basin with alluvial sediments over a considerable period of time - from about the middle and later Quaternary period to the present (over the last 500,000 years). Intermittent marine invasions during warmer interglacial periods have also contributed to the deposition of fine grained marine and estuarine deposits in the lower part of the basin (the offshore and southern part of onshore sections). The sedimentary sequence can therefore be envisaged to be the result of the progradation of an alluvial delta into a subsiding basin centred on the harbour. A c.350m thick wedge-shaped package of alluvial-deltaic-marginal marine sediments at the Petone coastline becomes thicker offshore where it is thought to exceed 600m between Somes Island and the Wellington Fault.

Gravel-rich horizons in a thick sequence of late Quaternary and Holocene alluvial and marine sediments infill the basin and host a significant groundwater resource which is recharged principally by the Hutt River. Onshore, the upper part of the Waiwhetu Artesian Aquifer (last glacial gravels) is an extraordinarily transmissive and laterally extensive gravel horizon which sustains a significant proportion (up to >70%) of the municipal water demand for the Wellington Region.

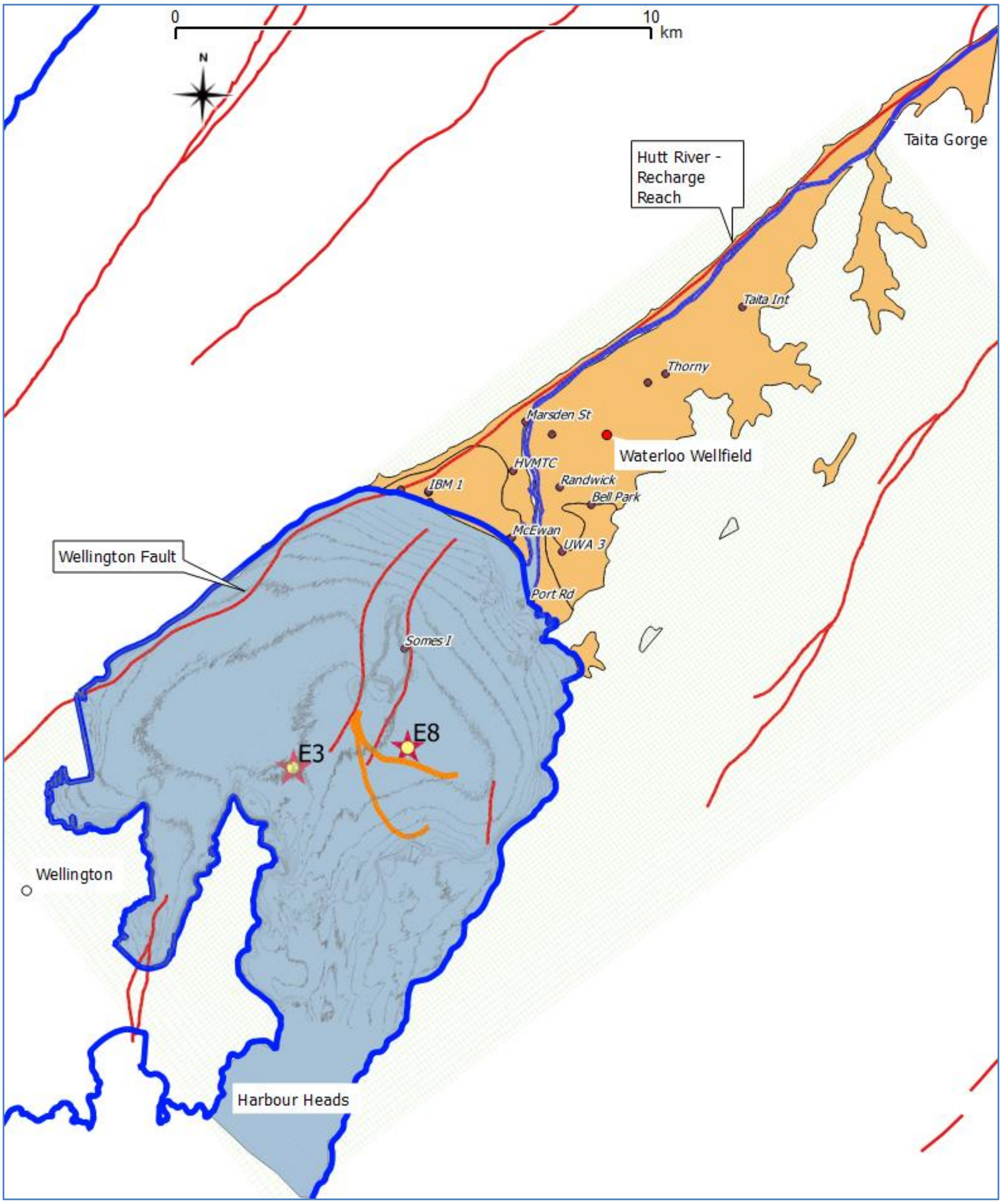


Figure 2.1 Lower Hutt Groundwater Zone – onshore (brown) and offshore (blue) sections. Map also shows continous groundwater level monitoring sites with names (mostly located in the confined upper Waiwhetu Aquifer), the two project exploration bore sites in the harbour (E3 and E8), principal active faults (red lines) and harbour bathymetry contours. Orange lines in harbour show probable extent of upper Waiwhetu coarse-grained gravel fan.

Comprehensive characterisation of the geological and hydrostratigraphic sequences of the onshore part of the groundwater system is possible due to the large number of drill hole records – the LHGZ is arguably one of the most intensively studied and modelled aquifer systems in New Zealand. The sub-harbour extension of the geological sequence is considerably less well understood because of the absence of drilling (except around the periphery). The new harbour exploratory bores and associated geophysical surveying has therefore resulted in a substantial improvement in understanding the offshore geology of Wellington Harbour. A comprehensive re-evaluation of the sub-harbour geology has been undertaken jointly by GNS Science and NIWA to support this project (Appendix 1).

The onshore succession was first characterised by Stevens (1956) using the large quantity of subsurface drill hole information available at that time. He called the fill sequence the 'Hutt Formation' which is comprised of four broad members:

- Holocene deposits: aquifers and marine aquitard (Taita Alluvium, Melling Peat, Petone Marine Beds)
- Waiwhetu Artesian Gravels: main aquifer (Q2-4, last glacial)
- Wilford Shell Beds: widespread major marine aquitard (Q5, last interglacial)
- Moera Basal Gravels: minor aquifers (Q6-7, penultimate glacial)

An older, undefined sequence of basal gravels (Q8-Q10?) is present in the deeper parts of the basin and is associated with successively older glacial and interglacial cycles.

This classification remains valid today and the same unit terminology is used to describe the hydrostratigraphy of the basin. There is however some refinement and a further subdivision of the Waiwhetu gravels. This is explained in Section 5.1.2.

Figure 2.2 illustrates the sediment sequence using a 3D box diagram (from Begg and Mazengarb, 1996) oriented along the Petone foreshore and extending up-valley to Knights road where the Waterloo Wellfield is located.

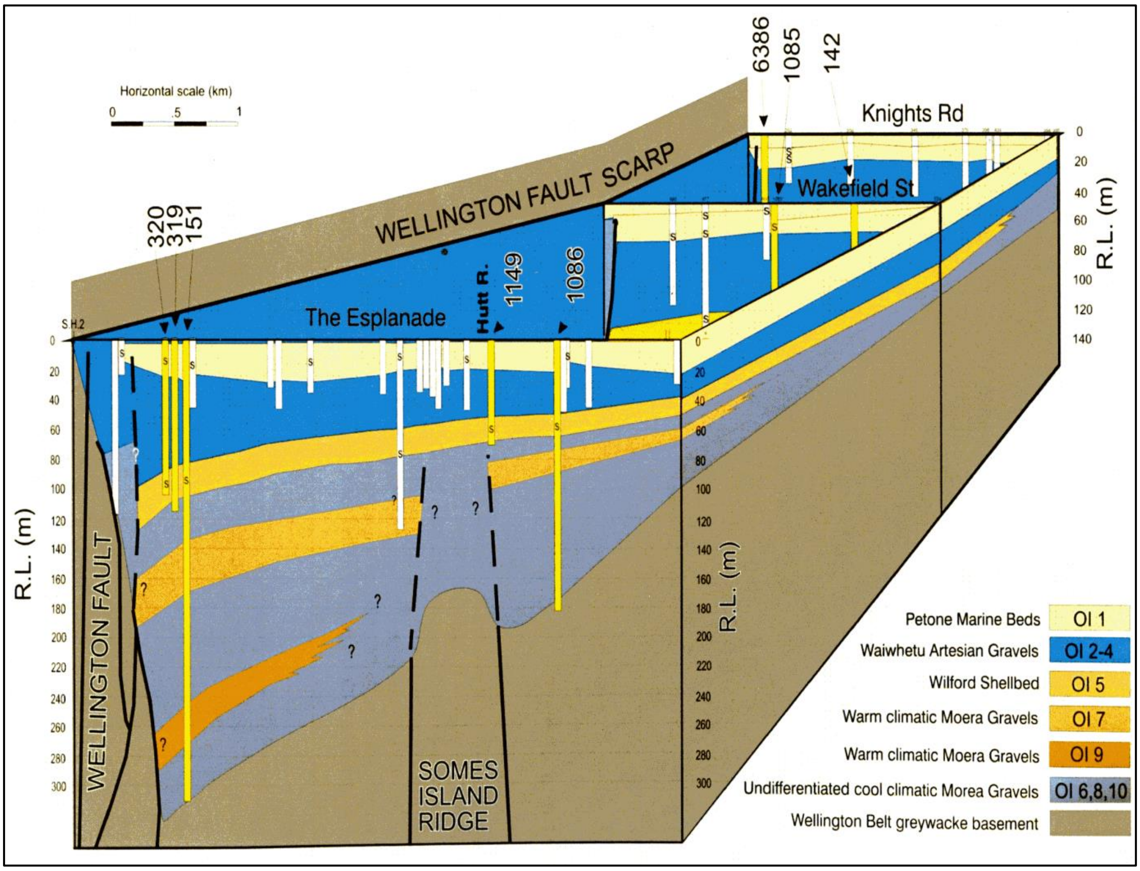


Figure 2.2 Three-dimensional representation of the sediments of the Lower Hutt basin from the Petone foreshore to Knights Road based on drill hole information (Begg and Mazengarb, 1996).

3. Geophysical surveying

Several phases of geophysical surveying were carried out for the project to assist in understanding the offshore hydrogeology and to inform the new HAM4 groundwater model. Interpretation of the geophysics was integrated with data obtained from the two exploration bores as well as other bore data around the periphery of the harbour and at Somes Island. Older seismic reflection data collected by GNS Science several decades ago have also supplemented the more recent project surveys

A full description of the geophysical survey activities and geological modelling is contained in Appendix 1. A summary is provided here (much of the text the figures are derived from Nodder et al, Appendix 1)

3.1 Marine geophysical datasets

Seismic reflection geophysical surveys across Wellington Harbour have provided a means to image and understand the structure and stratigraphy of materials beneath Wellington Harbour. Since 2015, NIWA has completed several investigations for WWL and Stantec/MWH regarding the subsurface character and extent of the Waiwhetu Aquifer beneath Wellington Harbour (Lamarche, Mountjoy et al. 2015; Nodder, Lamarche et al. 2015; Lamarche, Nodder et al. 2016). These data and interpretations subsequently provided the main basis upon which further geophysical interpretations of the various hydrostratigraphic unit definitions and the locations of the offshore exploratory boreholes were decided.

The main marine geophysical data-sets used in the project were those collected specifically for WWL, namely, from NIWA voyages KAH1505 in August 2015 (jointly with CentrePort Ltd; Lamarche, Mountjoy et al. 2015; Nodder, Lamarche et al. 2015) and KAH1602 in February 2016 (Lamarche, Nodder et al. 2016). These seismic reflection data were collected with a mini-GI air-gun source towed behind NIWA's Research Vessel *Kaharoa*. These data were integrated with shallow NIWA 'boomer' data from surveys conducted by Applied Acoustics Ltd (IKA1012) in 2010 and for an *It's Our Fault* project (IKA1303, Barnes et al., 2014) in 2013 on NIWA's coastal survey vessel *Ikatere*.

Figure 3.1 shows the locations of the various seismic survey lines, in addition to earlier GNS surveys, which together were used to analyse the geology of Wellington Harbour.

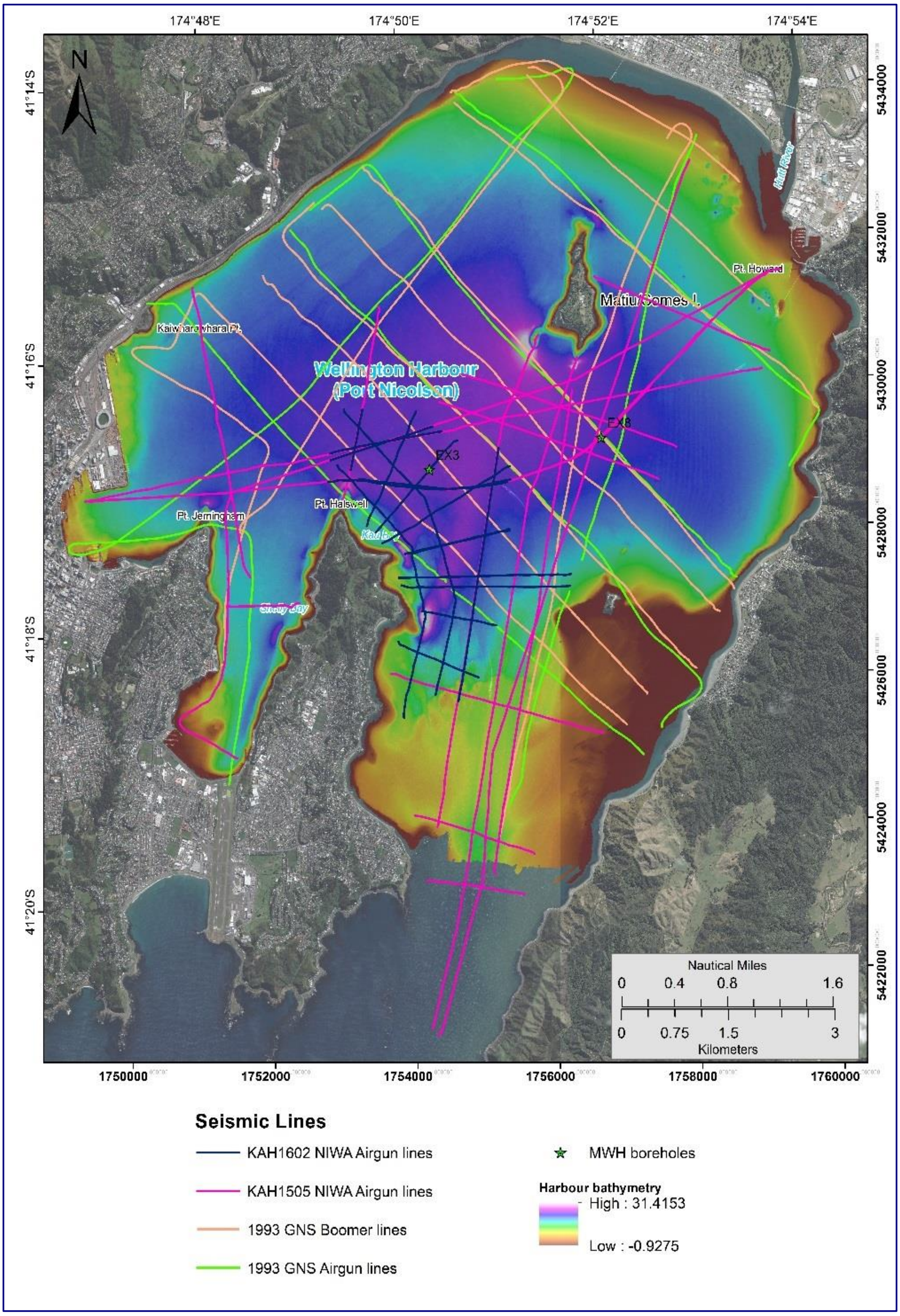


Figure 3.1 Marine geophysical survey tracks collected by NIWA and GNS Science in Te Whanganui a Tara/Wellington Harbour. NIWA data from KAH1505 and KAH1602 (Nodder, Lamarche et al. 2015; Lamarche, Nodder et al. 2016); GNS Science data from (Wood and Davy 1992; Davy and Wood 1993). NIWA bathymetry is in metres (Pallentin, Verdier et al. 2009).

All existing data were integrated within specialist 3D geological modelling software, Leapfrog Geo (version 4.1). Topography was established using the NZ Transverse Mercator 2000 projection and the Greater Wellington Regional Council LiDAR-derived digital elevation model (DEM), GWRC_DTM_1m. Harbour bathymetry in the form of a NIWA DEM (version “wh250cm”), was projected to NZTM and entered into Leapfrog.

3.2 Summary of geophysical interpretations

Interpretation of the seismic data was integrated with the information obtained from the two project exploration bores (E3a and E8), with existing bores within and close to the harbour and older geophysical datasets (e.g. the raw and interpreted sections collected during older GNS surveys by Wood and Davy (1992) and Davy and Wood (1993) using single and multi-channel airgun and ‘boomer’ data).

Interpretations from the NIWA marine geophysical data identified two key subsurface reflectors: the uppermost reflector was located at the base of the overlying, seismically transparent (Petone) marine muds and corresponding to the top of the upper Waiwhetu Gravels. A prominent deeper reflector was mapped reasonably confidently was interpreted as a “lower Waiwhetu” reflector and considered to be an intra-formational horizon (‘Q3 Aquitard’) within the gravels rather than the base of this aquifer unit (Lamarche, Nodder et al. 2016). The “Top Waiwhetu” reflector was correlated to offshore boreholes east of Matiu/Somes Island (Lamarche, Mountjoy et al. 2015) and off Kaiwharawhara (Barnes, Nodder et al. 2014) and corresponded to a transition from marine muds to terrestrial gravels. An acoustic basement was picked on the NIWA and GNS seismic sections. These interpretations were corroborated and strengthened by integrating previous interpretations of reflectors that represented the Base Holocene (equivalent to Top Waiwhetu), Base Waiwhetu and Base Wilford (= Top Moera) from earlier studies (Wood and Davy 1992; Davy and Wood 1993).

Figure 3.2 shows an example seismic reflection profile with interpretation along a line extending through exploration bore E8 orientated NE-SW.

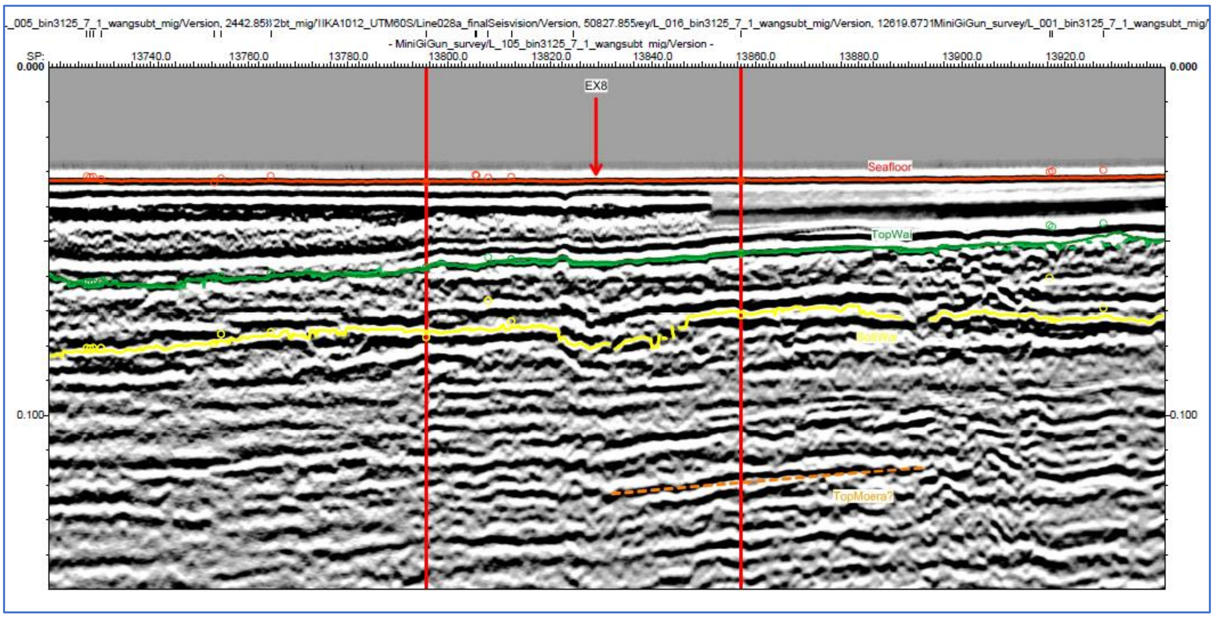


Figure 3.2 Main reflectors identified in Wellington Harbour geophysical data (Seismic line KAH1505_L105). Red = Seafloor, Green = Top Waiwhetu (TopWai), Yellow = lower Waiwhetu (BotWai), Orange (dashed) = Top Moera. The planned location of exploratory borehole E8 is shown (EX8).

The mapped unit between the Top Waiwhetu and lower Waiwhetu reflectors represents the upper part of the Waiwhetu Gravel Aquifer (Figure 3.2). This unit deepens in the stratigraphic section from off Petone-Seaview as it enters the harbour basin. Towards the southwest, between Matiu/Somes Island and Te Motu Kairangi/Miramar Peninsula, this unit becomes progressively thinner and eventually thins to less than a metre across the northern entrance to Evans Bay. Southwards into the harbour heads area, the unit deepens markedly to more than 30-40 m deep, as the overlying harbour muds thicken concomitantly, and it also thins, shoaling out towards the lower contact. At Falcon Shoals (see below), where seismic correlations have proved to be problematic (Lamarche, Mountjoy et al. 2015), the Waiwhetu unit is interpreted as starting to rise up the stratigraphic section, and probably laps onto or intersects channelised/incised "acoustic basement" further to the south off Oruaiti/Point Dorset. It is therefore possible that the gravels associated with the Waiwhetu Aquifer do not extend outside of the harbour entrance and onto the inner continental shelf. However, faint but coherent reflectors below the "acoustic basement" possibly continuous with the gravel units does not enable us to rule out further lateral continuity of the gravel beds out of the harbour towards Te Moana o Raukawa/Cook Strait.

Some new geophysical interpretations made over the course of the borehole drilling phase of the project are summarised in Figure 3.3 and explained further in Appendix 1.

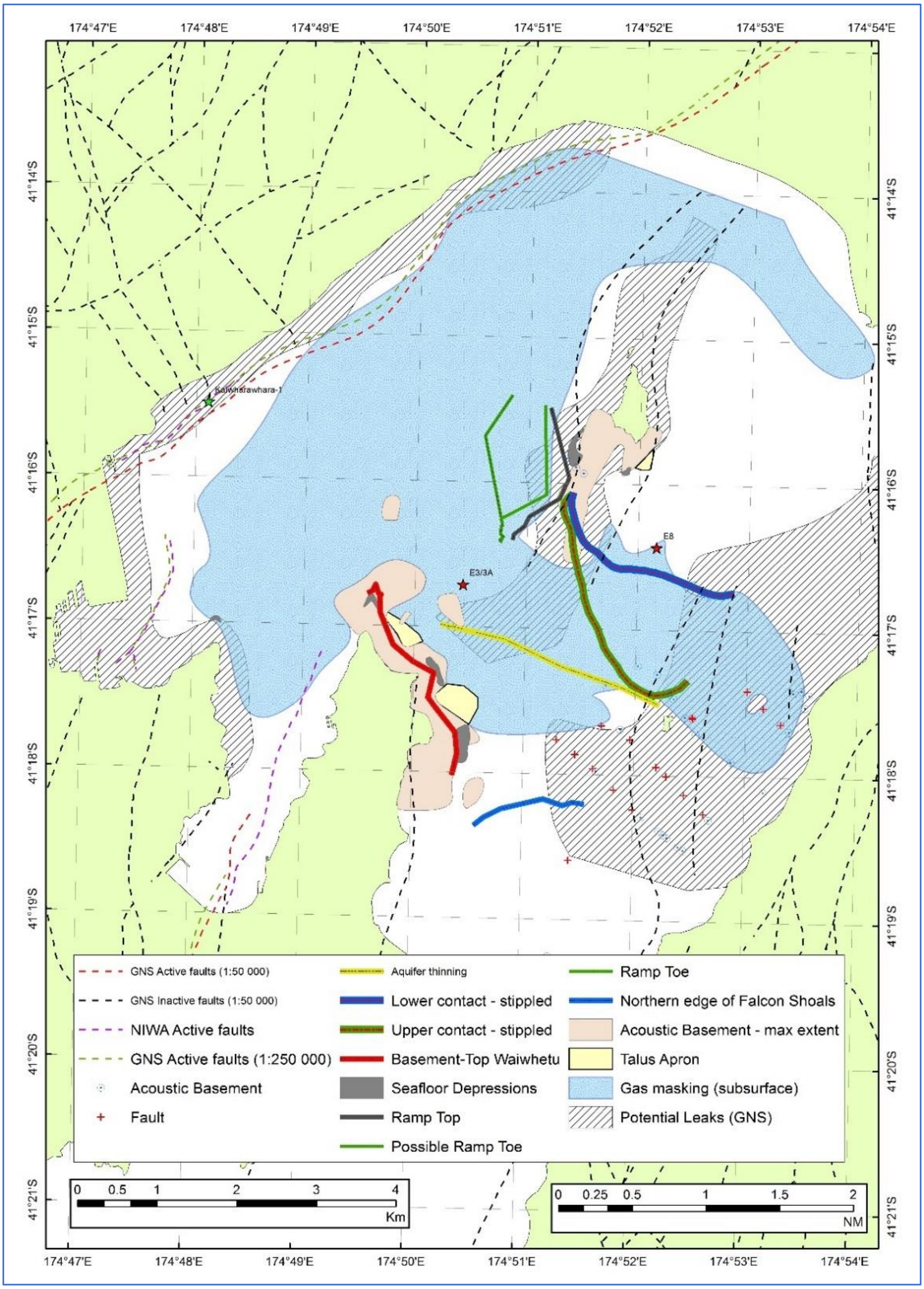


Figure 3.3 Summary of geophysical features identified and mapped by NIWA over the course of the project in Te Whanganui a Tara/Wellington Harbour (from Appendix 1 this report: Nodder et al, 2018)

4. Exploration drilling

4.1 Objectives

The key hydrogeological objectives of the exploration drilling were as follows:

- Identify whether potentially usable aquifers extend under the harbour;
- Obtain information on aquifer thicknesses, general hydraulic characteristics and aquifer pressures;
- Collect information on the water quality to identify whether the aquifer has potential as an alternative water source; and
- Test the connectivity of the intercepted aquifers to onshore aquifers.

4.2 Bore siting rationale

4.2.1 Data sources

The locations selected for the exploration bores were based on the review of the following information:

- Seismic survey interpretation of the aquifer thickness and extent (see Appendix 1);
- Geological conceptual model of the harbour;
- Location of known and suspected submarine freshwater springs;
- Location of known faults;
- Distance from Miramar Peninsula;
- Depth of harbour floor;
- Results of preliminary aquifer modelling (HAM3); and
- Groundwater quality information from Greater Wellington Regional Council long term environmental monitoring.

This information was used in conjunction with the drilling and testing results from E3a to refine the site location of E8.

4.2.2 Siting considerations

The key considerations during the selection of the first (E3a) exploratory bore site were;

- Preferentially locating the bore where thicker, well developed Waiwhetu gravels were indicated on geophysical profiles;
- Avoidance of perceived saline intrusion risks;
- Avoidance of, and provision of an adequate buffer, to seismic risks associated with known active and inactive faults;
- Conceptual understanding of likely groundwater quality patterns; and
- Distance from the proposed treatment plant on the Miramar Peninsula (i.e. pipeline costs).

The potential viability of the Waiwhetu aquifer was assessed using the seismic interpretation and geological conceptual model developed by NIWA and GNS. This information indicated that the aquifer was likely to extend between the Petone foreshore and the harbour entrance area at Falcon Shoals. The interpretation indicated that the aquifer is likely to be a relatively continuous unit across the harbour.

The risk of saline intrusion occurring as a result of pumping-induced aquifer drawdowns was evaluated through identifying the following vulnerabilities (refer also to Chapter 6):

- Saline intrusion where the aquifer abuts the basement rocks around the edge of the harbour and Somes Island;
- Saline intrusion at suspected submarine freshwater spring sites due to a reversal in vertical head gradients; and
- Saline intrusion at the Falcon Shoals area, where the interpretation suggested that the aquifer may discharge via diffuse flow or be unconfined.

Concerns associated with bore design and decommissioning were not considered during the siting rationale - but are part of the programme design process and are reported elsewhere.

To minimise the potential risk of saline intrusion as a result of the exploratory drilling and testing programme it was determined that any bores would need to be sited at least 2 km from Falcon Shoals and 1 km from any basement contact zone (where the Petone marine silts abut greywacke bedrock) or seafloor depression (indicating the possible presence of a spring). These distances were based on drawdown calculations and an assessment of the distance of the basement contact from the shoreline based on the available seismic information.

The principle seismic risks considered during the bore siting process were the faults associated with the Somes Island Horst structure (Figure 4.1). There are numerous faults running in an approximately north northeast to south south-westerly direction and there is good geophysical evidence that some of the faults influence the Waiwhetu gravels, suggesting that they are still active. Therefore, the Somes horst was excluded as being potentially too seismically active to provide a sensible location for water supply bores. Other faults are present running across the harbour floor and a 200m exclusion zone was included along all these faults during the bore siting processes.

The distance from the Miramar Peninsula was considered only after all the above risks had been assessed. The first exploratory bore (E3a) was located as close to the peninsula as the above considerations would allow to minimise the cost of a pipeline infrastructure.

When a second exploration bore (E8) was proposed, the geological conceptual model was revised based on the results of E3a. Locating groundwater of good quality became more critical than proximity to the peninsula (and pipeline costs) for the viability of the project.

The siting of the second exploratory bore (E8) had two refined objectives:

- to investigate favourable sites where aquifers (Waiwhetu and Moera) may be thicker and have higher permeability and therefore enhanced transmissivity (bore yield); and
- to investigate sites where aquifers may have improved water quality.

Two refined target areas were identified for potential sub-sea aquifer development – western and eastern areas – these are shown on Figure 4.1. The first exploratory bore (E3a) was situated in the western area. Note that site 'EX7' was subsequently replaced by 'E8' located in the same general area.

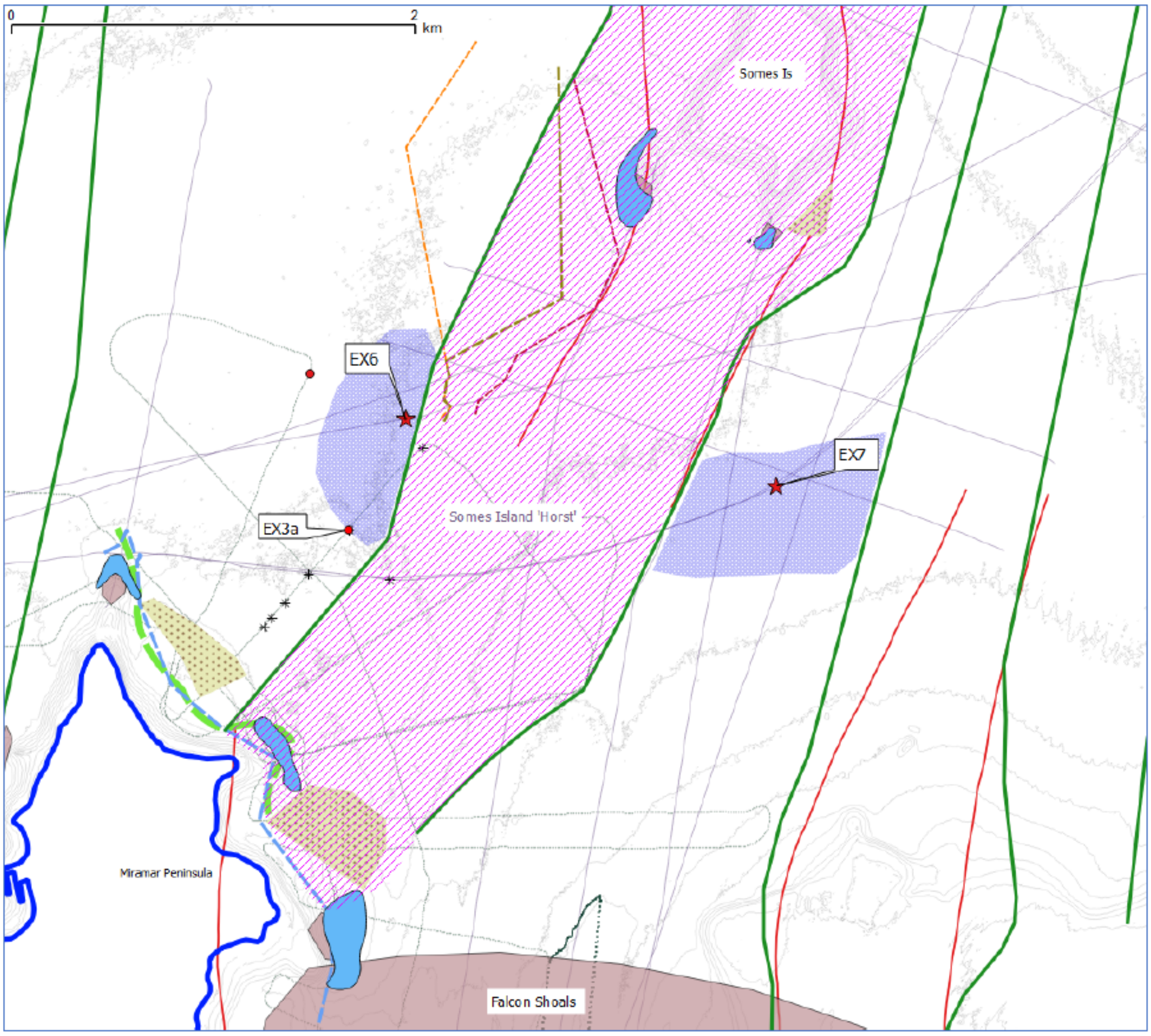


Figure 4.1 Recommended locations for EX6 and EX7 (EX7 was later replaced by E8 a short distance away). Pink shaded area is the Matiu/Somes Island Horst seismic exclusion zone. Target drilling areas – purple shading. Also shown are: the location of borehole EX3a (red dot), previously proposed borehole locations (black stars); seismic reflection survey lines (grey lines); basement contact zones (green and blue dashed lines); suspected freshwater spring depressions (blue polygons); talus aprons (brown speckled polygons); the location of potential freshwater seepage across Falcon Shoals (brown polygon); and mapped faults and associated buffer zones (red and green lines).

The target areas were constrained by three principal considerations – saline intrusion risk, the conceptual geological understanding of aquifer characteristics, and seismic risk related to the location of known active and inactive faults.

Saline intrusion risks considered during the siting of E8 included the basement contact zones with the aquifer, suspected submarine freshwater spring sites (sea floor depressions) and the Falcon Shoals area where the Waiwhetu aquifer is likely to be more unconfined (Figure 4.1). Safety buffers of about 1km from the basement contact and spring sites, and 2km from the Falcon Shoals area were adopted (based upon drawdown calculations).

Improved geological understanding of the Waiwhetu aquifer extent and underlying lacustrine silts (from E3a) also precluded extension of the western target zone any further to the west where the aquifer was considered to become thinner (and disappear) and where lacustrine sediments become thicker.

Seismic risks were identified using the seismic reflection surveys carried out by NIWA (2015/16) and earlier by GNS (Wood and Davey, 1992). Of relevance to the harbour area off the Te Motu Kairangi/ Miramar Peninsula was the 'Matiu/Somes Island Horst' - a complex array of possibly active faults that have uplifted Matiu/Somes Island and extend southwards from the island (pink shaded zone in Figure 4.1). It is also evident from the geophysics data that the upper aquifer (Waiwhetu) thins significantly over the horst structure. It was recommended that the horst is treated as an exclusion zone for any potential bore development.

E8 ('EX7' on Figure 4.1) was eventually located on the eastern target area on the opposite side of the Matiu/Somes Island Horst from E3a. There appeared to be a possibility that the Waiwhetu Aquifer (upper gravels) would be significantly different here – possibly thicker and more permeable (based upon the conceptualisation of the paleo-depositional environment). The water quality was also expected to be improved (compared to EX3a) as there was an expectancy that the water in the Waiwhetu unit ('upper aquifer') would be closer to the chemistry of the Somes Island bore (which has good potability similar to the onshore upper Waiwhetu aquifer).

The seismic reflection data showed that the upper part of the Waiwhetu aquifer has a very different characteristic at E8 compared to the eastern target area. The signature is more 'granular' compared to the very 'reflective' signature of the western area (where it most likely reflects alternating thin gravels and silts as found in E3a). The eastern granular signature was regarded to be indicative of channelised gravels closer in characteristic to the onshore upper Waiwhetu gravels and E8 was sited in an apparent channel feature. The granular zone seems to thin just south of E8.

4.3 Investigation methodology and analysis

The exploratory investigation was undertaken in two phases. The first phase included the drilling of cored bores E3 and E3a at a location approximately 1.3 km north of the Miramar Peninsula between 6th June and 24th August 2017. The first hole, E3 was abandoned at about 15m depth due to bad weather (necessitating the abandonment and sealing of the hole and moving the drilling barge to shore). Drilling recommenced a few metres away at E3a (it not being possible to relocated over E3). The second phase comprised drilling bore E8 at a location approximately 3.4 km northeast of the Miramar Peninsula and 1.3 km south east of Somes Island between 3rd and 31st January 2018. The locations of the bores are shown in Figure 2.1 and a summary of the bore information is presented in Table 4-1.

The investigation was undertaken in a phased approach to allow for the refinement of the location of E8 based on the findings from E3 and E3a.

Table 4-1 Bore details

Parameter	E3	E3a	E8
Easting (NZTM)	1754154.8	1754159.0	1756571.4
Northing (NZTM)	5428722.7	5428714.3	5429151.0
Barge Level (mamsl)	4.42	4.66	4.60
Depth to sea floor (mamsl)	-23.18	-23.37	-22.62
Bore depth (mbsf)	15.2	79.3	71.15
Date Drilled	6/06/2017 – 10/07/2017	17/07/2017 – 24/08/2017	3/01/2018 – 31/01/2018

The drilling and testing methodology is presented in Appendix 2, but in general, at each bore location the following sequence of activities were carried out:

- Drill to the top of the aquifer unit undertaking detailed logging of the sediments encountered (see Stantec 2018 Geotechnical Report for full details);
- Drill through the aquifer unit stopping to assess the permeability and water quality via constant/falling head tests and pumping from the open bore hole;
- Install and develop a temporary screen within the most productive part of the aquifer;
- Perform pumping tests (step discharge and constant rate) during which the Waterloo wellfield abstraction rate was smoothed/stabilised (before, after and during the test);
- Perform overnight monitoring before and after pumping tests during which the Waterloo wellfield was shut down for 5-6 hours and then ramped up quickly to maintain a high rate for as long as possible (‘shut-down’ test to provide supplementary data to calculate aquifer properties and ascertain aquifer connectivity);
- Remove the temporary screen and continued drilling;
- Repeat the above process at each aquifer unit;
- At the end of the hole, undertake geophysical logging (gamma and neutron density);
- Pull out of hole, grout up the bore to ensure that the integrity of the seal between each aquifer unit is maintained.

It should be noted that the results of the geophysical logging do not represent an undisturbed record of the stratigraphy because in both bores the Waiwhetu aquifers had been developed and tested prior to logging. This process removed some of the fines from around the screened section of bore which affected the results of the logging, although the records still provide a useful assessment of the formations.

The sonic coring drilling methodology allowed for excellent core recovery (even through the gravel units). The cores are stored securely at GNS Science in Lower Hutt.

4.4 Summary of E3a

The drilling at E3a identified two thin aquifers - the upper Waiwhetu Aquifer (22.9 to 27.8 m below sea floor) and the Moera Aquifer (74.5 to 78.5 m below sea floor). The lower Waiwhetu Aquifer was identified as silty gravel units between 34.5 and 36.5 m and 45 and 48 m, but these units were only poorly water bearing at best.

An initial pumping test was undertaken in the upper Waiwhetu Aquifer using a 4” submersible pump and a 1.5m long temporary screen. However, the results were significantly affected by the limited screen length and as such a second longer test was undertaken using a 3 m screen whilst pulling out of the hole.

A pumping test was undertaken using the temporary 3m screen in the Moera Aquifer following the geophysical logging, prior to pulling out of the hole. The restricted size of the submersible pump meant that limited drawdown was seen initially so additional shorter-term pumping tests at higher rates were undertaken within this aquifer using a 4” surface pump. The details of the installation of the screens and the pumping test methodology are presented in Appendix 2

Water level and water quality data was collected during the tests in both aquifers. The analysis methods used to assess and process this data are presented in detail in Appendix 3.

4.5 Summary of E8

The drilling programme at E8 identified two gravel aquifers with reasonable thickness, the upper Waiwhetu Aquifer (18.3 to 29.3 m below sea floor) and the lower Waiwhetu Aquifer (32.8 to 43.7 m below sea floor). The lower Waiwhetu Aquifer was found to contain a significantly poorer groundwater quality (850-900ppm chloride), although with reasonable transmissivity. In contrast, the upper Waiwhetu Aquifer contained good quality water (and exhibited a potentially very high transmissivity – the formation characteristics being consistent with those observed near the Waterloo wellfield. The Moera formation at E8 (top encountered at 61m below sea floor) was significantly different from that seen in E3a, being denser with angular clasts and significantly more fines suggesting a less fluvial depositional environment. This unit was not significantly water bearing and as such was not tested.

Overnight monitoring and pumping tests were undertaken within the upper and lower Waiwhetu Aquifer units using a 3” surface pump and the 3 m temporary screen. As at E3a, a Waterloo wellfield ‘shut-down’ test was also performed in these two aquifers to test for connectivity and provide estimate of aquifer properties. Details of the installation of the screens and the pumping test methodology are presented in Appendix 2.

Water level and water quality data was collected during the tests in both aquifers and the analysis methods used to assess and process this data are presented in detail in Appendix 4.

5. Offshore geological and hydrogeological conceptual model

Appendix 1 provides a comprehensive description of the offshore geology and the interpretation of the depositional and structural environments. An overview of this work is provided below.

A three-dimensional geological model for the onshore part of the Lower Hutt Basin was developed by GNS Science (Boon et al., 2010) by integrating all reliable pre-existing data. This work previously informed the HAM3 model and has been fully retained for the onshore part of new HAM4 model (refer to EIM, 2014 for a full description).

Offshore, a new three-dimensional geological model was developed for the current project which interfaces with the onshore model. The offshore model and the methodologies used to develop it are documented in Appendix 1.

Figure 5.1 summarises the revised offshore geological model by means of two schematic cross sections, one long-section along the groundwater flow path between the Petone foreshore and the harbour heads, the other orientated from west to east across the central part of the harbour. The various geological units shown in Figure 5.1 were introduced in Chapter 2.

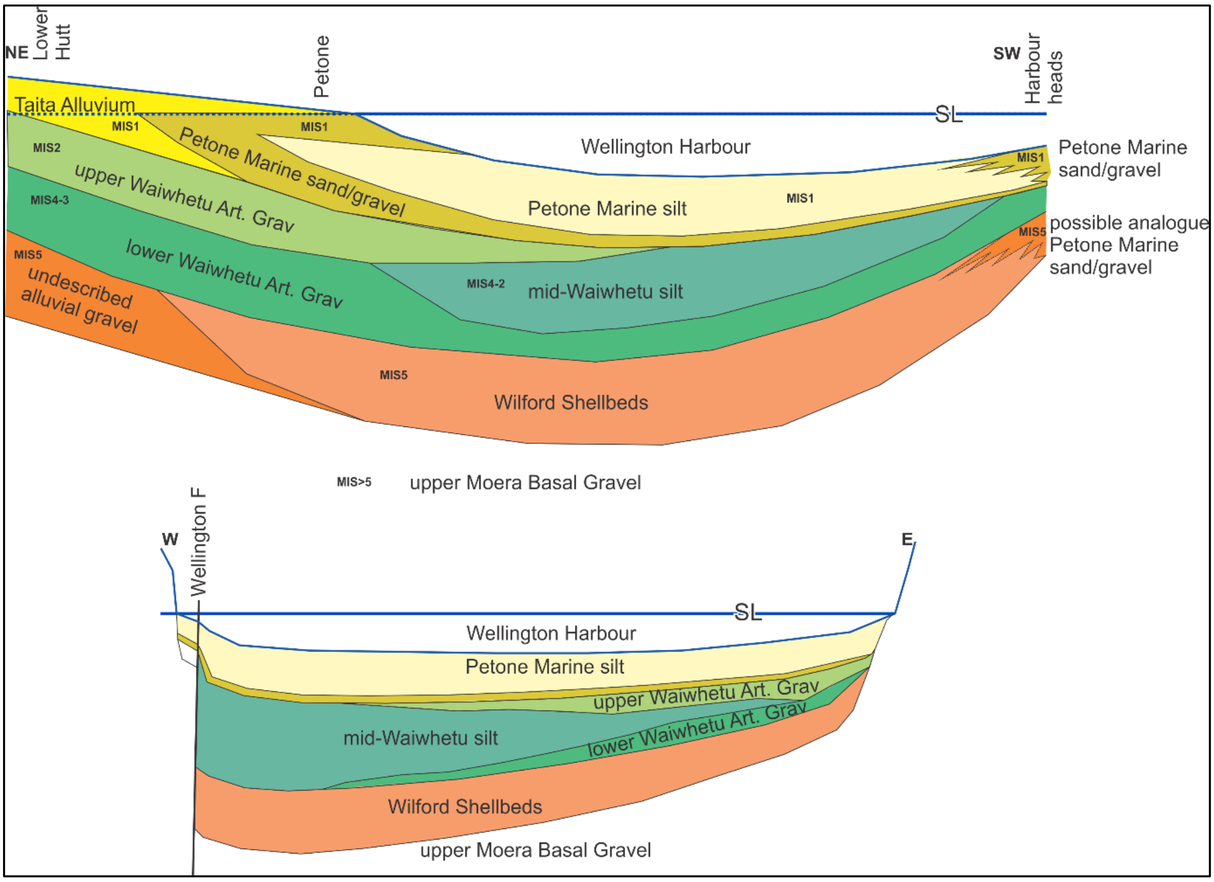


Figure 5.1: A conceptual stratigraphic model of younger Quaternary units beneath Wellington Harbour illustrating ages and relationships between units. The upper diagram illustrates the conceptual stratigraphic model down the axis of the basin, while the lower image shows a west-east conceptual cross section. Note thinning of materials towards Wellington Harbour heads; coarsening of marine units of the Petone Marine Beds and Wilford Shellbed close to the harbour heads; and thinning of the intra-Waiwhetu silt to the east and close to the harbour heads (figure credit: John Begg).

The geological sequence and aquifer units identified in Figure 5.1 are clearly identifiable in the two project exploratory bores (E3a and E8) as shown by the bore log summaries contained in Table 5-1.

Table 5-1 Geological sequence recorded in exploratory bore E3a and E8.

Wellington Harbour boreholes		E3A		E8	
	sea floor	-23.37		-22.62	
Stratigraphy		depth bsf	RL	bsf	RL
Petone Marine Beds (Holocene)	thickness	22.9		18.3	
upper Waiwhetu gravel (Q2)	top	22.9	-46.27	18.3	-40.92
	base	27.75	-51.12	29.3	-51.92
	thickness	4.85		11	
intra-Waiwhetu fine-grained aquitard (Q3)	thickness	17.25		3.5	
lower Waiwhetu gravel (Q4)	top	45	-68.37	32.8	-55.42
	base	48	-71.37	43.7	-66.32
	thickness	3		10.9	
Total Waiwhetu	thickness	25.1		25.4	
Wilford (Q5)	top	48	-71.37	43.7	-66.32
	base	74.5	-97.87	61	-83.62
	thickness	26.5		17.3	
Moera (Q6+)	top	74.5	-97.87	61	-83.62
	end of hole	80.06	-103.43	71.15	-93.77
	thickness drilled	5.56		10.15	

Figure 5.1 and Table 5.1 provide the context for the following descriptions of each of the geological units

5.1 Principal geological units beneath Wellington Harbour

5.1.1 Holocene sequence

Holocene materials (post glacial in age < c. 10,000 years old) occur at the sea floor and overlie the Waiwhetu gravel aquifer. These sediments continue to be deposited to the present time and are dominated by soft to firm silt and clayey silt, although they seem to become sandier near the base of the unit. Fine-grained harbour floor Holocene materials are 22.9 m thick at E3/3a and 18.3 m thick at E8. Across most of the harbour basin they mantle all underlying units. In shallower parts of the harbour (e.g. Petone Beach, Days Bay, Eastbourne and beneath the harbour heads) laterally equivalent Holocene marine materials may be sandy or even gravelly but are probably interbedded to greater or lesser degree with finer grained layers.

Therefore, the fine-grained silts and clayey silts confine much of the Waiwhetu Aquifer where it occurs beneath the harbour. The nature and thickness of the firm silts and clayey silts means that they probably form an effective aquitard with very low vertical leakage. However, the confining nature of this unit is perceived to dissipate into the peripheral shallower part of the harbour – particularly in the harbour entrance area and along the Eastbourne coastline where the higher energy environment mean that they probably transition into more of a silty sand, sand and gravel lithology. They are also probably mixed in with coarse grained longshore drift material being pushed in from the Cook Strait through the harbour heads and deposited on the Ward Island Platform along the eastern side of the harbour. Evidence for this is provided by the gravel dominated substrate in the harbour entrance and Falcon Shoals.

5.1.2 Waiwhetu Unit

Extensive cold-climate alluvial deposit, collectively known as the Waiwhetu Gravels, underlie the Holocene sediments at a depth of around 20-30m at the foreshore. These contain the principal aquifers in the Lower Hutt valley and are confined by the younger Petone Marine silts. The Waiwhetu Gravels comprise coarse, well-sorted, rounded water-bearing river gravels deposited under high energy conditions during the last glaciation (Otiran, oxygen isotope stages Q2-4). They extend from Taita Gorge to the Petone foreshore and extend under the harbour floor towards the harbour entrance area.

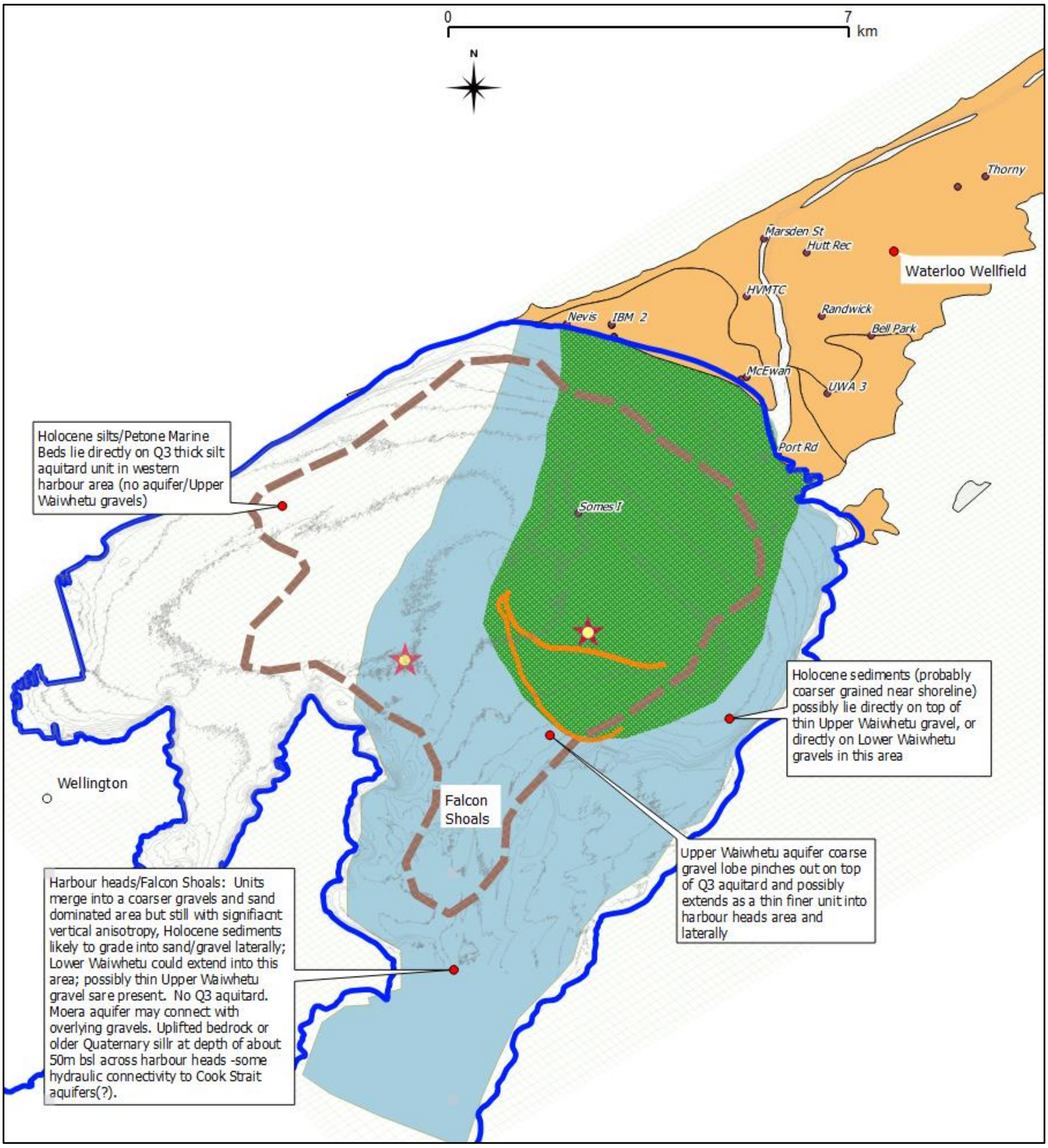
The Waiwhetu unit is recognised to comprise two distinct gravel layers separated in some areas by a silt and clay aquitard unit. It therefore has three components (as also as shown in Table 5.1):

- Upper Waiwhetu Aquifer – coarse highly permeable gravel aquifer (last glacial, Q2) – the most productive part of the Waiwhetu unit onshore.
- Intra-Waiwhetu 'aquitard' – interstadial warm period low energy lake/swamp deposits (Q3)
- Lower Waiwhetu Gravels – last glacial gravels, lower permeability, more sandy/silty than upper gravels (Q4)

Upper Waiwhetu gravels

The geological conceptualisation shown in Figure 5.1 depicts the upper Waiwhetu gravel fan (or lobe) to thin southwards and pinch out to the north of Falcon Shoals. The gravels are regarded to represent a prograding delta that propagated across a swampy lacustrine plain (the Q3 surface) and are thickest on the eastern side of Somes Island. They probably do not extend as a thick coarse unit all the way to Falcon Shoals or the harbour entrance.

Seismic reflection surveys (Appendix 1) have assisted in estimating the southerly extent of the main coarse gravel 'toe' of the fan prior to significant thinning and fining of the unit (as encountered at bore E3a). The extent of the main body (or lobe) of the upper Waiwhetu gravels is shown in Figure 5.2. The wider extent of thinner gravels/sands/silts belonging to this unit are also shown (blue shaded area).



Holocene silts/Petone Marine Beds lie directly on Q3 thick silt aquitard unit in western harbour area (no aquifer/Upper Waiwhetu gravels)

Holocene sediments (probably coarser grained near shoreline) possibly lie directly on top of thin Upper Waiwhetu gravel, or directly on Lower Waiwhetu gravels in this area

Upper Waiwhetu aquifer coarse gravel lobe pinches out on top of Q3 aquitard and possibly extends as a thin finer unit into harbour heads area and laterally

Harbour heads/Falcon Shoals: Units merge into a coarser gravels and sand dominated area but still with signifiacnt vertical anisotropy, Holocene sediments likely to grade into sand/gravel laterally; Lower Waiwhetu could extend into this area; possibly thin Upper Waiwhetu gravel sare present. No Q3 aquitard. Moera aquifer may connect with overlying gravels. Uplifted bedrock or older Quaternary sillr at depth of about 50m bsl across harbour heads -some hydraulic connectivity to Cook Strait aquifers(?).

Figure 5.2: Probable distribution of the coarse main lobe of upper Waiwhetu gravels beneath Wellington Harbour (green stippled area) based upon geophysics and exploration drilling (J. Begg, pers comm), and the anticipated spread of the unit as a thinner less well- developed aquifer (light blue). Probable extent of the intra Waiwhetu aquitard is also shown by the dashed brown line. Orange lines represent feature identified in seismic reflection surveys representing the possible upper and lower edges of the upper Waiwhetu gravel lobe of coarser gravels. The locations of the two harbour exploration bore sites are also shown (stars).

There is convincing evidence that the upper Waiwhetu gravels thin out and disappear in the western part of the harbour. The E3a bore shows that a thin upper Waiwhetu Aquifer (4.8m) occurs to the west of the 'main gravel lobe' – suggesting that the unit spreads out and continue as a thin layer (Figure 5.2). Monitoring of the upper Waiwhetu gravels in the E3a bore conclusively showed a connection to the onshore upper Waiwhetu gravels by monitoring groundwater pressure variations in response turning off the Waterloo Wellfield for several hours and then ramping up the pumping rate quickly (all intercepted aquifers were subject to this test – see Appendix 2).

Figure 5.3 illustrates the interpreted morphology of the upper Waiwhetu gravels with an emphasis on its possible relationship to the harbour entrance area. The cross-section, derived from the 2015 NIWA seismic reflection data along seismic line 003, depicts a progressive deepening and thinning of the Waiwhetu Gravels (termed fluvial sand/gravel/silt in Fig 5.3). The aquifer thickness at the northern end (left) of approximately 15-20m is consistent with the aquifer thickness recorded in boreholes onshore near the Petone foreshore. The merging of marine Holocene sediment (Petone Marine sediments) with marine sand and gravel transported northwards through the harbour entrance is also shown, as is the greywacke basement high through which channels have been eroded.

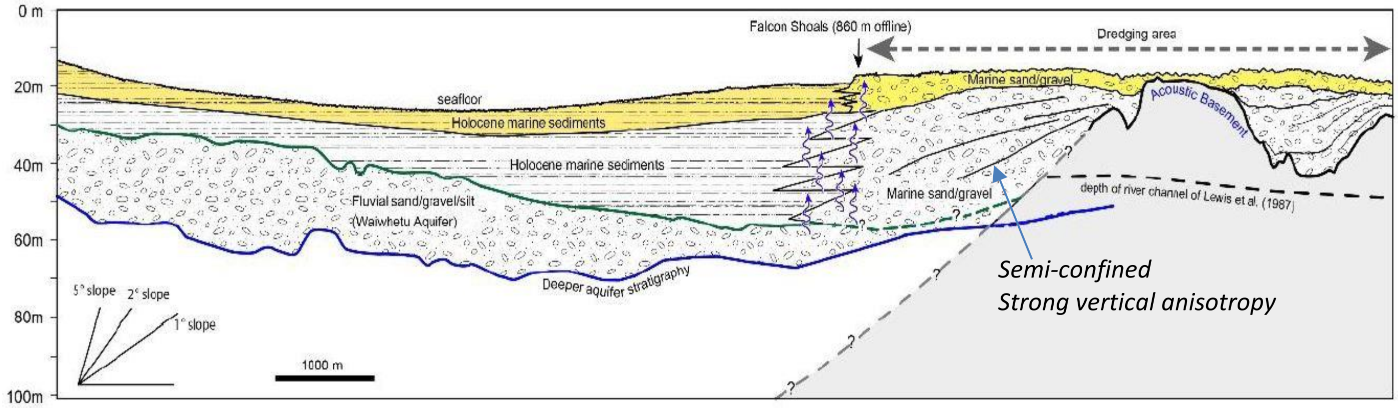


Figure 5.3 Conceptual model for the geometry of the Waiwhetu Aquifer through the Wellington Harbour entrance. Uncertain boundaries shown by dashed lines. Left side = north. From Lamarche et al. 2015.

The 30-40m thick sand and gravel sediment sequence above the Waiwhetu Aquifer in the harbour entrance is regarded to be more permeable than the Petone Marine Beds within the harbour. Therefore, more leakage from the aquifer could occur in this area. This is tentatively corroborated by anectodical evidence for diffuse sea floor freshwater discharge in the Falcon Shoals area (Harding, 2000). The vertical hydraulic conductivity of the sands and gravel sequence in the harbour entrance area must be highly anisotropic (as a result of layering and compaction) and significantly impede the vertical movement of water out of the aquifer to the sea floor. If this were not the case, the model showed that the Waiwhetu Aquifer would depressurise at Somes Island and at the Petone Foreshore. The Waiwhetu Aquifer is therefore regarded to be semi-confined south of Falcon Shoals and the geological succession above it has a high anisotropy due to layering and compaction (Kv several orders of magnitude lower than Kh).

Onshore, the upper Waiwhetu gravels attain a maximum thickness of about 55m on the western side of the Hutt Valley but elsewhere they are typically between 30m and 50m thick. Offshore, the two exploration drill sites (E3a and E8) encountered a total Waiwhetu unit thickness of about 25m. The E8 site (located to the east of Somes Island) has an overall considerably thicker and coarser sequence of gravels within the Waiwhetu unit. The upper Waiwhetu gravels at E8 are about 11m thick - almost 2.3 times thicker than at E3a (4.8m). At E3a the upper Waiwhetu gravel comprises mostly clayey gravel, sandy gravel and sand, with gravel clasts mostly rounded to sub-rounded. At E8 similar lithologies are present, but gravel clasts are recorded as largely sub-rounded to sub-angular.

The 'blind' or 'semi-blind' morphology of the upper Waiwhetu gravel fan explains why an artesian head (c. 3-4m amsl) is maintained in the offshore upper Waiwhetu Aquifer in both exploration bores and in the Somes Island monitoring bore.

Figure 5.2 also shows a thin continuation into the harbour entrance of the upper Waiwhetu gravels (<5m thick) downstream and laterally from the main gravel lobe. The E3a bore shows that a thin upper Waiwhetu Aquifer (4.8m) occurs to the west of the main gravel lobe – supporting this concept.

Intra Waiwhetu Q3 Aquitard

Figure 5.1 depicts the upper Waiwhetu Gravels as being deposited directly onto the lower Waiwhetu gravel onshore but largely over the top of the mid-Waiwhetu silt (the Q3 Aquitard described above). The upper Waiwhetu is therefore separated from the lower Waiwhetu beneath much of the harbour by the Q3 silt aquitard. However this separating unit appears to thin and dissipate to the east of Somes Island (<5m) and is considered to be heterogeneous and probably discontinuous towards the Eastbourne and Petone shorelines (J. Begg pers comm). Therefore, the upper and lower Waiwhetu gravels could be in hydraulic continuity in these areas.

It is of relevance to note that onshore, the similarity in heads between the upper and lower parts of the Waiwhetu Gravels (at McEwan Park and Tamatoa on the foreshore) could indicate (although not conclusively) that the Q3 intra Waiwhetu unit may not form an effective aquitard in this area. However, different hydraulic properties in the lower Waiwhetu Gravels appear to significantly affect groundwater flows as shown by differing chemical and isotopic signatures of groundwater above and below the aquitard (Brown and Jones 2000). Small increases in anions and cations are evident in the lower Waiwhetu Gravels together with a slight increase in conductivity and pH. Tritium dating of groundwater from the upper Waiwhetu Gravels indicates an age of < 2.5 years (42.3 m), whilst groundwater below the aquitard has been dated at about 45 years (66.4 m).

Figure 5.2 shows the conceptualised extent of the Q3 'intra-Waiwhetu aquitard' in the harbour area. The unit consists of sand, silt and clay with interbedded carbonaceous material of swamp and or lake origin which thickens considerably to the west where it dominates the last glacial sequence (i.e. upper Waiwhetu gravels are absent). It seems probable that it is associated with deposition during a period of warmer climate (interstadial – possibly Q3 in age) and a higher sea level stand – although it is unlikely that the sea level was ever high enough to invade the current harbour area at this time (a rock barrier across the harbour heads is regarded to have been too high for this to occur (J Begg, pers comm.). The Q3 aquitard is also recognised in some onshore bores, particularly towards the Wellington Fault.

Offshore, the Q3 intra Waiwhetu aquitard is clearly recognisable in both (E3a and E8) exploration drill logs (Table 2.1) as a silt and silty sand layer, with minor gravel and clay intervals. The Q3 fine-grained unit is 17.25 m thick at E3a but it is only 3.5 m thick at E8. The thinning of the unit between E3a and E8 is a significant difference between the two bore sites that has important implications in terms of the degree of effective separation between the upper and lower Waiwhetu aquifers.

Lower Waiwhetu gravels

Lower Waiwhetu gravels propagated across older marine (Wilford Shell Bed) deposits when the sea retreated from Wellington Harbour following the last interglacial (c. 71 ka). This unit is predominantly gravel and sandy gravel with a gritty clay, silt and sand matrix showing higher silt and sand content compared with the upper Waiwhetu Gravels. The lower Waiwhetu gravels are therefore recognised as being a much lower yielding part of the Waiwhetu unit. In the exploration bores, the lower Waiwhetu gravel is more than 3.5 times thicker in E8 (11m) than encountered in E3a (3m).

Like the upper Waiwhetu gravels, they are thickest on the eastern side of the Somes Island ridge but are considered to be spread more extensively across the harbour to the west of Somes Island and into the harbour entrance area where they are probably overlain by younger coarse-grained material (principally Holocene age). This unit therefore may have a greater connection to the ocean in the heads area through possible vertical flows through the overlying predominantly sand and gravel sequence in this area. However, since this unit also exhibits a similar (very slightly lower) artesian head to the upper Waiwhetu gravels in the E8 exploration bore, its connection to the ocean must also be somewhat restricted to prevent depressurisation of the system.

5.1.3 Wilford Shell Bed

The Wilford Shell Bed is a marine, shelly, silty sand which can be traced across the lower part of the basin beneath the lower Waiwhetu Gravels. It was deposited during the high sea levels associated with the last interglacial period (Q5, Kaihinu). An estuary tidal channel depositional environment is indicated by the shells present within these deposits and associated interglacial peat, peaty sand, silt and clay (coastal swamp/estuary paleoenvironment) occur inland as far as Mitchell Park.

The Wilford unit is recorded at depths of 70 to 83m at the Petone foreshore and is up to 30m thick but decreases in depth and thickness inland where it pinches out against older sediments - the inland extension of the unit appears to be around Knights Road about 4.5 km inland from the Petone foreshore.

Offshore the exploratory bores similarly show the Wilford Shell Bed to comprise a silt, silty clay and clayey silt, with dispersed shell fragments. A minor sand component is evident near its base at E8. The unit is substantially thicker at E3/3a (26.5 m) than at E8 (17.3 m).

The shell beds, which form a consistent and effective aquitard, appear to extend beneath most of the harbour. A distinctive change in the hydraulic properties, hydraulic head and water chemistry is recorded in bores screened above and below the Wilford Shell Bed onshore and offshore (E3a). This would indicate that the Wilford Shell Bed is continuous and acts as a low-permeability aquitard separating the lower Waiwhetu Gravels from the underlying Moera Gravels

5.1.4 Moera Gravels

Stevens (1956) termed the non-marine weathered gravels beneath the Wilford Shell Bed the 'Moera Basal Gravels'. The term is used to generally described the older sequence of glacial and interglacial deposits (Q8-Q10) lying on top of the greywacke basement surface.

Onshore, the upper part of the Moera gravels is a proven aquifer and a few bores tap into it for supply. It is much lower yielding unit than the Waiwhetu gravels and water quality is reasonable.

Only the uppermost part of the Moera Basal Gravels was drilled in the exploratory boreholes which recorded sandy, silty and/or clayey gravel. At E3a the bottom 2m of the thin interval drilled into the Moera (5.6 m) comprised a clayey silt whilst the upper 2.6m was a reasonably good yielding gravel aquifer. The sampled thickness at E8 was much thicker (10.2 m) which also included a thin (0.7 m) gravelly clay layer, but there was no significant groundwater due to the compact clay-bound nature of the formation. The continuity of the ‘Moera Aquifer’ (the upper part of this unit which seems to be a reasonable aquifer onshore) beneath the harbour has therefore not been proven by the exploratory drilling. It is possible that permeable horizons are localised (vertically and horizontally) – E3a having intercepted a thin aquifer, whilst in E8 no viable aquifer was identified in the 10.2m drilled (but aquiferous zones could occur deeper than this although the water quality is expected to become more saline with depth).

5.2 Modelled hydrostratigraphy

The sub-harbour geological sequence described in the previous section provides the hydrostratigraphic framework for modelling the offshore aquifer system. Distinctive and laterally continuous litho-stratigraphic units are identified in the basin represent a sequence of confined aquifers and aquitards.

The key aquifer units present beneath the harbour floor and identified in the exploratory bores (Table 5.1) are:

- Upper Waiwhetu Aquifer (main aquifer), present in both E3a and E8 but thickest in E8;
- Lower Waiwhetu Aquifer, present in both E3a and E8 but only significantly water bearing in E8; and
- Moera Aquifer, present in E3a but not water bearing in E8.

Important aquitard units are:

- Petone marine silts;
- Intra-Waiwhetu silts/silty sands: present in both E3a and E8 but considerably thicker in E3a;
- Wilford Shell Bed.

Table 5.2 provides a summary of the hydrostratigraphic units recognised in the offshore and onshore portions of the LHGZ.

Table 5-2 Onshore and Offshore Hydrostratigraphic Units of the Lower Hutt Groundwater Zone which are simulated in the HAM4 model.

Model Unit	Onshore - Lower Hutt Valley	Offshore - Wellington Harbour to Cook Strait
1 Holocene: Taita (Hutt River) Alluvium and Melling Peat (Holocene)	Taita Alluvium deposited by the Hutt River is locally a loose coarse gravel with high transmissivities forming the upper part of the unconfined aquifer in the north. Forms floor of the Hutt valley.	Not generally present across the harbour, but Hutt River alluvium will locally merge and interfinger with the Petone Marine Beds near to the Hutt River mouth.
2 Holocene: Petone Marine Silts (Q1) [Aquitard]	Petone Marine Beds are dominated by organic sediments, silts, sands and local gravels; overall represent leaky aquitard unit especially near to the Petone shoreline, becoming thinner, more heterogeneous and leaky northwards. Occur across lower half of Hutt Valley - deposits thicken as a low permeability wedge from about 5km inland of Petone foreshore	Clayey silts form a widely distributed aquitard across harbour and continue to accumulate to the present day. Silts are probably absent in harbour heads/Falcon Shoals area and east margin of harbour where coarser grained (gravels and sands interspersed with fines) equivalents occur in higher energy environments. Mixed in with coarse longshore drift deposits pushed in from Cook Strait.
3 Upper Waiwhetu Gravels (Q2) [Aquifer]	Coarse highly permeable coarse alluvial gravels. The principal aquifer used for public water supply. Throughout entire Lower Hutt valley	Coarse highly permeable gravel aquifer. Well-developed on eastern side of Somes Island horst as a fan deposit prograding towards south. Possible thin/poor representation close to immediate western side of the island. Not present beneath western half of the harbour – Q3 fine grained deposits dominate here. Probably does not extend through to Falcon Shoals or harbour heads or does so only as a thin unit (c. <5m)
4 Intra Waiwhetu silts (Q3) [Aquitard]	Intermittent clayey silts and sands representing hiatus in coarse gravel deposition. Present in many bores particularly in deeper part of the basin towards the Wellington Fault.	Clayey silts and sands form a thin aquitard which thickens considerably to the west where it dominates the last glacial sequence. The aquitard thins substantially to east of Somes Is and shoreward on eastern side, probably pinches out and is heterogeneous around margins. May extend a short distance into the Falcon Shoals area.
5 Lower Waiwhetu Gravels (Q4) [Aquifer]	Matrix-rich gravels, significantly lower permeability than upper Waiwhetu Gravels. Throughout entire valley	Matrix-rich gravels, significantly lower permeability than upper Waiwhetu Gravels. Widely spread over the harbour area (more extensive than the upper Waiwhetu) and regarded to extend out into the harbour heads where it is overlain by coarse grained Holocene deposit.
6 Wilford Shell Beds (Q5) [Aquitard]	Predominantly silts and sands, an aquiclude separating the Waiwhetu and Moera Basal gravels. From around Knights Road (3km from foreshore) to foreshore	Predominantly silts, clayey silts and sands, Widespread beneath harbour forming and an aquiclude separating the Waiwhetu and Moera Basal gravels. Possibly represented by a coarser grained or layered equivalent in harbour heads area.
7 Moera Basal Gravels (Q6+) [Intermittent aquifer]	Matrix-rich gravel aquifer, moderate resource potential Throughout entire valley	Matrix-rich gravel aquifer, moderate resource potential Distributed across entire basin
8 Older Deposits [Low k; aquifers?]	Sequence of compact gravels, silts, sands and clays Sub-harbour basin, extending onshore at depth	Sequence of compact gravels, silts, sands and clays at depth extending across the harbour and terminating against the harbour heads raised basement bar.
9 Basement Greywacke [Aquiclude]	Hard rock, minor fracture-controlled secondary permeability, generally regarded to be 'groundwater basement' Entire basin	Greywacke basement occurs at depth, possibly more than 600m against the Wellington Fault. The harbour heads is an area of uplift and basement is thought to occur at about 50m below msl – creating a partial barrier to the outflow of sediment and groundwater. Channels incised through the barrier are recognisable on geophysical surveys.

5.3 Groundwater levels and gradients

5.3.1 LHGZ - General characteristics

The offshore hydrogeological environment is a continuation of the onshore system - for which there is a very good understanding underpinned by the information provided by half a century of monitoring data. The previous HAM3 investigation (EIM, 2014) documented current understanding and analysis of the onshore groundwater environment – some of which is incorporated here to help place the offshore analysis and understanding within the context of the whole system.

Groundwater levels in the Lower Hutt Groundwater Zone, both onshore and offshore, are influenced by a range of factors including river stage, rainfall recharge and abstraction rates. Tidal and barometric pressure variations also significantly affect levels in the confined aquifers.

Abstraction drawdown effects extend across the entire valley and offshore (levels are also diurnally strongly influenced by tidal effects by up to about a metre). Previous modelling using HAM3 shows that the Waiwhetu Aquifer level draws down by about 2m across the entire harbour resulting from onshore abstraction which currently peaks at about 95-110MLD. Downstream of the Waterloo wellfield the groundwater flow gradient in the Waiwhetu aquifer becomes almost flat due to interception of nearly all the aquifer throughflow.

The GWRC maintain a groundwater level monitoring network across the onshore Lower Hutt Groundwater Zone comprising automatic and manually recorded observation bores in the Waiwhetu gravels, Moera gravels and in the Taita Alluvium in the unconfined aquifer area (Figure 5.4; see the HAM3 report for a comprehensive description of onshore groundwater level monitoring). Data from these sites were used in the calibration of the HAM3 model.

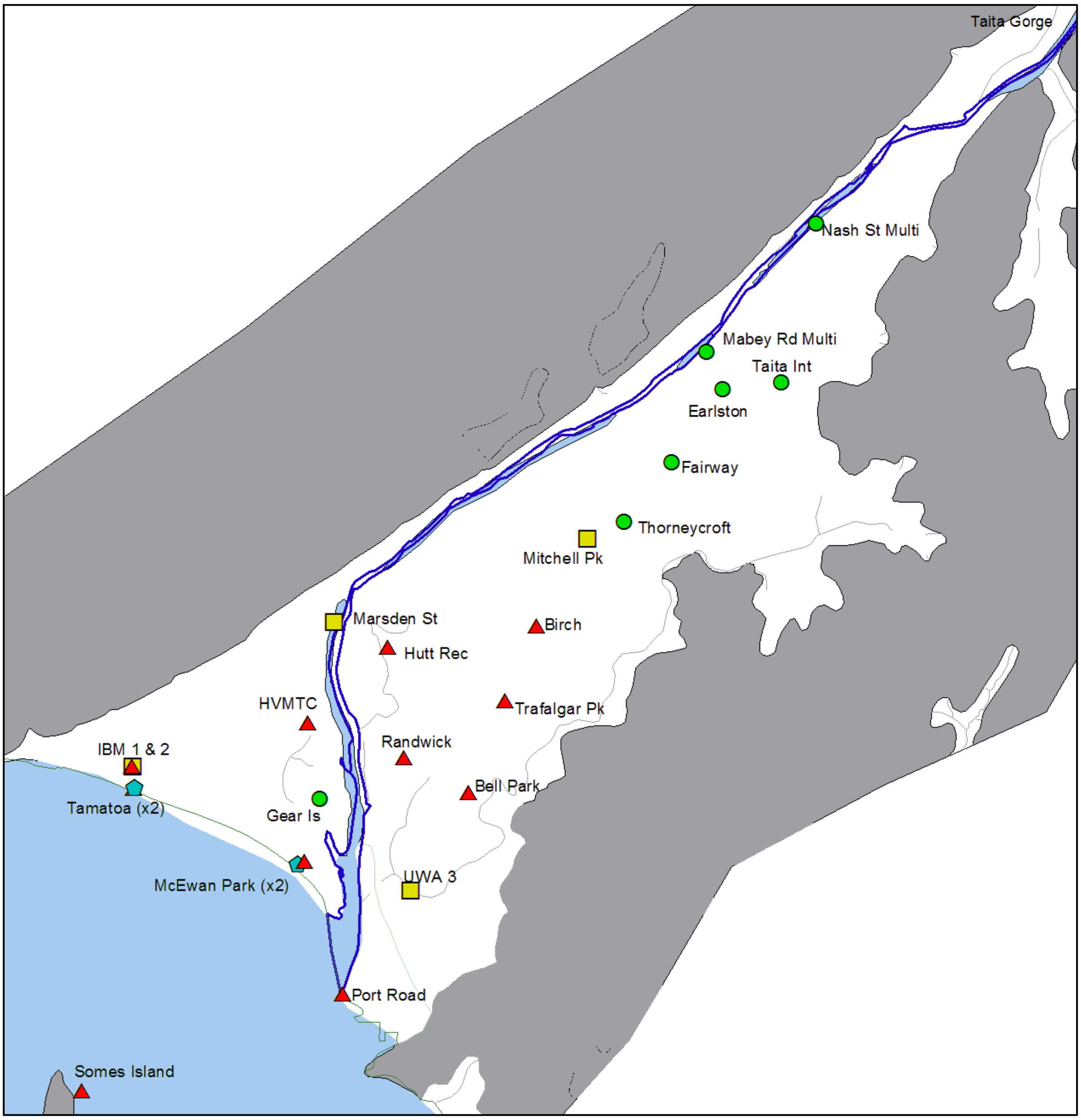


Figure 5.4 Locations of groundwater level monitoring sites in Lower Hutt. Green circles – Taita Alluvium; yellow squares – Moera Gravels; red triangles – upper Waiwhetu Aquifer; blue hexagons – lower Waiwhetu Aquifer. The only offshore monitoring site is located off Somes Island,

Monitoring of groundwater levels at the Petone foreshore provides useful information that can be extrapolated to the offshore aquifer extension. The McEwan Park and Tamatoa groundwater level monitoring sites on the Petone foreshore (Figure 5.4) are both dual-level and screened within the upper Waiwhetu and lower Waiwhetu aquifers. Figure 5.5 shows the data for the two McEwan Park recorders, illustrating that there is a negligible head difference between the upper and lower parts of the Waiwhetu Gravels. The negligible head difference indicates that they may have a good hydraulic connection even though they are lithologically distinct units. The seasonal fluctuations shown in Figure 5.5 are influenced by both natural recharge variability and abstraction from the Waterloo Wellfield (which tends to peak in summer).

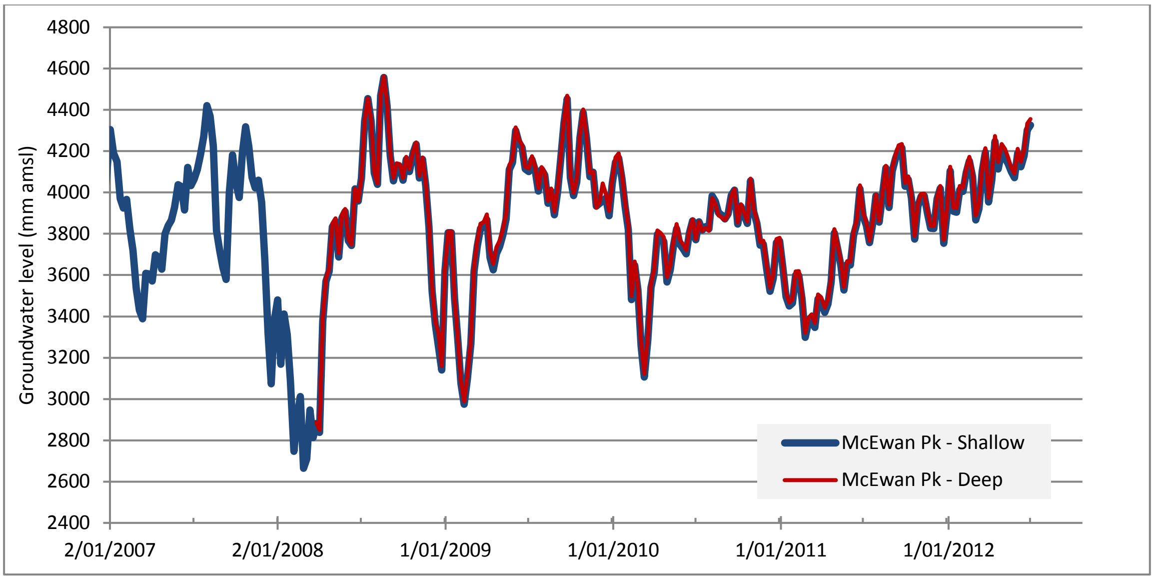


Figure 5.5 Comparison of McEwan Park dual level monitoring records (R27/7153 and R27/0122) for the Upper and lower Waiwhetu aquifers.

The effects of groundwater abstraction from the bulk water supply wellfield at Waterloo are illustrated in Figure 5.6 which shows wellfield abstraction and Waiwhetu Aquifer levels at McEwan Park on the foreshore and at Somes Island during early 2013. The plot shows the sensitivity of foreshore and Somes Island aquifer levels to abstraction located 3km and 6km respectively. Both observation bores show a very similar drawdown magnitude and time lag in response to pumping at Waterloo even though they are 3km apart – indicative of a highly transmissive aquifer between Somes Island and Waterloo. The very small offshore flow gradient between McEwan Park and Somes Island – generally there is only on average 0.2m difference between the two sites, which can drop to zero. The gradient can occasionally also reverse during summer periods as a result of high abstraction rates.

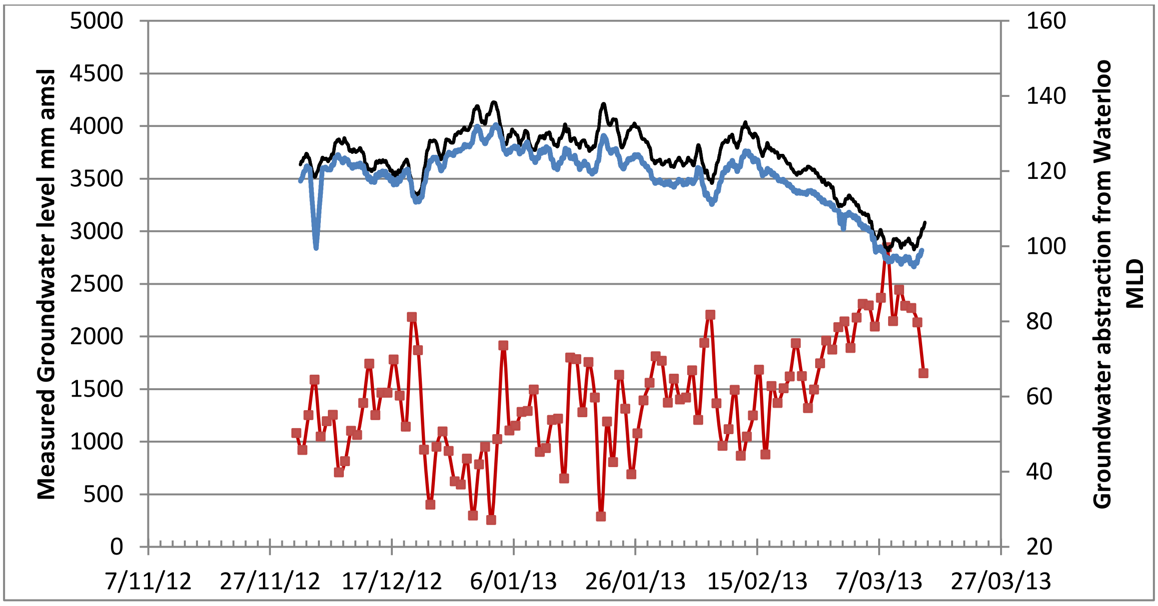


Figure 5.6 Relationship between groundwater abstraction at Waterloo (red line, right axis) and water level in the Waiwhetu Aquifer at the Petone foreshore (McEwan Park site, black line) and Somes Island (blue line) – left axis.

5.3.2 Somes Island groundwater level monitoring

There is one long term continuous GWRC monitoring site located near to the shore at Somes Island (R27/1171) and screened in the top of the upper Waiwhetu gravels. This site has been active since 1969. Figure 5.7 shows the long-term groundwater level monitoring record at Somes Island (plotted using 7-day mean values) from 1969 to the present. The levels of about 2-3m amsl up to 1977 represent a period when abstraction from the Waiwhetu aquifer was much higher than it is today and when the municipal water supply bores were mostly located at the Petone foreshore. The period between 1977 and 1993 shows very low groundwater levels and it is probable that the wellhead was leaking during this time and therefore the veracity of the data is questionable. Post 1993 represent the aquifer levels at Somes Island when municipal abstraction was occurring further inland at Waterloo.

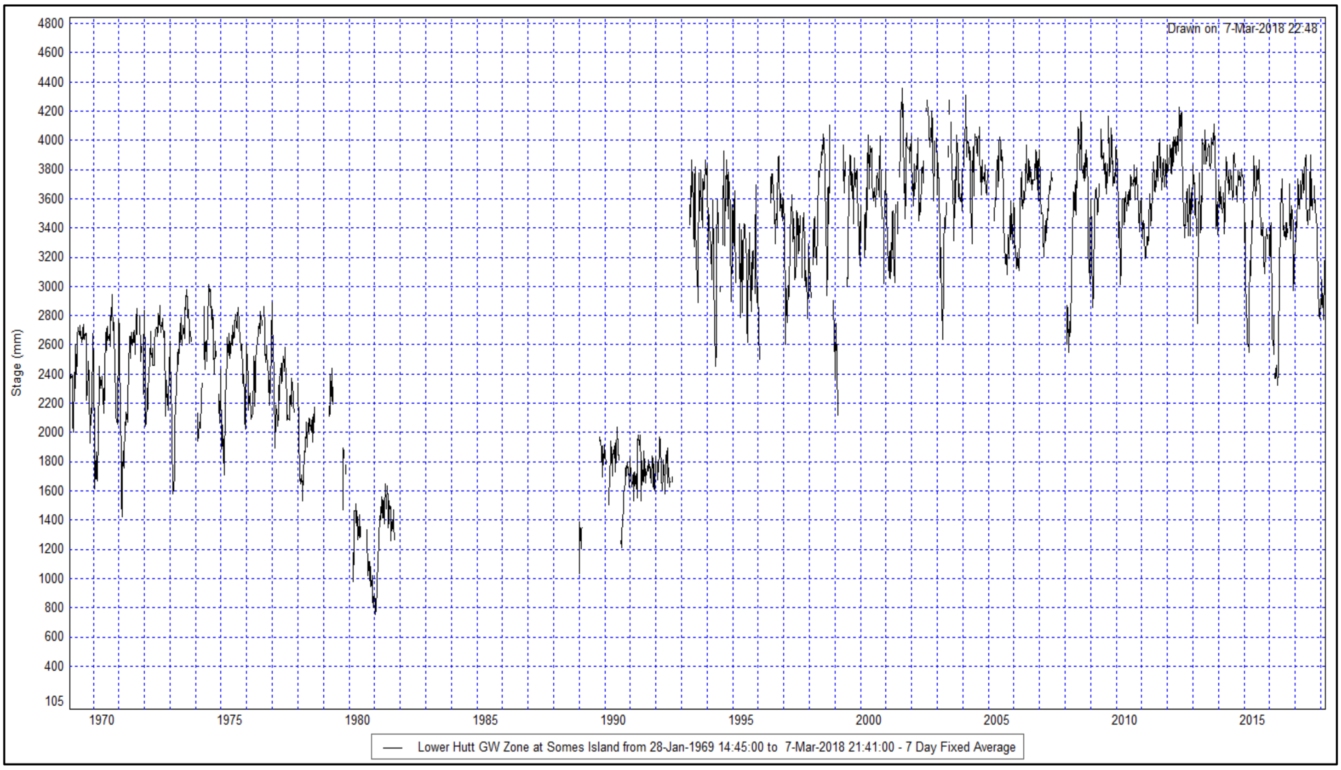


Figure 5.7 Piezometric level record for Somes Island monitoring bore (R27/1171) from 1969 to present. 7-day mean levels in mm amsl

Figure 5.8 shows the tidal effect on the sub-harbour groundwater levels in the upper Waiwhetu gravels. A range of about 1m is observed at Somes Island – about the same as observed in E3a and E8 (see Appendix 4 for further detail concerning the tidal efficiency in the sub-harbour aquifers and the methodologies used to correct observation data for tidal effects).

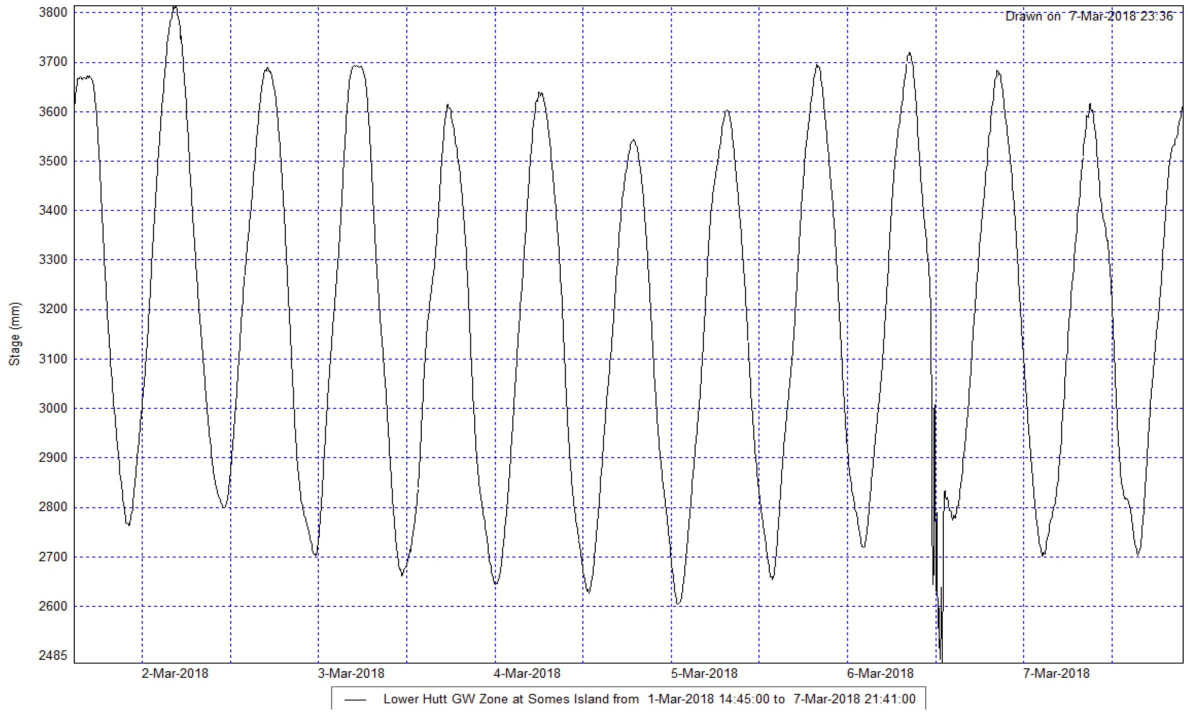


Figure 5.8 Continuous piezometric level record for Somes Island monitoring bore (R27/1171) in March showing the tidal range of about 1m.

5.3.3 Sub-harbour groundwater level monitoring on E3a and E8 exploration bores

The results of the baseline monitoring undertaken overnight before and after the pump testing are presented as a series of hydrographs in Appendix 4. These include the water levels for monitoring bores within the upper Waiwhetu Aquifer at Somes Island and McEwan Park, the lower Waiwhetu Aquifer at McEwan Park and the Moera Aquifer in bore UWA3 in the Hutt Valley (see Figure 5.5 for site locations). In addition, all monitoring data from bores E3a and E8 are included on a plot showing the longer-term water level trends at the Somes Island and McEwan Park bores (upper and lower Waiwhetu) and bore UWA3 (Moera) to show the variations associated with seasonal recharge and abstraction changes. Section 4 (and Appendix 2) also described the ‘shut-down’ tests carried out in all of the tested aquifers in E3a and E8. This was conducted primarily to investigate the connectivity between the tested aquifers and the onshore upper Waiwhetu aquifer through observation of pressure responses in the monitoring record.

The data provide evidence for the following:

- The offshore upper Waiwhetu Aquifer at E3a and E8 is hydraulically connected to the upper Waiwhetu Aquifer onshore;
- The lower Waiwhetu Aquifer below the harbour in E8 is connected to the upper Waiwhetu Aquifer on shore; and
- The Moera Aquifer below the harbour in E3a does not appear to be directly connected to the upper Waiwhetu Aquifer on shore as pumping effects were not detected. However, it is likely that the water levels within this unit will be affected by changes in onshore recharge which is thought to occur from downward leakage through the Waiwhetu Aquifer in the more northerly parts of the Lower Hutt Valley.

Estimates of the groundwater gradients within the aquifer units across the harbour are summarised in Table 5-3. This information is based on using the McEwan’s Park bores and the UWA3 as representing the onshore water levels. Because all monitoring sites in the Waiwhetu gravels are affected by pumping at the Waterloo and Gear Island wellfields, the gradients have been estimated using measured water levels at the end of Waterloo wellfield shutdown periods (the Wellfield was shut down during each test and then ramped up to test for hydraulic connectivity and to facilitate analysis for aquifer properties). However, it should be noted that the water levels in the bores did not have sufficient time to fully recover to resting levels during this period and therefore the gradients are indicative only. It has been assumed that the groundwater flow direction is towards the harbour mouth based on the geological and hydrogeological conceptual model.

Table 5-3 Offshore groundwater flow gradients

Aquifer	Gradient	Bores used in estimate
Upper Waiwhetu	0.00008 – 0.00013	E3a, E8, McEwan's Park
Lower Waiwhetu	0.00013*	E8, McEwan's Park
Moera	0.00003	E3a, UWA3
* Wellfield not shutdown so pump effected		

The measured groundwater flow gradients are very low and show that the offshore flow system is very slow and that aquifer throughflow must be correspondingly small. This means that there is expected to be very long aquifer residence times – as also shown by the groundwater chemistry (highly reduced, ammonia rich).

Given the inherent variation associated with the seasonal fluctuations within the aquifer and the pumping effects the gradient estimates for the upper Waiwhetu were very consistent. Initial inspection of the static water levels at Somes Island during the monitored periods suggested that the water levels at this bore were lower than anticipated based on the results of McEwan Park and the exploration bores (i.e. Somes was lower than the exploration bores). The onshore-exploration bore gradients were used to estimate the intermediate groundwater level at Somes Island and compare that value with the measured level. The results indicated that the groundwater level in the upper Waiwhetu at the Somes Island monitoring bore was 6% lower than anticipated in the winter and 3% lower in the summer.

These results provide support for the theory that groundwater seeps out of the upper Waiwhetu Aquifer as a series of small springs around Somes Island. If this is the case, then the groundwater in this area would be slightly depressurised compared to more strictly confined parts of the aquifer. However, given the limited data and the correction factors an error margin of 3 to 6 % may not be significant and caution should be given to assigning too much importance to this difference. However, if real, this theory would account for the fresher quality groundwater source from the Somes Island bore as there may be enhanced localised throughflow resulting in much lower levels of chloride and ammonia than measured in the E8 and E3a exploration bores.

The static water level monitoring also provided information on the head differences between the aquifer units. It is clear that there is a significant upwards head gradient between the underlying Moera Aquifer and the Waiwhetu Aquifers under the harbour, whereas the head difference between the Upper and Lower units of the Waiwhetu appears to be less significant (or even reversed). The results for E8 indicate that there may be a 0.15m downwards head gradient between the upper and lower Waiwhetu at this location. However, the monitoring of these units was not undertaken at the same time, so the results should be treated with some caution. However, the HAM4 modelling also predicts that the lower Waiwhetu Aquifer at E8 is about 0.2m lower than the upper Waiwhetu.

5.4 Aquifer parameters derived from previous investigations

Aquifer parameters (transmissivity and storage coefficient) for the offshore hydrogeological units have been characterised using a combination of the values used in the calibrated HAM3 model (based upon field testing and model optimisation), information obtained from the testing activities on the E3a and E8 exploration bores (reported in Appendix 2,3 and 5). The aquifer parameters used in the HAM3 model have largely been retained in the new HAM4 model for the onshore portion of the aquifer and adopted offshore where considered appropriate.

5.4.1 Petone marine silts

The confined and artesian conditions encountered in upper Waiwhetu Aquifer demonstrate that the confining Petone Marine Beds have a low hydraulic conductivity and must be laterally persistent. Measurements from various construction site investigations provide a horizontal hydraulic conductivity range of $1x10^{-3}$ to $1x10^{-4}$ m/day (WRC, 1995). Vertical hydraulic conductivity is expected to be at least an order of magnitude lower due to the stratified nature of the marine beds and the presence of laterally persistent silt layers. The HAM3 model (2015 version) estimated the hydraulic conductivity of the offshore Petone Marine silts to be $6x10^{-3}$ m/d whilst the vertical hydraulic conductivity was calibrated at $1x10^{-4}$ m/d.

5.4.2 Upper Waiwhetu gravels

Onshore, the upper Waiwhetu gravels are characterised as having consistent and exceedingly high transmissivity. They have been extensively tested during resource investigations over the past 80 years or so and WRC (1995) provides a thorough review and re-interpretation of historical testing which is presented in summary form here. A subsequent pumping test was carried out later in 1995 on the Waterloo Wellfield at a rate of 50 ML/day (Butcher, 1996), the results of which are also included here.

Table 5-4 presents a summary of hydraulic properties for the upper Waiwhetu Aquifer derived from three major pumping tests. Geometric mean values for transmissivity and storage coefficient have been calculated for all observation data and for bores in the immediate vicinity of the wellfield. The latter provide an estimate of local hydraulic properties for the aquifer, whilst the mean of all the observation bores provides an estimate of the average regional aquifer properties. More emphasis has been placed on the Waterloo tests since the earlier Gear Island test was of a short duration (24 hours) and at a lower pumping rate.

Table 5-4 Average hydraulic properties for the upper Waiwhetu Aquifer derived from pumping tests

Pumping Test	Transmissivity m^2/day (geometric mean)	Storage coefficient (geometric mean)
Gear Island 1991 (24 hours at 26.7 ML/day)		
Bores within 500m of pumping	23,400	1 x 10^{-3}
All observation data	22,000	8 x 10^{-4}
Waterloo 1993 (40 hours at 35 ML/day)		
Wellfield bores	34,900	9 x 10^{-4}
All observation data	28,000	7 x 10^{-4}
Waterloo 1995 (108 hours at 50 ML/day)		
Wellfield bores	38,900	3 x 10^{-4}
All observation data	27,980	5 x 10^{-4}

The pumping test results indicate that the mean aquifer transmissivity for the upper Waiwhetu Aquifer is approximately 28,000 m^2/day, locally increasing to between 35,000 and 40,000 around the Waterloo Wellfield. Assuming an average thickness of 20m for the gravels, this equates to a hydraulic conductivity of approximately 1,400 m/day. The pumping tests indicate a range for the confined aquifer storage coefficient of between $3x10^{-4}$ and $1x10^{-3}$. The HAM3 model was calibrated using an onshore and offshore hydraulic conductivity value of 1,400 m/d (Kh) and a vertical value of 0.1m/d (Kv).. The drawdown effects were relatively small, and the pumping test results can be solved with the Theis solution, so no values for vertical leakage through the aquitard have been defined.

5.4.3 Lower Waiwhetu gravels

There have been no pumping tests within the lower Waiwhetu Aquifer onshore. However, it has been possible to derive a qualitative assessment of the hydraulic conductivity nature of this aquifer using evidence provided by lithological description and water chemistry. Both suggest that the lower Waiwhetu gravels have a significantly lower groundwater throughflow and correspondingly lower hydraulic conductivity in comparison to the upper Waiwhetu Aquifer. The lower Waiwhetu gravels have a higher silt and sand content when compared with the upper Waiwhetu gravels, which is suggestive of a lower hydraulic conductivity. In addition, tritium analyses of groundwater from above and below the interstadial aquitard provides contrasting ages and flow rates for the two aquifers. Groundwater from the upper Waiwhetu Aquifer at the Waterloo Wellfield is dated at < 2.5 years old, whilst groundwater below the interstadial aquitard has a 45-year mean residence time (Brown and Jones 2000).

The HAM3 model optimisation process provided a Kh value of 336 m/day and a Kv value of 10 m/d for the lower Waiwhetu Gravels (both onshore and offshore).

5.4.4 Wilford Shell Bed

The Wilford Shell Bed represents an aquitard unit comprising silt, clay and sand deposits. The hydraulic conductivity for this unit is considered to be similar to the Petone Marine Beds/Melling Peat as it shares comparable lithological and depositional characteristics. An average horizontal hydraulic conductivity of between 0.1 and 0.01 m/day has been estimated for the Wilford Shell Beds on the basis of lithology, with the vertical hydraulic conductivity being an order of magnitude lower due to the occurrence of clay and silt layering.

The HAM3 model optimisation process provided a Kh value of 6 m/day and a Kv value of $2x10^{-4}$ m/d for the lower Waiwhetu Gravels (both onshore and offshore).

5.4.5 Moera gravels

There is very little pumping test information available for the Moera gravels. The most reliable is a test performed on the exploratory Marsden Street bore which provided transmissivity range of 2,100 to 2,600 m^2/day, and a confined storage coefficient in the range of $4x10^{-5}$ to $1x10^{-4}$. The hydraulic conductivity of the Moera Gravels can therefore be estimated to be in the range of 150 to 200 m/day if the test bore screen is assumed to be drawing on about a 15m thickness of the gravels. It is however acknowledged that the Moera aquifer is likely to be heterogeneous.

5.5 Aquifer parameters derived from E3a and E8

The results of the aquifer testing undertaken within the exploratory bores are contained in Appendix 5 and summarised in Table 5-5.

Table 5-5: Pumping test results for exploratory bores E3a and E8

Bore and Aquifer	Pumping Test Rates (L/s)	Max. Drawdown (m)	Well Losses (% drawdown)	Transmissivity (m^2/d)
Upper Waiwhetu (E3a)	5.5 – 17	3.9 – 6.9	78 – 80	26 – 1,056
Upper Waiwhetu (E8)	5.1 – 13.5	0.9 – 1.1	55 – 75	2,860 – 5,370
Lower Waiwhetu (E8)	5.9 – 11.5	1.3	50 – 73	812 – 930
Moera (E3a)	12.3 – 13	1.2 – 4.9	62 – 63	195 – 3,530

It is clear from the results that most of the tests were highly inefficient due to the size and temporary nature of the bore installation and greatly restricted by the maximum pumping rates. The majority of the drawdown observed was associated with well losses and when the maximum drawdown values are corrected for this the aquifer losses represent less than 2-3% of the water column within the bore. This means that the aquifers were not sufficiently stressed during the testing and as such the transmissivity values estimated from these tests should be regarded to be more representative of the bore conditions and local variations than the regional aquifer parameters.

Aquifer recovery and drawdown observations made on E3a and E8 during the Waterloo wellfield shut-down tests were also analysed to obtain more regional aquifer parameter information for the upper Waiwhetu Aquifer. The data processing and interpretation methodologies are contained in Appendices 3 and 5 and are summarised in Table 5-6. Transmissivity values interpreted for selected onshore bores have been included for comparison.

Table 5-6 Aquifer parameters for the upper Waiwhetu Aquifer derived from Waterloo wellfield shut-down tests

Bore	**Distance from Wellfield (m)**	**Transmissivity (m^2/d)**	**Storativity**
E3a	9,417*	12,900	0.0003
E8	7,670	30,200 – 35,500	0.0002 – 0.0004
Somes Island	5,992	25,000	0.0002 – 0.0003
McEwan Park	2,838	28,000 – 31,600	0.0002 – 0.0003
Randwick	1,362	19,500 – 20,000	0.002 – 0.006
Hutt Rec	725	10,900 – 11,000**	0.002 – 0.003
** Gear Island wellfield also active so average distance from both wellfields rather than just Waterloo Wellfield* *** Difficult to accurately remove tidal influence so accuracy may be questionable.*			

The Moera Aquifer and lower Waiwhetu Aquifer were not assessed in this manner because the Moera Aquifer did not appear to be connected to the Waiwhetu Aquifer. Monitoring for the lower Waiwhetu Aquifer during the wellfield shutdown was undertaken in an open hole containing drilling fluids due to time constraints.

The results of this analysis are significantly higher than the results from the pumping tests and are more consistent with onshore observations for the upper Waiwhetu Aquifer (Table 5-4). The hydraulic properties presented in Table 5-6 however represent an average or bulk estimate of aquifer transmissivity and storage between the monitored bore and the wellfield and may not therefore be representative of local conditions in the vicinity of the exploration bores. In the absence of full-scale robust pumping tests on the exploration bores, it probably needs to be conservatively assumed that the transmissivity values lie within the ranges shown in Table 5.5. The HAM4 modelling conservatively assumes a hydraulic conductivity value for the offshore upper Waiwhetu Aquifer in the vicinity of E8 of 600m/day – which equates to a transmissivity at this location of about 6,000m^2/day (i.e. the upper end of the range shown in Table 5.5). At the E3 site, a transmissivity of about 1,000m^2/day is assumed.

5.6 Groundwater recharge

Recharge mechanisms for the LHGZ are discussed in detail in the HAM3 report (EIM, 2014). Recharge occurs principally by infiltration through the bed of the Hutt River at the upper end of the groundwater zone between Taita Gorge and Kennedy Good Bridge at an average rate of about 100,000 m^3/day (100 ML/day). The river recharges the unconfined aquifer along with minor localised rainfall recharge. The down-valley flow is then partitioned into the shallow Taita Alluvium, the confined Waiwhetu Aquifer system and the upper part of the underlying confined Moera Aquifer. Most of the flow from the unconfined aquifer enters the highly transmissive Waiwhetu Gravels and, to a significant extent, is induced to do so by abstraction drawdowns associated with the Waterloo wellfield.

5.7 Submarine fresh groundwater discharge

The confined Waiwhetu Gravels and deeper aquifers naturally discharge through vertical leakage across overlying aquitard mostly offshore (a small amount of vertical leakage may occur onshore). In the context of this project, a good understanding of the submarine aquifer discharge process is therefore necessary.

The submarine discharge is to a large extent controlled by terrestrial groundwater conditions and stresses and is likely to be very responsive to changes in, for example, abstraction, due to the observed short piezometric pressure responses to abstraction show in the Somes Island monitoring bore (Figure 5.7). Offshore, the main aquifer discharge mechanisms are conceptualised to be outflow through discreet submarine spring vents, widespread slow discharge across the Petone Marine silts, and outflow through the coarser grained sediment sequence in harbour entrance area.

The amount of total offshore groundwater discharge is relatively low because onshore abstraction captures most of the throughflow in the Waiwhetu Aquifer. Previous HAM3 modelling simulated an average offshore discharge of about 17,000 m^3/day, of which 25-30% occurred in the harbour entrance area via vertical leakage and about 10% was from discreet spring vents. This indicates that the total aquifer throughflow beneath the harbour is very small – as evidenced by the observed very low groundwater flow gradients. The discharge rates are likely to be highly seasonal, reducing substantially during summer when groundwater pressures drop due to reduced recharge and increased onshore abstraction.

5.7.1 Submarine Springs

Discharge from the upper Waiwhetu Aquifer is known to occur offshore at discrete points in the form of submarine springs. These are assumed to be discharging from the Waiwhetu Gravels where the artesian pressure has breached or burst through the Petone Marine silts. The high-resolution and high-accuracy MBES bathymetry survey of the harbour floor (NIWA, 2010) is particularly useful for locating spring vents and for relating the vent depths to the estimated top of the Waiwhetu Aquifer beneath the harbour. Harding (2000) investigated several submarine springs and was able to conduct some basic flow measurements in some of the active vents. This work contains detailed descriptions of the springs and their postulated modes of formation (possible methane release and/or seismic decoupling of unconsolidated sediments where they lap on to the basement greywacke bedrock of the Somes Island horst structure). Scouring of the relatively thin Petone Marine Beds, particularly around the Hutt River mouth, may also account for some of the submarine springs.

The enlarged bathymetry contour map shown in Figure 5.9 highlights the locations of spring vents on the harbour floor. There are three main spring clusters:

- Hutt River mouth – at least 6 substantial vents up to 10m deep (below surrounding sea floor) and 100m across. The closest is about 500m from the Petone beach.
- Point Howard wharf area – a cluster with about 2 main vents some 5 to 6m deep.
- Somes Island – three large vents on the north, south and south-western tips of the island. The south-western vent is over 300m across and 6-7m deep.

There are also other potential discreet spring flow depressions around the Miramar Peninsula (e.g. off Point Halswell).

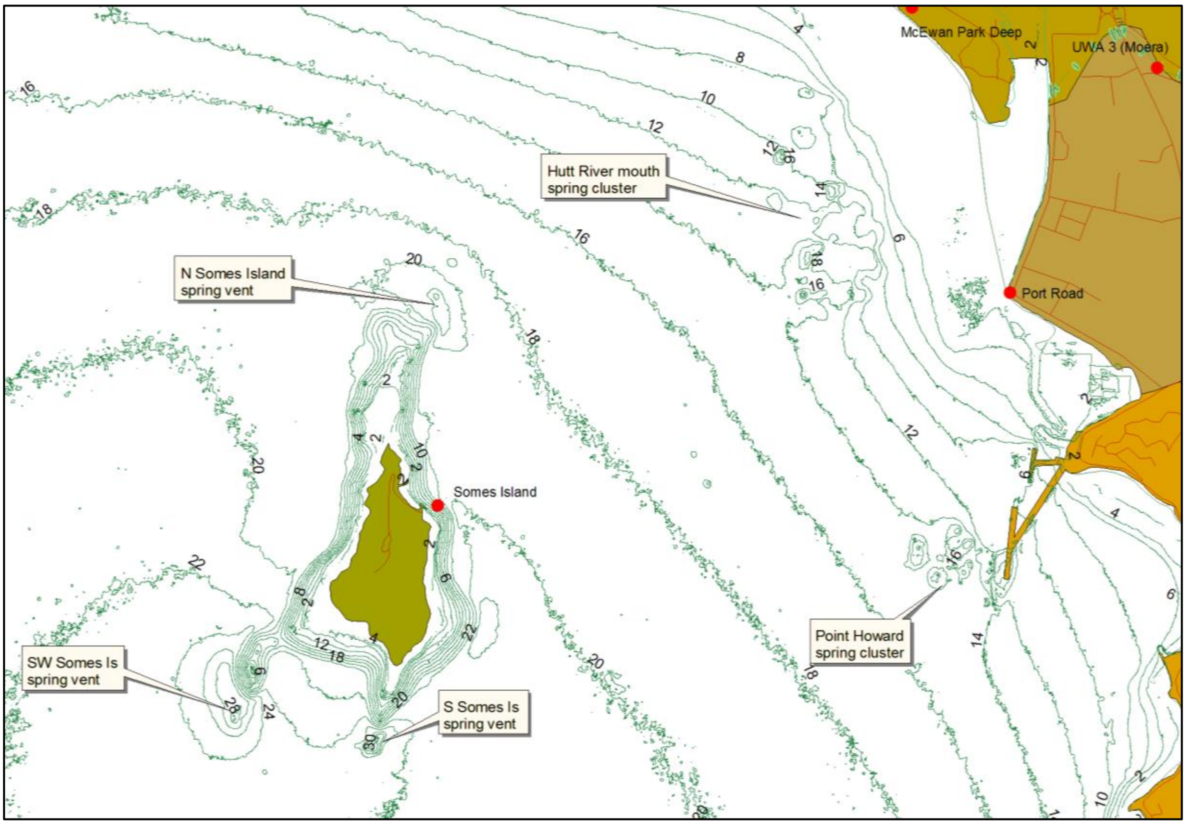


Figure 5.9 Location of submarine spring vents off the Hutt River mouth and around Somes Island based on multi-beam sonar bathymetry survey (NIWA, 2010). Contours are in metres below mean sea level. Red circles are monitoring bores.

Information suggesting that the submarine spring vents relate to fresh groundwater discharge from the Waiwhetu Aquifer is as follows:

- Somes Island: the Waiwhetu Aquifer in bore R27/1170 is recorded at 12.5m below the sea bed (which is at -13.5m, from the bathymetry survey). This places the top of the aquifer at minus 26m below datum (mean sea level). The spring vent on the northern tip of Somes Island is about 5-6m deep and the base lies at minus 25m (using bathymetry data) – at about the same level as the top of the Waiwhetu Gravels. Figure 5.10 schematically illustrates the south-western Some Island spring vent.
- Hutt River mouth: the deepest spring pits have a depth of -23m below mean sea level whilst the undisturbed harbour floor sits at about -13m. The vents are therefore substantial features, being up to 10m deep. The top of the Waiwhetu Gravels in this area can be extrapolated from foreshore bore data and are estimated to lie at about -25m.

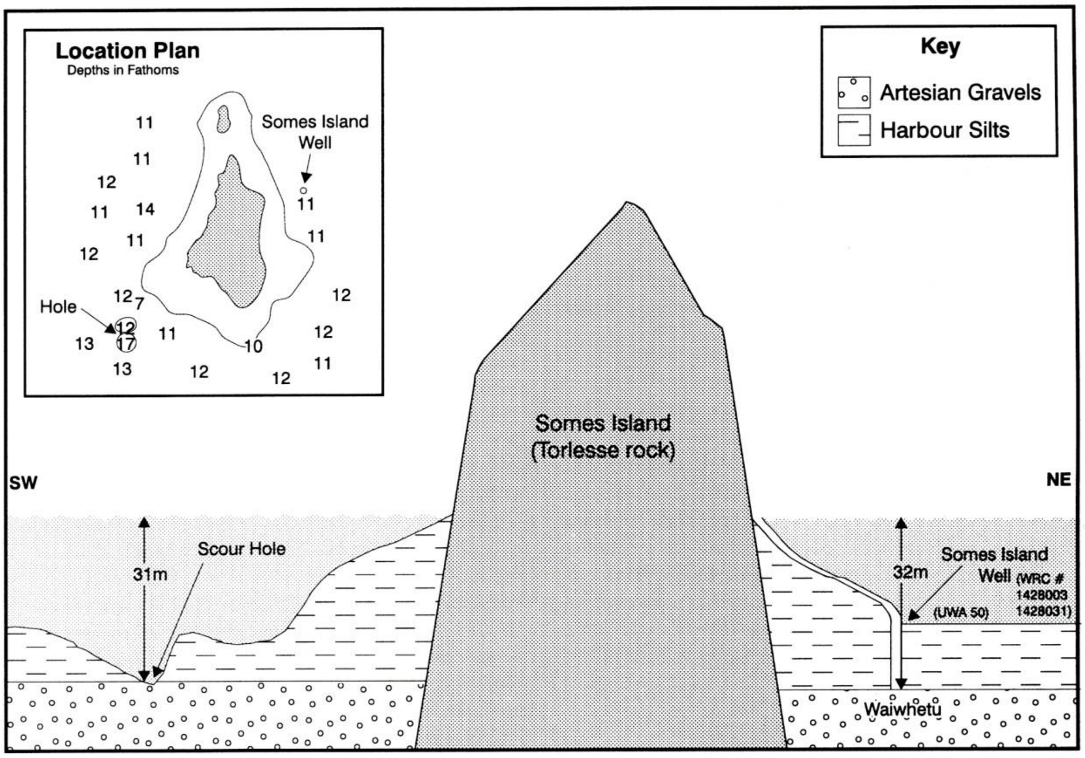


Figure 5.10 Cross-section of the Somes Island area showing the relationship between the Waiwhetu Aquifer and the spring vent (or scour hole) off the south-western tip of the island (from Begg and Mazengarb, 1996).

Harding (2000) evaluated the flows emanating from many of the spring vents and determined that only the ones at the Hutt River mouth, Point Howard wharf and northern end of Somes Island seemed to be weakly active at the time of his inspection. Examination of the large vents on the south-western side of Somes Island did not yield any evidence for active spring flow.

Previous modelling (HAM3) has indicated that the total spring discharge could be in the order of 2-3 ML/day. However, quantification of the total spring discharge is problematic and somewhat uncertain without sufficient data, but it appears the total spring emission is relatively minor in terms of the overall water balance for the sub-harbour groundwater system. Model sensitivity testing has assumed a total spring discharge of up to about 10-12MLD.

Since the spring vents appear to be a source of artesian discharge from the upper Waiwhetu Aquifer, their existence is of critical relevance when assessing saline intrusion risk as they are potential conduits for the backflow of seawater if the underlying aquifer pressures are down below critical thresholds (see Section 6).

5.7.2 Harbour entrance leakage

In addition to submarine spring discharge, the conceptualisation of the offshore groundwater system also suggests that there could be significant discharge in the Falcon Shoals and harbour entrance area. The geological model predicts that the sediment sequence in this area is likely to be dominated by coarser grained material and that the main aquitard units do not extend into this area (see Figure 5.1). There is also anecdotal evidence of widespread freshwater discharge on the ocean floor in the Falcon Shoals area (geophysical data also indicates possible fluid escape in this area). Previous HAM3 (2015) modelling, based upon a revised conceptualisation of the offshore aquifer which recognised a potentially higher hydraulic connectivity in the harbour entrance area, indicated that about 5,000 m^3/day discharged from the harbour entrance area. The harbour entrance area may also allow, if the groundwater pressures were conducive, seawater to flow downwards into the aquifers thereby creating a saline interface.

5.8 Groundwater chemistry

5.8.1 Water sample laboratory analyses

Groundwater samples were taken from each of the exploration bores during the pump testing of the different aquifers encountered during drilling. The sampling methodology and full results of the water quality laboratory analysis are presented in full in Appendix 6 and are also summarised in Table 5-7.

Table 5-7: Summary of water quality results

Parameter	Unit	NZ DWS		Upper Waiwhetu		Lower Waiwhetu	Moera
		Aesthetic	Human Health	E3a	E8	E8	E3a
pH		7-8.5		7	7.5	7.2	7.6
Total Suspended Solids	g/m^3			7.5	<3	10	3
Total Organic Carbon	g/m^3			0.9	2.3	5.7	0.7
Alkalinity - Total	$g\ CaCO_3/m^3$			93	88	343	159
Conductivity at 25°C	mS/m			62.4	45.3	334	133
Carbonate Alkalinity	$g\ CaCO_3/m^3$			<2	<2	<2	<2
Bicarbonate Alkalinity	$g\ CaCO_3/m^3$			93	88	343	158.5
Turbidity	NTU	2.5		6.28	0.84	24.5	9.51
Anion Sum	meq/L			5.05	3.63	29.7	11.5
Cation Sum	meq/L			5.96	4.28	30.0	11.3
Ion Balance	%			8.29	8.27	0.91	0.67
Fluoride	g/m^3		1.5	0.47	0.49	<0.2	0.06
Chloride	g/m^3	250		125	74.8	854	314
Nitrite-Nitrogen	$g\ N/m^3$		0.91	<0.01	<0.01	<0.1	<0.01
Bromide	g/m^3			0.48	0.31	3.69	1.275
Nitrate-Nitrogen	$g\ N/m^3$		11.3	0.01	0.03	<0.01	<0.01
Sulphate	g/m^3	250		0.24	3.43	0.77	0.065
Colour	TCU	10		6	6.5	14.9	1.5
Ammonia Nitrogen	$g\ N/m^3$	1.2		3.41	1.08	7.75	5.14
Total dissolved solids	g/m^3	1000		283	236	1750	595.5
Salinity	ppt			<2	<2	<2	<2
Calcium - Total	g/m^3			10.6	6.94	70.7	39.3
Magnesium - Total	g/m^3			9.53	4.94	37.7	20.6
Potassium - Total	g/m^3			6.57	6.03	23.9	11.5
Sodium - Total	g/m^3	200		94.2	75.2	508	159
Total hardness	$g\ CaCO_3/m^3$	200		66	37.5	332	183
Calcium - Dissolved	g/m^3			10.4	6.62	71.7	38.9
Magnesium - Dissolved	g/m^3			9.33	4.82	37.6	20.4
Potassium - Dissolved	g/m^3			6.31	5.76	24	11.2
Sodium - Dissolved	g/m^3			92.9	72.5	509	156

Parameter	Unit	NZ DWS		Upper Waiwhetu		Lower Waiwhetu	Moera
		Aesthetic	Human Health	E3a	E8	E8	E3a
Silica - Dissolved	g/m^3			24.7	21.8	41.6	25.8
Aluminium - Total	g/m^3	0.1		0.083	0.007	0.004	0.003
Arsenic - Total	g/m^3		0.01	0.006	0.023	<0.001	<0.001
Boron - Total	g/m^3		1.4	0.07	0.10	0.19	0.1
Cadmium - Total	g/m^3		0.004	<0.0002	<0.0002	<0.0002	<0.0002
Chromium - Total	g/m^3		0.05	<0.001	<0.001	<0.001	<0.001
Copper - Total	g/m^3	0.1	2	0.0018	<0.0005	0.001	<0.0005
Iron - Total	g/m^3	0.2		2.65	0.515	2.45	1.585
Lead - Total	g/m^3		0.01	<0.0005	<0.0005	<0.0005	<0.0005
Manganese - Total	g/m^3	0.04	0.4	0.537	0.123	0.389	0.299
Nickel - Total	g/m^3			<0.0005	<0.0005	<0.0005	<0.0005
Zinc - Total	g/m^3	1.5		0.050	0.007	0.016	0.042
Aluminium - Dissolved	g/m^3	0.1		<0.002	0.005	<0.002	<0.002
Antimony - Dissolved	g/m^3		0.02	<0.001	<0.001	<0.001	<0.001
Arsenic - Dissolved	g/m^3		0.01	0.006	0.023	<0.001	<0.001
Barium - Dissolved	g/m^3		0.7	0.021	0.021	0.171	0.115
Beryllium - Dissolved	g/m^3			<0.001	<0.001	<0.001	<0.001
Boron - Dissolved	g/m^3		1.4	0.07	0.10	0.19	0.1
Cadmium - Dissolved	g/m^3		0.004	<0.0002	<0.0002	<0.0002	<0.0002
Chromium - Dissolved	g/m^3		0.05	<0.001	<0.001	<0.001	<0.001
Copper - Dissolved	g/m^3	0.1	2	<0.0005	<0.0005	0.0007	<0.0005
Iron - Dissolved	g/m^3	0.2		1.53	0.30	0.01	0.72
Lead - Dissolved	g/m^3		0.01	<0.0005	<0.0005	<0.0005	<0.0005
Lithium - Dissolved	g/m^3			0.004	0.002	0.021	0.003
Manganese - Dissolved	g/m^3	0.04	0.4	0.502	0.119	0.382	0.292
Mercury - Dissolved	g/m^3		0.007	<0.0005	<0.0005	<0.0005	<0.0005
Molybdenum - Dissolved	g/m^3		0.07	0.0006	0.0053	<0.0005	<0.0005
Nickel - Dissolved	g/m^3		0.08	<0.0005	<0.0005	<0.0005	<0.0005
Selenium - Dissolved	g/m^3			<0.005	<0.005	<0.005	<0.005
Silver - Dissolved	g/m^3			<0.0005	<0.0005	<0.0005	<0.0005
Tin - Dissolved	g/m^3			<0.0005	<0.0005	<0.0005	<0.0005
Zinc - Dissolved	g/m^3	1.5		0.039	0.005	0.017	0.033
Uranium - Dissolved	g/m^3			<0.0002	<0.0002	<0.0002	<0.0002
Total Coliforms	MPN/100mL		1	<1	1	72	<1
E.Coli	MPN/100mL		1	<1	<1	<1	<1

The chemical analyses in Table 5-7 generally meet the New Zealand Drinking Water Standards for human health and aesthetics apart from the following parameters:

- Turbidity exceeds the aesthetic guideline of 2.5 NTU in samples taken from the upper Waiwhetu in E3a, the lower Waiwhetu in E8 and the Moera Aquifer in E3a;

- All aquifers encountered in the exploration bores have elevated chloride, indicative of mixing with a small proportion of saline water. Chloride exceeds the aesthetic guideline of 250 mg/L for the lower Waiwhetu (E8 bore) and Moera Aquifer (E3a);

- Ammonia exceeds the aesthetic guideline value of 1.5 g N/m^3 in samples taken from the Upper Waiwhetu in E3a, the lower Waiwhetu in E8 and the Moera Aquifer in E3a;

- Total Dissolved Solids and hardness both exceed the aesthetic guidelines in the lower Waiwhetu Aquifer at E8;

- Arsenic exceeds the guideline for human health of 0.01 g/m^3 in the upper Waiwhetu at E8;

- Iron exceeds the aesthetic guideline value of 0.2 g/m^3 in the upper Waiwhetu at E3a and E8, the lower Waiwhetu at E8 and the Moera Aquifer at E3a;

- Manganese exceeds the human health guideline value of 0.4 g/m3 in the upper Waiwhetu in E3a and exceeds the aesthetic guideline of 0.04 in the Upper and lower Waiwhetu and the Moera; and

- Coliform detects were noted in the samples taken from E8 from the Upper and lower Waiwhetu Aquifers. Both sets of samples were collected over weekends and although every effort was made to ensure that the samples were stored chilled, the hot weather meant that keeping the samples sufficiently cold was difficult. It is not known whether this may have resulted in higher than anticipated coliform detects from these samples.

The water quality results for the aquifers encountered within the exploratory bores indicate that some treatment would be necessary before this water could be used for drinking water supply. The majority of the exceedances are typical of anoxic older waters, but the higher salinity seen in the lower Waiwhetu and Moera Aquifers is likely to be indicative of mixing with saline water. Whether this takes the form of a diffuse boundary formed from recent saline water intruding into aquifer units towards the harbour mouth or is representative of influence of older connate water has yet to be determined.

5.8.2 Evaluation of hydrochemical characteristics and evolution

GNS Science have undertaken a hydrochemical assessment of the exploratory bore water quality analyses to ascertain the likely processes that have produced the observed chemistry (Appendix 7). The study characterises the groundwater in exploratory bores E3a and E8 as being highly anoxic and methanogenic possibly indicating high residence times and a very slow groundwater flow system. The high concentrations of dissolved Fe, Mn and ammonia are not unexpected in such an environment.

The water in E3a and E8 differs significantly from groundwater in the terrestrial part of the aquifer. High chloride concentrations (above that observed at Somes Island and on the Petone foreshore) are indicative of saltwater contamination at low levels. Geochemical modelling shows that the chemistry observed in E3a and E8 cannot evolve from upgradient groundwater observed at the Petone foreshore and Somes Island without the addition of seawater (accompanied by expected geochemical processes such as mineral dissolution and ion exchange). For the upper Waiwhetu Aquifer at E3a, a mixing of 0.55% seawater is predicted, whilst the Moera aquifer at the same site has an estimated 1.5% proportion of seawater. For E8, the modelling predicts a 0.3% and 4.2% mixing proportion of seawater for the Upper and lower Waiwhetu aquifers respectively. The lower

Waiwhetu Aquifer at E8 therefore has the highest percentage of saline water encountered in the drilling programme, whilst the upper Waiwhetu Aquifer at the same site has the lowest proportion.

There is insufficient evidence to determine whether this is the effect of modern seawater intrusion, or connate water. Based on the geological conceptual model and the water quality data obtained from the investigation, it is postulated that the relatively high salinity seen in the lower Waiwhetu at E8 is sourced either from trapped paleowater within the aquifer, or the long-term diffusion/dispersion of salinity from the aquitards following the flushing of this material from the aquifer over time. Modelling does not indicate that it could be caused by diffusion from the southern harbour area.

To assess whether there are any inherent chemical differences the water quality results have been plotted on a Piper diagram in Figure 5.11 (refer also to Table 5.8).

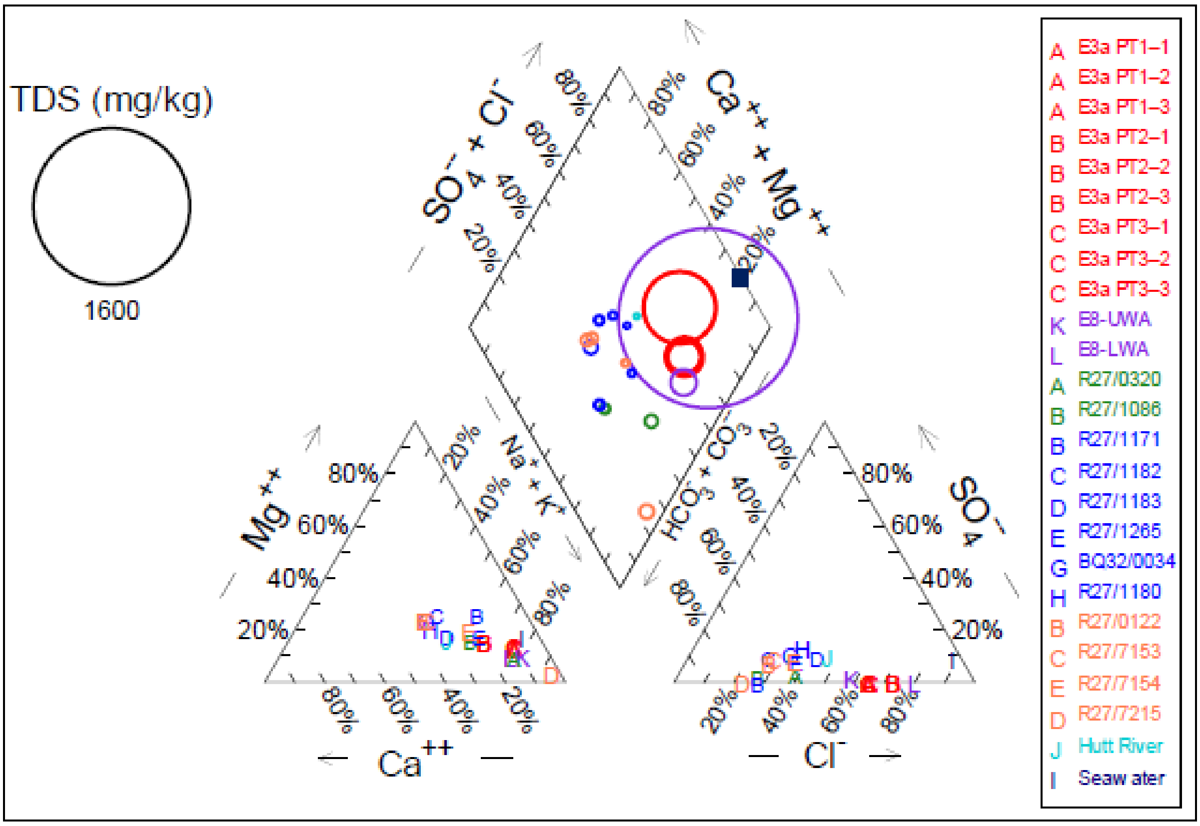
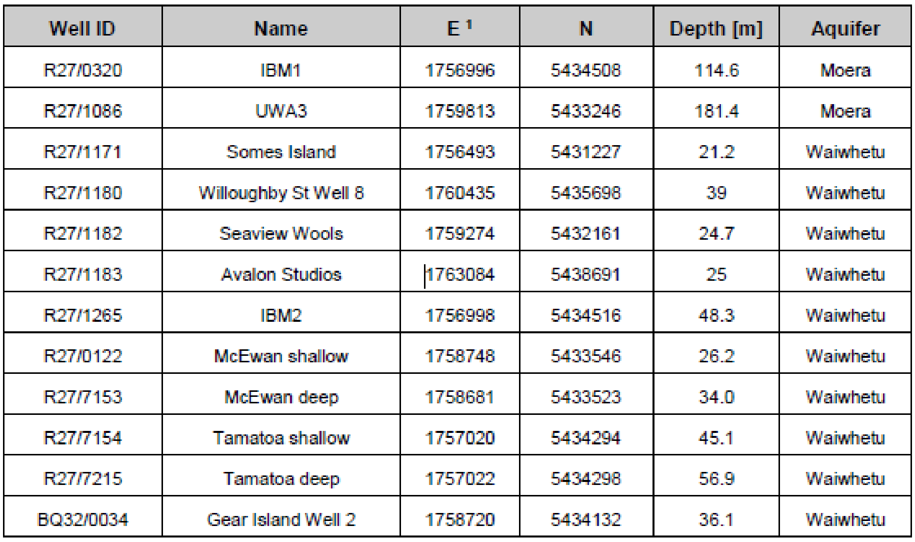


Figure 5.11 Piper diagram showing the hydrochemical characteristics of the water samples taken from E3a and E8 (source: R van der Raaij, Appendix 7). Details of wells plotted shown in Table 5.8.

Table 5.8 : Details of wells shown in piper diagram (Figure 5.11)



Well ID	Name	E[1]	N	Depth [m]	Aquifer
R27/0320	IBM1	1756996	5434508	114.6	Moera
R27/1086	UWA3	1759813	5433246	181.4	Moera
R27/1171	Somes Island	1756493	5431227	21.2	Waiwhetu
R27/1180	Willoughby St Well 8	1760435	5435698	39	Waiwhetu
R27/1182	Seaview Wools	1759274	5432161	24.7	Waiwhetu
R27/1183	Avalon Studios	1763084	5438691	25	Waiwhetu
R27/1265	IBM2	1756998	5434516	48.3	Waiwhetu
R27/0122	McEwan shallow	1758748	5433546	26.2	Waiwhetu
R27/7153	McEwan deep	1758681	5433523	34.0	Waiwhetu
R27/7154	Tamatoa shallow	1757020	5434294	45.1	Waiwhetu
R27/7215	Tamatoa deep	1757022	5434298	56.9	Waiwhetu
BQ32/0034	Gear Island Well 2	1758720	5434132	36.1	Waiwhetu

The groundwater samples are all of a sodium chloride type and the chemistry of the sub-harbour samples appear to sit more towards the chloride end of the spectrum than the results of regional monitoring of the onshore bores and the bore at Somes Island from the same aquifers. This indicates that the groundwater encountered in E3a and E8 is likely to be older than that seen on shore, which is not surprising given the shallow groundwater flow gradient across the harbour and the greater distance from the recharge zone in the northern part of the Lower Hutt valley.

5.8.3 Age dating

The results of the age dating analysis undertaken on groundwater samples collected from the Upper and lower Waiwhetu Aquifers and the Moera Aquifer are presented in Appendix 8. The full results for E8 are not yet available, but the preliminary results indicate that the groundwater in the aquifers testing in both E3a and E8 have a mean residence time of more than 100 years old and are likely to be significantly older.

The results for the upper Waiwhetu and Moera Aquifers in E3a suggest that the mean residence time of water within these aquifers is at least 205 and 175 years respectively. These values represent a minimum likely limit and the groundwater could be significantly older.

Age dating of samples collected from Somes Island indicates that groundwater there is generally younger with a mean residence time of 18 to 20 years. The results suggest that flow across the sub harbour aquifer is relatively slow and provides support for the theory that groundwater is discharging via springs near Somes Island, allowing for more throughflow in this part of the aquifer.

6. Saline water in the offshore aquifers and saline intrusion risk

6.1 Potential sources of saltwater intrusion in Wellington Harbour

Abstraction from the offshore Waiwhetu Aquifer requires that all potential sources of saltwater intrusion (SI) risk be fully considered and analysed. There are several potential SI mechanisms that could pose a risk to the sub harbour fresh groundwater environment, they fall into two categories:

Active SI derived from the overlying ocean

- Lateral encroachment of a saline interface located at some point in the southern part of the harbour;
- Inducement of flow through the harbour floor where formation characteristics permit and where aquitards are absent or weak;
- Backflow of ocean water through submarine spring vents in the Petone marine silt aquitard and along bedrock-aquitard contacts where a decoupling may create seepage pathways to the underlying Waiwhetu gravels;
- Seepage down the outside of the casings of harbour floor bores

SI derived from trapped (connate) saltwater

- Lateral migration from formations that contain trapped (connate) saltwater;
- Vertical migration from a saltwater-bearing formation below the Waiwhetu Aquifer and through pumping-induced ‘up-coning’.

Figure 6.1 conceptually shows the sources of SI, whilst Figure 6.2 shows the identified locations in the harbour presenting risk of saline intrusion.

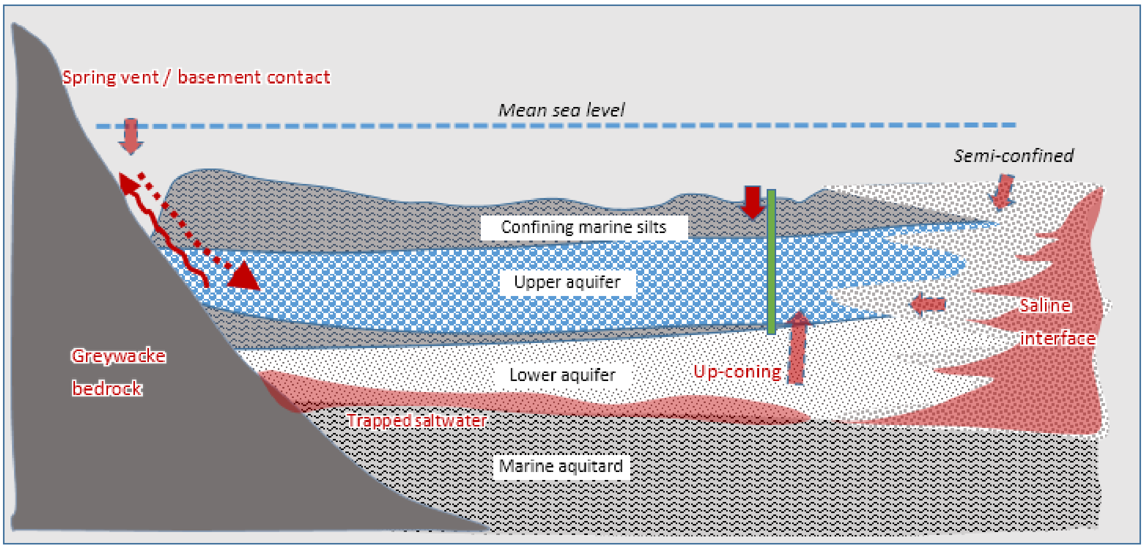


Figure 6.1 Schematic diagram showing potential sources of saline intrusion in the offshore Waiwhetu Aquifer due to pumping (red arrows). Bores located near the bedrock interface may be more vulnerable to saline intrusion due to higher aquifer drawdowns and potential adjacent seepage pathways along the bedrock-aquitard interface. Saline up-coning may also occur beneath the bore and lateral migration of saltwater may occur from areas of the aquifer already containing sea water.

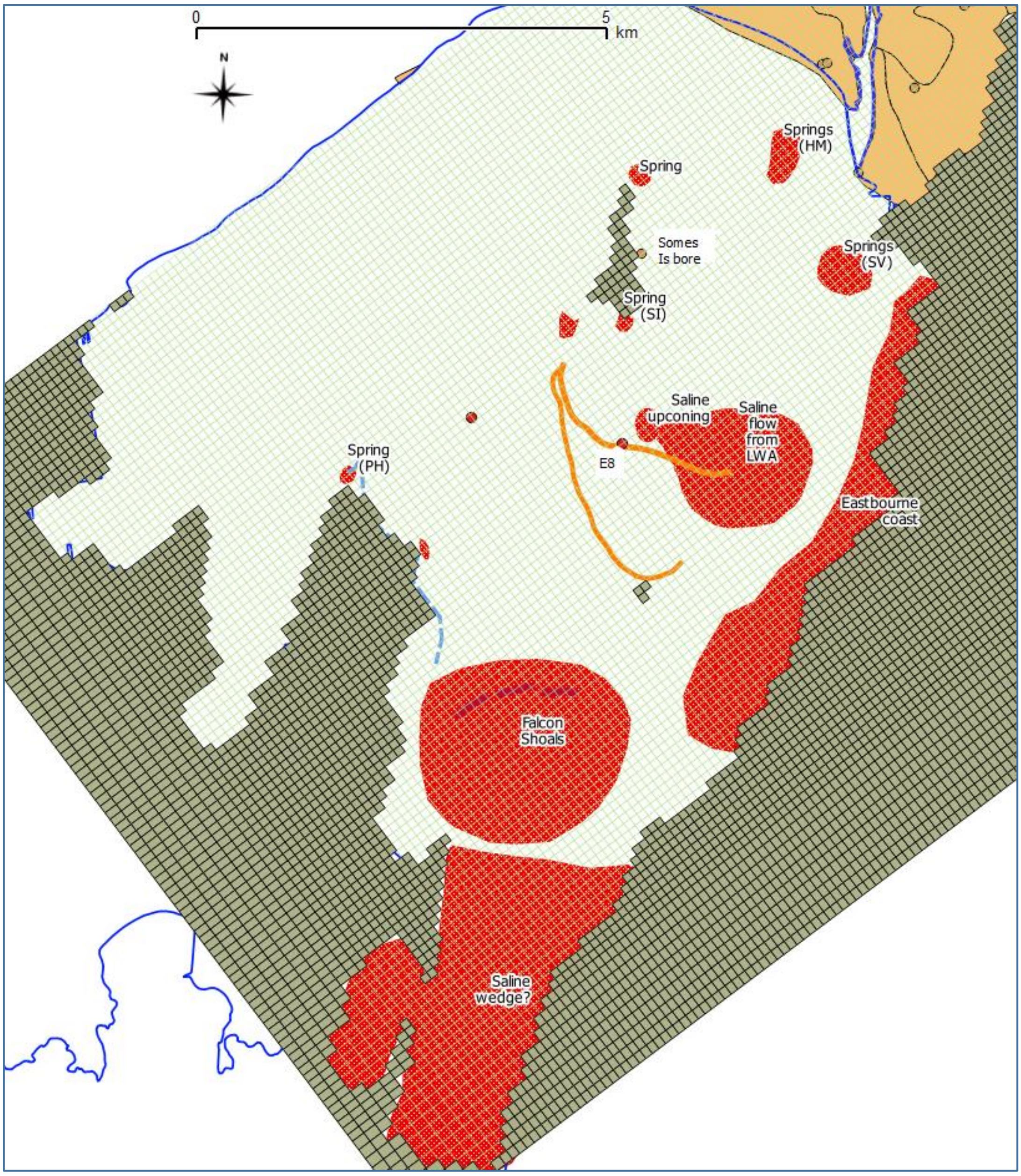


Figure 6.2 Location of identified principal saline intrusion risk areas in Wellington Harbour. Submarine springs are: HM-Hutt Mouth; SV-Seaview; SI- Somes Island; PH-Point Hallswell. Other broad shaded zones represent generalised areas of thin/absent aquitard (Falcon Shoals, Harbour heads, Eastbourne coast). Areas of potential contamination from deeper connate saline water in the lower Waiwhetu aquifer (LWA), and upconing at potential abstraction site E8 also shown. Orange line represents probable extent of main/core upper Waiwhetu gravel fan. The two exploration bores sites are also shown (red circles).

The artesian pressure in the sub harbour Waiwhetu Aquifer of 3 to 4m amsl (as measured at Somes Island and in the exploratory E3a and E8 bores) is generally sufficient to prevent saltwater ingress, and to force out any trapped saline water from the more permeable formations. This is demonstrated by the SEAWAT modelling described later in this report. SI can only occur if there is a significant reduction in aquifer pressures as a result of abstraction. Diffusion and dispersion of saline water can also be of significance in groundwater systems with very low groundwater flow velocities. Conservative estimation of the drawdowns associated with abstraction proposals and the incorporation diffusion/dispersion are therefore important aspects of the SI risk assessment for this project.

6.2 Encroachment of a saline interface

It is unknown whether there is a fresh-saline water interface in the harbour. The artesian pressure measured in the two exploration bores suggests that it cannot be in the main part of the harbour north of Falcon Shoals (although a diffuse mixing zone could extend into the main part of the harbour). The conceptual model suggests there is potential for greater vertical hydraulic connectivity in the harbour entrance area (where the aquitard sediments transition into coarse grained material). It is also possible that the Waiwhetu gravels extend out in the Cook Strait where they may contain saline water (see discussion in Section 3.2). An interface therefore could exist in the 'harbour heads' area to the south of Falcon Shoals. Sensitivity testing with the southern boundary of the HAM4 groundwater model (Section 7) confirms that this could be the case. The movement of the interface shoreward as a result of sub harbour abstraction is therefore a plausible SI mechanism. The SEAWAT modelling introduced in the next chapter investigates the movement of the interface under various abstraction and sensitivity scenarios.

It is also possible to gauge the vulnerability of the aquifer to the lateral migration of the interface through using a simple Ghyben-Herzberg minimum level (calculated using the base elevation of the aquifer). The Ghyben-Herzberg equation applies to hydrostatic conditions (i.e. there is no flow in the aquifer) and is therefore likely to be conservative. The equation is based on a simple hydrostatic relationship between the density differences of sea water and freshwater:

$$z = (\rho_f \ / \rho_s - \rho_f) h_f$$

where:

z = the depth below sea level of the freshwater interface;

h_f = the height of the freshwater column above sea level that maintains a balance with the saltwater interface

ρ_f = density of freshwater

ρ_s = density of sea water

The relationship demonstrates that sea water occurs at depths below sea level equivalent to approximately 40 times the height of freshwater above sea level when typical values for ρ_f of 1.0 tonne/m^3 and for ρ_s of 1.025 tonnes/m^3 are used:

$$z = 40 h_f$$

Acknowledging the assumptions of the Ghyben-Herzberg relation, it provides a simple and conservative guideline (PDP, 2011) to calculate groundwater pressures above which no sea water intrusion problems should occur (this does not exclude the possibility of a dilute mixing zone being present however). Variable density groundwater modelling (using SEAWAT) provides a more accurate prediction of the saline interface. However, the Ghyben-Herzberg principal has been employed as a high-level general criterion and check to assess saline intrusion risk at critical points in the aquifer, particularly where the hydrogeological conceptualisation is less confident (e.g. Falcon Shoals and the Eastbourne coastline).

6.3 Risk of backflow from the ocean and critical pressures

Potential 'short circuits' into the Waiwhetu Aquifer from the sea bed are known to occur beneath Wellington Harbour. Numerous freshwater springs and seepage zones attest to localised breaches in the confining layer. These were described in Section 5.7 (see Figure 5.9). There is also the potential for leakage at the contact between the greywacke bedrock and the unconsolidated harbour fill sediments. Decoupling at the interface between the Petone Marine Beds and the greywacke (as a result of seismic activity?) may allow freshwater seepage into the harbour floor. A precautionary approach to the possible vulnerability of the greywacke-harbour sediment contact zone is consequently recommended through ensuring that any abstraction bore is sited at sufficient distance from the interface. A nominal buffer of approximately 1km between any bore and bedrock contact or spring vent or sea floor depression is recommended.

With regards the known submarine spring vents, it is possible to calculate critical aquifer pressures for the upper Waiwhetu Aquifer above which backflow from the ocean via the spring conduit should be prevented.

A critical condition at the spring sites occurs when the ocean pressure at the sea floor equalises with the freshwater pressure in the underlying aquifer. At this point, submarine springs would cease to flow. The piezometric pressure in the aquifer under this critical condition was originally evaluated by Donaldson and Campbell (1977) using the Darcy flow equation, taking into account the density difference between sea water and freshwater, as:

$$Q = R\ (h - \rho_s\, g\, d_t)$$

where:

Q = spring flow
R = the leak parameter incorporating the size of the leak and the resistance (kA)
h = head in the Waiwhetu Aquifer at the spring site (L, amsl)
ρ_s = density of sea water (ML^{-3}) = 1.025 tonnes/m^3
ρ_f = density of freshwater = 1.0 tonnes/m^3
g = acceleration due to gravity
d_t = total depth of sea water column above the spring vent (L)

According to this relationship, higher freshwater outflows will occur in shallower waters and, conversely, salt water inflow would occur preferentially at the deeper leak sites. Using the above equation, flow from the submarine springs will cease when:

$$\begin{aligned} h &= \rho_s\, g\, d_t \\ &= \rho_f\, g \times 1.025 d_t \end{aligned}$$

Reducing $\rho_f\, g$ to 1, and referencing h to the mean sea level datum:

$$h = (1.025 \times d_t) - d_{msl}$$

where:

d_{msl} = depth of sea water column above spring vent from a mean sea level datum (note d_{msl} can be different to d_t as discussed below).

This is recognised as a post-critical situation as salt water could move into the aquifer upon equalisation of the aquifer and harbour floor pressures.

Using the high resolution bathymetric survey discussed in Section 5.7.1, the maximum depth of the submarine spring vents (d_{msl}) occurring on the western side of the harbour is 30m below mean sea level (the spring off the southern end of Somes Island is the deepest). Figure 5.9 shows the locations and depths of the spring vents based on the bathymetry survey.

If a tidal range of 0.8m above mean sea level and a 0.2m sea level rise (Section 7.5.1) are taken into account, the adjusted seawater column depth above the deepest spring vent base (dt) is 31m. The critical head (for the deepest spring vent at Somes Island) in the underlying aquifer (h) therefore becomes:

h = (0.025 x 31) +1 = **1.8m** above mean sea level

Table 6-1 shows the calculated critical heads at principal submarine spring sites in the eastern harbour area. These levels have been used to help guide the evaluation of sustainable abstraction rates from the upper Waiwhetu beneath the harbour (See Section 7).

Table 6-1: Calculated critical freshwater heads beneath principal submarine spring sites in the upper Waiwhetu aquifer (UWA)

Principal submarine spring sites used to evaluate offshore abstraction SI risk	Depth of seawater above spring vent d_t (m)	Recommended min head in UWA beneath spring vent taking into account high tide and a 0.2m sea level rise (m amsl)
Hutt Mouth	26	1.65
Seaview	26	1.65
Somes (deepest spring – southern tip of island)	31	1.8
Pt Halswell	16	1.4

6.4 Saltwater ingress along bore casing

The construction of the bore is also critical in terms of minimising the risk of leakage via the bore annulus (outside the well casing). This can be achieved through careful construction, grouting and the use of double casing in the aquitard.

Drawdowns in the vicinity of a sub harbour pumping well may drop below sea level. Some of the drawdown will be associated with well losses, but the aquifer level outside the bore casing will locally drop below sea level. This is not considered an issue provided that there is a guaranteed and tested annulus seal. The very plastic nature of the Petone marine silts means that it is expected that the bore casing will naturally seal and that it will reseal quickly if it is disturbed by a seismic event. The risk of this SI mechanism is therefore considered low. The greater contamination risk from a seismic event would relate to potential casing rupture.

6.5 Cross-contamination from deeper aquifers

The occurrence of dilute saline water residing in some areas of the offshore Waiwhetu Aquifer and in deeper formations has been proven by the exploration drilling (e.g. the lower Waiwhetu Aquifer at E8). The salinity possibly represents the edge of a mixing zone which has varying concentrations at different levels of the aquifer system due the heterogenous nature of the sediments – higher concentrations being indicative of enhanced contaminant mobility conditions (i.e. higher dispersivity and diffusion). Given the very flat offshore flow gradients, very small changes in aquifer parameters could result in significant differences in saline water mixing. If a fragile equilibrium exists between the underlying saline water and overlying freshwater, the saline water could be drawn up into overlying freshwater aquifer. This is a particular risk where separating aquitards are thin, absent or likely to be heterogenous. Water quality samples from all aquifers intercepted in the E3a and E8 exploratory bores show a small percentage (2-4%) of seawater mixing. Some areas, such at the E8 bore site (lower Waiwhetu aquifer), exhibit considerable higher salinity concentrations suggesting that background salinity concentrations are highly localised and variable – and potentially concentrated at the base of the aquifer.

This SI mechanism is perhaps the most probable and problematic, given the knowledge of the aquifer system and water quality following the exploration drilling. Analysis of the risk of SI through aquifer cross-contamination has therefore been a strong focus of the groundwater modelling work.

7. Numerical modelling

7.1 HAM4 development

7.1.1 Purpose and objectives

The purpose of developing a revised Hutt Aquifer Model – 'HAM4' – is to assist Wellington Water Limited evaluate the feasibility of the sub-harbour extension of the Waiwhetu Aquifer and its potential to provide alternative water supply to Wellington. In particular, the HAM4 model must be able to guide a conservative evaluation of the saline intrusion risks associated with abstraction of groundwater from offshore aquifers by identifying any obvious 'failure mechanisms'.

Specific objectives or outcomes for the HAM4 model are as follows:

a) Develop a simulation of the Lower Hutt groundwater system and its offshore extension that is compatible with field observation data and geological conceptualisation;

b) Undertake a set of abstraction scenarios and identify the potential risks of saline intrusion mechanisms;

c) Provide initial guidance on the sustainable yield of the offshore aquifers;

d) Identify any 'fatal flaws in the proposal for sub-harbour abstraction (i.e. whether there are clear risks that would prevent the project from progressing further);

e) Identify important uncertainties and limitations associated with the model and recommendations for further modelling work.

7.2 Summary of modifications to previous HAM3 offshore conceptual model

The offshore aquifer conceptualisation of the original HAM3 model was based upon earlier geophysical surveys and other information – such as the locations of submarine springs and evidence from the Somes Island bores. The HAM3 model assumed that the Waiwhetu Aquifer is present under the entire harbour and through the harbour entrance area, and that it is confined by fine grained marine sediments (Petone Marine Beds). Discharge through the confining layers through widespread diffuse leakage and through known active discreet sea floor spring vents located off the Hutt River mouth, Seaview and Somes Island was simulated. HAM3 recognised that the sub-harbour Waiwhetu Aquifer remains under pressure (it has an artesian pressure 3-4m amsl), and that there can be no direct (i.e. unconfined) connection to the sea. The location of most of the leakage out of the offshore aquifer was largely assumed to be diffuse and evenly distributed except at known active submarine spring sites where more water was locally released. However, a later revision of the HAM3 (2015) simulated a greater connectivity in the harbour entrance area and consequently a greater proportion of leakage in this area (EIM, 2015).

The new geological model developed for this project does not substantially alter the general HAM3 offshore conceptualisation. However, it provides a major refinement of the offshore morphology of, and relationships between, the more important hydrostratigraphic units – namely the Petone marine silt aquitard, upper and lower Waiwhetu gravels and an intervening Q3 aquitard. The much more limited extent of the upper Waiwhetu gravels is a particularly important deviation from the previous conceptualisation, as is the probable merging of units into a generally coarser grained but highly anisotropy harbour heads area where vertical leakage from the system may be enhanced. The extension of the aquifers out into the Cook Strait is also recognised as being possible but restricted by an uplifted bar of low permeability older geological materials beneath the harbour heads area. These have major implications in terms of modelling the effects and risks of sub-harbour abstraction.

7.3 Modelling approach and uncertainty context

Due to the risk of saline intrusion associated with offshore groundwater abstraction, the HAM4 modelling has been undertaken within an over-arching context of uncertainty.

There is a high level of uncertainty regarding the nature of the offshore groundwater environment because of a heavy reliance on geological and hydrogeological conceptualisation and indirect investigation methods (i.e. geophysics), albeit 'ground-truthed' by the two new exploratory bores. This requires that a conservative, sensitivity-based approach be adopted regarding all aspects of the modelling.

Components of the conservative sensitivity-based modelling approach employed in HAM4:

- Run abstraction scenarios using a conservative, but realistic, hydrogeological conceptual model which forces greater connectivity to the ocean in the harbour heads area and along the eastern coastline (principal distributed saline intrusion risk areas);

- Test an alternative calibration scenario whereby more water is released closer to the foreshore from the submarine spring vents, thereby flattening the offshore gradients and potentially encouraging the saline interface to move closer to shore;

- Set a conservative ocean head boundary (constant head boundary) of 0.55m amsl (this takes into consideration current mean sea level of 0.2 m and the upper quartile of the tidal range). This means that saline water will be able to back flow into the aquifer (through springs and through the harbour floor) at higher aquifer pressures. Long term sea level rise may however be up to 1m greater this – the effects of this are also examined;

- Consider the density difference between saline water and freshwater in the HAM4 simulations by using concentration-dependent equivalent freshwater heads in the SEAWAT modelling package;

- Calibrate the transient flow model using equivalent freshwater heads at the sea floor to replicate actual pressures of the denser saline water column (compared to a freshwater column);

- Adopt a low vertical hydraulic conductivity (Kv) value for the Petone marine silt confining layer to force connectivity in the harbour entrance area (this results in the need to set higher Kv values in the harbour entrance area to release aquifer pressure and thereby enhance vertical hydraulic connectivity to the ocean);

- Preferentially use the lower end of a plausible range for horizontal hydraulic conductivity for the upper Waiwhetu gravels to induce higher aquifer drawdowns (even at most distant sites) against which to assess saline intrusion risk;

- Undertake a sensitivity analysis of critical boundary conditions (GHB) and hydraulic conductivity of aquifer parameters (upper Waiwhetu gravels and harbour entrance Holocene);

- Assume that the Q3 aquitard thins and dissipates to the north and east of E8 and becomes more heterogeneous (consistent with the geological model);

- Run scenarios in which brackish water is simulated with constant concentration in the lower Waiwhetu gravels beneath much of the harbour south of Somes Island (consistent with observations in E8) over a wide area.
- Although Figure 5.1 would suggest that the UWA has pinched out and it is the LWA that has the more permeable southern connection to the ocean, assume that the UWA also connects to the Cook Strait area at the southern model boundary (the previous HAM3 models assumed no connectivity). Groundwater south of the boundary is assumed to be saline and under artesian pressure and can flow northwards into the harbour heads area;
- Use one-year constant abstraction scenarios, even though the bores may only be used for 4-6 months (possibly longer?);
- Adopt critical heads in the upper Waiwhetu gravels beneath spring vents using high tidal levels;
- Run all abstraction scenarios using a stress period representative of low summer aquifer recharge conditions;
- Hold abstraction from Waterloo constant for scenario durations;

7.4 Model set-up

7.4.1 Model code

Because of the saline intrusion focus of the modelling, the USGS code SEAWAT 2000 (Langevin et al, 2007) has been used in conjunction with Modflow 2000 to develop HAM4. SEAWAT is specifically designed for the simulation of saltwater intrusion and uses MODFLOW 2000 (finite difference) to solve the flow system and MT3D with its many solution techniques to solve the solute transport equations. SEAWAT models variable-density groundwater flow which is formulated in terms of equivalent freshwater head and fluid density.

SEAWAT has been employed via data processing interface Groundwater Vistas (Environmental Simulations Inc., 2012, version 6).

7.4.2 Model grid and layer structure

The original HAM3 model structure has been used as a basis for developing HAM4. Definition of the model layer structure has been redefined in the offshore area of the model based upon the geological analysis and conceptualisation presented in Chapter 5. The model domain, shown in Figure 7.1, extends from Taita Gorge to the entrance of Wellington harbour; the active model grid covers an area 107.5km^2, of which a two-thirds third (c. 80km^2) lies offshore.

The grid has been rotated 37^o to align it with the principal groundwater flow direction and the north-western fault-bound edge of the basin. The default grid cell size is 100m x 100m which is applied in HAM4 to the entire model (in HAM3 the grid was gradually coarsened southwards from Somes Island).

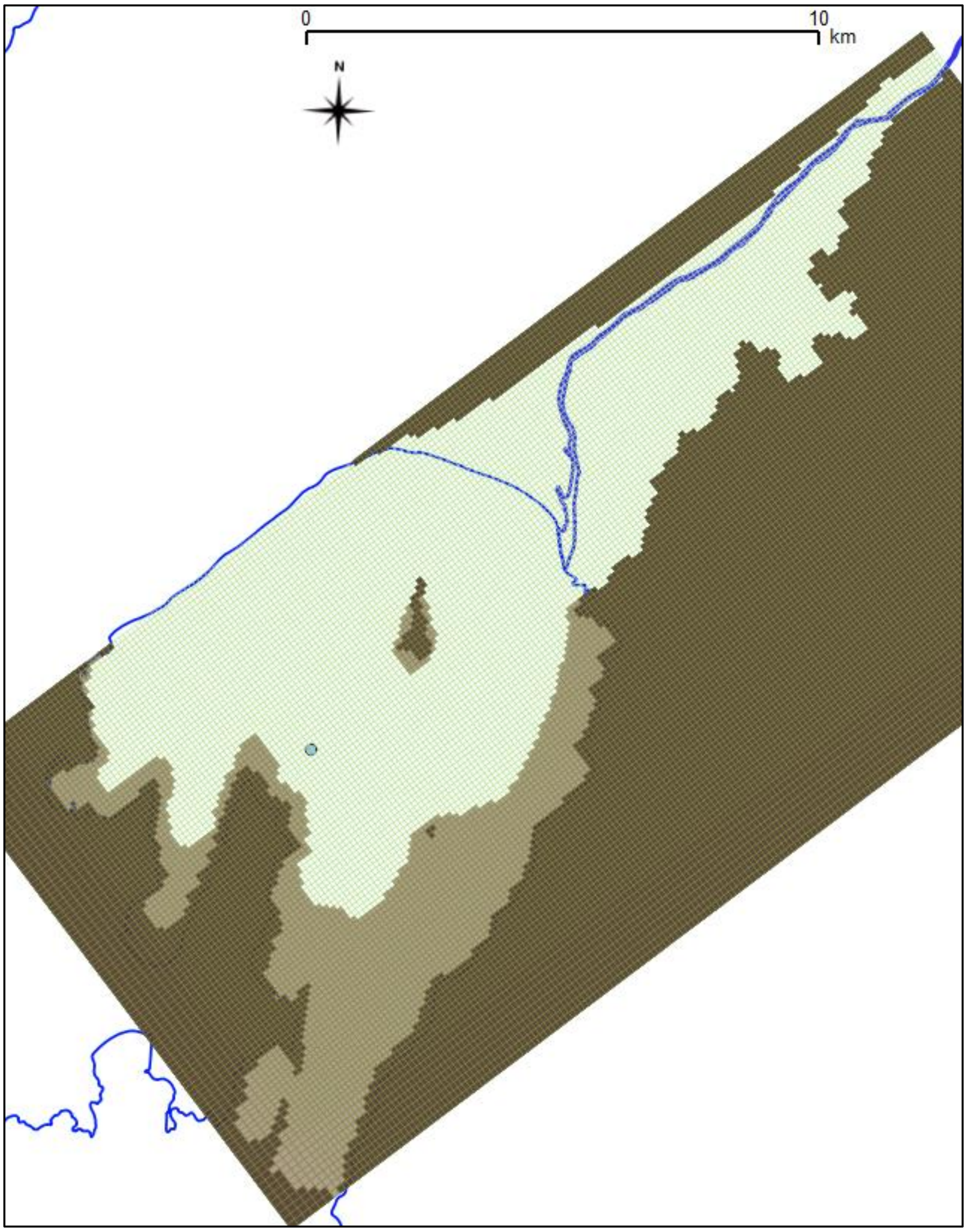


Figure 7.1: HAM4 model domain and grid showing inactive cells – dark brown = Layer 5 inactive cells; light brown = Layer 12 inactive cells

HAM4 comprises 14 layers in which the main units (Petone marine silts, upper Waiwhetu aquifer, Q3 aquitard and lower Waiwhetu aquifer) have been split into two layers to increase the vertical layer resolution and facilitate more accurate solute transport simulation in MT3D.

A description of the model layers is contained in Table 7-1. The Waiwhetu Gravel unit is simulated as three distinct units - an upper and lower gravel aquifer and the Q3 intervening (discontinuous) aquitard (HAM3 did not simulate the Q3 aquitard explicitly). Figure 7.2 shows the layer configurations schematically along a section line between the top of the terrestrial groundwater zone (Taita Gorge) and the harbour heads to illustrate the representation of the conceptual model described above.

Table 7-1 HAM4 layer structure and corresponding hydrostratigraphic units in offshore and terrestrial areas

Layer no.	Onshore/terrestrial area	Offshore area
1	Taita Alluvium-Petone Marine Beds. Offshore – ocean/constant head	Ocean CH layer
2	Petone Marine Beds aquiclude and Taita Alluvium in unconfined area	Ocean CH layer (0.2m layer to force Seawat to calculate equivalent fw head at seafloor rather than at mid-point of seawater column)
3+4	Petone Marine Beds aquiclude and Taita Alluvium in unconfined area	Petone marine silts
5+6	Upper Waiwhetu Aquifer / semi-confined gravels upstream	Upper Waiwhetu gravels / Q3 aquitard on western side of harbour
7+8	Lower Waiwhetu Gravels	Q3 mid Waiwhetu aquitard / lower Waiwhetu aquifer where Q3 aquitard not present (harbour entrance, eastern side of harbour)
9+10	Lower Waiwhetu Gravels	Lower Waiwhetu Gravels
11	Wilford Shells Beds / Moera Gravels unconfined area	Wilford Shell Bed / small part of lower Waiwhetu gravels in harbour entrance
12	Upper Moera gravels	Upper Moera gravels
13	Older Basal Gravels	Older Basal Gravels
14	Older Basal Gravels	Older Basal Gravels

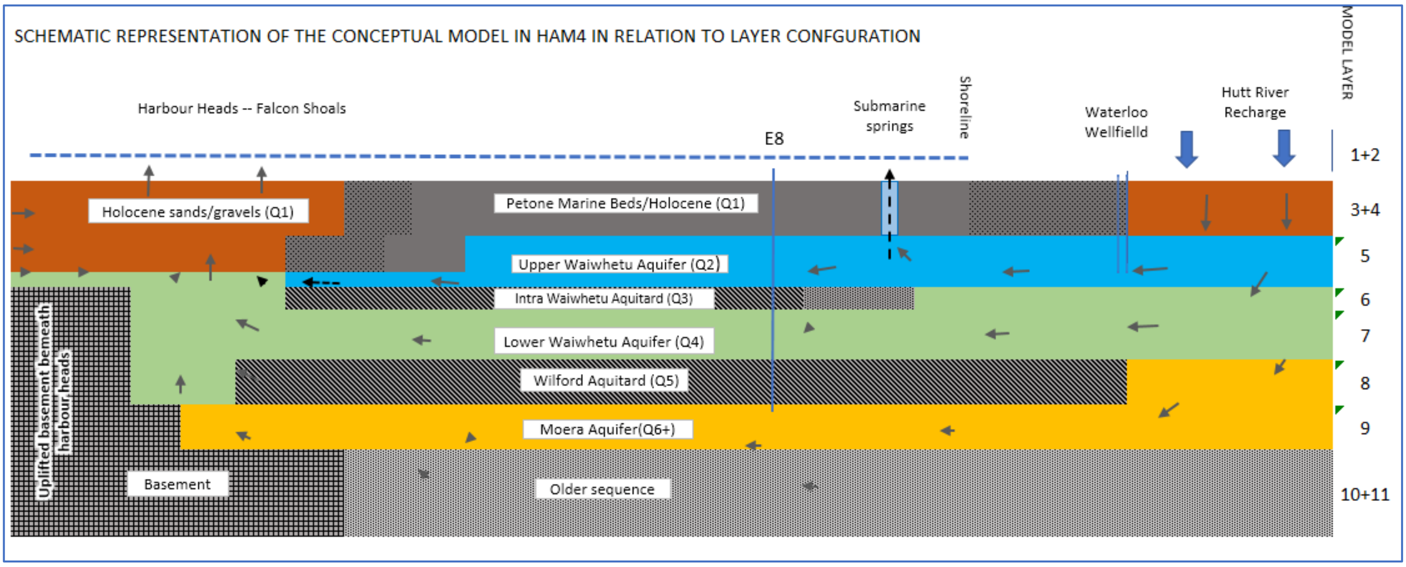


Figure 7.2 Schematic representation of the conceptual model in HAM4 in relation to layer configuration

7.4.3 Layer elevations

The geological modelling (Appendix 1) has generated surfaces for the interfaces between the various stratigraphic units of the model listed in Table 7-1 for the offshore part of the model. The surfaces are contiguous with the onshore geological model surfaces so that the two parts of the model seamlessly integrate. Figure 7.3 shows the depth of the seafloor based on the NIWA bathymetry survey (NIWA, 2009). Figure 7.4 to Figure 7.6 show some of the principal surfaces as depths below the sea floor (Base Holocene/top of upper Waiwhetu gravels, top of the lower Waiwhetu gravels, top of the Moera gravels). Figure 7.7 and Figure 7.8 show the thickness of the upper Waiwhetu gravels and the Q3 silt mid-Waiwhetu aquitard.

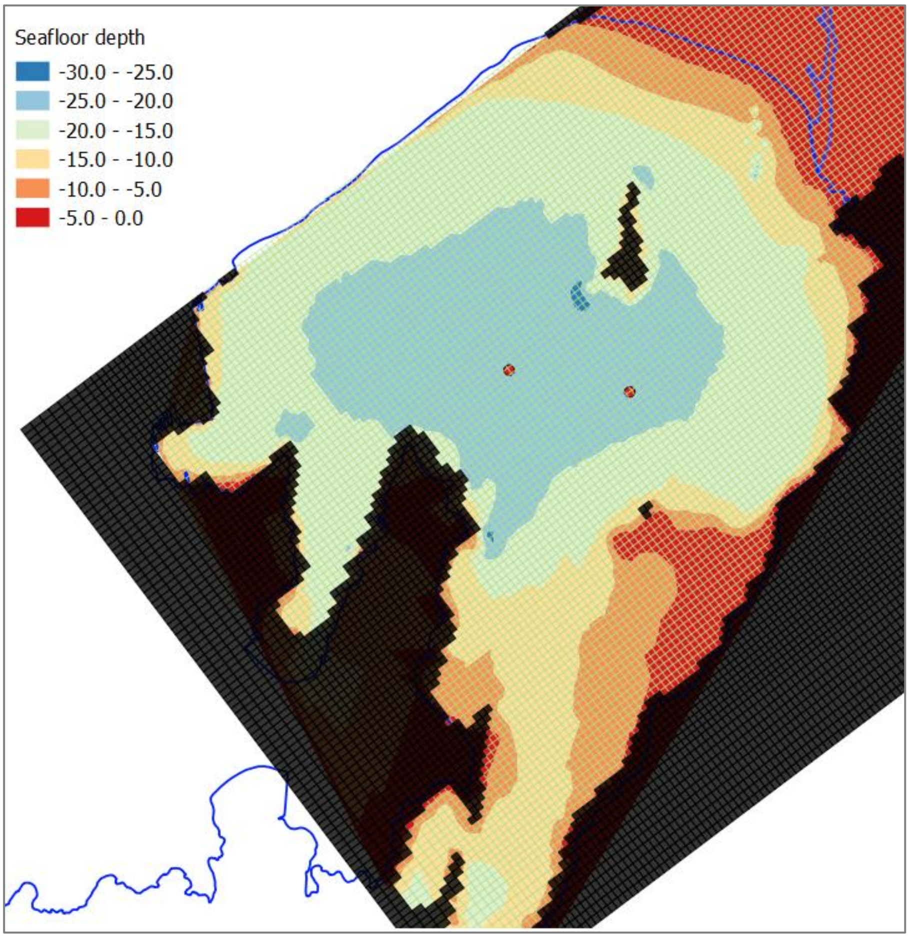


Figure 7.3 Seafloor depth (m amsl) based on NIWA (2009) bathymetry survey. Base of model layer 2 (sea level constant heads are set in this layer).

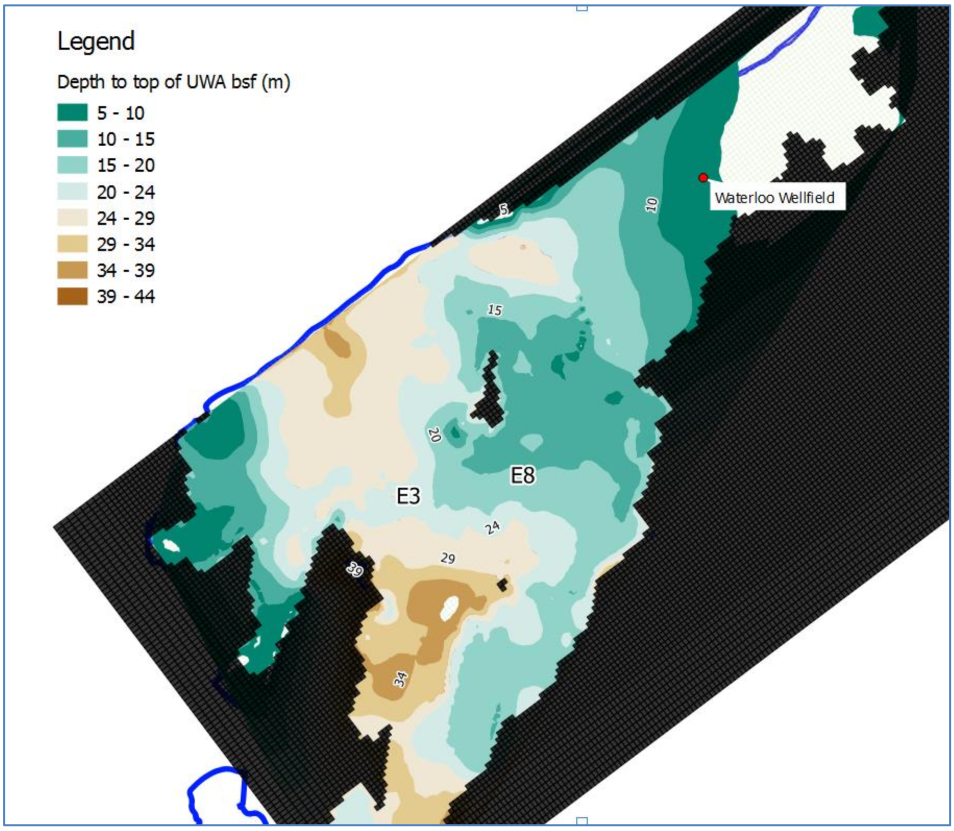


Figure 7.4 Modelled depth to top of upper Waiwhetu Aquifer (UWA) below sea floor (where UWA is not present depth to base of Holocene sediments).

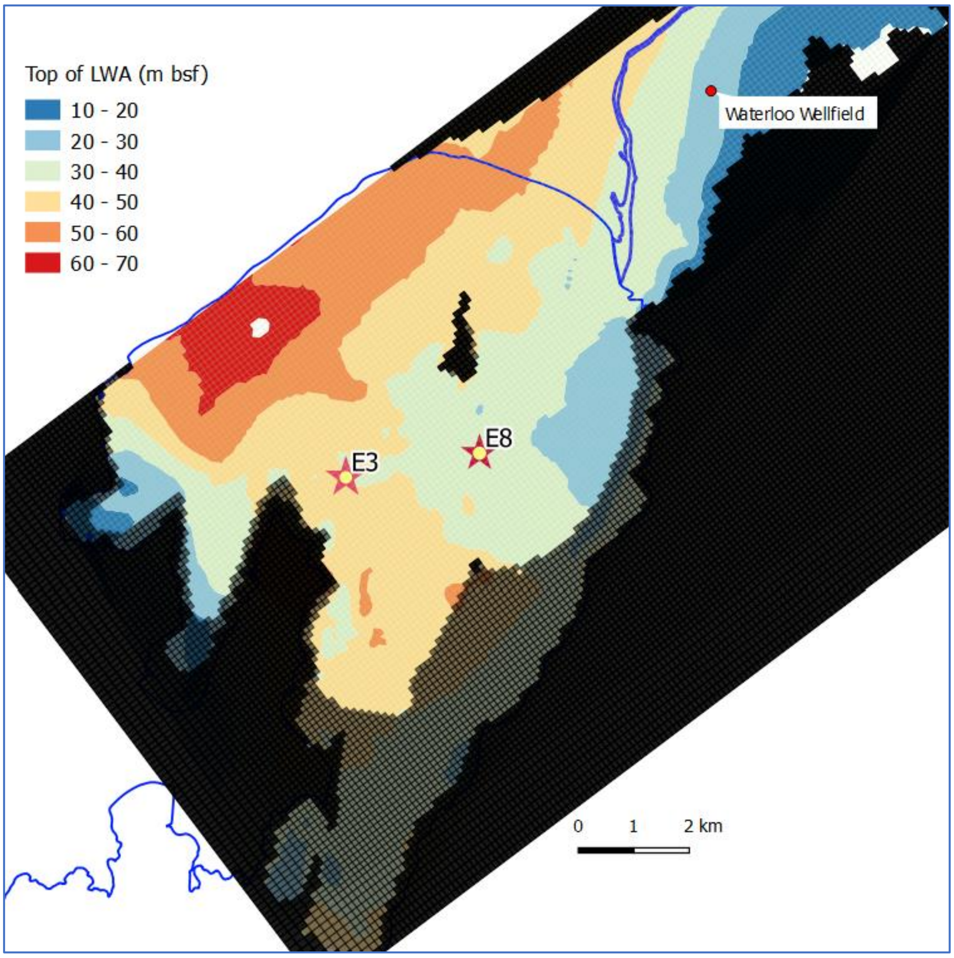


Figure 7.5 Modelled depth to the top of the lower Waiwhetu gravels (in metres below sea floor).

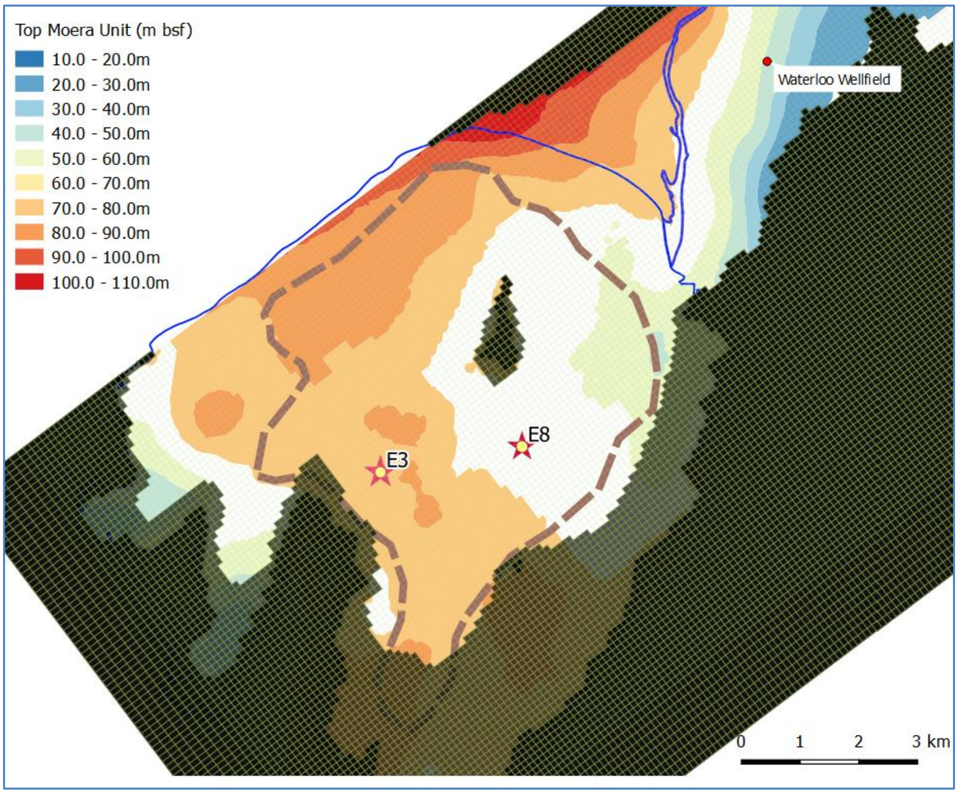


Figure 7.6 Modelled top of Moera unit (in m below sea floor). Note rising basement, especially in the harbour entrance area - no continuity to the south. (model layer 12). Brown dashed line is probable extend of the Q3 aquitard.

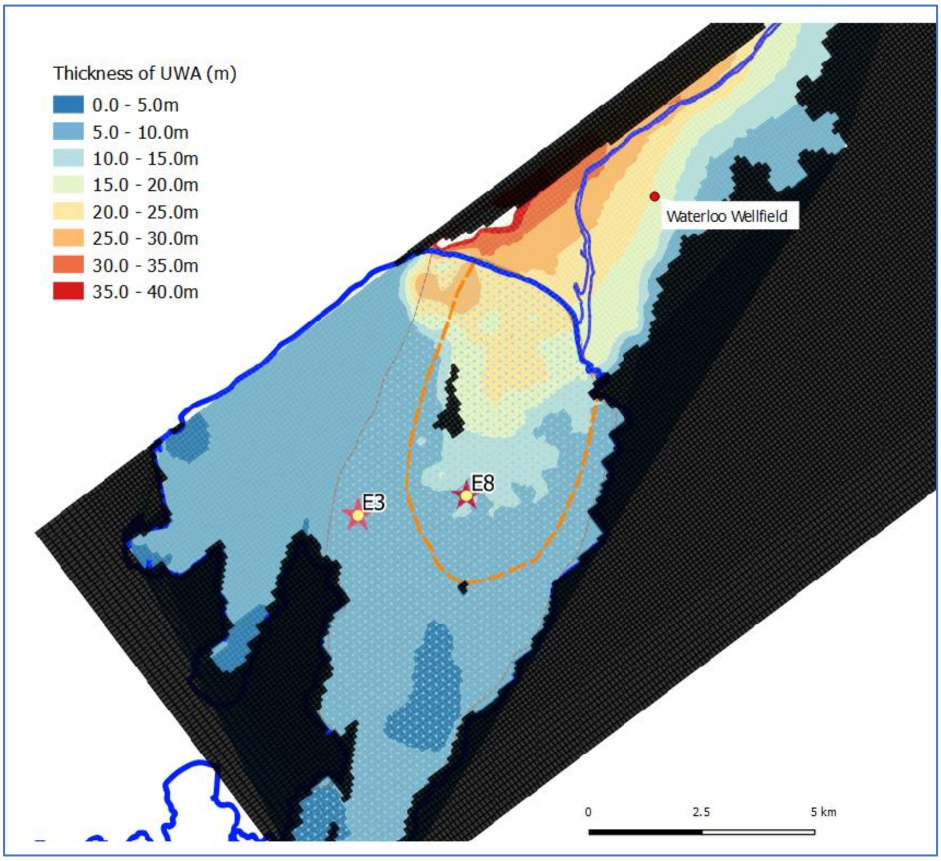


Figure 7.7 Modelled thickness of the upper Waiwhetu gravels. Probable extent of offshore UWA shown by stippled area, the limits of the main coarse fan lobe is shown by the orange dotted line

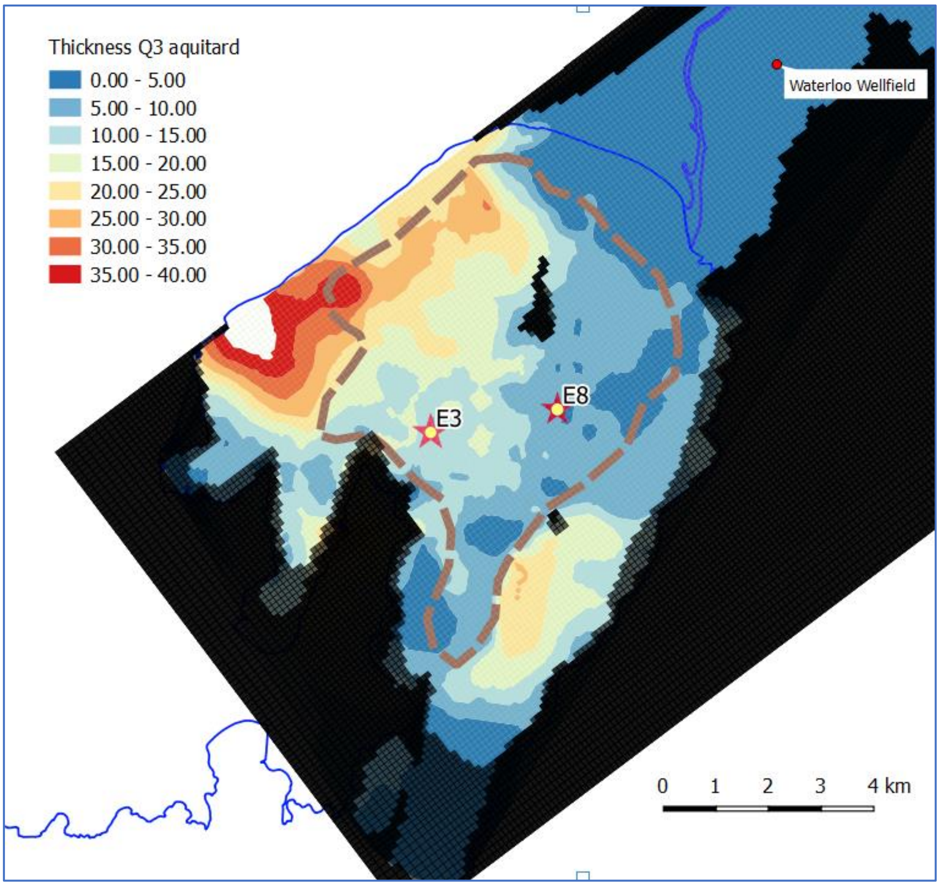


Figure 7.8 Modelled thickness of the Q3 intra-Waiwhetu aquitard. This unit is present mostly within the area delineated by the brown dashed line. (model layer 8)

7.5 Boundary conditions

The boundary conditions for the terrestrial part of the model are described in the HAM3 documentation (EIM, 2014). These include river and drain boundaries.

Offshore, the three principal boundary conditions are the constant head condition set in layers 1and 2 at the ocean floor to simulate the pressure of the seawater column, a general head boundary at the southern model margin to simulate connectivity into the Cook Strait, and general head boundaries representing the submarine springs. No-flow boundaries are set at the sides and base of the model where the quaternary deposits intersect basement (greywacke) bedrock.

7.5.1 Ocean level constant head and constant concentration boundary

A great deal of attention has been invested in ensuring the correct assignment of the constant head value to represent the ocean and the density-corrected pressures at the sea floor. The normal practice of simply assigning a value of zero for the coastal heads (i.e. mean sea level) was not considered appropriate for the reasons described below.

Current mean sea level in Wellington Harbour is higher than mean sea level referenced by the Wellington Vertical Datum-1953 (WVD-53) used in the HAM4. Use of a mean sea level 0.2m from about 1990 is more appropriate based on an analysis of long-term sea level monitoring in Wellington Harbour (NIWA, 2012).

Seawater intrusion risk assessment is also required to take into consideration the tidal range (up to about 0.8m around the mean). Even though the HAM4 model is calibrated to 7-day stress periods, many of the pumping scenarios use a timestep of a day or less. It is therefore considered necessary to conservatively use a sea level which acknowledges the risks posed by the tidal range. This concept is supported by Werner et al (2013) who write:

> *" Tides not only create dynamic conditions in the near-shore aquifer, but they also influence time-averaged ocean boundary conditions, which regulate regional aquifer hydrology. Tidal water table over-height refers to the super-elevation of head conditions at the coast arising from tidal effects. That is, tides impose time-averaged head conditions at the coast that exceed mean sea level. Accurate representation of tidal over-height in the ocean boundary conditions of SI management models is essential to produce reasonable guidance on well-field operation protocols for avoiding SI [saltwater intrusion].."*

Although this recommendation relates to tidal water table over-heights in unconfined coastal aquifers, it is considered prudent to incorporate some higher tidal level in the HAM4 as the potential saline intrusion risk is high - particularly above submarine spring vents whereby a high tide could trigger a saline intrusion event.

The constant head ocean boundary has consequently been set using the upper quartile value of the tidal range (i.e. 25% above the mean sea level). This equates to 0.55m above the WVD-53 datum (this takes into account the 0.2m current sea level). Figure 7.9 illustrates where the assumed 0.55m sits in the context of tidal monitoring at Queen's Wharf in Wellington Harbour.

A sensitivity analysis has been carried out using a constant head of 0.2m showing that the model calibration is insensitive to the additional 0.35m assigned to the ocean constant head.

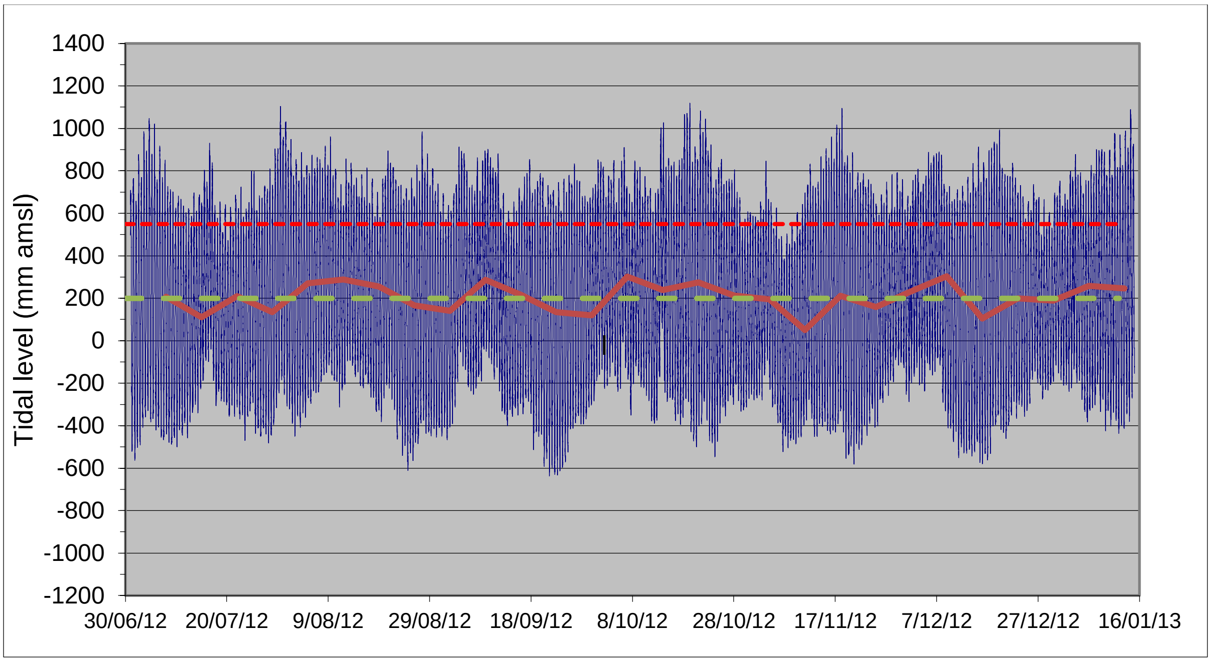


Figure 7.9 Tidal range in Wellington Harbour (Queen's Wharf) showing upper quartile of the range (red dashed line) of 0.55m above WVD-53 assigned to constant heads representing sea level in the model. Data are normalised to a 0.2m mean sea level (green dashed line) above WVD-53 datum. The orange solid line is a 30d moving mean.

Calculation of equivalent freshwater head

SEAWAT relies on the concept of equivalent freshwater head for the simulation of density differences between sea water (or any modelled or specified salinity concentration) and freshwater.

Since seawater (with a salinity of 35kg/m^3) has a density of 2.5% more than freshwater, the conversion to equivalent freshwater head (EFWH) is:

EFWH = depth to sea floor from sea level * 0.025 + sea level (0.55m)

Since the sea depth varies throughout the harbour (see Figure 7.3), a matrix of EFWH is calculated by SEAWAT for each model cell according to its sea bed level.

SEAWAT 2000 automatically converts the head data entered (i.e. 0.55m) to an equivalent freshwater head (EFWH), so the above conversion to EFWH does not need to be manually performed. Because SEAWAT will calculate an equivalent freshwater head for the finite difference node (located in the mid-point model cell) it will tend to underestimate the EFWH at spring locations (i.e. if there is a 20m depth of water in a cell, it will calculate an EFWH at the mid-point, in this case, 10m). To force SEAWAT to calculate the EFWH at the seafloor (where the pressures are highest), a 0.2m thick layer was introduced at the base of Layer 1 and assigned a constant head value of 0.55m. SEAWAT then calculates the EFWH for the centre of the node for the thin layer 2, then adds the density corrected pressure for the remaining water depth from the top of the layer 2 cell to the assigned constant head level (0.55m).

Figure 7.10 shows the equivalent freshwater heads used in the HAM4 mode when a sea level of 0.55m above WVD-53 is applied together with the seawater depths.

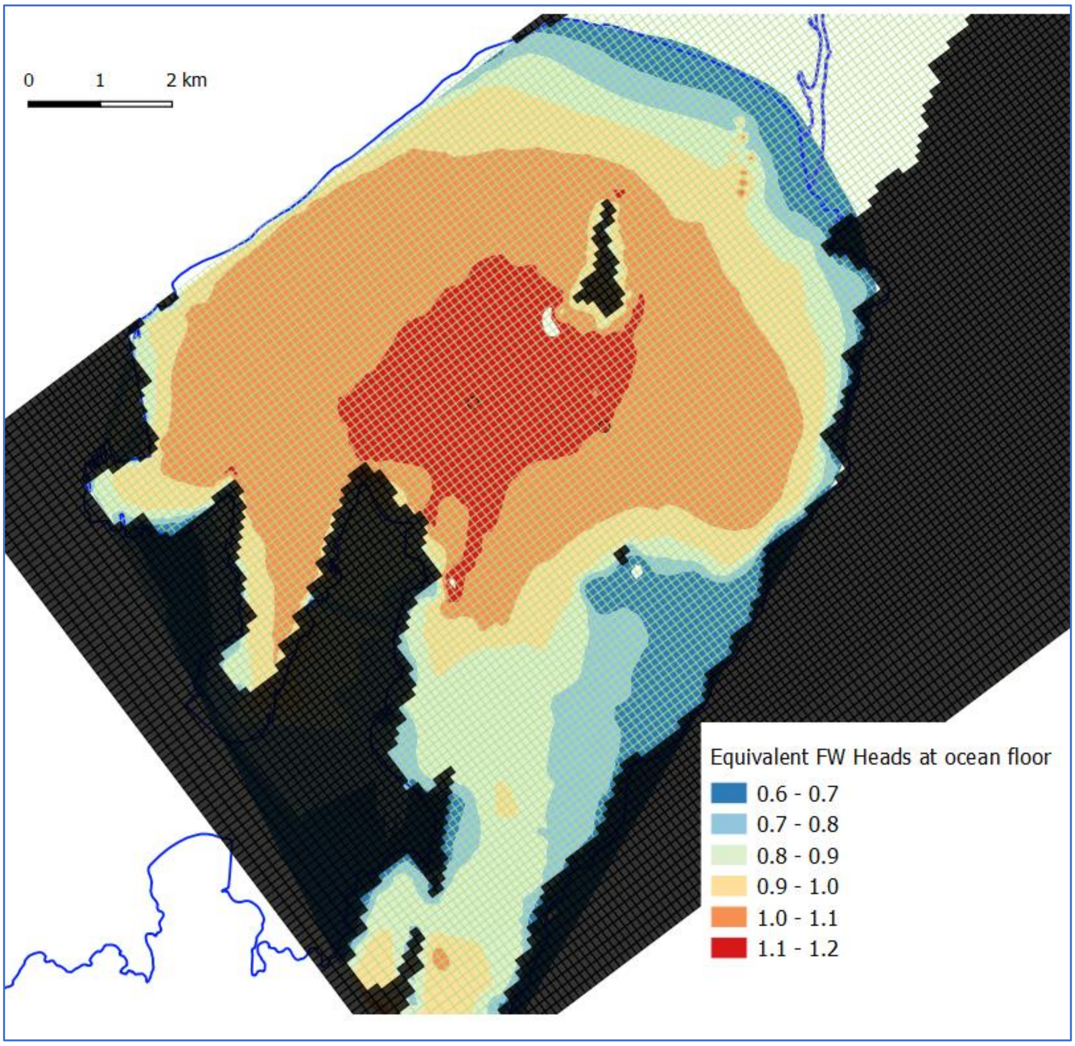


Figure 7.10 Equivalent freshwater heads (in m amsl) applied to an ocean constant head boundary set at 0.55m in the HAM4 Seawat model.

7.5.2 General head boundaries

A general head boundary (GHB) was assigned at the southern harbour entrance boundary to Cook Strait in model layers 4 and 5 (lower Holocene and upper Waiwhetu). The lower Waiwhetu Aquifer extends into the harbour entrance area but cannot connect to the Cook Strait and terminates against a raised bedrock bar. The GHB boundary conservatively represents connectivity to the Cook Strait area through coarser-grained material over the top of the uplifted coastal barrier (which is estimated to lie at about 50 m below msl). The groundwater to the south of this boundary is assumed to be saline. The head on the boundary is placed at a level consistent with the heads observed further into the harbour, allowing for a small gradient. They have also been placed on the basis of the previous HAM3 model which did not simulate this connection but allowed vertical leakage in the harbour entrance area at a rate necessary to maintain the observed heads at Somes Island and McEwan Park. It is conservatively assumed that the UWA at the coastal boundary has a pressure above sea level which would allow the backflow of seawater into the harbour area.

A GHB head of 2.5m was consequently selected, although a sensitivity analysis using a range of GHB heads, and one without the GHB, showed that the modelled groundwater heads in the harbour area are insensitive to the GHB head – except very locally around the Point Dorset area at the very southern end of the model (see Figure 7.21). The distance to the GHB of 1000m was nominally set and a high hydraulic conductance of 100m/day was applied (equivalent to a conductance of about 2,500m^2/d).

It is evident that at the selected GHB head that the boundary allows a small amount of northward inflow to the harbour aquifers of saline water and generates a saltwater interface further upgradient in the Point Dorset area. The boundary moves slightly inland if the GHB head is raised, but not significantly. The use and assignment of the GHB boundary is considered to be a necessary conservative conceptualisation since there is no information regarding salinization of the aquifers in the harbour heads area or the continuation of the aquifers into Cook Strait, it is necessary to assume this is the case. Overall, the GHB boundary does not appear to play an important part in terms of evaluating the saline intrusion risk in the main part of the harbour.

A general head boundary condition was also used in the top layer of the upper Waiwhetu Aquifer (layer 5) to represent the submarine spring vents off the Hutt River mouth, Seaview and Somes Island. The head on these boundaries was specified at 0.55m (sea level) with a salinity concentration of 35kg/m^3. The hydraulic conductivity was set to 15m/d to provide a mean total spring discharge of 2-3 MLD, with distance to the GHB cell specified at 25m. The hydraulic conductivity of the GHB cells was also increased to 100m/d and spring discharge increased to 10-12MLD in the alternative calibration presented in Section 8.

7.6 Hydraulic properties (offshore)

7.6.1 Hydraulic conductivity

The hydraulic property zonation and parameter value used for the HAM4 model honours the conceptual hydrogeological model. Onshore, HAM4 retains the HAM3 hydraulic conductivity framework and calibrated values. The HAM3 model underwent a comprehensive parameter optimisation and sensitivity analysis using PEST (Dougherty, 2008) during the calibration process (documented in EIM, 2014). The calibrated parameters are therefore regarded to be relatively well assigned and can be incorporated into the HAM4 model.

The offshore part of the HAM4 also retains some of the parameter values for some of the terrestrial units which extend beneath the harbour or have been adjusted to reflect the geological conceptualisation and exploration drilling/testing of E3a and E8. Zonation patterns have also been modified to reflect the conceptual geological model.

Figure 7.11 to Figure 7.18 show the hydraulic conductivity zonation applied to each of the model layers guided by the conceptual geological model.

Figure 7.11 and 7.12 show the two uppermost layers beneath the harbour floor (Layers 1 and 2 are assigned constant head values as described above). These layers represent the Holocene age sediments – the extent of the Petone marine silts and their gradation into coarse grained material in the southern part of the harbour and the harbour heads area. Also evident in these figures are the submarine spring vents – originally represented by single cells of higher hydraulic conductivity. However, instability problems associated with juxtaposing cells with very low hydraulic next to much higher hydraulic conductivity cells required that the springs be represented using GHB cells located in the top of the UWA (Layer 5). The terrestrial Petone marine beds (and Taita Alluvium) have much higher hydraulic conductivity to represent the greater variability in sediment types and absence of thick, continuous and compact marine silts.

Figure 7.13 (Layers 5 and 6) shows the upper Waiwhetu gravels represented as three zones - the most permeable zone (2) is an extension of the onshore aquifer with very high transmissivity (calibrated HAM3 Kh = 1,400 m/d), this grades into a zone of lower hydraulic conductivity (zone 20) which represents the limit of the main gravel fan identified in the geophysics (refer to Figure 5.3). The third zone (19) represents a thin continuation of the upper Waiwhetu gravels as the fan disperses and spreads out. This zone creates a hydraulic connection into the harbour entrance area where they merge with lower Waiwhetu gravels and overlying coarse Holocene material. This conceptualisation is regarded to be conservative (the geological model suggested that the upper Waiwhetu gravels did not extent into the harbour entrance area). Note this layer is divided into two in the scenario model version, as are the underlying two layers.

Figure 7.14 (Layers 7 and 8) represents the Q3 intra Waiwhetu aquitard which is more developed and thicker on the western side of the harbour (zones 18 and 15). Zone 24 represents the thinner, more heterogenous eastern part of the Q3 unit which is assigned higher vertical hydraulic conductivity. Elsewhere in this layer, the lower Waiwhetu gravels make their first appearance – they underlie the Q3 unit but are represented in this layer where the Q3 unit is absent. The greywacke basement (or groundwater basement) is starting to shallow down through the sequence, particularly in the harbour entrance area where there is tectonic uplift. The top of the basement in this area sits at about 50 m below msl.

Figure 7.15 (layer 9 and 10) contains the lower Waiwhetu gravels which extend across the entire basin. Figure 7.16 (Layer 8) shows the Wilford Shell bed extent and its absence in the southern harbour entrance.

The upper Moera gravels are represented in Layer 12 (Figure 7.17) as two zones offshore – a higher K extension to the terrestrial aquifer, grading offshore to a lower hydraulic conductivity (consistent with the findings of the exploration drilling). Figure 7.18 shows the hydraulic conductivity zonation for the two bottom model layers (13 and 14) which represent older Moera sediments.

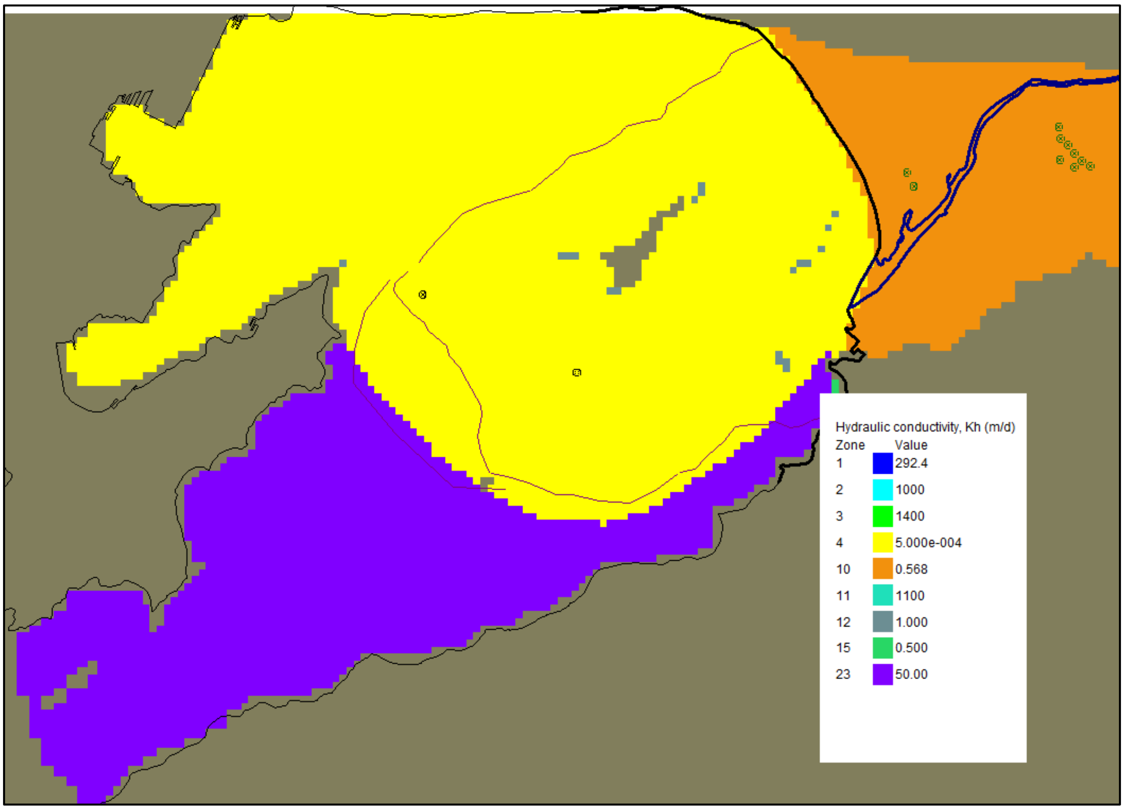


Figure 7.11 Hydraulic conductivity zones and Kh values for Layer 3 (topmost layer on contact with sea bed). Holocene sediments – Petone marine silts (zone 4 - yellow) grading into coarser material (zone 23 – purple) in harbour entrance and eastern side of the harbour. Spring vents also shown as grey squares represented by GHB boundaries set in Layer 5 (UWA) with a head set at sea level.

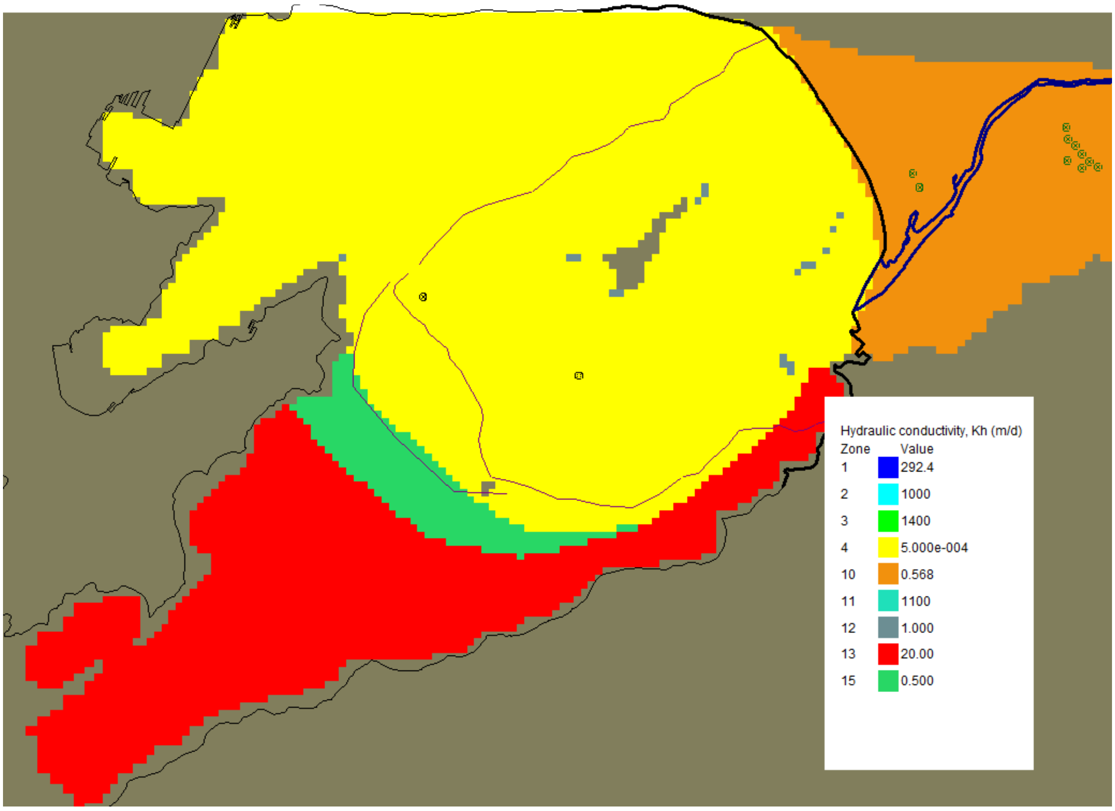


Figure 7.12 Hydraulic conductivity zones and Kh values for Layer 4 - Holocene sediments – Petone marine silts (zone 4 - yellow) grading into coarser material (zone 13 and 15) in harbour entrance and eastern side of the harbour.

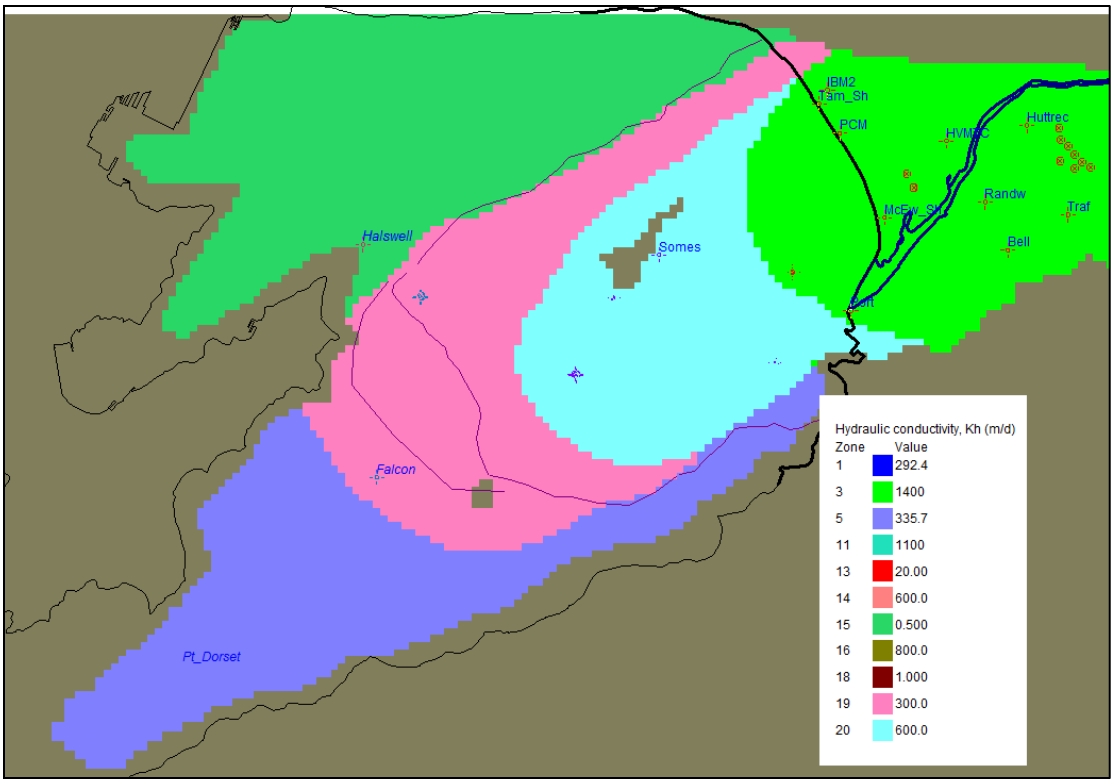


Figure 7.13 Hydraulic conductivity zones and Kh values for Layers 5 and 6 – upper Waiwhetu gravels (zone 3, and 20 = main fan lobe, and 19 = thin continuation), Q3 aquitard (zone 15) and lower Waiwhetu gravels (zone 5).

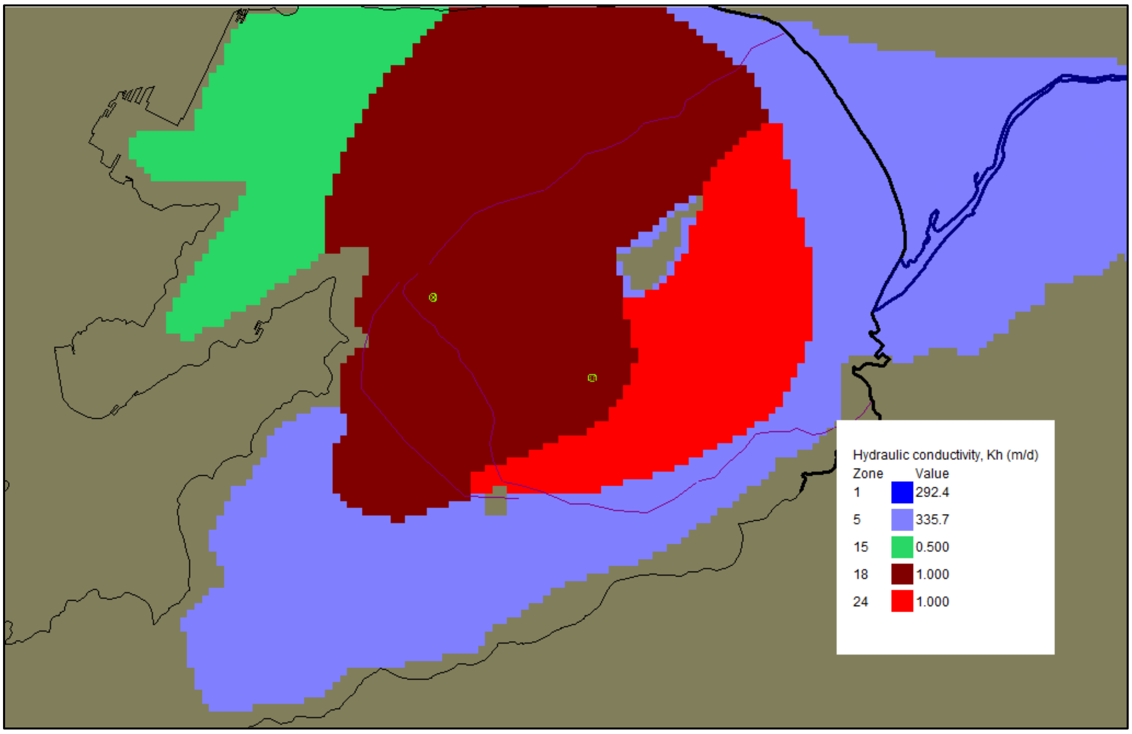


Figure 7.14 Hydraulic conductivity zones and Kh values for Layers 7 and 8 – Q3 aquitard (zones 18, 24 and 15) and lower Waiwhetu gravels (zone 5). Zone 24 of the Q3 aquitard has a much higher vertical hydraulic

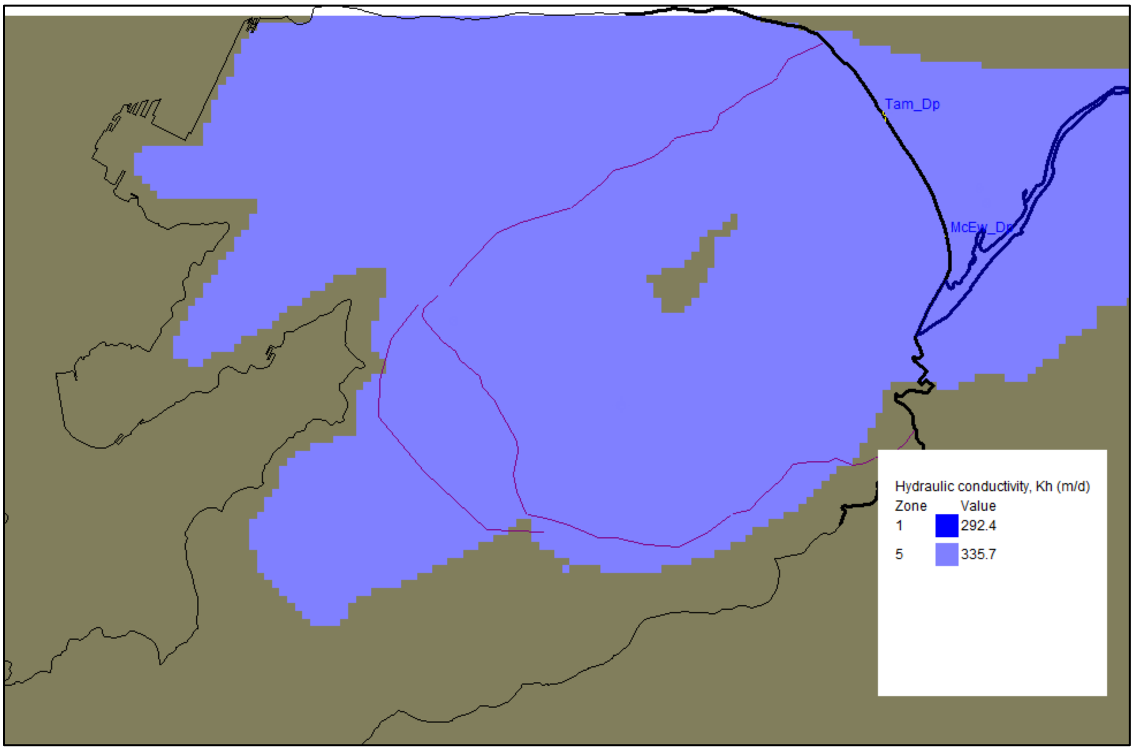


Figure 7.15 Hydraulic conductivity zones and Kh values for Layers 9 and 10– lower Waiwhetu gravels (Zone 5)

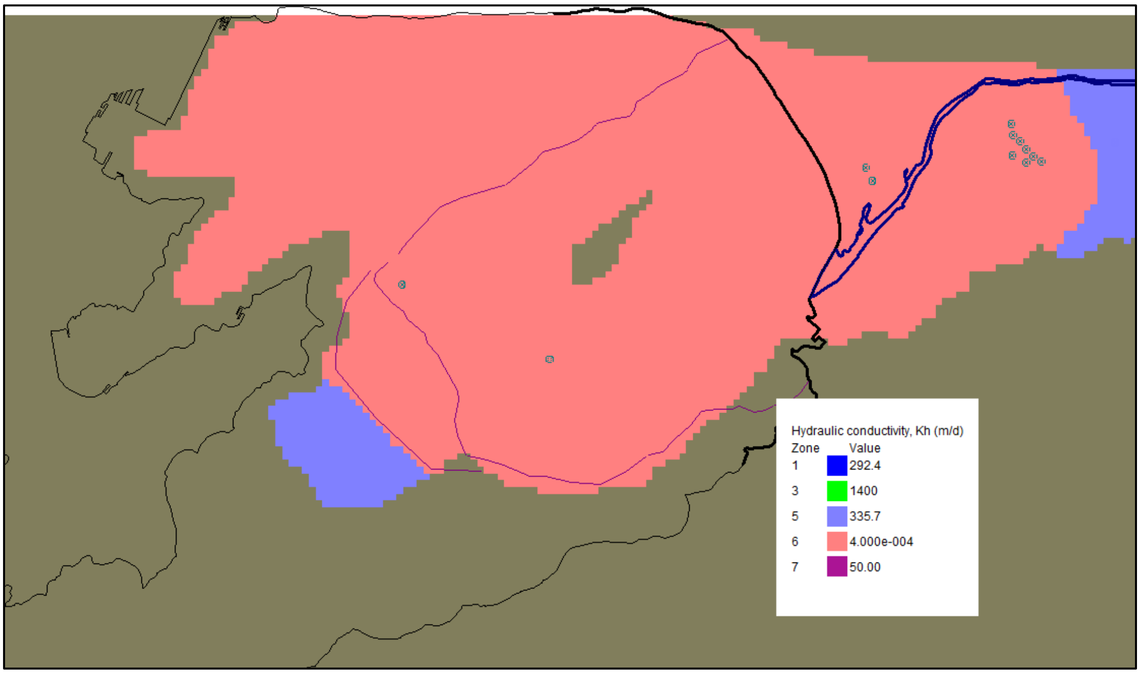


Figure 7.16 Hydraulic conductivity zones and Kh values for Layer 11 – Wilford Shell bed aquitard (zone 6) and lower Waiwhetu gravels (Zone 5)

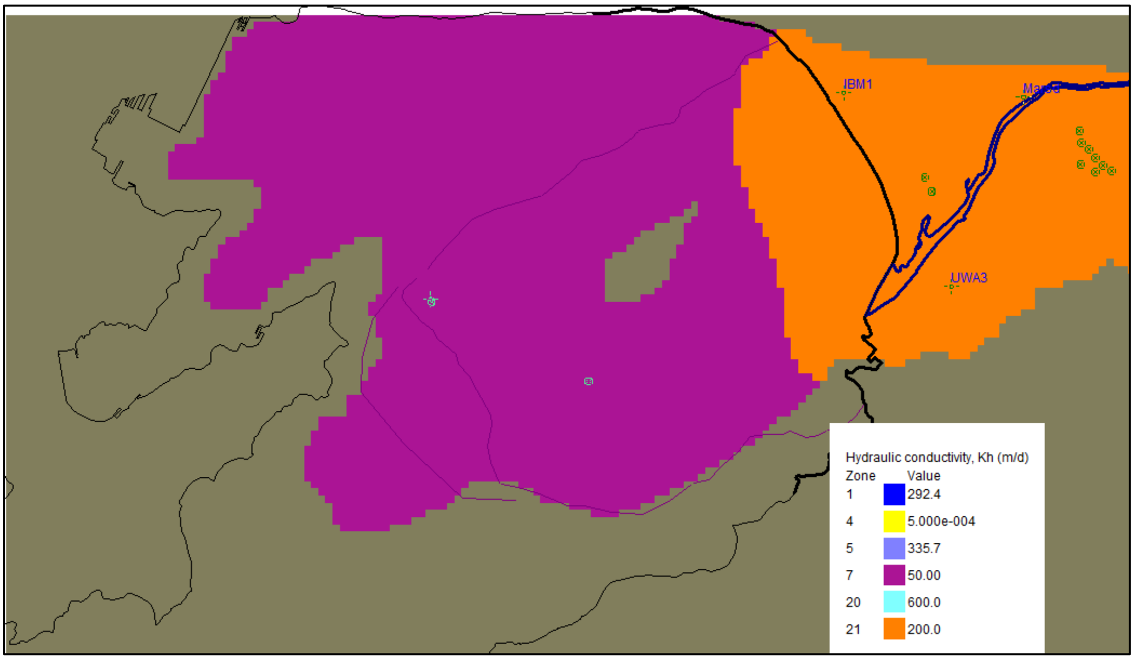


Figure 7.17 Hydraulic conductivity zones and Kh values for Layer 12 – Upper Moera gravels (zones 7 and 21)

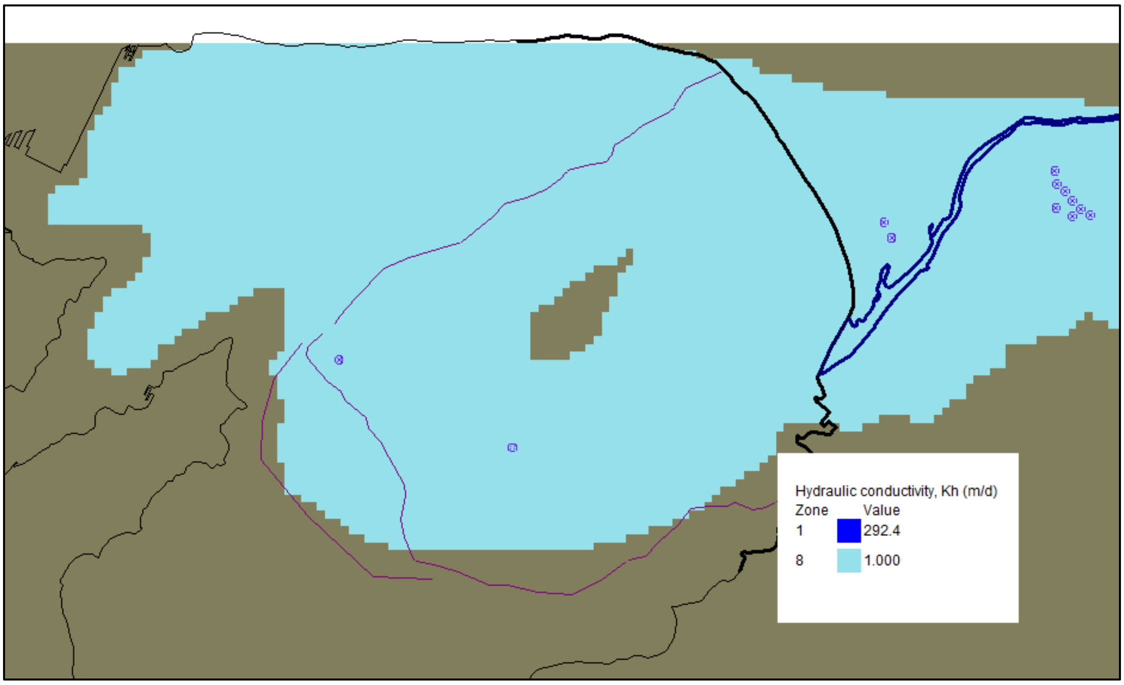


Figure 7.18 Hydraulic conductivity zones and Kh values for Layers 13 and 14 – Older basal sediments.

7.6.2 Storage and porosity

The storage parameters used in the offshore HAM4 remain the same as the calibrated values used in the HAM3 model (EIM 2014). MT3D also required the assignment of porosity for advective transport modelling. An effective porosity value of 0.2 has been used for all offshore layers – a value considered typical of alluvial sediments.

7.7 Model calibration

7.7.1 Calibration strategy (flow model)

The onshore part of the HAM4 model (and the previous HAM3 model) is categorised as an 'aquifer simulator' of high complexity (Middlemis 2001) which is required to have a Class 3 confidence level (Barnett et al. 2012) to meet its prediction-focused purpose. However, the offshore portion of HAM4 does not have the same confidence level (as it is heavily based upon geological conceptualisation with few observation points). It is therefore best to characterise the offshore HAM4 model as having a Class 1 or 2 relatively low confidence level associated with model predictions. It is nevertheless it is deemed appropriate for providing insights into key processes, salinity distributions, saline intrusion risks and exploring of potential 'fatal flows' in the proposal to abstract from the sub-harbour aquifer.

A calibration approach has been designed to provide conservative predictions through acknowledging the large degree of uncertainty (both in the conceptual model and aquifer parameterisation). Manual calibration of the HAM4 has been integrated with and restrained to some extent by the previous HAM3 calibration which was based upon a parameter optimisation and sensitivity analysis (using PEST – see EIM 2014 for details of the calibration process). A quantitative fit to monitored groundwater levels was used as an objective function for the parameter estimation algorithm. The calibration dataset consisted of 13 continuously recorded wells and 11 manually recorded wells (only one offshore – the Somes Island site). A correlation coefficient (R^2) of 0.99 for head data fits was achieved, with a root mean square error of 0.17m. A manual quantitative fit to monitored river flows and losses and spring flows was also used to constrain the calibration. Analysis of residuals indicated no systematic spatial or temporal bias was occurring in the model simulations.

Since the HAM4 model structure, boundary conditions and parameter assignments remain the same as the HAM3 simulation for the onshore part of the model (where over 90% of the calibration target data and prior knowledge information is located), it was considered that there would be no benefit in repeating the parameter optimisation process for HAM4. This is principally because the changes to the offshore part of the model are more of a refinement to the previous models, and because very little additional information exists with which to provide a greater calibration focus on the offshore aquifer (the only new calibration data is provided by the head information obtained from the E3 and E8 monitoring bores for single points in time).

However, it is acknowledged that significant predictive error can exist even when a head calibration appears to be perfect because the calibration datasets samples only a few aspects of the real world complex flow system. This leads to correlation issues in parameter assignments which propagate to predictive error. This can be minimised to a large extent by ensuring that the model is calibrated using conservative parameter values regarding the required model purpose and predictions (i.e. saline intrusion). This approach has been taken in the transient calibration of HAM4 which has been used as a basis for predicting the potential effects of offshore abstraction and identifying any obvious fatal flaws.

It is therefore recommended that the HAM4 model be subject to a formal model parameter and predictive uncertainty analysis to quantify the confidence limits of the predictions (see Chapter 9 for further discussion).

7.7.2 HAM4 transient model flow calibration

The HAM4 model calibration process has entailed the adjustment of independent variables (primarily hydraulic conductivity parameters) within realistic limits to produce the best match between simulated and measured data - groundwater levels and water balance components such as spring flows and measured river flow losses/gains). Only offshore aquifer parameters have been adjusted to attain a calibration – principally vertical hydraulic conductivities in the harbour entrance area since these control the pressurisation of the sub-harbour Waiwhetu aquifers (measured continuously at Somes Island with additional measurements available for exploration bores E3a and E8). As such, the calibration process in HAM4 is relatively simple and represents an ‘inverse approach’ to match observed data.

One difference between the HAM3 and HAM4 is assignment of the ocean boundary constant head condition. The HAM4 flow calibration model uses the equivalent freshwater head values shown in Figure 7.10.

Calibration period and stress period set up

The transient calibration model was set up using 5 years of data for the period 1/7/2007 to 27/6/2012. The relatively short time period was selected to ensure workable model run times for manual and automated calibration activities. The calibration period incorporates a wide range of climatic conditions and therefore represents a window of time in which there was a large range in system stresses. The transient groundwater models were run using a weekly stress period divided into 5 timesteps with a multiplier of 1.2. The 5-year calibration run therefore has 260 stress periods and a run duration of 1,820 days. The first stress period was set to run to steady state to provide a stable starting head condition for the run. The USGS PCG2 (Hill, 1990) solver was employed using a head change criterion of $1\text{x}10^{-6}$. The model is very stable and converges quickly -the 5-year simulation takes about 20 minutes to run.

Calibration targets

Calibration of HAM4 has used the same dataset as HAM3 for the 5-year period 2007 to 2012 (using the HAM3 calibration dataset). These are shown in Figure 5.4 and are distributed across the Lower Hutt Valley and principally located in the upper Waiwhetu Aquifer, Moera Aquifer and the unconfined aquifer zone in the north. The Somes Island observation bore is the only offshore site with a continuous level record. For the transient model calibration process, the continuous groundwater level monitoring data were averaged over 7 days. This has the effect of smoothing out the tidal variation – which, at the Petone foreshore in the Waiwhetu Aquifer, can be up to about 70% of the tidal range measured in the harbour, and at Somes Island, E3a and E8 the tidal variation indicates a 80-90% efficiency (see Appendix 3 Table A3.1). Head observation data measured at the E3a and E8 exploration bores, corrected for tidal effects, provided additional information to guide the offshore calibration for the upper Waiwhetu (E8), lower Waiwhetu (E8) and Moera aquifers (E3a).

An approximation of the offshore spring discharge of 1-2,000 m^3/day was also used to guide the amount of water released at the spring nodes.

Offshore hydraulic conductivity parameter adjustment

The HAM4 model was calibrated solely by adjusting the hydraulic conductivity parameters in critical units and reconfiguring the hydraulic conductivity zonation to provide consistency with the geological model. The onshore and some offshore parameter values remain the same as the HAM3 model. Critical sensitive parameters are the vertical hydraulic conductivity values in the harbour entrance area which control the artesian pressures in the main aquifer units beneath the harbour.

Transient calibration has adopted a conservative approach to the assignment of hydraulic conductivity to the upper Waiwhetu gravels. The lower end of the plausible range has been preferentially assigned in order to simulate higher aquifer drawdowns (and therefore increase the inducement of saline intrusion) during pumping simulations across the offshore aquifer.

The upper Waiwhetu gravels have also been zoned with progressively decreasing hydraulic conductivity from the shore to the southern extension of the fan beneath the harbour (see Figure 7.13). Although this aquifer was pump tested during exploration drilling, at E8 it was not possible to induce sufficient drawdown for analysis. Analysis of the Waterloo shut-down test data (see Table 5-6) provides a bulk or average transmissivity value which may not be representative of local aquifer conditions.

The hydraulic conductivity values assigned to the upper Waiwhetu aquifer were also subject to a sensitivity analysis and varied during scenario testing.

The lower Waiwhetu gravels retain their calibrated HAM3 onshore and offshore values whilst the Moera has been assigned a lower representative value commensurate with observations obtained from exploratory drilling.

The hydraulic conductivity values used to achieve calibration are contained in Table 7-2.

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Table 7-2 Calibrated offshore hydraulic conductivity values and comparison to HAM3 calibration. Refer to the stipulated figures for maps showing the locations of the zones (layer numbers refer to 'base model'). Kh = horizontal hydraulic conductivity; Kv = vertical hydraulic conductivity.

Layer	Figure No.	K zone	Kh m/d	Kv m/d	comments
1,2	-	22 (Ocean constant head)	1000	10	Nominally high values to ensure connectivity to underlying Holocene layers.
3	Figure 7.11	23 (Holocene at sea floor – coarse equivalent harbour entrance and eastern margin)	50	1	Sea floor layer, Z23 allows saline water into upper Holocene.
3+4	Figure 7.12	4 (Petone silts aquitard)	5x10^{-4}	1x10^{-5}	Main aquitard, low Kv conservatively promotes connectivity in to sea in harbour entrance.
3_4	Figure 7.12	12 (spring vent cells in aquitard)	1	0.1	Constrained Kv as these are not open holes, values restrained by estimated flow volumes derived from analysis of springs.
4	Figure 7.12	15 (Holocene – heads transition Falcon Shoals)	0.5	1x10^{-4}	Increased k values simulate transition to coarse grained deposits in harbour entrance areas
4	Figure 7.12	13 (Holocene – harbour heads area)	20	3x10^{-3}	Harbour entrance area deposits, high anisotropy, Kv regulates aquifer pressures upgradient. Model very sensitive to this parameter – sensitivity analysis undertakes (see Figure 7.20).
5	Figure 7.13	3 (Upper Waiwhetu gravels close to Petone shoreline)	1,400	0.11	Retain HAM3 calibrated values for the main aquifer.
5	Figure 7.13	20 (Upper Waiwhetu gravels – main offshore fan lobe, E8 located within)	600	0.1	Assign low end of plausible range based on testing and bore logs to provide conservative drawdown predictions. Sensitivity undertaken on this zone (see Figure 7.19).
5	Figure 7.13	15 (later merging of UWA with finer Q3 aquitard)	300	1	UWA is deposited on top of Q3
5	Figure 7.13	19 (Upper Waiwhetu gravels – thin lateral extension of deposits into Falcon Shoals and E3 areas)	0.5	1x10^{-4}	Outer zones of upper Waiwhetu gravel fan – much thinner deposit, distal reduction in Kh.
5, 6, 7,8	Figure 7.13,Figure 7.14, Figure 7.15Figure 7.16	5 (lower Waiwhetu gravels – appear where UWA fades out)	336	10	Kv values high to conservatively enhance vertical connectivity to shallow layers and ocean.
6	Figure 7.14	18 (Main Q3 aquitard)	1	1x10^{-3}	This unit was not included in HAM3, Kv's assigned on basis of lithological descriptions
6	Figure 7.14	24 (Eastern part o of Q3 aquitard where thinner and heterogeneous)	1	0.1	This unit was not included in HAM3, Kv's assigned on basis of lithological descriptions
6	Figure 7.14	15 (Port area Q3 aquitard and marginal colluvial deposits)	0.5	1x10^{-4}	K values set on basis of conceptual geology and drilling data
8	Figure 7.16	6 (Wilford Shell Bed aquitard)	4x10^{-4}	4x10^{-4}	
9	Figure 7.17	7 (offshore Moera aquifer)	50	1x10^{-4}	Assigned in basis of exploration drilling and geological model
9	Figure 7.17	21 (nearshore and terrestrial Moera aquifer)	200	5x10^{-3}	Remains the same as HAM3 calibration – appears better aquifer onshore.
10,11	Figure 7.18	8 (deeper Quaternary basin fill)	1	1x10^{-4}	Guided by conceptual model and deep onshore drilling.

Selected parameter and GHB boundary sensitivity analysis

In additional to the sensitivity analysis carried out on the HAM3 model (EIM, 2014) further analysis has been conducted on critical aquifer parameters in the offshore HAM4 and also upon the GHB boundary at the southern model extent. This was principally undertaken to ensure that the property values and boundaries are set to provide conservative predictive simulations.

Figure 7.19 shows a sensitivity analysis for hydraulic conductivity zone 20 – the main upper Waiwhetu gravel fan beneath the harbour within which E8 is located (Figure 7.13). The model was run in steady state for various combinations of Kh and Kv using average aquifer stresses and head were output at various points along a general transect between the Petone foreshore and the southern model boundary, through the harbour entrance. The recording points within the upper Waiwhetu gravels layer are: McEwan Park (1), Hutt mouth springs (2), Somes Island (3), E8 (4), E3a (5), Falcon Shoals (6), and Point Dorset (7). The sensitivity analysis was also conducted for a non-abstraction and abstraction conditions from the E8 site. Abstraction runs used a rate of 20MLD.

The model is clearly insensitive to the assigned Kh and Kv in this zone when there is no offshore abstraction occurring. Kv can be increased by two orders of magnitude without discernible effect on the calibrated head values. However, when abstraction occurs there is an inevitable difference in aquifer drawdown when hydraulic conductivity is varied. The model has been calibrated at the low end of a plausible range for the upper Waiwhetu gravels (red dashed line in Figure 7.19) to ensure conservative (i.e. maximised) potential aquifer drawdowns occur across the sub-harbour aquifer during predictive abstraction simulations.

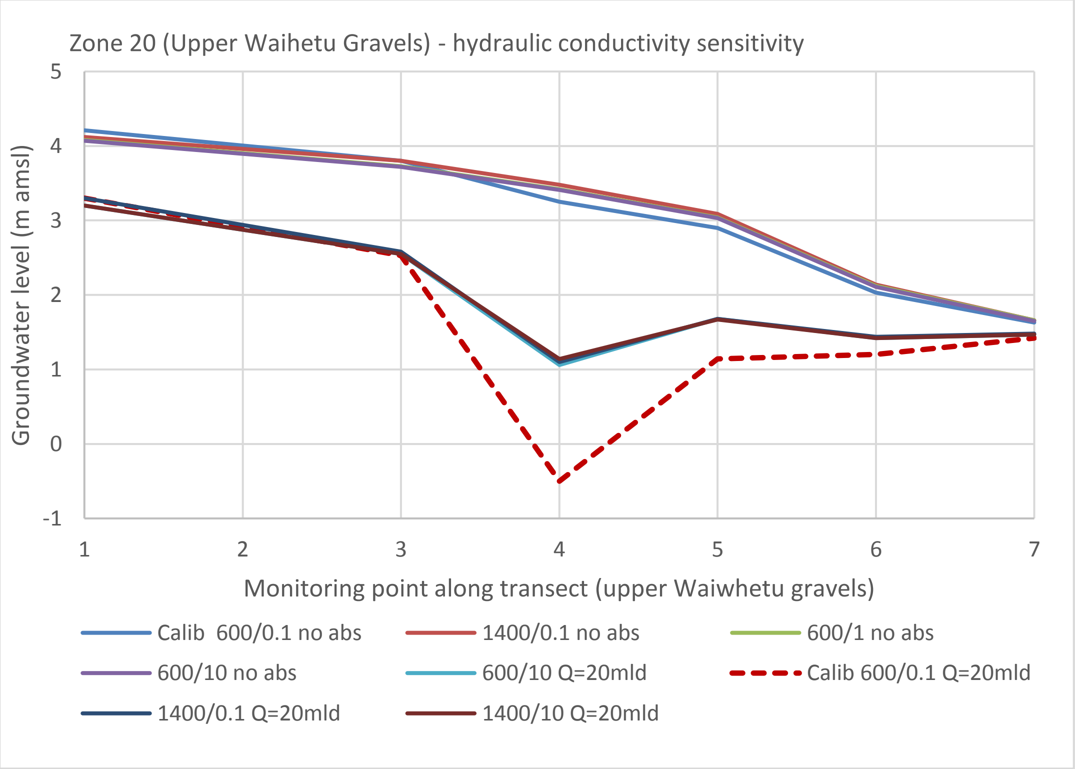

Figure 7.19 Sensitivity analysis for offshore upper Waiwhetu gravels hydraulic conductivity (zone 20) in HAM4 for sub harbour non-pumping and pumping scenarios (from E8). Plot shows simulated steady state heads along a transect from the Petone foreshore (point 1) , Hutt mouth springs (2), Somes Island (3), E8 (4), E3a (5), Falcon Shoals (6) and Point Dorset (7). Hydraulic conductivity values are in m/day, as kh value/kv value. Q = pumping rate from E8 site. No abs = no abstraction from E8. Abstraction rate from E8 = 20MLD.

Another sensitivity analysis was carried out on the lower Holocene gravels in the harbour entrance area – zone 13 (Figure 7.12). The same methodology as described for Zone 20 was used for the sensitivity analysis – except that no abstraction was simulated from E8. This analysis, shown in Figure 7.20, was undertaken to show the sensitivity of this parameter to small changes (particularly in Kv) – this being one of the main pressure 'valves' maintaining the offshore aquifer heads in the main part of the harbour. The aquifer pressures are also controlled by the hydraulic conductivity in the overlying Petone marine silts and spring discharge vents. The selected model calibration parameters promote a greater degree of hydraulic connectivity in the harbour entrance area – perceived to be one the principal risk areas for saline intrusion.

A further sensitivity analysis addresses the uncertainty around the southern general head boundary (GHB). Figure 7.21 shows that the model inland of the Point Dorset area (at the very southern end of the harbour heads area) is totally insensitive to the head assigned to the GHB under non-abstraction and abstraction conditions. It is evident that the boundary head used in the calibrated model (red dashed line) facilitates a small reversal of gradient in the southern harbour entrance areas – and will therefore allow backflow from the Cook Strait area into the heads (assuming the aquifer continues offshore – which is plausible). The GHB boundary is therefore considered to be set conservatively and allows for a small northward inflow from the boundary. It has no bearing however on model simulations and the calibration under the main part of the harbour

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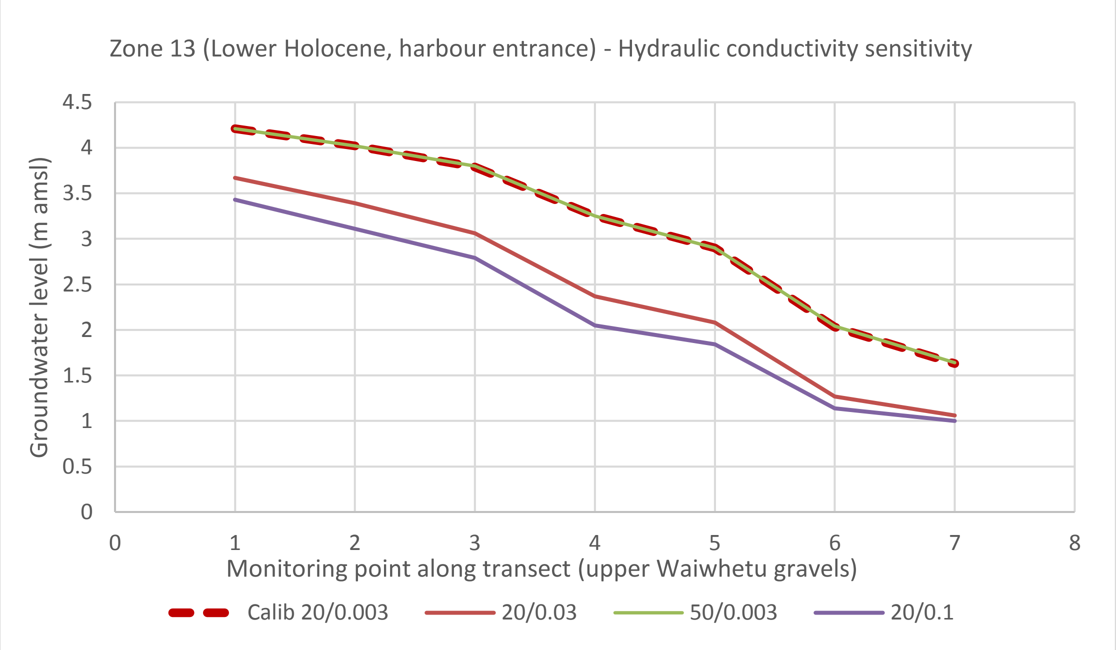

Figure 7.20 Sensitivity analysis for zone 13 (lower Holocene in harbour entrance) hydraulic conductivity. Plot shows simulated steady state heads along a transect from the Petone foreshore (point 1) , Hutt mouth springs (2), Somes Island (3), E8 (4), E3a (5), Falcon Shoals (6) and Point Dorset (7). Hydraulic conductivity values are in m/day, as kh value/kv value. Calibrated parameter values represented by the red dashed line.

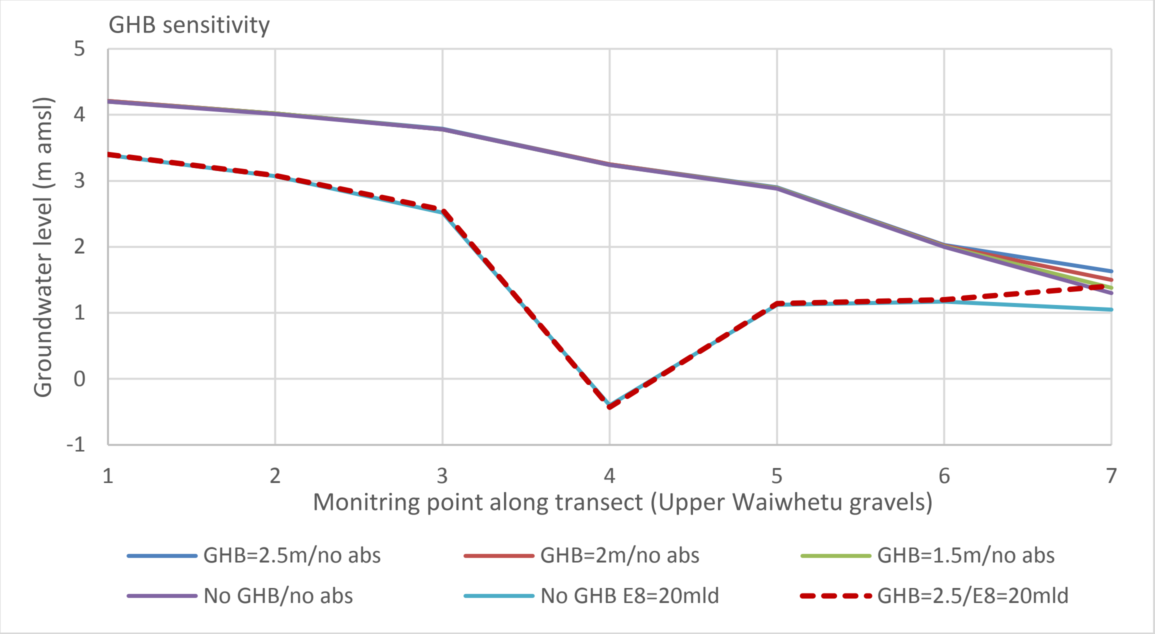

Figure 7.21 Sensitivity analysis for the general head condition (GHB) assigned to the southern model boundary. Plot shows simulated steady state heads along a transect from the Petone foreshore (point 1) , Hutt mouth springs (2), Somes Island (3), E8 (4), E3a (5), Falcon Shoals (6) and Point Dorset (7). GHB head values are indicated. Abstraction occurs from the E8 site at 20MLD. Calibrated model GHB condition shown by red dashed line.

Transient flow calibration results

Figure 7.22 shows the head calibration plots for selected bores along a transect down through the catchment, from Taita Intermediate in the northern terrestrial unconfined area, to Somes Island in the harbour. A good head calibration fit is achieved for all monitoring sites.

The simulated heads at the two exploration bore sites (E3a and E8) are shown in Figure 7.23. The head measurements at the bore sites were made over a short period (a day or so) during September 2017 (E3a) and January 2018 (E8). The tidally corrected head ranges for E8 (upper Waiwhetu) and E3a (upper Waiwhetu and Moera aquifers) are shown in the calibration plots to ensure that the model calibration is consistent with the observations at these sites. Precise head matching has not been attempted due to various influences which could affect the observation (i.e. error margins inherent in the tidal corrections, surveying, and levels affected by remnant influences of abstraction or recovery from pump shut down at Waterloo). The match at the E8 site for the upper Waiwhetu gravels is good, as is the Moera aquifer at E3a. The model is simulating a slightly lower level for the UWA at E3a than observed – the E3a level was measured in winter - the simulated winter levels are about 0.2 – 0.6m lower however. This could be explained by the effects of the Waterloo Wellfield shutdown influencing the observed heads, or simply the error margin in the observation readings, survey datum and tidal correction processes. It is expected that E3a has a lower head than E8 since it is across and down gradient – as shown by the calibration outputs.

Figure 7.24 is an overplot of HAM4 monitoring points in the harbour showing the levels in the upper Waiwhetu aquifer (UWA) and the lower Waiwhetu aquifer (LWA). At all sites, the lower Waiwhetu aquifer shows a slightly lower groundwater level than the upper Waiwhetu at the same location (about 0.1-0.2m). This is also observed in the field at E8. This is possibly because in the conceptualisation the lower Waiwhetu aquifer has a more enhanced connection to the ocean in the harbour entrance area.

Figure 7.25 and Figure 7.26 show the offshore simulated head distribution in the upper Waiwhetu gravels for two different periods – for an average stress period in November (Figure 7.25) and for a dry summer period in March (Figure 7.26). The flow vectors are also shown on these maps –

highlighting the main offshore flow pathway to the east of Somes Island and a reversal of flow from the southern GHB boundary (which will supply saline water into the southern harbour heads area, see also Figure 7.29). The head contours show the marked flattening of the hydraulic gradient downstream of the Waterloo wellfield abstraction, in the main harbour area, but a steepening of the gradient again through the harbour heads as the flow system become restricted towards the discharge areas.

The simulated water balances are shown in Figure 7.27 to Figure 7.29. These provide an insight to the distribution of groundwater discharge into the harbour. A relatively minor proportion is discharged via the submarine springs at a rate - higher discharges from the springs would depressurise the aquifer and drop the heads at Somes Island and the exploration bore sites. Most of the groundwater discharge in the summer period is simulated to occur in the harbour entrance area – reflecting enhanced connectivity to the ocean in this area.

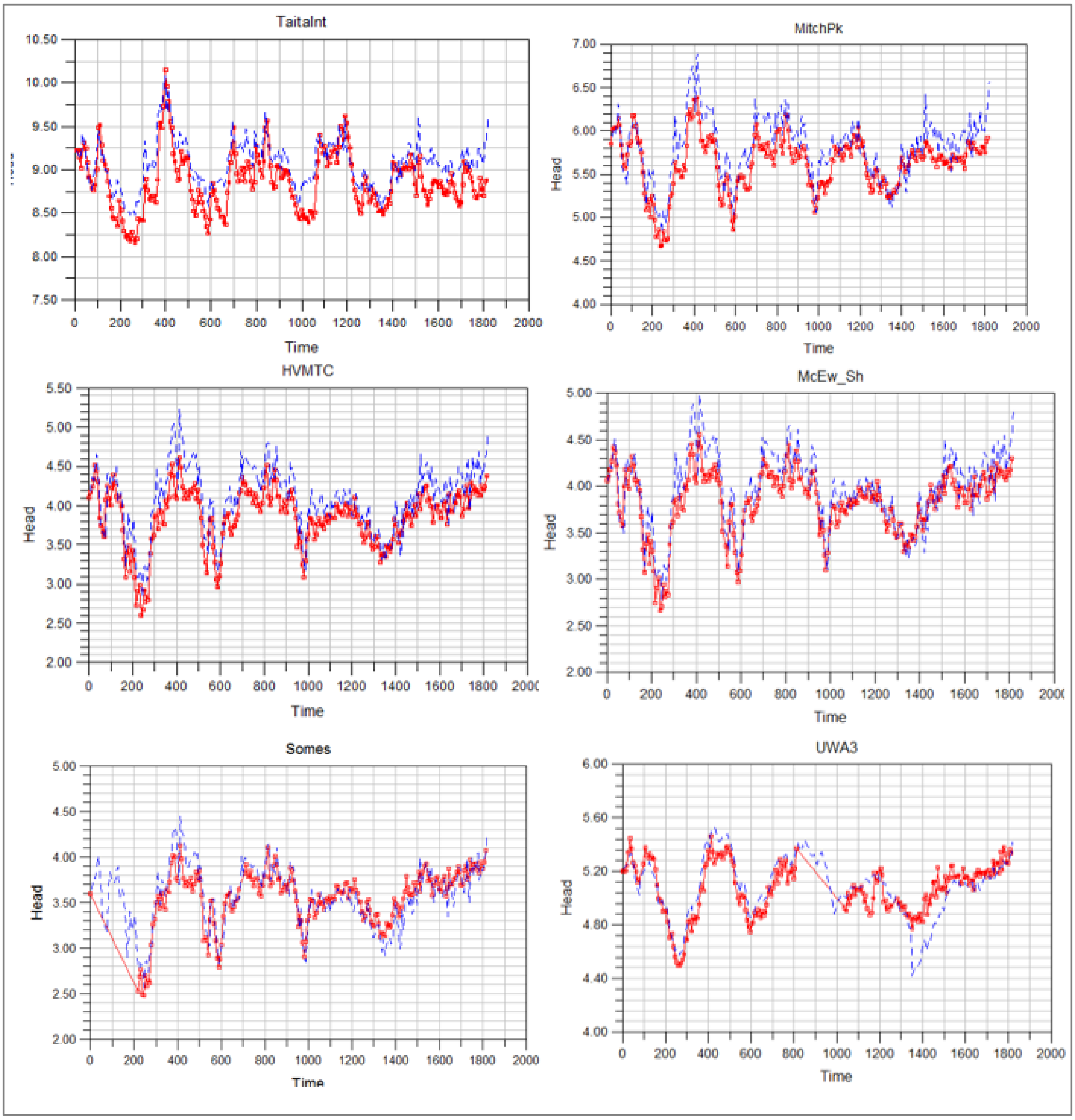

Figure 7.22 HAM4 transient head calibration for a selection of monitoring sites along a transect down through the aquifer system from Taita Gorge (unconfined aquifer) to Somes Island in the harbour. All sites represent to upper Waiwhetu gravels, except UWA3 (Moera aquifer). Head is in metres above mean sea level. Time axis is in days and ranges from 2007 – 2012. Observed measurements are in red, modelled data is in blue.

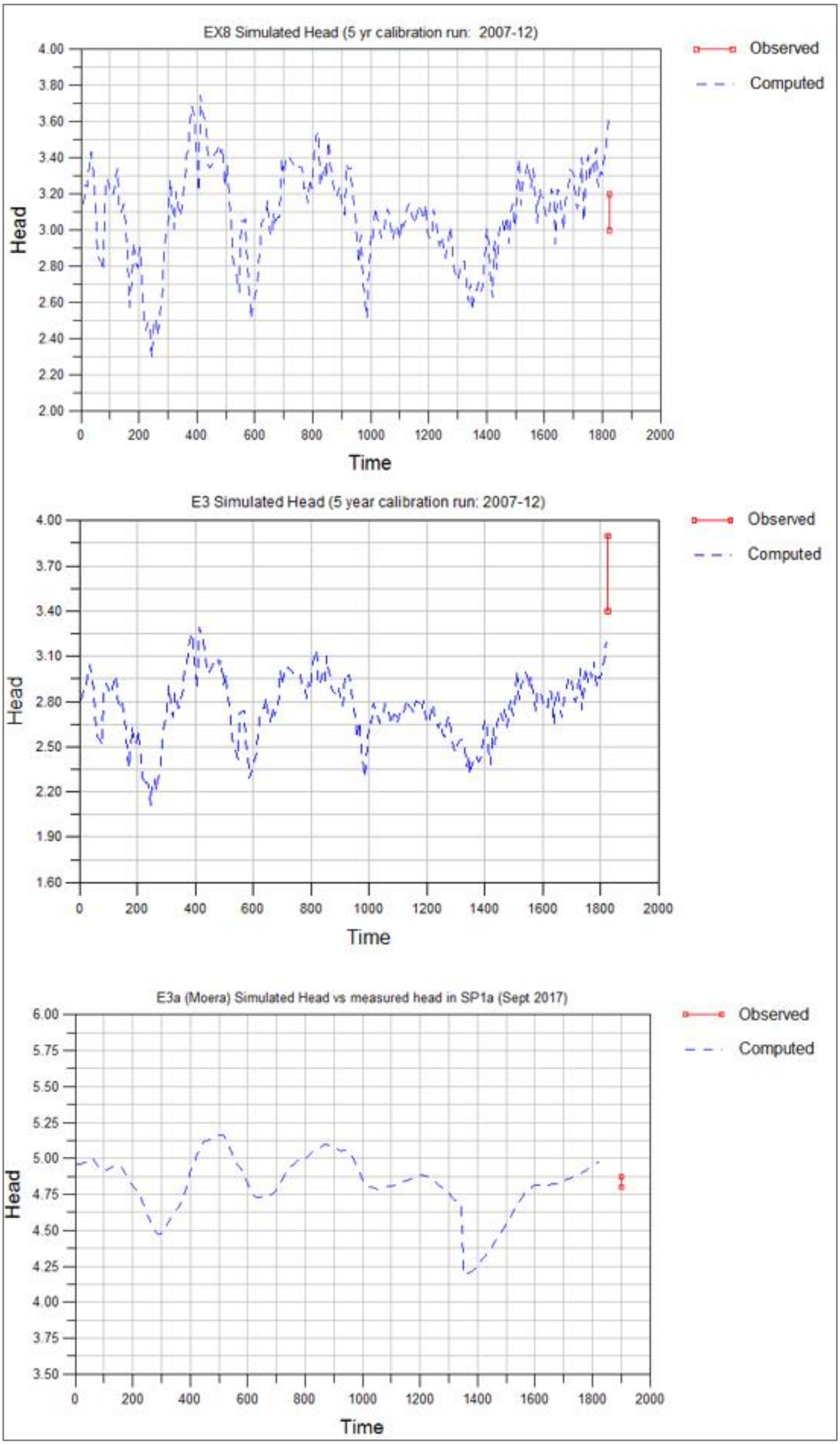

Figure 7.23 Simulated heads at exploratory bore sites E8 (top plot: upper Waiwhetu gravels) and E3a (middle plot: upper Waiwhetu; bottom plot: Moera aquifer).

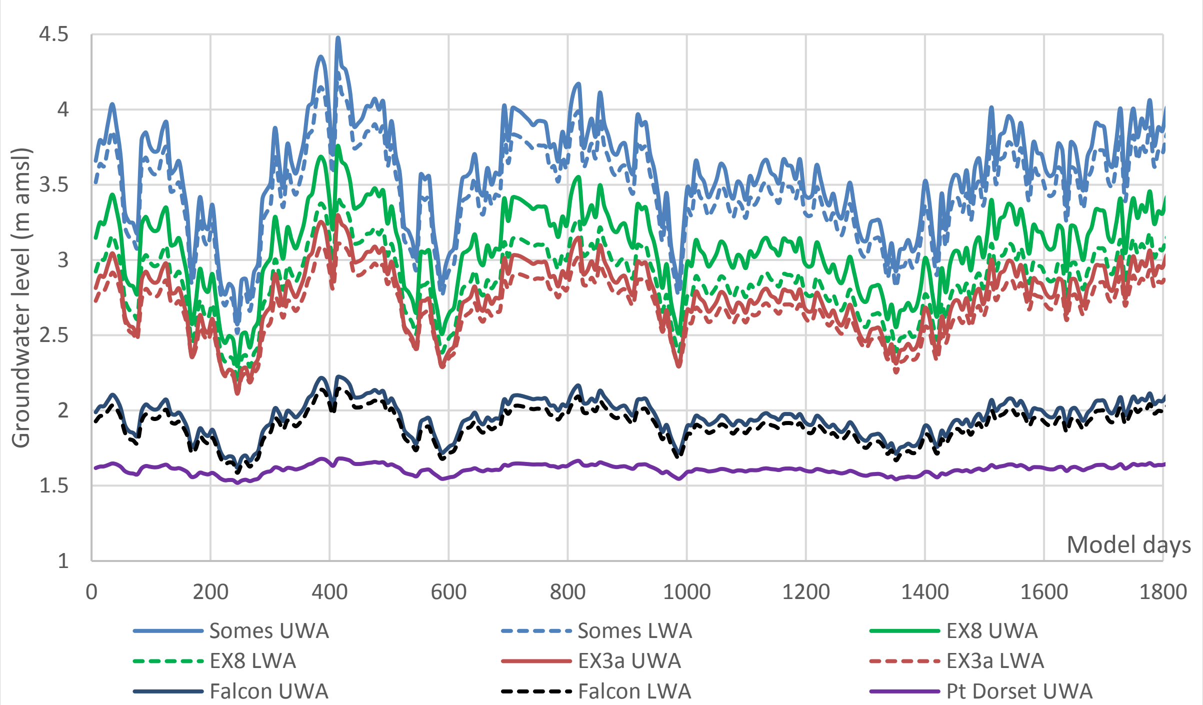

Figure 7.24 Overplot of hydrographs for harbour monitoring sites in HAM4 for calibration period 2002-2007. LWA = lower Waiwhetu Aquifer; UWA = upper Waiwhetu Aquifer. There is no LWA at Pt Dorset.

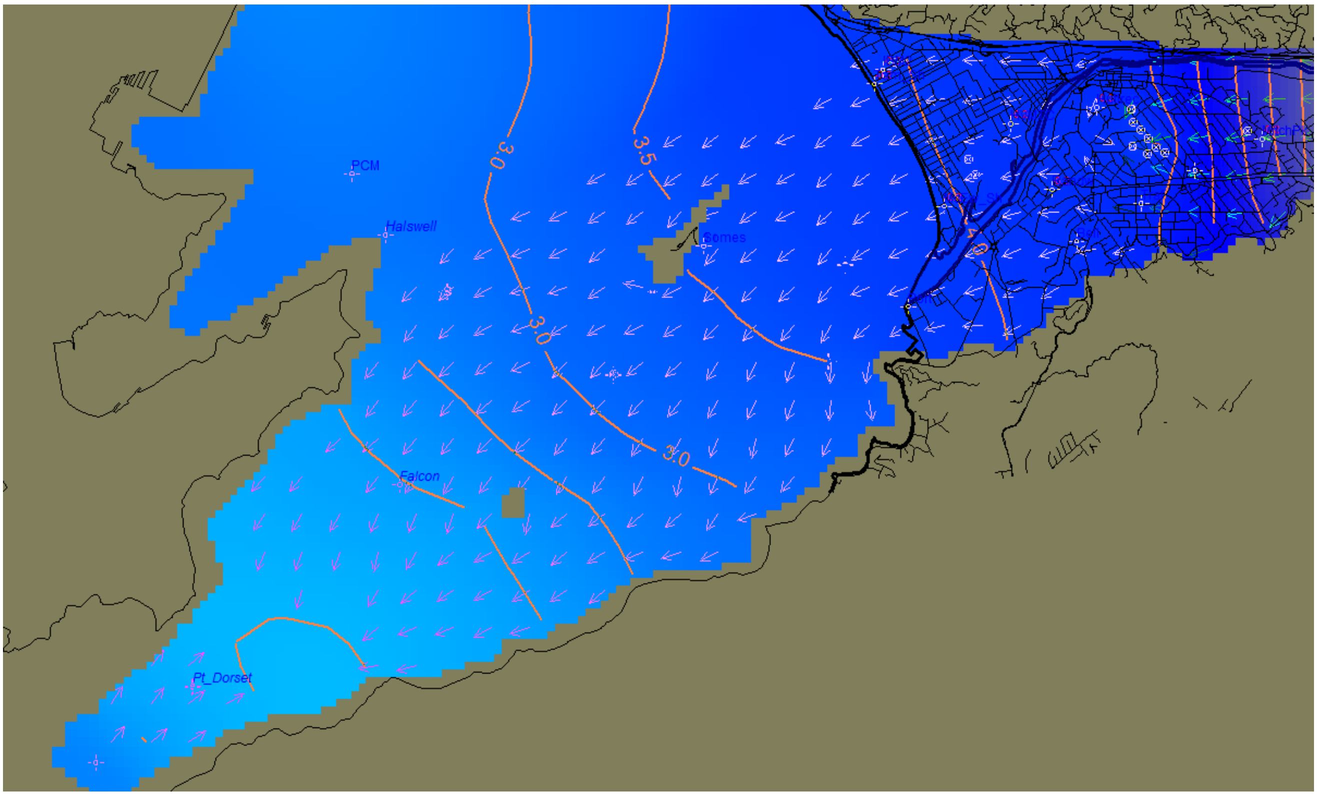

Figure 7.25 Simulated groundwater heads for the upper Waiwhetu gravels – Layer 5 (model time SP229, 1603 days = Nov 2011). Waterloo pumping at 64MLD. Ground level contours in m amsl at 0.5m intervals. Flow vectors are also shown.

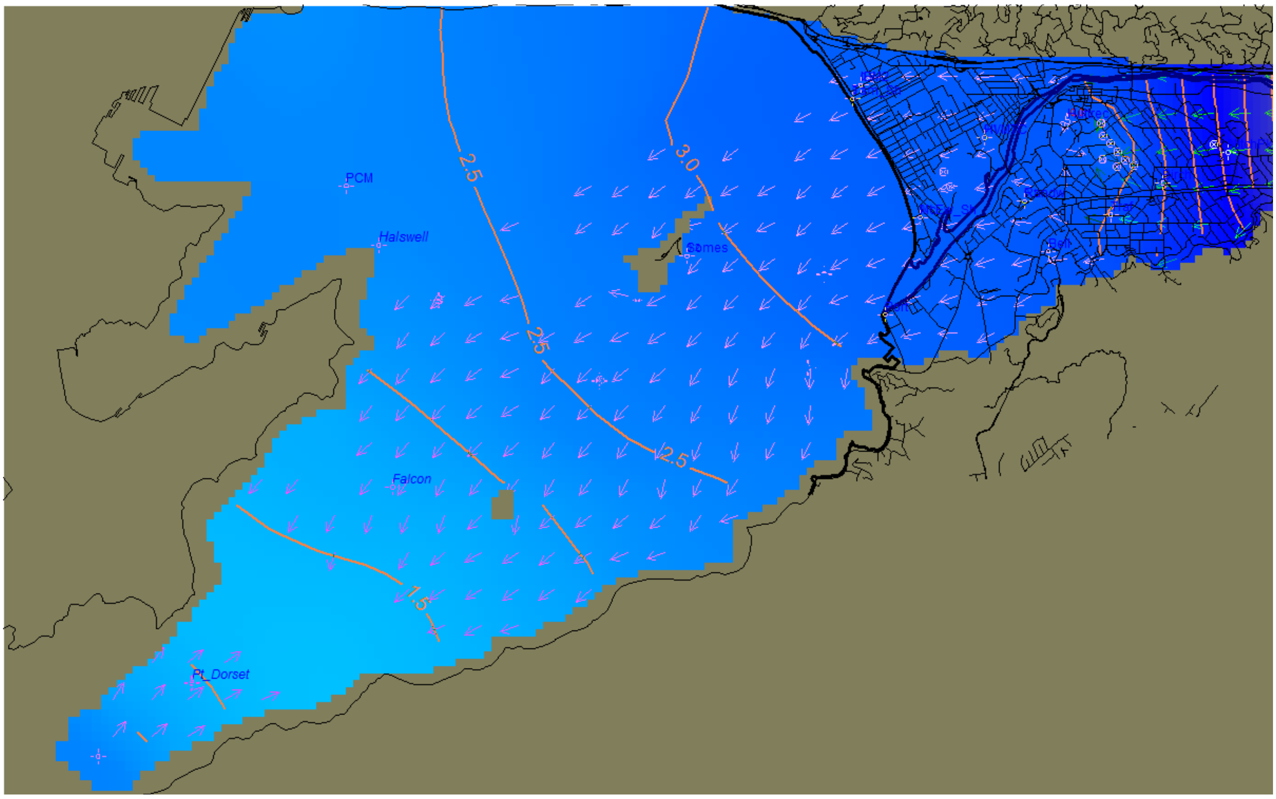

Figure 7.26 Simulated groundwater heads for the upper Waiwhetu gravels – Layer 5 (model time SP193, 1351 days = March 2011). Waterloo pumping at 75MLD. Ground level contours in m amsl at 0.5m intervals. Flow vectors are also shown.

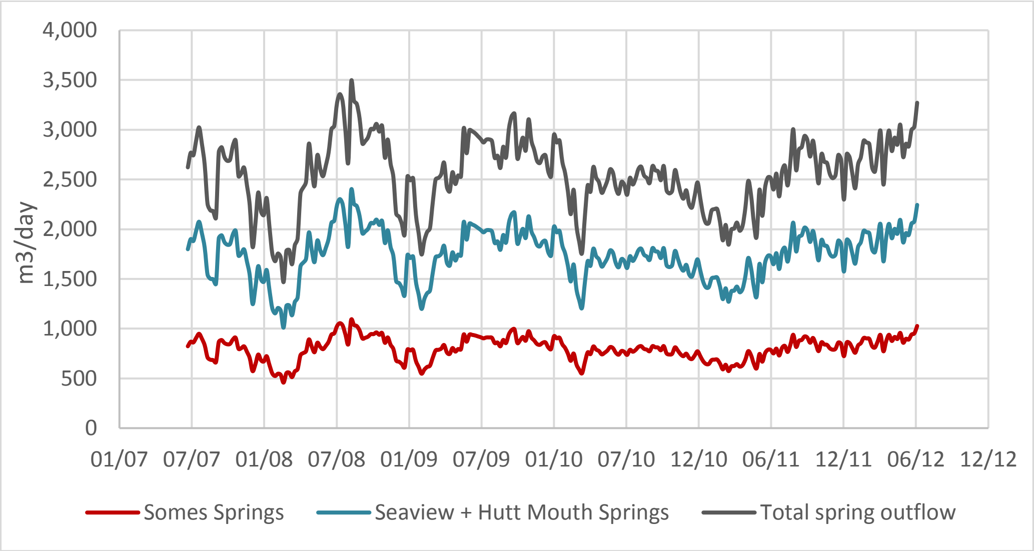

Figure 7.27 Simulated submarine spring discharge – for Somes Island spring, Seaview + Hutt mouth springs, and total spring discharge.

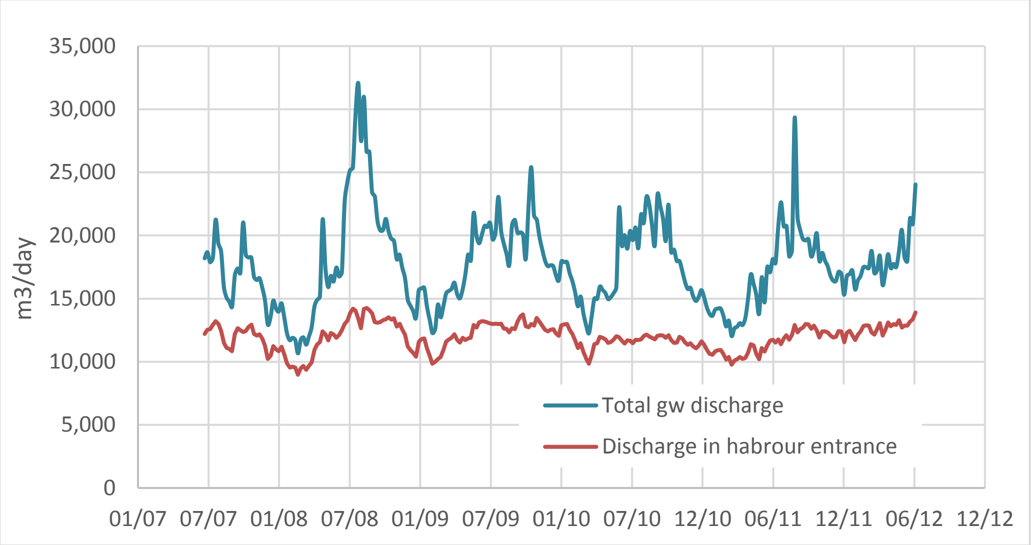

Figure 7.28 Simulated total groundwater leakage into Wellington Harbour, and discharge only in the harbour entrance area over the 5-year transient calibration model run (2007-2012).

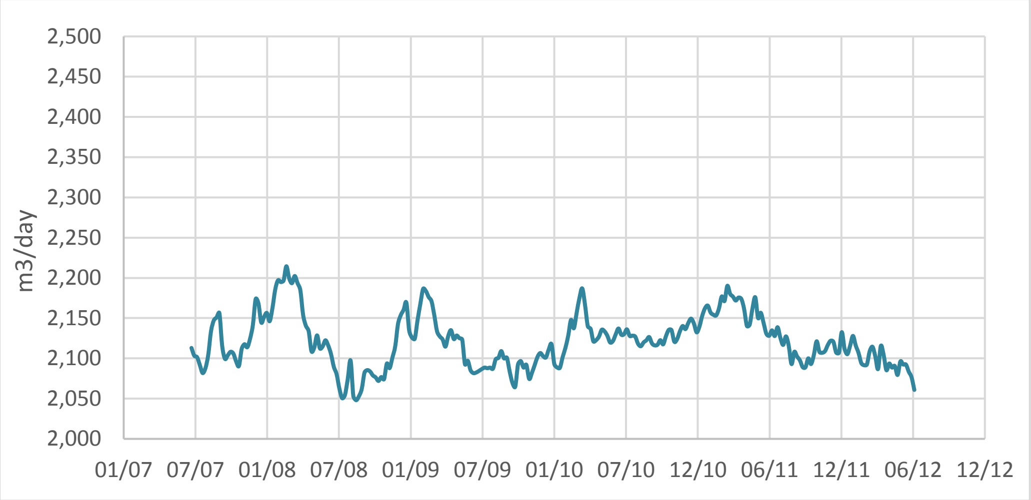

Figure 7.29 Simulated input from the general head boundary (GHB assigned to the southern harbour margin).

7.7.3 Note on calibration to concentrations using SEAWAT

The SEAWAT model has been calibrated to the salinity concentrations observed in the offshore bores in the upper Waiwhetu (E3a, E8 and Somes Island). This process was undertaken during the establishment of the equilibrium aquifer conditions and is described in Section 7.10.5.

However, due to the run times and Seawat model stability limitations encountered during the equilibrium modelling it was not possible to introduce heterogeneity using the transport parameters, or perform a thorough contaminant transport sensitivity analysis.

It was not possible to simultaneously calibrate to the observed salinity concentration in the lower Waiwhetu Aquifer (850mg/L Cl) – although it was evident that the higher salinity concentrations could be replicated for both the upper and lower Waiwhetu aquifers through manipulation of aquifer dispersivity parameters – the model is highly sensitive to these parameters and given the very flat offshore flow gradients, very small changes in aquifer parameters could result in significant differences in saline water mixing. This suggests that there is probably significant vertical and horizontal heterogeneity in the dispersive and diffusive properties of the formations – and that the higher salinity observed in the lower Waiwhetu Aquifer is probably a result of dispersive processes from a saline water body downgradient. Limitations in the modelling (such as extremely long model run times) prevented exploration of exploring such heterogeneity – however this may be explored by a further model calibration and uncertainty analysis (see Chapter 9).

7.8 SEAWAT modelling

7.8.1 Modelling strategy

The calibrated Modflow model was converted to SEAWAT 2000 – which combines Modflow 2000 with the USGS solute transport code MT3DMS.

Preparation for running offshore abstraction scenarios using SEAWAT has required a two-stage process:

- **Preparation run 1 (Equilibrium simulation):** the model was run under constant and average aquifer stress condition for a long period of time (1,000 years) to obtain naturalised (i.e. a natural non-pumped state) equilibrium or steady state heads and concentrations. During this run some calibration adjustments were made (entailing running the model for an additional 400 years) to ensure the model simulated the observed salinity concentrations in the UWA.
- **Preparation run 2 (Stabilised abstraction effects):** since abstraction has strongly influenced the hydrodynamics of the aquifer system for about 50 years, the model was run (using the output from the equilibrium simulation as starting conditions) to provide a stable starting head and concentration pumping-affected starting condition. This model used average stress conditions and a long term average Waterloo pumping rate of 40MLD.

The head and concentration conditions provided by preparation run 2 were used in subsequent 1-year duration abstraction and sensitivity scenarios. Since it was not possible to calibrate the model to the observed brackish concentrations in the LWA (in E8), the scenarios also use an artificial (or ‘forced’) initial concentration in the LWA to replicate field observations, as described below.

7.8.2 MT3D settings and accuracy checks

MT3D has been used to simulate advective, dispersion and diffusion solute transport processes as part of the SEAWAT simulation.

Constant concentrations were set in the ocean layer (1 and 2) using a value of 35 kg/m^3 (i.e. 35 parts per thousand, ppt) to represent the salinity of seawater. A constant concentration of the same amount was also set on the southern GHB boundary and on the spring GHB boundaries.

Time-stepping for the flow (Modflow) model was generally set according to the simulation length – varying from about 1 day to 1 year under constant stress conditions. The transport timestep was generally set either the same or lower than the flow model timestep and designed to balance reasonable model run times with solute mass balance accuracy. A sensitivity analysis was performed to check if there any significant differences between timestep lengths but generally MT3D would terminate if the timestep length was too large. The length of the time stepping was resolved on a trial and error basis by comparing different lengths and checking the solute mass balance errors (.mas output file).

The implicit finite difference (FD) solver was used for all simulations as it is numerically stable in HAM4 (the HAM4 flow simulation being relatively linear and numerically stable) and allows SEAWAT to take longer timesteps without resulting in significant numerical dispersion. It also allows for reasonable run times (the 1-year simulations take about 40 minutes to run using the FD solver). The alternative total variation-diminishing (TVD) solver is often cited as providing more accurate solutions, but forces very short timesteps resulting in exceedingly long run times (c. 10 hours for a 1-year solution). Testing of the TVD solver for a 1 year run produced high numerical dispersion and some erratic concentrations in monitoring bores – unlike the finite difference solver. The finite difference solver has therefore been used for all SEAWAT simulations.

7.8.3 Dispersion and diffusion

MT3D was initially run using a dispersivity of 20m (longitudinal), 2m (transverse) and 1m (vertical). These are typically acceptable values employed for this kind of aquifer system. The longitudinal dispersivity was subsequently adjusted down to 10m in order to simulate observed salinity concentrations in the UWA – the ambient salinity in the UWA is highly sensitive to dispersivity.

The diffusion coefficient was set at a value of 1E-4 and subsequently reduced to 1E-5 during the calibration process.

7.8.4 SEAWAT settings

An important consideration in the design of the variable-density groundwater flow model is the assignment of an appropriate grid resolution, particularly in the horizontal direction (Langevin et al, 2007). The resolution in the vertical direction often requires a greater detail to represent complex flow patterns near areas of high concentration gradient. This is probably more important for local scale models and where a high degree of accuracy is required. The principal layers were subdivided – so that the Petone Marine silts, upper Waiwhetu gravels, Q2 aquitard and lower Waiwhetu gravels are each represented by two layers.

General SEAWAT settings:

- Implicitly coupled flow and transport mode
- Reference fluid density (DENSREF) = 1,000 kg/m^3
- Maximum fluid density of seawater (DENSEMAX) = 1,025 kg/m^3
- Density concentration slope (DENSESLP) = 0.7143
- Concentration of pure seawater: 35 kg/m^3
- Fractional increase in density between seawater and freshwater: 0.025

7.8.5 Preparation Run 1: Baseline equilibrium simulation and calibration

It is considered important to run the SEAWAT model with constant hydrologic stresses until heads and concentrations do not change with time – at which point the model has essentially come to a steady sate with respect to flow and transport. This can be tested using the total solute mass balance for the model (.mas output file).

An important reason for simulating equilibrium conditions is to provide a stable salinity distribution in the offshore aquifers and aquitards for subsequent scenario modelling. The HAM4 (SEAWAT) model was run for 1,000 years under constant hydrologic stresses and without any abstraction.

Other setup conditions for the 1,000-year equilibrium run are as follows:

- A single stress period from the transient calibration run was chosen to represent average recharge conditions – this was stress period 109 (see Figure 7.30).
- Initial concentrations: zero

- Constant head ocean level: 0.55 (Seawat 2000 will convert to equivalent freshwater head)
- Southern boundary GHB head: 2.5 m amsl
- Stress periods: 1 (SP109) – constant stresses
- No abstraction
- Run duration: 365,000 days, 500 time steps (730 day duration steps)
- MT3D time step: 150 days

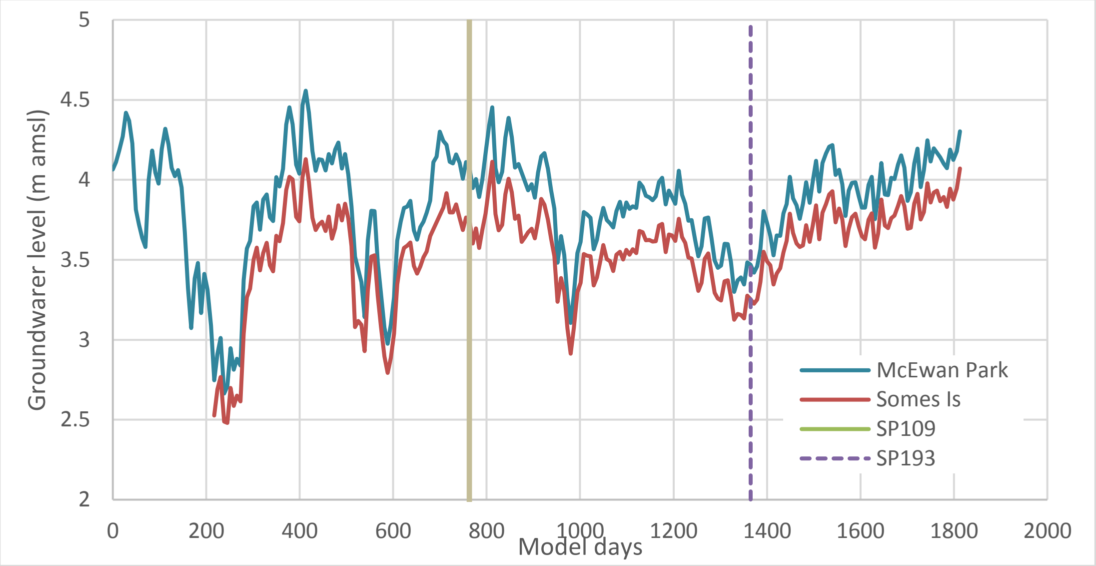

Figure 7.30 Selected stress periods used in SEAWAT scenario modelling in relation to groundwater level monitoring at McEwan Park and Somes Island – SP109 (Stress Period 109 - average condition) and SP193 (typical dry summer condition). Periods of very low groundwater levels coincide with exceptionally high pumping from Waterloo.

Figure 7.31 shows the salinity trend at the E8 bore during the 1,000 year equilibrium model run. An equilibrium salinity concentration condition was reached after around 400 years (150,000 days) at about 0.4 kg/m^3 (about 1% seawater - equivalent to about 220mg/L Cl[6]). This is higher than observed at E8 (about 0.16, or 75mg/L Cl). The simulated salinity concentration at the E3 site was 0.55 kg/mg (c. 300mg/L Cl) - again higher than the observed value of 0.23 kg/m^3 (125mg/L Cl). The modelled salinity in the LWA is about the same as the UWA, therefore substantially lower than the 850mg/L observed. The modelled salinity 0f about 50mg/L Cl in the UWA at the Petone foreshore was also about double that observed – indicating that the assigned dispersivity (and diffusion) values were set too high.

In order to calibrate the UWA to observed salinity concentrations at E3 and E8, the longitudinal dispersivity was reduced from 20m to 10m. The diffusion coefficient was also reduced from 1E-4 to 1E-5. The model was then run for a further 400 years from the end of the 1,000 year run – this duration was previously observed to be sufficient to attain equilibrium (‘steady state’) concentration conditions. The results of this model run are shown in Figure 7.32 to Figure 7.34

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[6] Note: Convert salinity (kg/m3, or parts per thousand - ppt) to mg/L chloride by dividing salinity ppt by 0.0018. Seawater salinity = 35ppt = 19,400ppm Cl.

Figure 7.33 shows the stabilisation of salinity concentrations during the 400-year calibration simulation at about 0.17 kg/m^3 (94mg/L Cl) at E8 in the UWA. This is close to the observed UWA chloride concentration of 75mg/L. At E3a the simulated salinity at the end of the calibration run was 0.23kg/m^3 (128mg/L Cl) – close to the observed value of 125mg/L Cl. At Somes Island the simulated chloride was 55 mg/L (observed c. 30 mg/L). Again, the simulated salinity in the LWA at E8 was about the same as the UWA – was not possible to simultaneously calibrate to the observed salinity concentration in the LWA (850mg/L Cl) for the reasons described in 7.7.3 .

Figure 7.33 and Figure 7.34 display the salinity distribution at 1,400 years (end of 1,000 year and 400year calibration runs) in Layer 5 (top of the UWA) and Layer 4 (base of Holocene) repectively. The outputs show a low salinity area over higher permeability upper Waiwhetu gravels. Near the Petone foreshore the salinity concentration is simulated at about 0.04 kg/m^3 (22mg/L Cl) – similar to that observed in the coastal monitoring sites.

The plots indicate tue presence of a diffuse saline interface in the Falcon Shoals area. This is caused by a combination of saline influx from the southern GHB boundary and downwards migration from the seafloor. The 'S' shaped form of the interface is controlled by the geology in this area – particularly the Ward Island shallows where the aquifer units shallow. Saline intrusion is also evident along the Eastbourne coastline shallows and in the Oriental Bay area where the aquifer is shallow and less confined. It is interesting to note that the general location and width of the interface does not significantly change when the longitudinal dispersivity is reduced from 20m to 10m (during the 400-year calibration run), and diffusion coefficient reduce from 1E-4 to 1E-3

The results of the equilibrium run provide evidence that it is possible to generate the observed salinity in the UWA from an ocean source via dispersion-diffusion process over time. It is plausible that the highly brackish water observed in the lower Waiwhetu Aquifer at E8 (850-900mg/L Cl; 4.5% seawater) represents the tip of a diffuse saline mixing zone. The high salinity concentrations could easily be explained by aquifer heterogeneity resulting in preferential enhanced dispersion/diffusion along the LWA horizon from the harbour entrance area. The brackish water and the overlying fresh water in the upper Waiwhetu aquifer could also exist in a state of fragile equilibrium where there is no intervening aquitard.

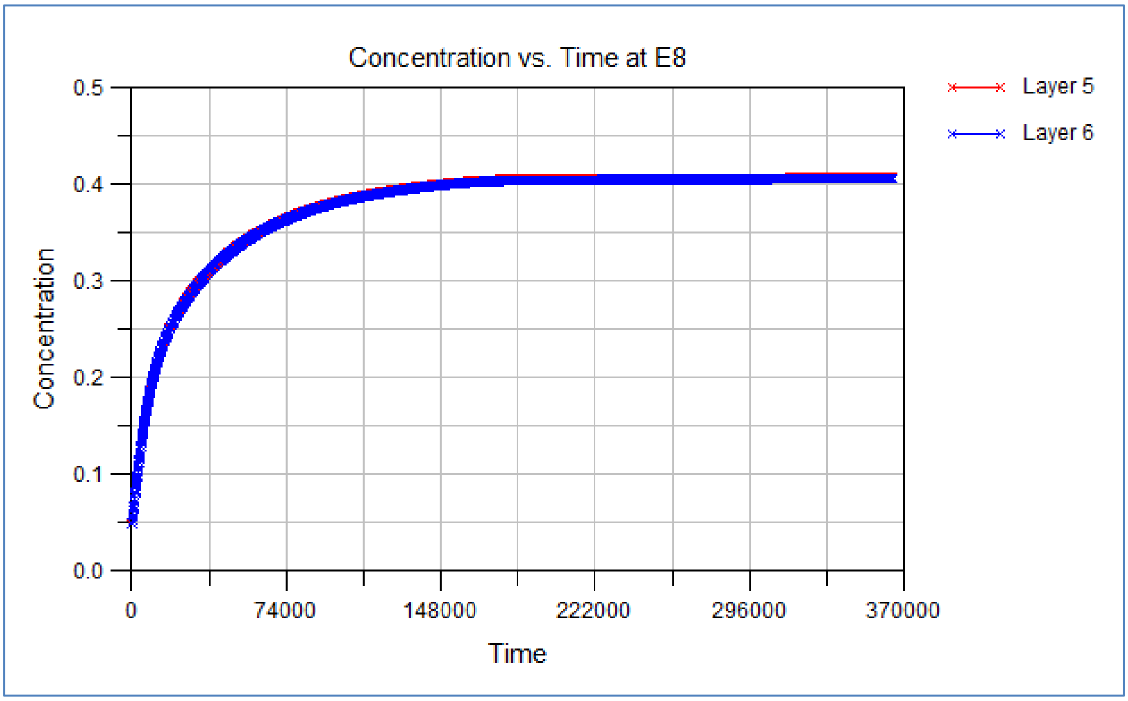

Figure 7.31 Simulated salinity concentration (salinity, kg/m3) at Bore E8 (no abstraction) in upper Waiwhetu Aquifer (layers 5 and 6) during the 1,000 year equilibrium model run – showing the attainment of steady state concentrations to provide a background level of 0.4 kg/m3 (equivalent to about 220mg/L chloride). Longitudinal dispersivity = 20m; diffusion coefficient = 1E-4.

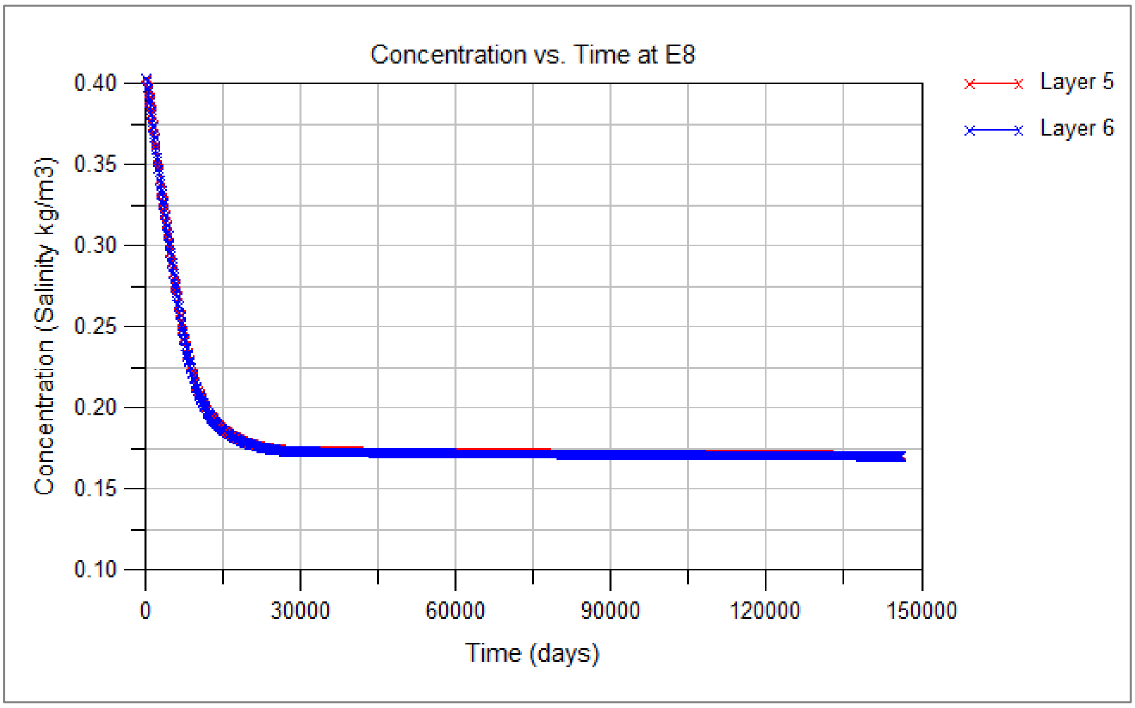

Figure 7.32 Simulated salinity concentration (salinity, kg/m3) at Bore E8 (no abstraction) in upper Waiwhetu Aquifer (layers 5 and 6) during a 400 year additional equilibrium model run (from end of the 1,000 year equilibrium run) using a revised longitudinal dispersivity of 10m and diffusion coefficient of 1E-5 – showing the rapid attainment of steady state concentrations to provide a background level of 0.17 kg/m3 (equivalent to about 95mg/L chloride).

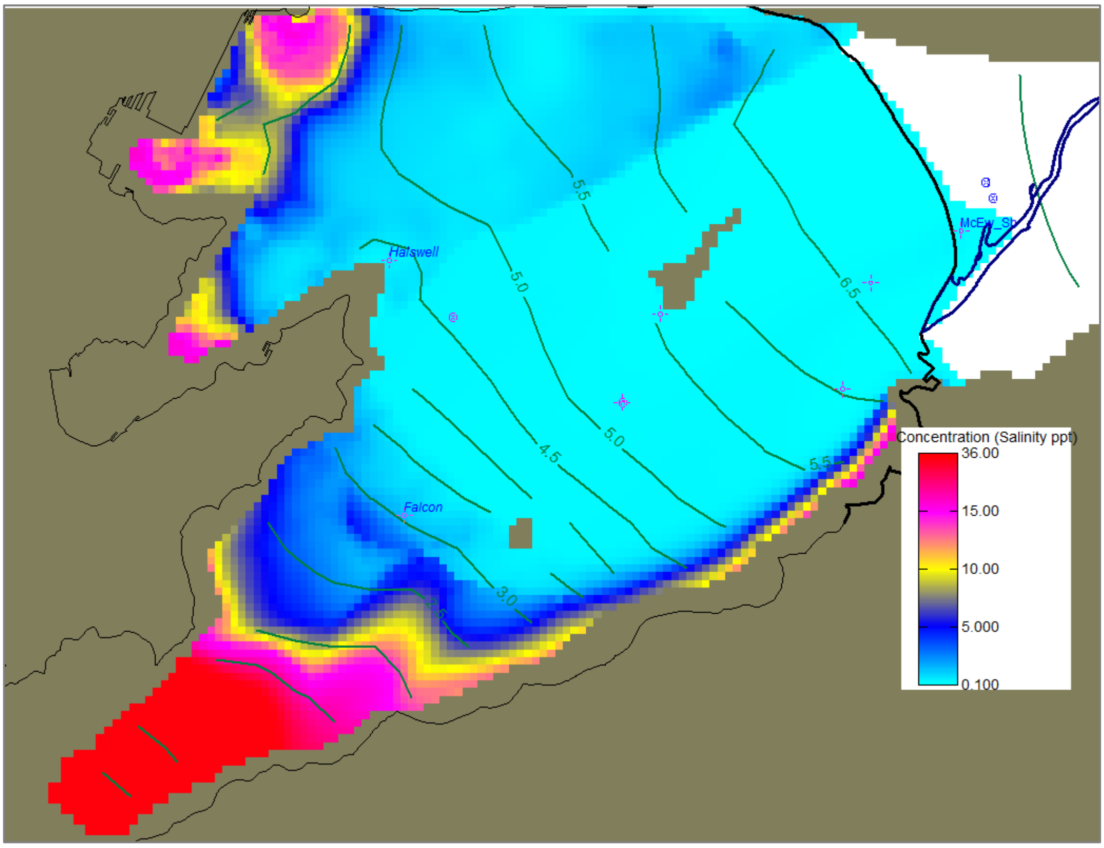

Figure 7.33 Layer 5 – upper Waiwhetu gravels: Simulated heads and salinity concentrations at end of 1,400-year model equilibrium run. No abstraction.

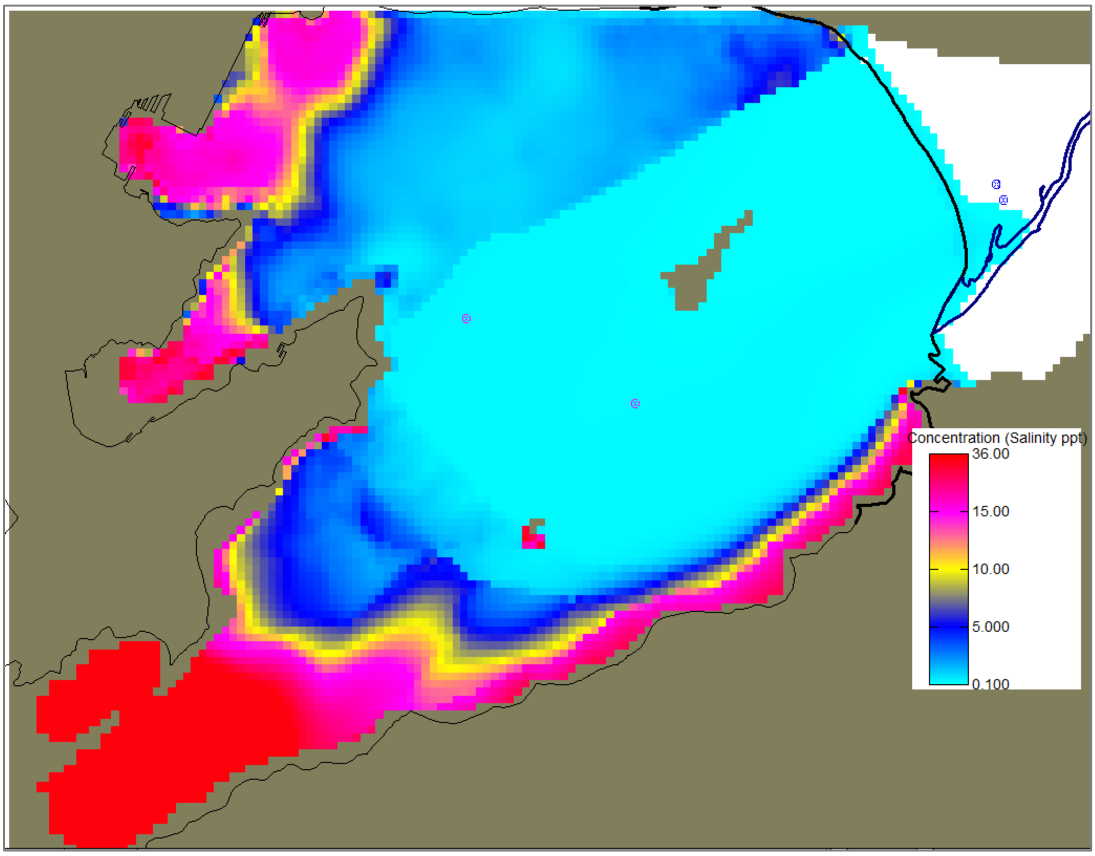

Figure 7.34 Layer 4 – Holocene sediments above UWA: Simulated heads and salinity concentrations at end of 1,400-year model equilibrium run. No abstraction.

7.8.6 Preparation run 2 (Stabilised abstraction effects)

The second preparation for the predictive simulations was to run the model from the end of the 1,400 year run for a further 50 years with abstraction turned on at Waterloo. This broadly simulates the abstraction history from the terrestrial upper Waiwhetu gravels and provides stable starting heads and concentrations for subsequent abstraction scenario testing.

The eight bores of the Waterloo wellfield were set to run at a combined 40 MLD for this model run. The flow model was run using a single stress period representing average conditions (SP109) for 1,825 days with a timestep of 60.8 days (300 timesteps in total). MT3D used a time step of 30.4 days.

Figure 7.35 to Figure 7.37 show the outputs at the end of the 50-year simulation. When compared to the end of the 1,400 year unpumped simulation, the saline interface has moved inshore by about 1km as a result of pumping drawdown. The low-level salinity concentrations in the central part of the harbour (at E3, E8 and Somes Island) remain unchanged from the calibration run.

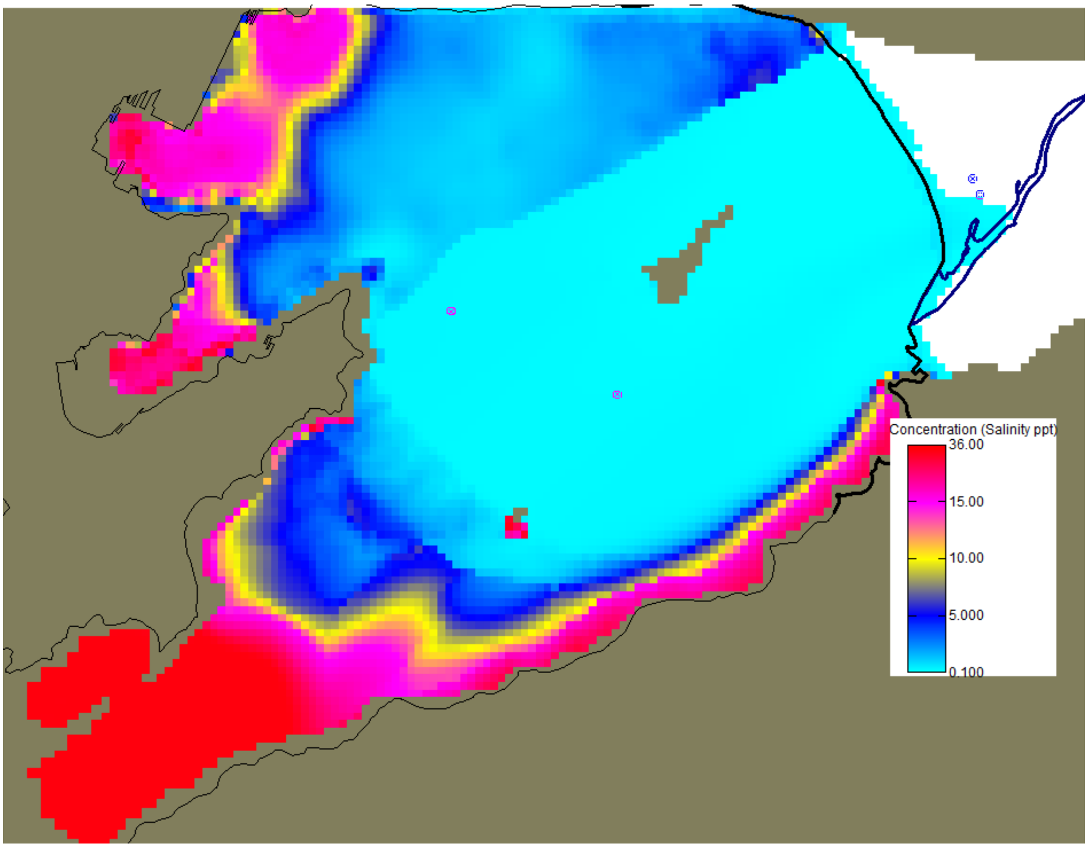

Figure 7.35 Layer 4 – Lower Holocene deposits: Simulated heads and salinity concentrations at end of 50-year model preparation run. Waterloo abstraction at 40MLD.

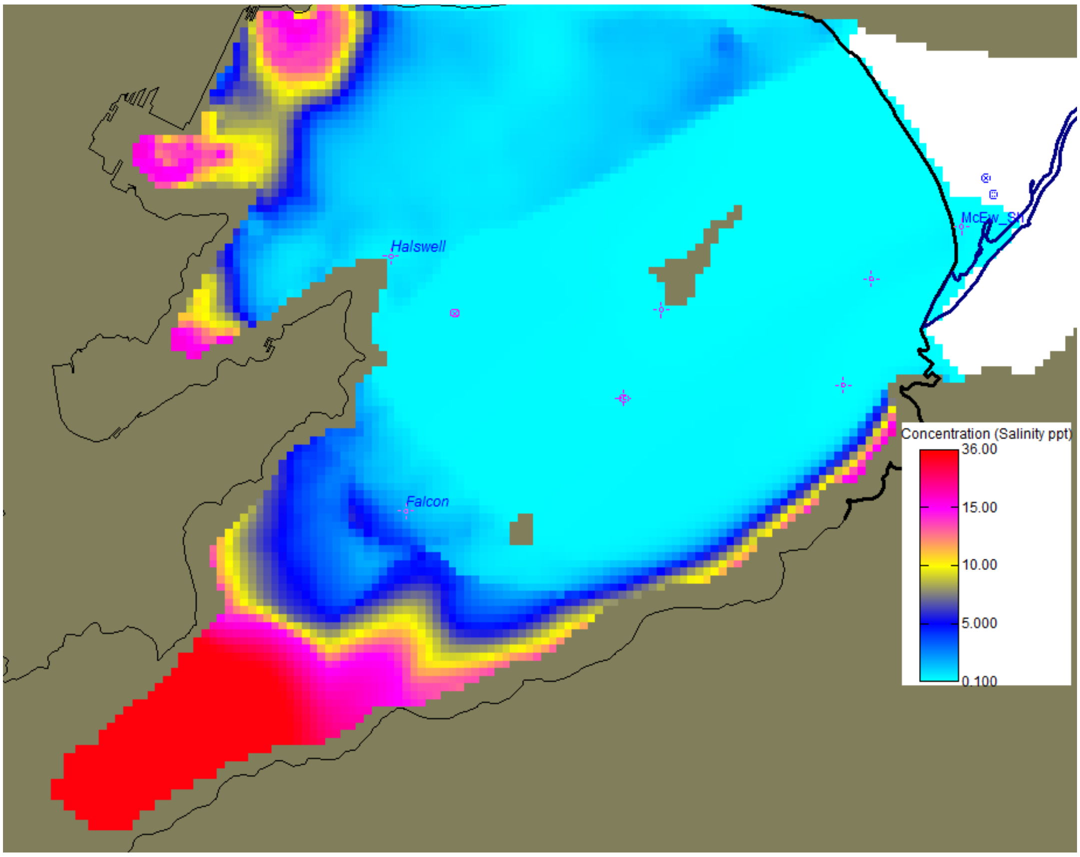

Figure 7.36 Layer 5 – upper Waiwhetu gravels: Simulated heads and salinity concentrations at end of 50-year model preparation run. Waterloo abstraction at 40MLD.

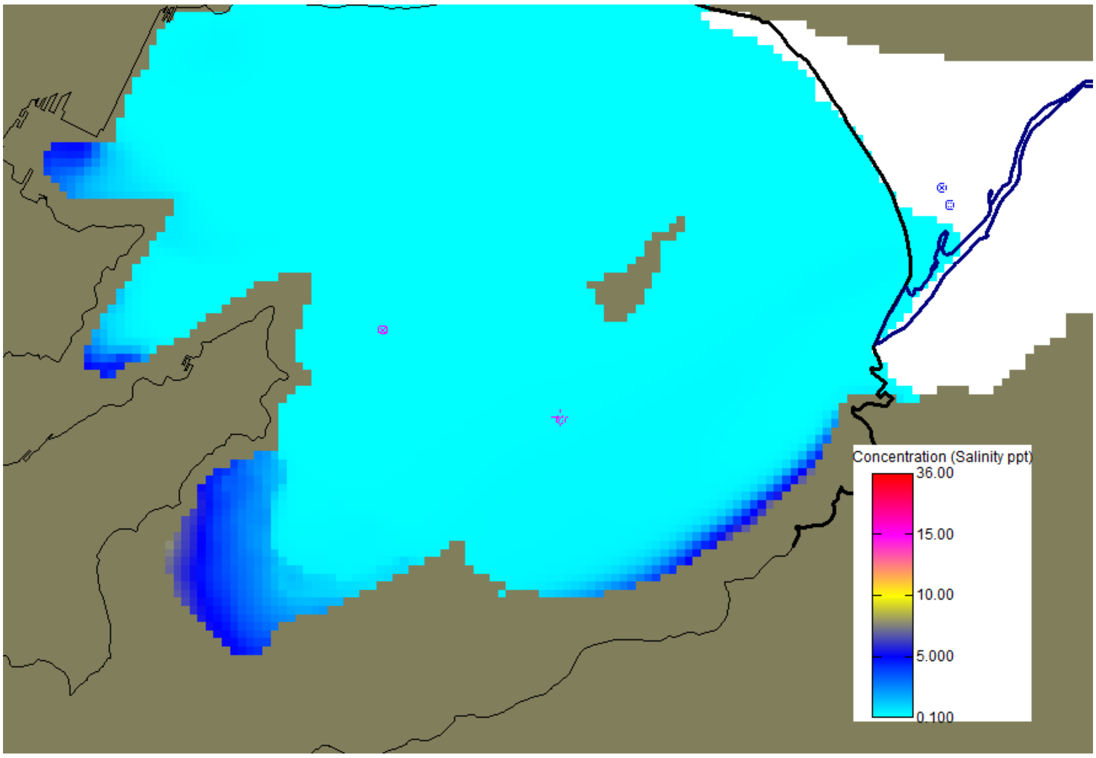

Figure 7.37 Layer 9 – lower Waiwhetu gravels: Simulated heads and salinity concentrations at end of 50-year model preparation run. Waterloo abstraction at 50MLD. Summer conditions.

7.9 Offshore groundwater abstraction simulation

7.9.1 Approach to abstraction scenario modelling

The SEAWAT model was used to run a series of abstraction and sensitivity scenarios to help evaluate the feasibility of abstraction from the upper Waiwhetu gravels at the E8 site and to identify the activation of possible saline intrusion mechanisms that may inidcate a fatal flaw to the project.

E8 was considered to be the most favourable location for abstraction as it is regarded to take advantage the good aquifer thickness, transmissivity and water quality properties whilst avoiding known saline intrusion risks and seismic hazards (i.e. active faults; see Appendix 1 and Section 4.2 for E8 siting rationale). No other preferred locations for abstraction from the upper Waiwhetu gravels have been identified. The aquifer thickness and water quality at E3a has proven to be comparatively poor.

The E8 site does not provide an opportunity to abstract from the lower Waiwhetu aquifer since it contains brackish water (c. 850mg/L chloride; see Section 5.8 and Appendix 8). A water-bearing Moera aquifer was not identified at this site.

Each of the abstraction scenarios was run for 1 year using constant aquifer stresses (a single stress period) and daily timesteps. Stress Period 193 was used to represent summer (low recharge) aquifer conditions (refer to Figure 7.30).

The Waterloo Wellfield was operational at a reduced rate as specified for each of the scenarios. This was generally 25-40MLD to satisfy anticipated reduced demand during an emergency or alternative supply situation.

The starting conditions for all the scenarios were derived from the end of the 50-year baseline pumping simulation described above (preparatory run 2). In all scenarios, a constant salinity concentration of 2 kg/m^3 (equivalent to about 1,000 mg/L chloride) was used in the lower Waiwhetu Aquifer to conservatively 'force' the groundwater quality close to that observed in E8 (850-900 mg/L chloride). Due to the slight downward hydraulic gradient between the UWA and LWA (see Figure 7.24), non-pumping aquifer cross-contamination was not observed.

All scenarios used a vertical dispersivity of 1m - except Scenarios 3a-c which provide a sensitivity analysis for this parameter. Longitudinal and transverse dispersivities remained the same as the model calibration (10m and 2m respectively).

7.9.2 Evaluation criteria

The SEAWAT model has been used to provide guidance as to whether saline intrusion could occur via backflow through the springs, through the harbour floor where aquitards are thin or weak, or via the northward encroachment of the saline interface simulated in the Point Dorset area. A description of potential saline intrusion pathways and risks is contained in Section 6. In addition, manual checks on critical groundwater heads beneath the submarine spring sites and in areas potentially at risk to the lateral encroachment of saline water were used – these are described below.

A principal saline intrusion risk is via backflow through submarine spring vents (Figure 5.9 and Figure 5.10). Minimum equivalent freshwater heads beneath submarine spring vents have therefore been used to provide an alert for potential backflow from the ocean due to E8 drawdown effects. Although the SEAWAT model will simulate the backflow if the head gradient reverses (using the GHB cells located at the spring sites), calculated minimum freshwater heads in the aquifer are more conservative because they take into consideration the highest tidal level. The calculated minimum heads in the upper Waiwhetu aquifer beneath important spring sites around the E8 sites are shown in Table 7.3. Section 6 describes the methodology used for the calculation of the minimum levels and Figure 5.9 shows the spatial location of the spring vents). For reference, Table 7.3 also shows the minimum levels when a sea level rise of 0.8m is assumed (equivalent to a 1m mean sea level rise above datum).

Table 7-3 Minimum groundwater head in upper Waiwhetu aquifer required to prevent backflow of seawater

Submarine spring sites used to evaluate E8 abstraction	Recommended min head in UWA beneath spring vent (m amsl)	Recommended min head in UWA beneath spring vent with 1m seal level rise (m amsl)
Hutt Mouth	1.65	2.5
Seaview	1.65	2.5
Somes (deepest spring – southern tip of island)	1.8	2.6
Pt Halswell	1.4	2.2

In addition to the minimum aquifer levels to prevent spring backflow, other areas are regarded to be vulnerable to the lateral encroachment of saline water. These are:

- Falcon Shoals to the south of E8: The northward encroachment of the saline interface would occur if levels at Falcon Shoals were to drop too low as a result of abstraction. The SEAWAT model would simulate this effect. Falcon Shoals is used as a sentinel or inidcator site to assess whether the groundwater levels theoretically permit the encroachment of the saline interface to the north.
- The Eastbourne coastline: the conceptual model indicates that this area may have a weak or more permeable Holocene aquitard above the Waiwhetu gravels. The HAM4 model has been set up to reflect this. Therefore, a sentinel level site in this area has also been established.

For both the Falcon Shoals and Eastbourne areas, sentinel observation sites have been introduced to the HAM4 model in the upper Waiwhetu gravels. For these, Ghyben-Herzberg minimum levels based on the modelled aquifer base level have been used as a general guide to flag excessively low pressures (these have been calculated by dividing the depth of the aquifer below sea level by 40) For the Falcon Shoals sentinel site the G-H level is 1.55 m amsl; for Eastbourne site the G-H level is 1.1 m amsl.

For some scenarios, the simulated head distribution matrices have been compared on a spatial basis the Ghyben-Herzberg minimum level to identify areas where the modelled levels are vulnerable to seawater ingress.

7.9.3 Abstraction scenario and results

Table 7-4 contains the model scenarios that have been run using SEAWAT to determine a sustainable yield for abstraction from the upper Waiwhetu gravels at the E8. The table also contains a commentary on the results of each scenario.

Further details on the simulated heads for each scenario at the critical points in the aquifer described in the previous section are contained in Table 7-5.

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Table 7-4 Model scenario matrix and assessment of outputs

Models	*Commentary*	Results/Analysis
BASE MODELS & CALIBRATION		
Transient 'HAM4' flow model calibration (MODFLOW2000) HMA4 is a hybrid of HAM3 (onshore) and new geological model offshore. Sea water constant head levels set at 0.55m (current mean sea level) and manually density corrected for salinity and seawater column to provide an equivalent freshwater pressure at the sea floor. GHB boundary at southern edge introduced. Model set up using 7-day stress periods divided into 5 time steps. Selected sensitivity analysis undertaken for hydraulic conductivity and GHB settings.	5-year transient flow calibration (MODFLOW) for the period 2007 to 2012 (original HAM3 calibration period).	Good transient head calibration to all continuous monitoring sites and to spot head measurements made at E3 and E8 during 20017/18 testing.
Equilibrium preparatory run 1 (SEAWAT) **Base calibrated flow model:** Density corrected levels for CH's used in L1+L2 Sea level = 0.55m (upper quartile tidal range)	1,000-year run, one stress period representing average recharge conditions (SP109 of transient calibration). No abstraction. No initial concentrations.	Model provides an equilibrium naturalised baseline from which to start the 50-year abstraction baseline simulation. Equilibrium concentrations attained at about 400 years.
Baseline 50- year abstraction run 2 (SEAWAT)	50-year run with Waterloo pumping at 40 MLD. Model run using one stress period representing average recharge conditions (SP109). Run started using outputs from end of 1,000 year equilibrium model run.	Simulation provide stable starting conditions (heads and concentrations) for abstraction scenarios.

Abstraction Scenarios

SEAWAT model runs (using SP193 – summer conditions; 1 year runs):

Scenario 1 - Waterloo 40MLD; E8 0 MLD;	Scenario to test migration of salinity from LWA to UWA with no pumping at E8	No upwards salinity migration observed when E8 is not pumped.
Scenario 2: - Waterloo 70MLD; E8 30MLD	Exploration of model response under high pumping stresses from Waterloo and E8	Shows saline intrusion via backflow through the submarine springs at the southern end of Somes Island and Point Halswell. Saline ingress from LWA and movement of saline water from the south. Maximum chloride concentration modelled in E8 UWA is about 300 mg/L (increase of about 200 mg/l from starting conditions). Critical aquifer levels met or exceeded at Seaview, Somes and Halswell submarine springs. Figure 7.38 Figure 7.39
Scenario 3a-c: - Waterloo 40MLD; E8 20MLD - Vertical dispersivity a) 1m, b) 2m, c) 3m.	Abstraction scenario and vertical dispersivity sensitivity analysis	Drawdowns do not cause critical aquifer levels to be exceeded. Dispersivity sensitivity analysis indicated salinisation of the UWA over a broad area due to upwards migration of salinity from the LWA through the Q3 aquitard where it is thinner and more heterogeneous to the east of E8. Upwards migration also occurs around the southern margin of Somes Island where the Q3 aquitard is regarded to be absent nearshore. Increases in salinity are sensitive to the vertical dispersivity used in the model – a range of 0.4-0.6ppt (kg/m3) is shown – this is equivalent to 220 to 330 mg/L chloride. Starting (ambient) chloride levels in the UWA was about 95mg/L. The time lag between pumping commencing and salinisation is longer when a lower vertical dispersivity is assumed (1-2m). At a higher vertical dispersivity, the time lag is minimal. Figure 7.40
Scenario 4: - Waterloo 25MLD; E8 20MLD	Abstraction scenario	Drawdowns do not cause critical aquifer levels at springs to be exceeded. Salinity in E8 increases to about 0.4ppt (220mg/l Cl) due to contamination from LWA. Figure 7.41
Scenario 5: - Waterloo 25MLD; E8 25MLD	Abstraction scenario	Drawdowns do not cause critical aquifer levels at springs to be exceeded. Salinity in E8 increases to about 0.45ppt (250mg/l Cl).

		Figure 7.41
Scenario 6: - Waterloo 25MLD; E8 30MLD	Abstraction scenario	Drawdowns do not cause critical aquifer levels at springs to be exceeded. Falcon Shoals aquifer level drops below GH level. Salinity in E8 increases to about 0.6ppt (330mg/l Cl) due to contamination from LWA. Figure 7.41
Scenario 7: - Waterloo 0MLD; E8 30 MLD	Abstraction scenario	Drawdowns do not cause critical aquifer levels at springs to be exceeded. Salinity in E8 increases to about 0.5ppt (280mg/l Cl) due to contamination from LWA.
Scenario 8: - Waterloo 40MLD; E8 30 MLD	Abstraction scenario	Drawdowns cause critical aquifer levels to be breached at the Somes Island Spring. Aquifer levels at Eastbourne coastline and Falcon Shoals also drop below GH levels. Salinity in E8 increases to about 0.5ppt (280mg/l Cl) due to contamination from LWA.
Scenario 9: - Waterloo 40MLD; E8 10 MLD	Abstraction scenario	Drawdowns do not cause critical aquifer levels at springs to be exceeded. Salinity in E8 increases to about 0.4ppt (220mg/l Cl) due to contamination from LWA. Figure 7.41
Scenario 10: - Waterloo 40MLD; E8 20	Sea level rise scenario	Drawdowns do not cause critical aquifer levels at springs to be exceeded. Salinity in E8 increases to about 0.4ppt (220mg/l Cl) due to contamination from LWA. An increase in groundwater heads beneath the harbour a resulting from sea level rise seems to provide a partial balance to saline intrusion risk. Figure 7.42 and Figure 7.43

Table 7-5 E8 abstraction scenarios: Simulated heads at critical spring and aquifer locations for each SEAWAT scenario. Minimum spring levels take into account high tidal levels. Cells in red indicate that minimum levels are exceeded

Site	Min Level m amsl (SLR[7] levels in brackets)	**1**	**2**	**3 (a-c)**	**4**	5	6	7	8	9	10 SLR
Waterloo MLD E8 MLD		40 0	70 30	40 20	25 20	25 25	25 30	0 30	40 30	40 10	40 20
E8 UWA	-	3.86	-2.2	0.36	0.7	-0.14	-1.3	-0.3	-1.5	2.18	1.0
McEwan SWI	2.0	4.95	2.54	4.13	4.75	4.55	4.34	5.36	3.73	4.55	4.4
Hutt Mouth Spr	1.65 (2.5)	4.78	2.21	3.84	4.43	4.2	3.9	4.94	3.37	4.32	4.13
Seaview Spr	1.65 (2.5)	4.44	1.65	3.3	3.83	3.55	3.2	4.1	2.71	3.9	3.65
Somes Spr	1.8 (2.6)	4.1	0.50	2.36	2.82	2.4	1.9	2.72	1.5	3.18	2.76
Halswell Spr	1.4 (2.2)	1.9	1.4	1.6	1.8	1.7	1.7	1.8	1.6	1.82	2.74
Eastbourne SWI	1.1	3.4	0.39	1.9	2.4	2.05	1.6	2.2	1.1	2.7	2.42
Falcon SWI	1.55	2.44	0.7	1.6	1.8	1.6	1.35	1.7	1.1	2.0	2.33

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[7] SLR = sea level rise

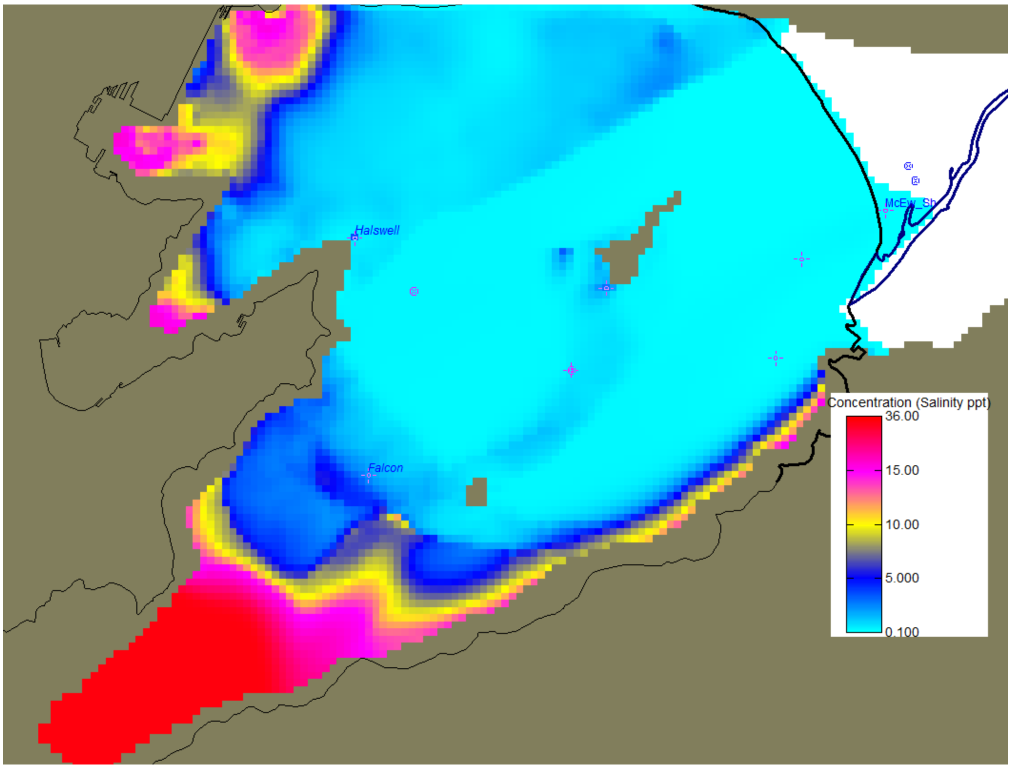

Figure 7.38 Scenario 2 (Waterloo 70mld; E8 30mld) upper Waiwhetu gravels (L5) showing saline intrusion via spring backflow and slight encroachment of the saline interface.

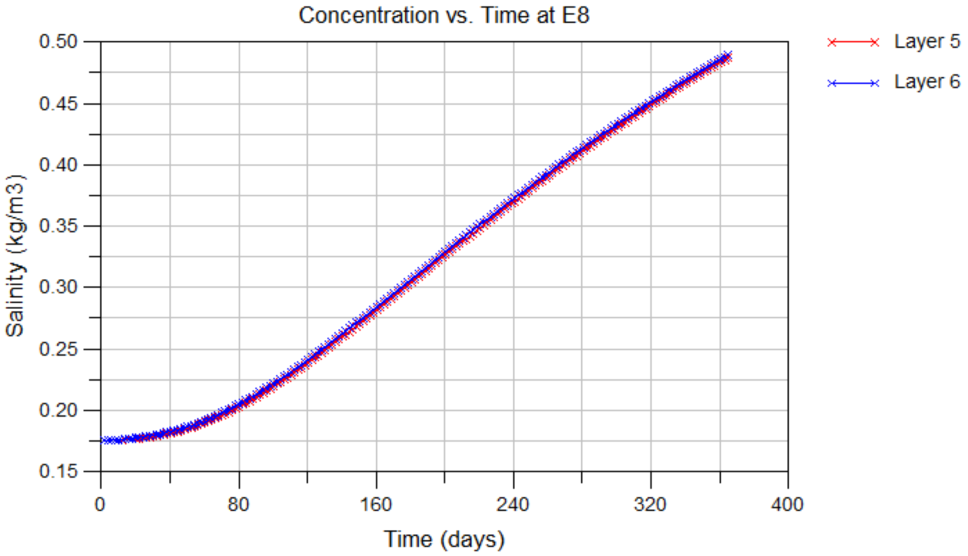

Figure 7.39 Scenario 2 - Simulated increase in salinity in abstraction bore (E8 – UWA).

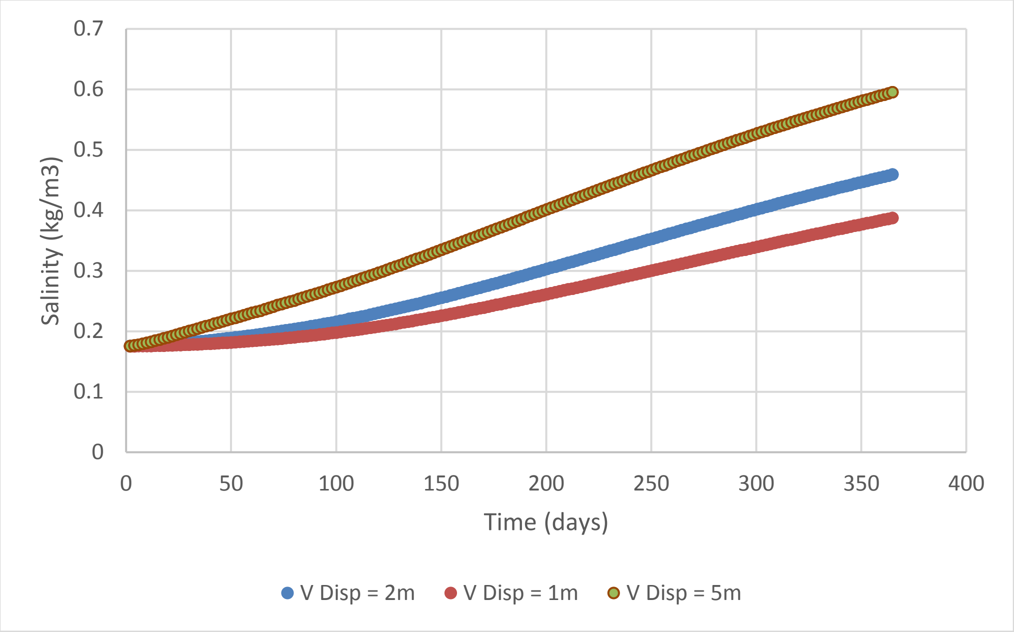

Figure 7.40 Scenario 3a-c – Salinisation of the UWA due to abstraction at E8 under a range of vertical dispersivity values.

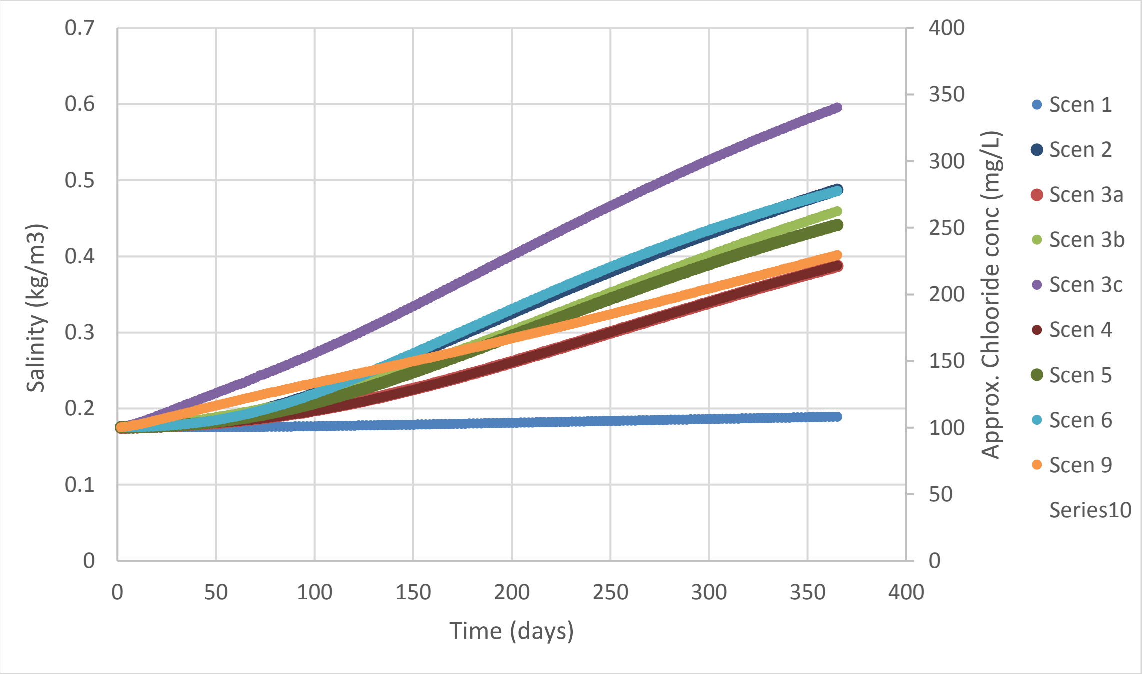

Figure 7.41 Modelled salinisation trends of Bore E8 in UWA as a result of brackish water contamination from the LWA for different scenario runs

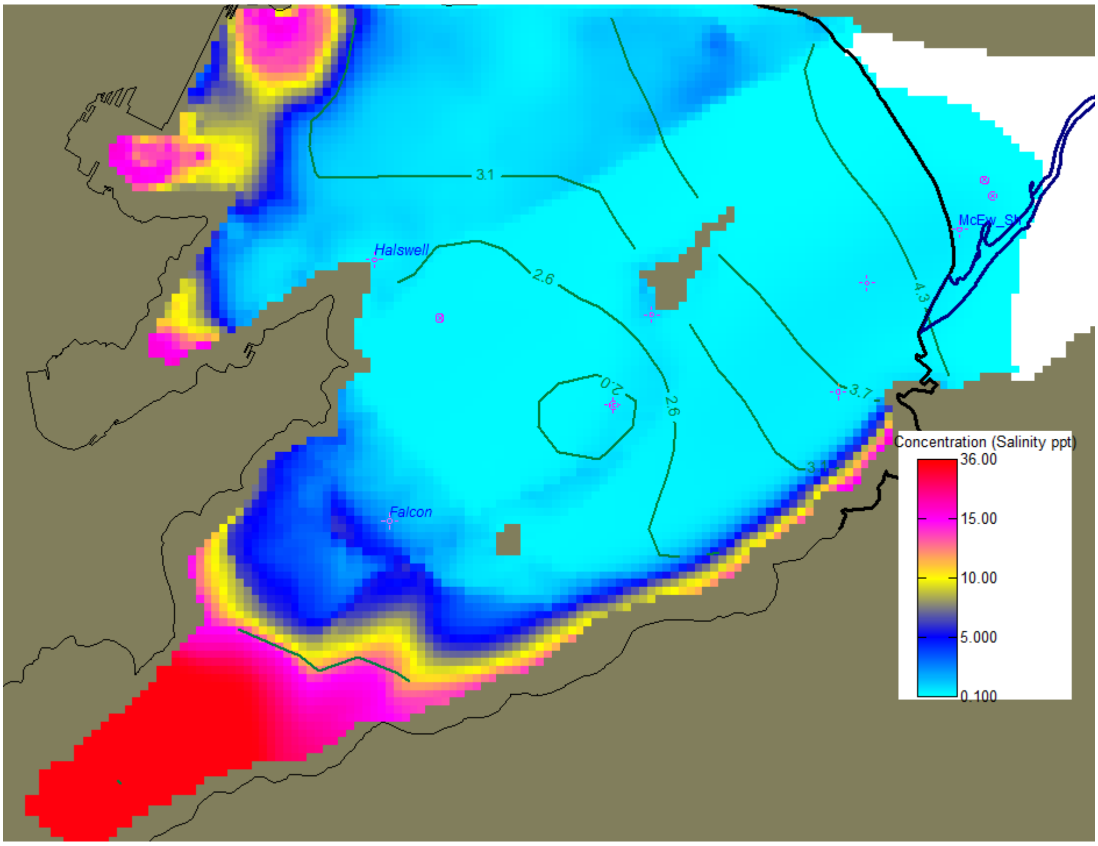

Figure 7.42 Scenario 10 – Sea level rise evaluation - heads and concentration in upper Waiwhetu aquifer.

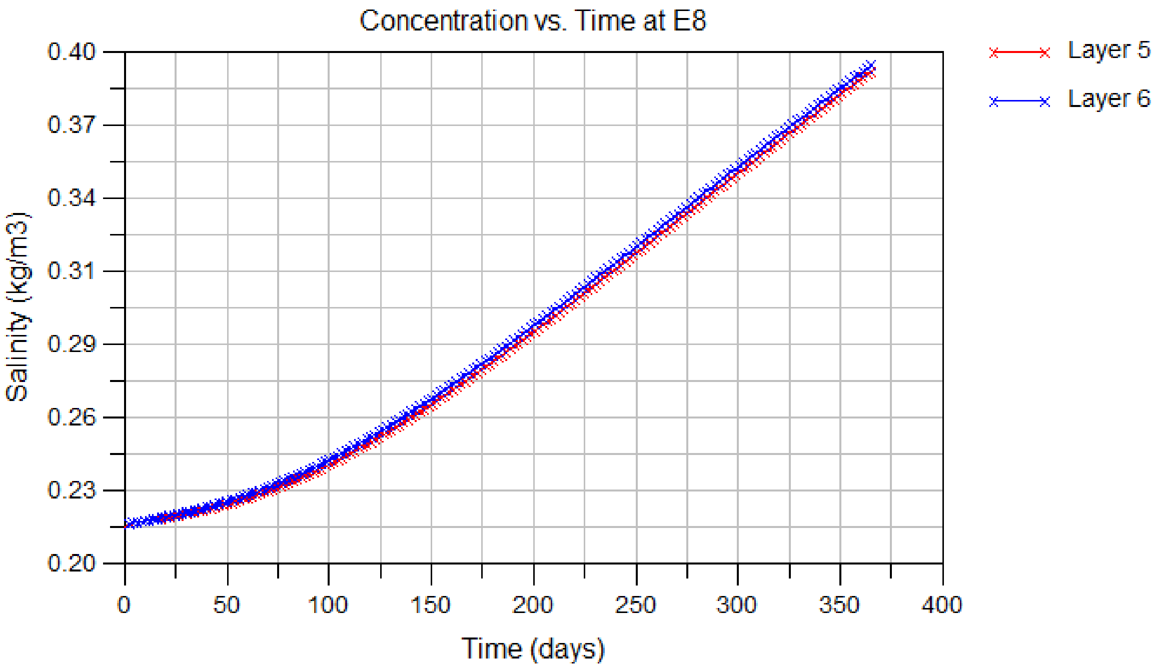

Figure 7.43 Scenario 10 – increase in salinity in pumping bore E8 (UWA). Value of 0.4 kg/m3 salinity is equivalent to about 230 mg/L chloride.

8. Alternative calibration scenario

8.1 Purpose and rationale

The model calibration and scenario simulations presented in Chapter 7 represent a preferred, conservative analysis. However, it is recognised that alternative calibrations are possible and could provide an expanded insight to the nature of the offshore groundwater environment and its potential to provide an alternative water source. A slightly different calibration has therefore been undertaken as a kind of sensitivity analysis and partly in response to peer review comments.

The alternative calibration simulates a flatter sub-harbour hydraulic gradient as a result of increased vertical leakage through the overlying Holocene aquitard and seafloor springs. This theoretically has the effect of reducing aquifer throughflow further offshore, reducing the hydraulic gradient into the harbour entrance area thereby potentially inducing the saline interface to move closer to the shore. However, because this scenario depressurises the aquifer (below the levels observed at Somes Island, E3a and E8) there is a requirement to counter this to achieve sub-harbour aquifer head calibration by attenuating the connectivity of the aquifers to the sea in the harbour entrance area and raising the pressure in this area. This restricts seawater infiltrating through the seabed to the aquifer in the southern area of the model meaning the general head condition at the southern boundary becomes the principal source of saline water.

Since the hydraulic gradients are flatter in the alternative calibration, the model becomes more sensitive to dispersive and diffusive contaminant transport process and it has been necessary to reduce dispersive fluxes in order to obtain a calibration to salinity concentrations in the upper Waiwhetu Aquifer. This sensitivity further emphasises the probability that the salinity observed in the lower Waiwhetu Aquifer at E8 could be accounted for by dispersion and diffusion within a heterogeneous environment (i.e. there does not need to be connate/trapped seawater in the system).

8.2 Parameter modifications

The principal changes made in the alternative calibration are:

- The vertical hydraulic conductivity of the offshore Holocene (Petone Marine Beds) aquitard was increased by an order of magnitude from 1e-5 to 1e-4 m/d. Observation of the nature of the aquitard material observed in the exploration bore cores – a plastic silty clay – warrants this range, but the higher value will allow slightly more leakage from the upper Waiwhetu Aquifer.

- The submarine spring discharge (Hutt mouth, Seaview and Somes Island) has been increased from 2-3MLD to 8-12MLD to allow more discharge from the aquifer system closer to the shoreline. The spring discharge has not been independently quantified and it is considered that such a discharge is plausible given the persistence of deep spring depressions on the seafloor (i.e. there must be a healthy outflow to prevent them from silting up). To achieve the increase spring discharge, the hydraulic conductivity of the GHB cells representing the springs was increased from 15 to 100m/d (conductance = 200m^2/d).

- Hydraulic conductivity of Zone 23 in Layer 3 (Figure 7.11) in the harbour entrance area was adjusted: Kz reduced from 1 to 0.005m/day; Kh reduced from 50 to 20m/day (i.e. there is a very high anisotropy which plausible given the probable highly layered nature of the sediments (J Begg, pers comm).

- Hydraulic conductivity of Zone 13 in Layer 4 (Figure 7.12) in the harbour entrance area was adjusted: Kz reduced from 0.003 to 0.001m/day.

- Upper Waiwhetu Aquifer hydraulic conductivity was dropped slightly (to help maintain aquifer pressure): Zone 20 (Figure 7.13) Kh was reduced from 600 to 500m/day to more closely reflect the lower range obtained from pumping tests at E8. Zone 19 Kh was reduced from 300 to 250m/d.

- An intermediate upper Waiwhetu Aquifer hydraulic conductivity zone (zone 25 – 800m/day) was assigned between the much higher onshore hydraulic conductivity zone 3 (1,400m/d) and zone 20 (500m/day) to create a smoother transition between these zones as shown in Figure 8.1

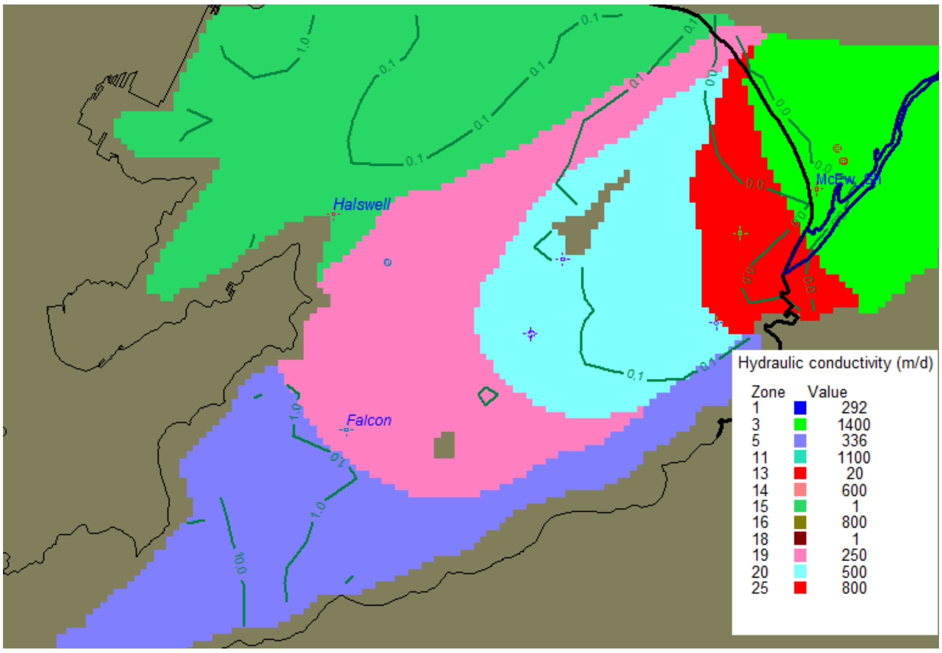

Figure 8.1 Alternative model calibration hydraulic conductivity zones in layers 5 and 6 (upper Waiwhetu Aquifer)

- Constant concentrations were placed along the southern model boundary of layers 9 and 10 (lower Waiwhetu Aquifer) – GHB boundaries are set down to the top of the raised basement bar (layer 6). The constant concentrations deeper and lightly further inshore along the northerly dipping basement surface, simulate potential saline water residing at depth.

8.3 Calibration results

Figure 8.2 shows the head calibration plots for selected bores onshore, around the Waterloo Wellfield, Petone foreshore and at Somes Island. A good head calibration fit is achieved for all monitoring sites.

The simulated heads at the two exploration bore sites (E3a and E8) are shown in Figure 8.3. The head measurements at the bore sites were made over a short period (a day or so) during September 2017 (later winter) for E3 and January 2018 for E8 (summer). The tidally corrected head ranges for E8 (upper Waiwhetu) and E3a (upper Waiwhetu and Moera aquifers) are shown on the calibration plots to ensure that the model calibration is consistent with the observations at these sites. The match at both the E8 and E3a sites for the upper Waiwhetu gravels is good, as is the Moera aquifer at E3a. The original model calibration simulated a slightly lower level for the UWA at E3a than observed – with the alternative calibration providing a better fit due to the simulation of a flatter gradient across the harbour.

The alternative calibration does not however simulate the small downwards head gradient between the UWA and LWA (as the original calibration does – consistent with observed heads, albeit within a probable margin of error).

Figure 8.4 shows simulated water balances for the offshore part of the aquifer in terms of discharge to the ocean – distinguishing spring discharge from seepage through the aquitard/harbour entrance area. Comparison with Figure 7.28 shows that the alternative calibration simulates approximately the same total (springs plus seepage) quantity of water leaking into the harbour up to about 20MLD. However, the alternative calibration shows that spring discharge now dominates and is about twice the seepage discharge, with small discharge in the harbour entrance area – about 3MLD (original calibration was 10-15MLD to create a greater connectivity to the ocean and therefore allow the backflow of seawater if groundwater heads dropped sufficiently).

Modelled offshore head distributions in the upper Waiwhetu gravels for two different periods – November and March - are shown in Figure 8.5 and Figure 8.6 . The flow vectors are also shown on these maps – highlighting the main offshore flow pathway to the east of Somes Island and a reversal of flow from the southern GHB boundary. When compared to the original calibration (see Figure 7.25 and Figure 7.26) the effect of changing the aquifer discharge dynamics means that the flow gradient in the harbour entrance area is much flatter and the gradient remains consistent across the harbour. Under this condition, the heads in the Somes Island, E3a and E8 bores are calibrated. The flow-field in the upper Waiwhetu Aquifer is therefore extremely shallow and the simulated heads in the harbour entrance area are higher than simulated previously (now sitting at c. 2-2.5m) – this is necessary to calibrate the model. The only access for seawater into the system is therefore laterally through the southern model boundary (seawater could also be trapped in some formations during deposition).

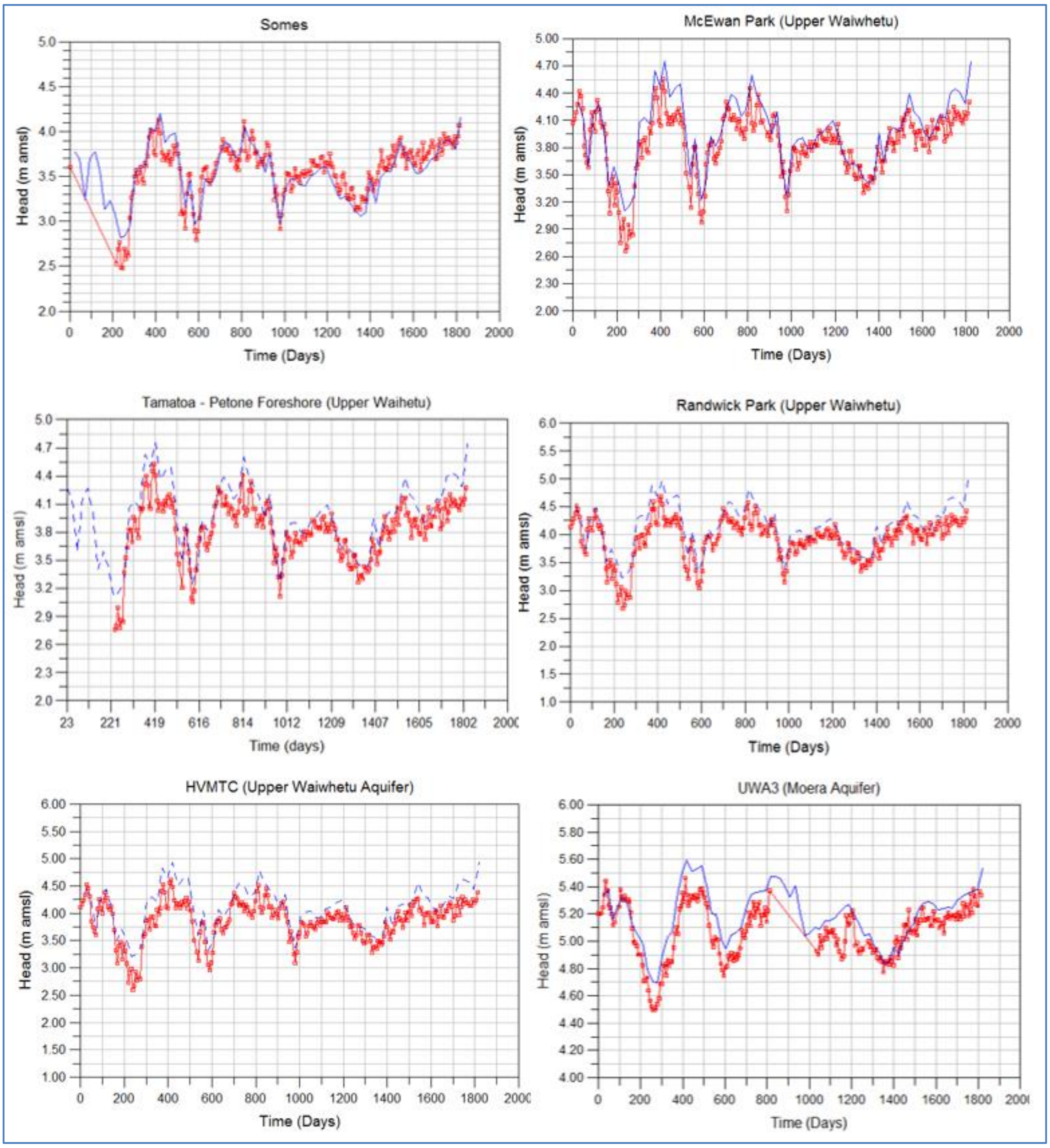

Figure 8.2 Alternative calibration results: Five-year transient model calibration simulated heads (blue lines) and observed heads (red lines with symbols).

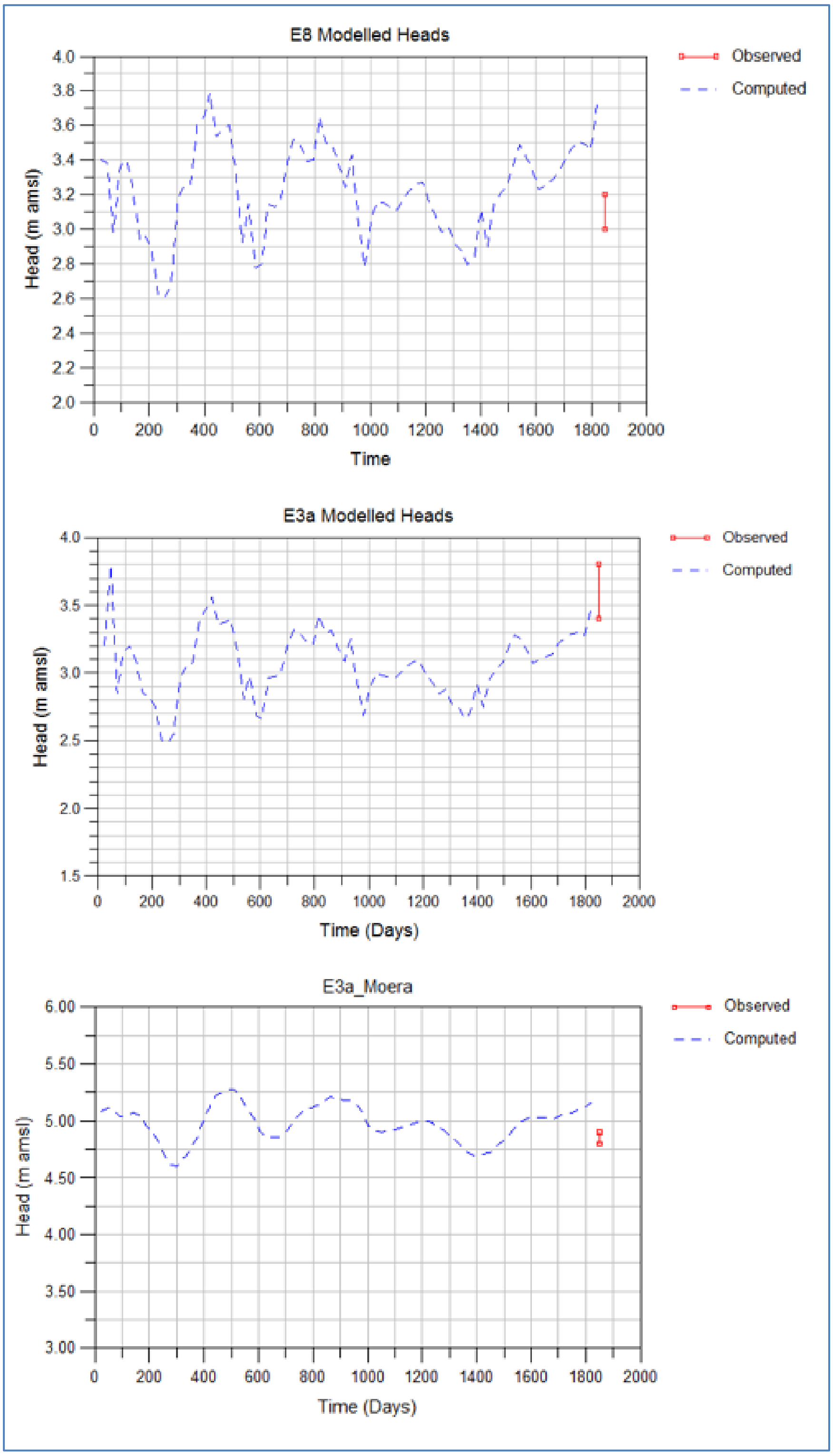

Figure 8.3: Simulated heads during 5 year model calibration period at exploration bores locations showing aquifer levels observed during monitoring and testing. Top two plots are for upper Waiwhetu Aquifer, lower plot is Moeara Aquifer at E3a.

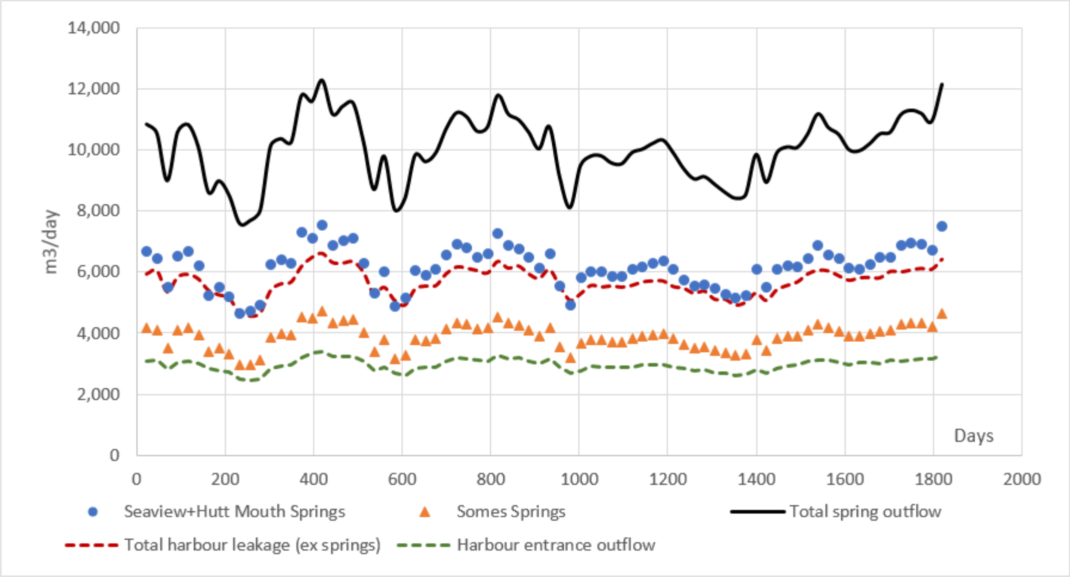

Figure 8.4 Alternative calibration offshore water balance simulation (5-year calibration run).

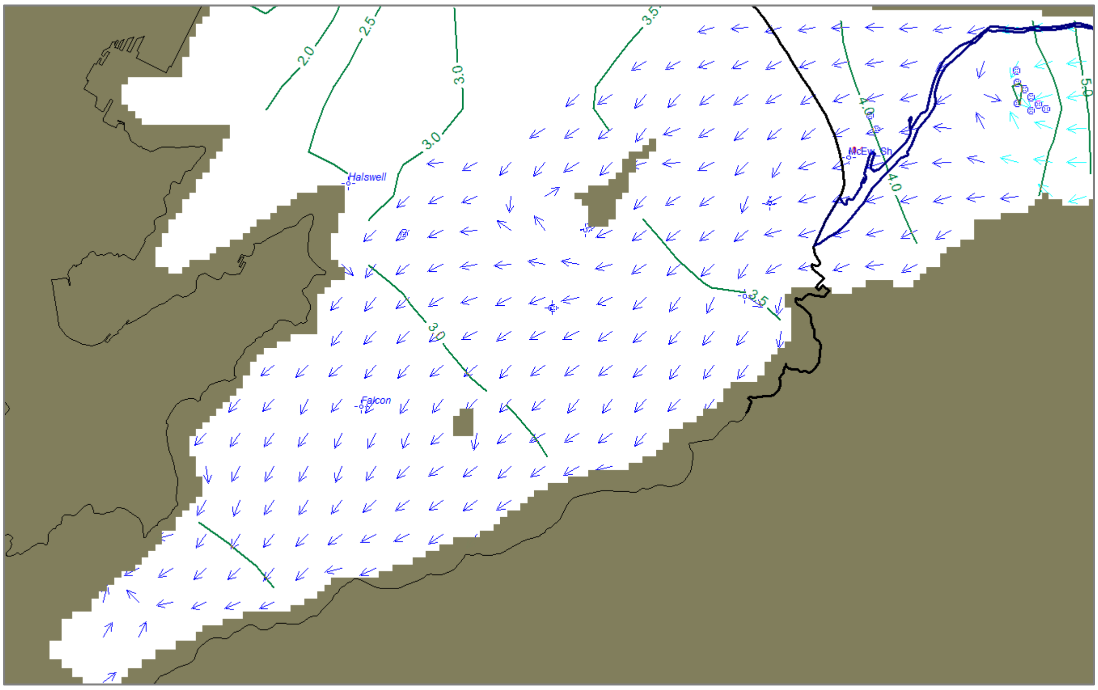

Figure 8.5 Alternative calibration – simulated head distribution in the upper Waiwhetu Aquifer (Nov 2011). Waterloo pumping at 66MLD. Contours in m amsl at 0.5m intervals. Flow vectors also shown.

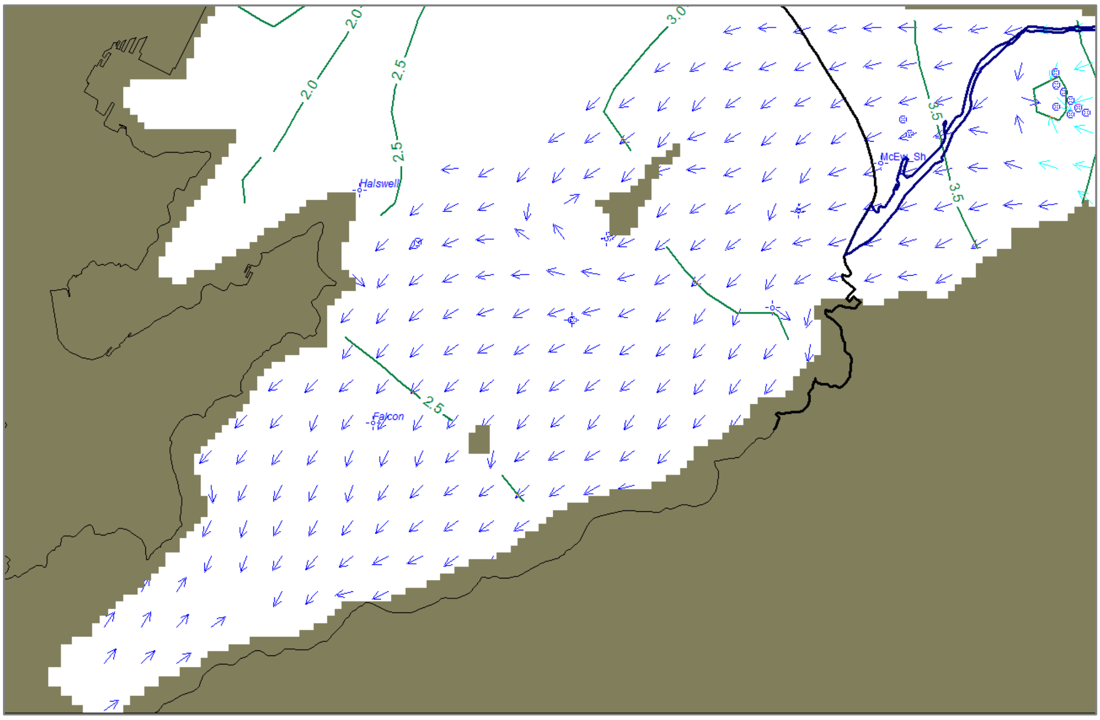

Figure 8.6 Alternative calibration – simulated head distribution in the upper Waiwhetu Aquifer (March 2011). Waterloo pumping at 71MLD. Contours in m amsl at 0.5m intervals. Flow vectors also shown.

8.4 Seawat modelling calibration

The Seawat modelling carried out on the alternative calibration followed the same procedure and settings as described in Section 7.9. However, due to model instability and the need to adopt short transport timesteps, the equilibrium run was carried out to only 230 years, with a further 50-year Waterloo abstraction equilibrium run (at 40MLD). It was evident that salinity concentrations had reached stable conditions after about 100 years as shown in Figure 8.7.

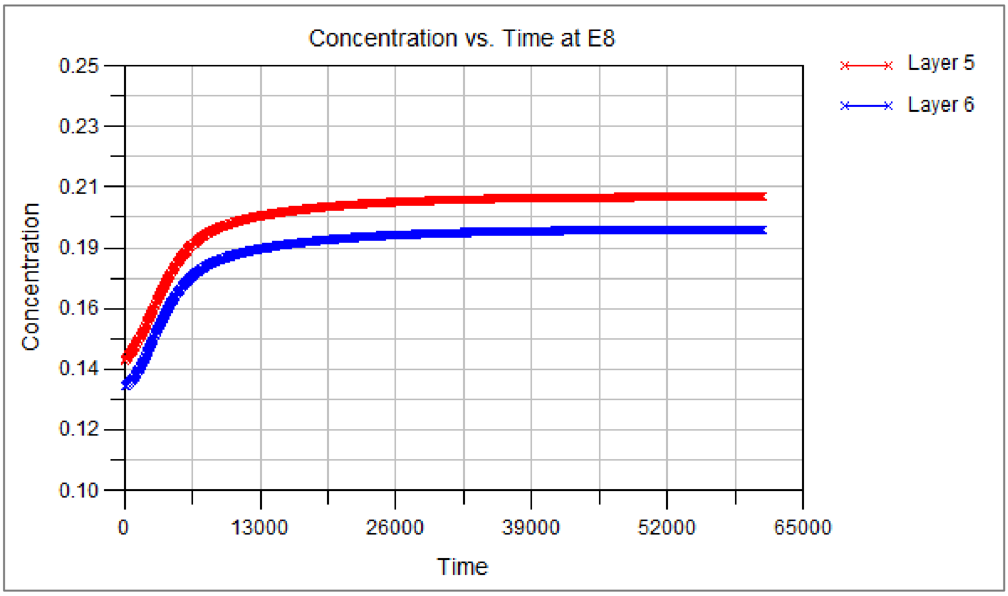

Figure 8.7 Simulated salinity concentration in layers 5 and 6 (upper Waiwhetu Aquifer) during the first part of the equilibrium model run showing stabilised concentrations at about 30,000 days. Time scale is in days, concentration is salinity in kg/m^3.

During the equilibrium run, calibration to observed salinity concentrations was also carried out by modifying the longitudinal dispersivity values. The salinity of the upper Waiwhetu Aquifer in the central part of the harbour was observed to be highly sensitive to dispersivity – the final calibrated values were:

- Longitudinal dispersivity: 1.5m
- Transverse dispersivity: 1m
- Vertical dispersivity: 0.1m

Such values lie within acceptable ranges for this type of aquifer but are significantly lower than the original calibrated model (see Section 7.8.3). The diffusion coefficient was also reduced to 1E-5. The salinity concentration in lower Waiwhetu Aquifer at E8 was again not simulated - heterogeneities in aquifer transport parameters could not be practically tested due to restrictions in model run times and stability issues. Table 8-1 shows the results of the calibration.

Table 8-1 Calibrated salinity concentrations – end of 230yr equilibrium model run

	Modelled Salinity Kg/m^3	Modelled chloride mg/L	Observed Chloride mg/L
UWA E3a	0.37	205	125
UWA E8	0.14	78	75
LWA E8	0.04	22	850
Somes UWA	0.08	45	30

Figure 8.8 and Figure 8.9 show the simulated salinity patterns in the upper Waiwhetu Aquifer at the end of the 230-year and subsequent 50-year Waterloo equilibrium model runs for the upper and lower Waiwhetu aquifers respectively. The results are quite different to the original calibration outputs (Figure 7.33, Figure 7.36, Figure 7.37) showing a much smaller area of salinized aquifer in the harbour entrance area with a diffuse mixing zone extending towards Falcon Shoals. This is possibly due to the reduced dispersivity used in the model and also the higher simulated aquifer pressures in the harbour entrance area. It is also evident that this model version will not allow saline water to enter the aquifer along Eastbourne coastline or disperse into the lower Waiwhetu Aquifer – despite assigning fixed seawater concentration heads along the southern boundary in this aquifer. In this respect, it is evident that the original calibrated model is more conservative.

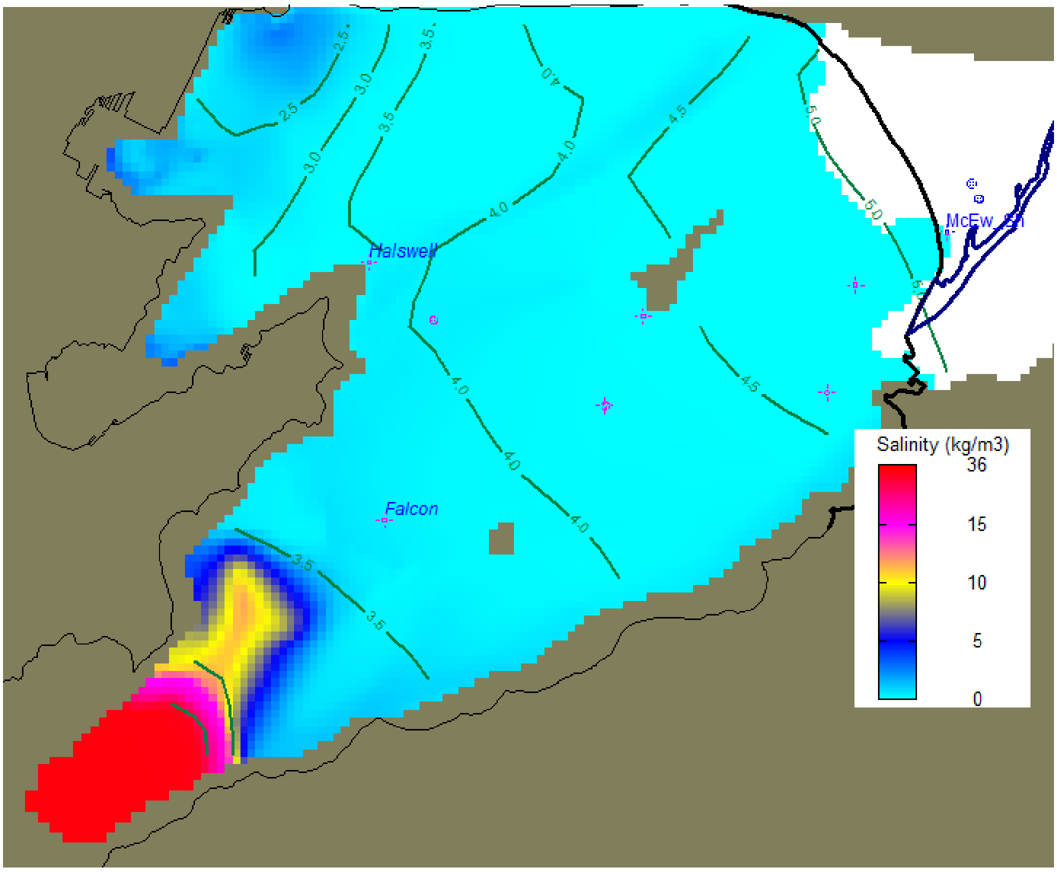

Figure 8.8 Simulated salinity distribution in the upper Waiwhetu Aquifer (layer 5) at the end of the equilibrium model run (with Waterloo abstraction) for the alternative model calibration. A prominent saline interface is present in the harbour entrance area with a wide mixing zine extending into the main part of the harbour. Groundwater head contours also shown (in m amsl).

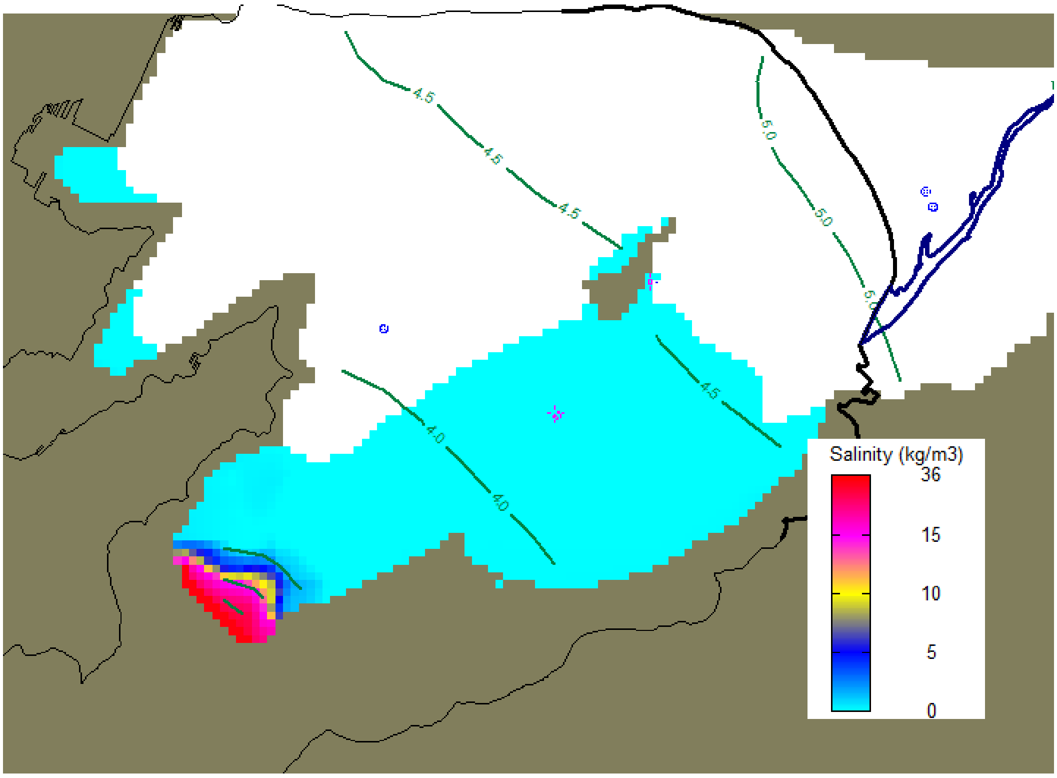

Figure 8.9 Simulated salinity distribution in the lower Waiwhetu Aquifer (layer 9) at the end of the equilibrium model run (with Waterloo abstraction) for the alternative model calibration. Groundwater head contours also shown (in m amsl).

8.5 Seawat abstraction scenarios

The alternative calibration version of the SEAWAT model has been used to replicate selected abstraction scenario run using the main calibrated model presented in Chapter 7. These have been used to ascertain whether there are any significant differences in model predictions between the two model versions. The abstraction conditions and model set ups are the same as those described in Section 7.9

The following four abstraction scenarios were re-run using the alternative calibration model version:

- Scenario 1: Waterloo 40MLD; E8 zero
- Scenario 3: Waterloo 40MLD; E8 20 MLD
- Scenario 8: Waterloo 40MLD; E8 30
- Scenario 9: Waterloo 40 MLD; E8 10 MLD

Table 8-2 shows the outputs in terms of the simulated heads in the upper Waiwhetu Aquifer at critical saline intrusion risk locations. The table also shows the heads calculated using the main model calibration. In general, the simulated heads in the southern part of the model (Somes Island to the harbour heads) are higher, elsewhere they are similar.

Table 8-2 E8 abstraction scenarios using the alternative model calibration: Simulated heads in the upper Waiwhetu Aquifer at critical spring and aquifer locations for each SEAWAT scenario. Minimum spring levels take into account high tidal levels. Cells in red indicate that minimum levels are exceeded. Numbers in brackets show the heads simulated using the main model calibration.

Site	Min Level m amsl	**1**	**3**	8	9
Waterloo MLD E8 MLD		40 0	40 20	40 30	40 10
E8 UWA	-	3.86	-0.5 (0.36)	-1.5	2.15 (2.18)
McEwan SWI	2.0	5.1 (4.95)	4.26 (4.13)	3.82 (3.73)	4.68 (4.55)
Hutt Mouth Spr	1.65	4.79 (4.78)	3.8 (3.84)	3.27 (3.37)	4.29 (4.32)
Seaview Spr	1.65	4.5 (4.44)	3.28 (3.3)	2.68 (2.71)	3.9 (3.9)
Somes Spr	1.8	4.2 (4.1)	2.27 (2.36)	(1.34) 1.5	3.23 (3.18)
Halswell Spr	1.4	1.75 (1.9)	1.84 (1.6)	1.59 (1.6)	1.73 (1.820)
Eastbourne SWI	1.1	4.17 (3.4)	2.17 (1.9)	1.27 (1.1)	3.2 (2.7)
Falcon SWI	1.55	3.65 (2.44)	2.0 (1.6)	1.18 (1.1)	2.82 (2.0)

Figure 8.10 and Figure 8.11 shows the salinity distributions in the upper Waiwhetu Aquifer for scenarios 3 and 4. These shows an encroachment of the saline interface into the harbour entrance area and salinisation from the lower Waiwhetu Aquifer as a result of abstraction. Scenario 8 also results in saline intrusion through the Somes Island springs (Figure 8.11).

Figure 8.12 shows the simulated increases in salinity in the E8 bores as a result of cross-contamination from the lower Waiwhetu Aquifer. When compared to the equivalent plot for main model calibration (Figure 7.41), the overall magnitude of salinisation is very similar. However, the alternative calibration shows a slightly faster rise in salinity and a later reduction in the rate of increase when compared to the main calibration.

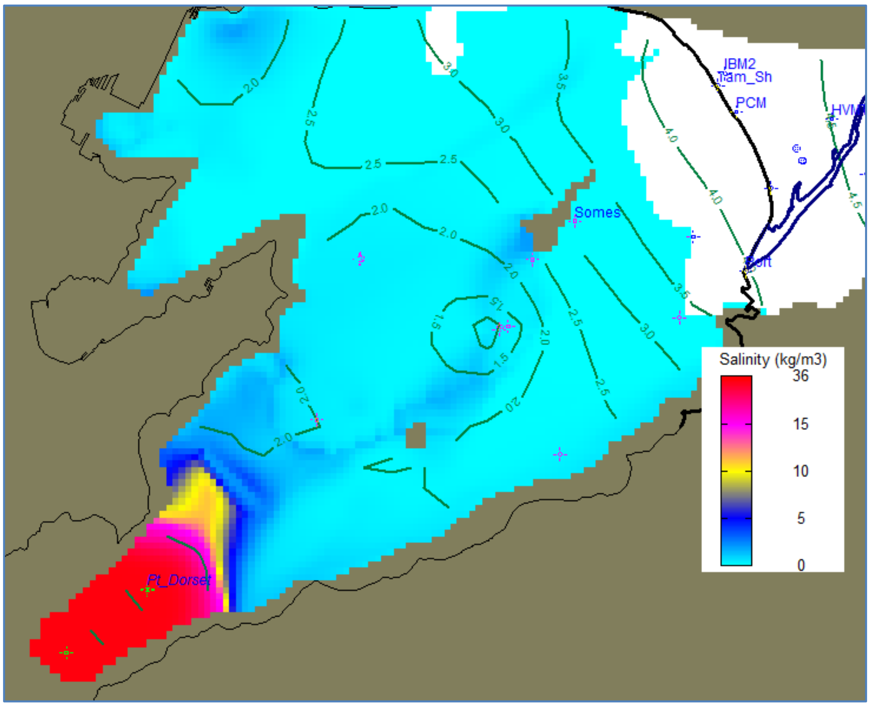

Figure 8.10 Scenario 3 – Salinity distribution in the upper Waiwhetu Aquifer when E8 is abstracting at 20MLD and Waterloo at 40MLD. Groundwater level contours also shown (m amsl).

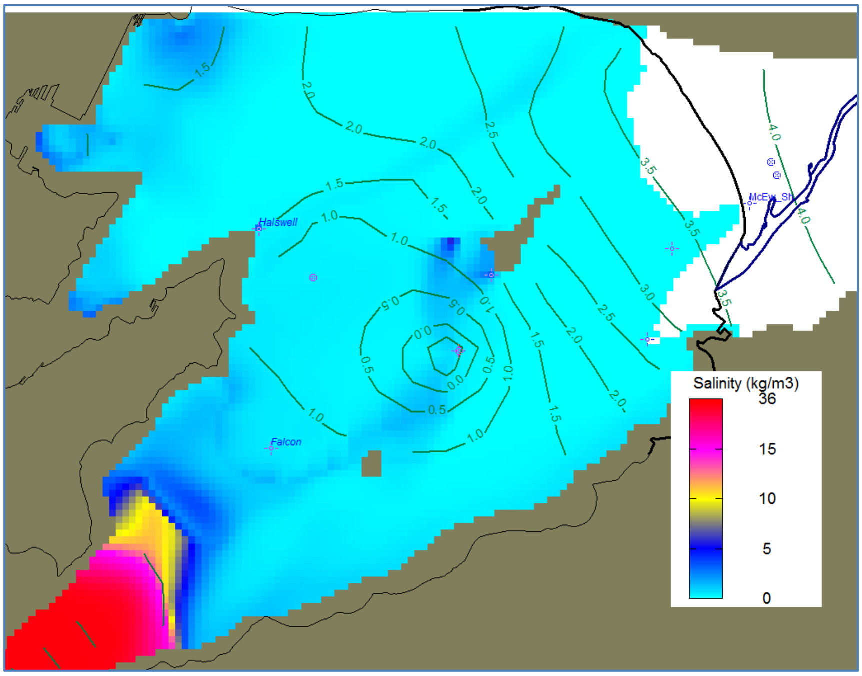

Figure 8.11 Scenario 8 – Salinity distribution in the upper Waiwhetu Aquifer when E8 is abstracting at 30MLD and Waterloo at 40MLD showing saline intrusion at the Somes Island springs as well as salinisation from the lower Waiwhetu Aquifer. Groundwater level contours also shown (m amsl).

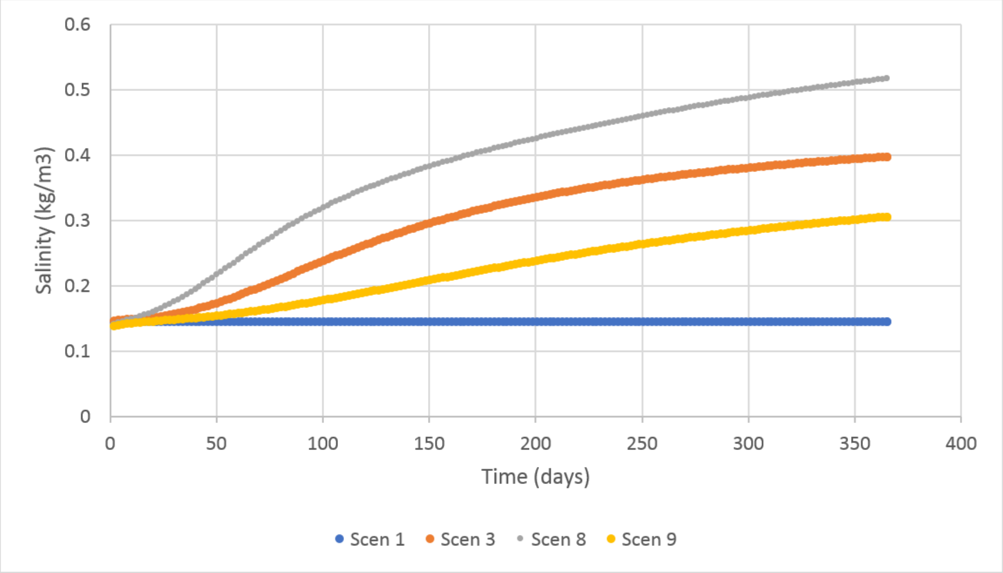

Figure 8.12 Modelled salinisation trends of Bore E8 in UWA as a result of brackish water contamination from the LWA for different scenario runs (alternative model calibration).

8.6 Summary of model calibration versions

The alternative model calibration has been carried out to investigate whether the simulated saline intrusion risks characterised using the main model calibration would be sensitive to a different plausible representation of the flow dynamics in the offshore Waiwhetu Aquifer. In general, comparison of the scenarios results from the two calibrations show that there is no significant increased change in saline intrusion risk when the two calibrations are compared. Both are predicting the potential activation of an aquifer cross-contamination salinisation mechanism of a similar order of magnitude.

9. Further modelling: Calibration/uncertainty analysis and using the HAM4 model to test selected hypotheses

This chapter and the associated Appendix 10 are authored by GNS Science.

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Further modelling has been carried out by GNS Science to explore in more detail the identified salinisation risk from the lower Waiwhetu Aquifer. This modelling work comprised an analysis of the uncertainty associated with model outputs, which underpin the recommendations made in the previous chapters. This work, and the recommendations for additional modelling work arising from it, are described further in Appendix 10.

Stochastic calibration attempts using the HAM4 model encountered numerical instability and excessive model run times. These factors significantly compromised the model's ability to provide a robust basis for quantifying uncertainty and risk (which involves many model evaluations with different parameter sets). Furthermore, it was shown that some critically important observed phenomena, namely the existence of brackish water in the lower Waiwhetu aquifer and its absence in the upper Waiwhetu aquifer, was not able to be reproduced by the existing form of the HAM4 model. See Appendix 10 for details. This is a critical finding, which ultimately meant that that the model cannot be used as a basis for quantifying risk, nor to test the hypothesis of salinisation of the upper Waiwhetu aquifer at E8 in response to abstraction. This in-turn meant that the hypothesis that the upper Waiwhetu aquifer at E8 will become salinised in response to abstraction could not be rejected on the basis of the HAM4 modelling.

However, the above limitations should not be construed as criticism of the HAM4 model and its application in previous chapters. These limitations simply recognise the problems that the model faces in simulating complex flow and transport conditions in sufficient detail over a large model domain, and that purpose-driven, prediction-specific models are required for exploration and understanding of local processes (e.g., local-scale aquifer heterogeneities and its impact of drawdown and thus vertical hydraulic gradients) that a regional model can represent only in an approximate fashion (see recommendations for future modelling below). The HAM4 model was designed to explore the veracity of the offshore aquifer/geological conceptualisations and evaluate a range of potential salinisation risks and regional-scale responses to abstraction in terms of drawdown and salinity distributions. It was designed to be a "whole-system" model recognising that onshore and offshore systems are intimately associated and that onshore stresses (i.e., recharge and onshore abstraction) need to be considered in a risk assessment. The HAM4 model has been successful in exposing a potential salinisation risk mechanisms (i.e., from the lateral ocean/aquifer boundary and brackish water mixing from the underlying lower Waiwhetu Aquifer at E8). The modelling results presented in chapters 7 and 8 identified that the principal salination risk relates to the upward migration of brackish water from the lower Waiwhetu Aquifer which could contaminate a supply well located in the upper Waiwhetu Aquifer at E8 (a potential 'fatal flaw'). However, the HAM4 model was not designed solely for the purposes of a detailed and localised assessment of upward salt migration at E8 in response to abstraction and is therefore limited by the factors described above.

Considering the limitations of the regional HAM4 model discussed above and considering the remaining need for a robust probabilistic risk assessment of potential aquifer salinisation (following upward advection from the brackish lower Waiwhetu aquifer), additional modelling is recommended. This would take the form of a “streamlined”, prediction- and decision-targeted modelling approach, designed specifically from the outset to be able to quantify risk and test (and potentially reject with some level of confidence) the hypothesis that the upper Waiwhetu aquifer will become salinised and be rendered unpotable from upward flow of the brackish water in response to abstraction. The use of a simpler, smaller-scale, fast-running model would allow rapid exploration of the risk associated with abstraction from E8. This would include reliable simulation of the rate at which salt travels from the lower Waiwhetu and into the upper Waiwhetu in response to abstraction, which will depend on the extent of local drawdown and the vertical hydraulic conductivity of the intervening aquitard (or possible absence of the aquitard). It would also include reliable simulation of the mixing of the salt transported from below with the large amount of freshwater being drawn horizontally to the abstraction well through the upper Waiwhetu aquifer.

The model would also provide a basis for exploring the following factors (among others):

- local hydraulic property variability both of the aquifer and underlying aquitard;
- extent of lateral continuity of the aquitard, and/or of holes in the aquitard;
- impact of different rates of extraction from the upper Waiwhetu aquifer;
- relative risks of pumping impacts at 1 month, 6 months, 12 months, etc.

Such a model would also possess a greater flexibility to assess alternative abstraction scenarios such as whether pumping takes place from one of a number of wells (the latter scenario presumably reducing local drawdown and hence upward salt movement) and would assist in the design of further exploration activities.

The proposed model would provide an enhanced potential for the reduction in uncertainty of local hydraulic properties and hence model predictions based on the utility of detailed data available from well pump tests for calibration.

10. Discussion, limitations and recommendations

The hydrogeological analysis and modelling presented in this study, based on the first stage (SP1a) Wellington Harbour exploration activities, examines the feasibility of sub-harbour groundwater abstraction.

The HAM4 SEAWAT model has been used to simulate a series of abstraction and sensitivity scenarios to provide guidance on the potential sustainable yield from the Waiwhetu Aquifer beneath the harbour and to identify any potential 'fatal flaws' in the proposal in terms of saline intrusion risk.

10.1 Model Limitations

The offshore HAM4 model is unavoidably heavily based upon geological and hydrogeological conceptualisation, supported by geophysical surveys and field data derived from the two exploratory bores. As such, it should be appreciated that there is a high degree of uncertainty regarding the modelled interpretation of the sub-harbour hydrogeological environment.

The Waiwhetu aquifer is considered to be highly heterogenous at both local (10's-100's metres) and at larger (100's-1000's metres) scales. Since characterisation of the heterogeneity is not possible (both onshore and offshore), the modelling necessarily assumes homogenous aquifer property zones. In reality, aquifer heterogeneity, in particular the presence of localised preferential flow pathways, is likely to strongly influence the movement of groundwater and salinity through the aquifer.

An important limitation of the HAM4 SEAWAT model is that it also has a high degree of uncertainty in the estimation of salinity concentrations and time lags due to the assumptions and simplifications made in the model conceptualisation, its regional or 'whole system' scale, parameter assignment and calibration. However, the HAM4 has proved useful in contributing to the risk and fatal flaw assessment by identifying the activation of potential saline intrusion pathways and contamination trends.

In the context of uncertainty, the confidence classification of the model is not high enough to forward a confident estimation of a sustainable (safe) aquifer yield. The yield estimates presented here should be viewed as representing a broad conservative range. More detailed uncertainty and sensitivity modelling (as recommended by GNS Science – see Chapter 9 and Appendix 10), could provide an improved risk assessment and enhance the decision-making potential of the modelling in terms of aquifer yield and saline intrusion risks.

10.2 Salinisation risks

A principal salinisation risk associated with abstraction from the offshore Waiwhetu Aquifer is seawater invasion of the upper Waiwhetu Aquifer through submarine spring vents and through the weak aquitard materials on the eastern (Eastbourne) margin of the harbour. This could occur if abstraction rates, and therefore aquifer drawdowns, are excessive. This is a principal constraint on the sub-harbour groundwater abstraction rate. The 'backflow risk' risk can be managed by restricting abstraction rates and will only represent a fatal flaw if the pumping rates prove insufficient to make the project viable. This cannot be confirmed using currently available information. A sea level rise scenario (assumed 1m rise) indicates that the potential aquifer yield would not change significantly.

Evidence from the exploration bores and the HAM4-SEAWAT model indicates that seawater resides in the sub-harbour Waiwhetu and that a diffuse mixing zone with pure seawater possibly occurs between the Falcon Shoals area and Point Dorset. The location of the interface is shown to be sensitive to onshore and offshore abstractions and is pulled closer into the Falcon Shoals area from the south when abstractions are increased significantly. The drawdown effects from any large abstraction in the onshore and offshore groundwater system extend into this area and would therefore affect the interface position - which seems to naturally occur about 1km further south than it is under the current abstraction regime onshore.

Evidence from the exploration bores shows that the main (central) part of the sub-harbour Waiwhetu Aquifer contains very dilute seawater (at about a 0.3-0.5% dilution) but at low enough concentrations in the upper Waiwhetu Aquifer (at E3a, E8 and Somes Island) to allow the water to be used for potable purposes. The HAM4 modelling indicates that it is plausible that the low salinity levels observed throughout the upper Waiwhetu Aquifer (E8 and E3) are caused by the dispersion of saltwater from an ocean source. The highly brackish water observed in the lower Waiwhetu Aquifer at E8 (850-900mg/L Cl; 4.5% seawater) possibly also represents the tip of a diffuse saline mixing zone with higher concentrations, extending south into the harbour entrance area. The brackish water and the overlying fresh water in the upper Waiwhetu aquifer could exist in a state of fragile equilibrium - which might be disturbed through abstraction from a bore located in the upper Waiwhetu Aquifer.

An important aspect of the SEAWAT modelling analysis was therefore to examine whether the salinized water observed in the lower Waiwhetu Aquifer at E8 may cross-contaminate the upper Waiwhetu Aquifer and enter the abstraction bore (and also possibly contaminate the Somes Island water supply bore). Since the base of the upper Waiwhetu aquifer (at about 29m below the sea bed) has a very small vertical separation distance from the top of the lower Waiwhetu gravels (33m deep) of only about 3.5m, and recognising that the immediate lateral continuity and integrity of the intervening sandy silt aquitard is tenuous, there is conceptually a significant risk of aquifer cross-contamination.

The HAM4 model could not simulate the brackish water in the lower Waiwhetu Aquifer at E8 and therefore could not provide an insight to the origin of the salinity, its mobility or its spatial variability. Regardless of its origin, an assumption, based on observation, has been made that the lower Waiwhetu aquifer contains an extensive body of brackish water (1,000mg/L chloride – a concentration of about 850-900 mg/L was recorded at E8 during drilling). It is acknowledged however that higher or lower salinity concentrations may occur at different locations ad that they may change over time if the aquifer is impacted by drawdown effects associated with abstraction from the upper Waiwhetu aquifer.

SEAWAT abstraction scenario modelling at rates of 10-30MLD from the E8 site has indicated that saline water from the lower Waiwhetu Aquifer would migrate into the upper Waiwhetu Aquifer and into the pumped bore. Low concentration saline water (estimated to be about 250- 350mg/L chloride after one year of pumping (but see the caveat on salinity accuracy prediction below) is drawn into the bore and also over a wider area of the upper Waiwhetu gravels. Figure 7.41 shows that the salinisation occurs at all pumping rates and would continue to rise if pumping were to continue for longer. The salinisation pathway appears to be around the intervening aquitard where it is assumed to thin out to the north and east of E8, or through the aquitard unit where it becomes more heterogenous. Some scenarios indicate a lag time of 50-60 days until salinity concentrations begin to increase, but other scenarios show a much smaller lag time.

Although SEAWAT cannot accurately predict the salinity concentrations induced into the overlying aquifer or the time lags, it does show that a salinisation mechanism is potentially activated when abstraction from the upper aquifer occurs and that the effects may extend over a wide area, even at lower pumping rates. The increase in salinity may be low enough to ensure that the water remains potable, or it may take a long period of time to occur. But there is also the risk that it may render the upper Waiwhetu Aquifer non-potable at the bore site and over a wider area. It is also possible that under abstraction stress, the salinity of the lower Waiwhetu Aquifer may also increase over time resulting in a higher degree of contamination in the upper Waiwhetu Aquifer. It is not possible to confidently predict such effects using the HAM4 model and on the basis of currently available information.

A better understanding of the range of uncertainty inherent in the model predictions and the probability of salinisation causing the Upper Waiwhetu aquifer to become unpotable could be provided by the predictive uncertainty analysis proposed by GNS Science.

It is evident that insufficient physical information exists at this stage and the only way to provide certainty regarding the cross-aquifer salinisation and other risks is to undertake further exploration work which would need to include a full scale, extended duration pump testing accompanied by appropriate monitoring of the resource.

10.3 Provisional yield estimation and yield constraints

The E8 site is considered to be the most favourable general location for abstraction as it is regarded to take advantage the good aquifer thickness, transmissivity and water quality properties, whilst avoiding known saline intrusion risks from the overlying ocean and seismic hazards. The lower Waiwhetu Aquifer is not viable at either the E8 site (it is brackish and unpotable) or at the E3a site (the aquifer is too thin, exhibiting a low yield and poor water quality).

The results of the SEAWAT abstraction scenarios from the upper Waiwhetu aquifer are contained in Table 7-4. The scenarios represent a range of pumping rates from the E8 site and from the Waterloo Wellfield. The Waterloo wellfield is simulated at a lower pumping rate of 25-40MLD to satisfy anticipated reduced demand during times when the offshore source would be required.

The abstraction scenarios from the E8 bore indicate that, solely from an ocean-sourced saline intrusion risk perspective, that between about 10-20MLD could be abstracted – with the higher end of the range being attainable at lower Waterloo pumping rates.   The model results suggest that this abstraction range would prevent aquifer pressures at critical sites beneath submarine spring vents and levels on the eastern side of the harbour (Eastbourne coastline) dropping below critical thresholds thereby preventing invasion by seawater. This yield assessment however does not consider the risk of aquifer cross-contamination (from the brackish lower Waiwhetu Aquifer) – management of this risk may require that the yield is further restricted as discussed above.

It should be stressed that the simulated aquifer drawdowns, and therefore yield assessments, are based upon an unverified aquifer transmissivity for the upper Waiwhetu Aquifer (regarded to be conservative). The E8 abstraction rates could be more confidently assessed on the basis of a full-scale pumping test at E8 and the yield revised upwards should a higher aquifer transmissivity than conservatively assumed is shown. It should also be appreciated that a pumping test accompanied by monitoring of water quality and levels and subsequent modelling may also result in the recommendation of a lower yield than this.

10.4 Fatal flaw assessment

In terms of a ‘fatal flaw’ assessment, the HAM4 model indicates that dilute saline contamination of the freshwater upper Waiwhetu aquifer from the underlying brackish lower Waiwhetu Aquifer could occur as a result of abstraction in the vicinity of E8. This is because abstraction from the upper Waiwhetu aquifer causes a drawdown in aquifer pressures which results in an upwards hydraulic gradient from the lower Waiwhetu Aquifer. This may be viewed as a potential fatal flaw since even at lower pumping rates (Waterloo and E8) this risk remains evident. The salinity concentrations in the lower Waiwhetu Aquifer could also increase over time if the observed brackish water represents the edge of a diffuse mixing zone associated with the harbour entrance saline interface – in which case the cross-contamination of the upper Waiwhetu Aquifer may also increase over time. Mixing of salinized water from the lower Waiwhetu Aquifer may either significantly limit the amount of water that could be abstracted from the upper Waiwhetu Aquifer, or entirely prevent abstraction.

Should salinisation occur, it is also possible that it would be irreversible since the aquifer throughflow dynamics are very slow beneath the harbour. If a fragile equilibrium exists between the water quality of the two aquifers, a pumping induced mixing effect may not be easily reversed, or may take considerable time.

Conceptually, the very close proximity of an underlying brackish aquifer to the fresh upper Waiwhetu resource (separated by only 3.5m of silt aquitard) and the anticipated diminishment of the aquitard nearby, raises considerable concern. There could be merit in exploring different options for abstracting groundwater from the upper Waiwhetu Aquifer so that drawdowns are minimised – such as horizontal collector wells or an array of low yielding wells – that would reduce the risk of aquifer cross contamination or saline intrusion by reducing aquifer drawdown.

Since the uncertainties and assumptions inherent in the modelling are high – the degree of salinisation and time lags – may be significantly higher or lower than predicted. More confidence can be placed in the fact that the model indicates the activation of a saline intrusion mechanism however – rather than its magnitude and time lag. Further detailed uncertainty modelling proposed by GNS Science may further elucidate the risk and provide additional decision-making support. But ultimately, it will be necessary to physically pump test a production bore at full capacity for a long period of time and monitor the aquifer closely to gain sufficient confidence and prove that this is a reliable water source.

It should be noted that there is a possible risk that an extended test pumping (as recommended below) could also result in salinisation of the upper Waiwhetu Aquifer. If this were to occur, it is possible that the contamination may persist for a significant period of time (or be 'irreversible') and may even impact the Somes Island supply. A carefully designed monitoring and pump management regime is therefore necessary to minimise the risk of such an occurrence during any testing activities at high abstraction rates.

10.5 Recommendations for further investigation

It is currently recognised that there is insufficient physical information to confidently assess the risk associated with the identified potential fatal flaw (cross-aquifer contamination) and increase confidence in the risk of abstracting from the offshore resource generally. The following activities are considered necessary in order to provide sufficient information and reduce uncertainty:

10.5.1 Additional modelling (GNS)

Should a decision be made to proceed with investigations, it is recommended that an initial step would be to proceed with the additional modelling recommended in Chapter 9 and Appendix 10 by GNS Science. Modelling may proceed in parallel with field exploration activities to provide ongoing guidance and decision-making support.

The modelling may help elucidate the cross aquifer salinisation risk and at the same time provide guidance for the design and siting of additional exploration, pumping and monitoring bores. Optimal monitoring designs can be guided using a "data worth" analyses whereby the worth of head/drawdown/salinity observations at various potential monitoring well locations are evaluated with respect to their ability to reduce the uncertainty surrounding predictions of salinity or head changes (following abstraction)[8]. The investment in monitoring wells and their longer-term function (e.g., to monitor salinity changes over time) may warrant such a relatively straightforward analysis.

A further purpose of modelling could be to assess whether potential risks could be reduced by adopting feasible alternative abstraction methodologies - for example, investigation of the technical and economic feasibility of using an array of low yielding wells, or a horizonal collector well in the upper Waiwhetu Aquifer.

10.5.2 SP2 exploration stage recommendations

Should a decision be made to proceed with a second SP2 exploration phase to increase confidence in the abstraction feasibility and risk assessment, the following staged recommendations for exploration activities are forwarded. It should be appreciated that there would be a possibility that the outcomes of further field and modelling investigations may confirm a fatal flaw and a recommendation that offshore abstraction should not be considered:

- ***Second phase of exploration drilling targeting the E8 area***: Prior to construction of production/test bores, additional exploration drilling is recommended to improve hydrogeological knowledge of the sub-harbour groundwater system to the east of Somes Island and towards Falcon Shoals. Drilling of c. 3 exploration bores in the general E8 area (within 1km or so) to the top of the Wilford Shell bed would provide valuable information regarding the wider aquifer conditions and characterise the lower Waiwhetu water quality and intervening aquitard. This information would be used to guide the optimal placement of a test pumping well. Consideration should be given to designing exploration bores so that they could be converted to monitoring wells;

- ***Exploration test pumping and modelling update:*** Selected pumping tests should be carried out in the lower and upper Waiwhetu aquifers during the exploration drilling. Comprehensive water quality sampling should also be undertaken. This should be followed by refinement of geological and geophysical interpretation and reviewing/updating the conceptual and numerical modelling. A decision would be made on the basis of this information whether to proceed to the construction of a full-scale production test bore;

- ***Production test bore construction and initial test pumping:*** A single production scale test bore should be drilled and pump tested to provide confirmation of aquifer hydraulic properties and water quality. This bore should be designed to abstract at a rate high enough (c. 120L/sec?) to stress the aquifer sufficiently so that robust aquifer properties can be obtained. During the pumping test, the water quality in the upper and lower Waiwhetu aquifers should be closely monitored to ensure that salinisation of the upper Waiwhetu Aquifer is avoided. Pumping should cease if an increasing salinity trend is detected. This will require that at least one monitoring bore is constructed during this stage. Modelling analysis should then be updated on the basis of this information. A decision wold be made on the basis of this information as to whether to proceed to the long-term test pumping stage;

- ***Long-term test pumping:*** A staged long-term pumping test should be carried out for an extended duration at the intended production capacity (ideally over several months representing the duration over which to bore(s) is likely to be used). This may require construction of an additional production bore. Testing should ideally be carried out when it is possible to reduce and manage the abstraction rate from the Waterloo wellfield (during average recharge conditions). The production test bores should be equipped to continuously monitor aquifer pressure, salinity and flow rate using a telemetry system, and should be

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[8] See https://pubs.usgs.gov/sir/2010/5159/pdf/sir20105159.pdf for a data worth example.

intermittently sampled to show water quality trends. During the pumping test, the water quality in the upper and lower Waiwhetu aquifers should be closely monitored to ensure that salinisation of the upper Waiwhetu Aquifer is avoided (at two observation bores, Somes Island, Point Howard and Port Road). Pumping should cease if an increasing salinity trend is detected;

- ***Observation bore construction:*** At least two dedicated observation bores should be installed to continuously measure aquifer levels and salinity/electrical conductivity in both the upper Waiwhetu and lower Waiwhetu aquifers. One should be constructed for the initial short-term test and the second installed prior to the long term test;
- ***Somes Island bore monitoring:*** The Somes Island water supply bore should be equipped to continuously monitor electrical conductivity/salinity using the current GWRC telemetry system;
- ***Port Road monitoring bore re-instatement and possible additional site on Point Howard Wharf:*** The existing GWRC foreshore Port Road monitoring bore should be re-instated and equipped to automatically monitor water level and electrical conductivity. Consideration should also be given to constructing a new monitoring site off the end of the Point Howard Wharf (in close proximity to the Seaview submarine springs – a principal saline intrusion risk location);
- ***Modelling:*** Additional numerical modelling should be carried out during and upon completion of the field exploration works.

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Wellington Water Limited

Wellington Harbour Exploration Bores Project

Hydrogeological Analysis of SP1a Exploration Phase: Abstraction Feasibility Assessment & Recommendations

Appendix Volume

APPENDIX 1:	Geological and geophysical summary report (NIWA/GNS)
APPENDIX 2:	Field investigation methodology
APPENDIX 3:	Data analysis methodology
APPENDIX 4:	Groundwater monitoring hydrographs
APPENDIX 5:	Pumping test results
APPENDIX 6:	Water quality laboratory test results
APPENDIX 7:	Hydrochemistry assessment (GNS)
APPENDIX 8:	Age dating results (GNS)
APPENDIX 9:	Site photographs
APPENDIX 10:	Additional GNS modelling: Calibration/uncertainty analysis and hypothesis testing

Final Report: 30/5/2018

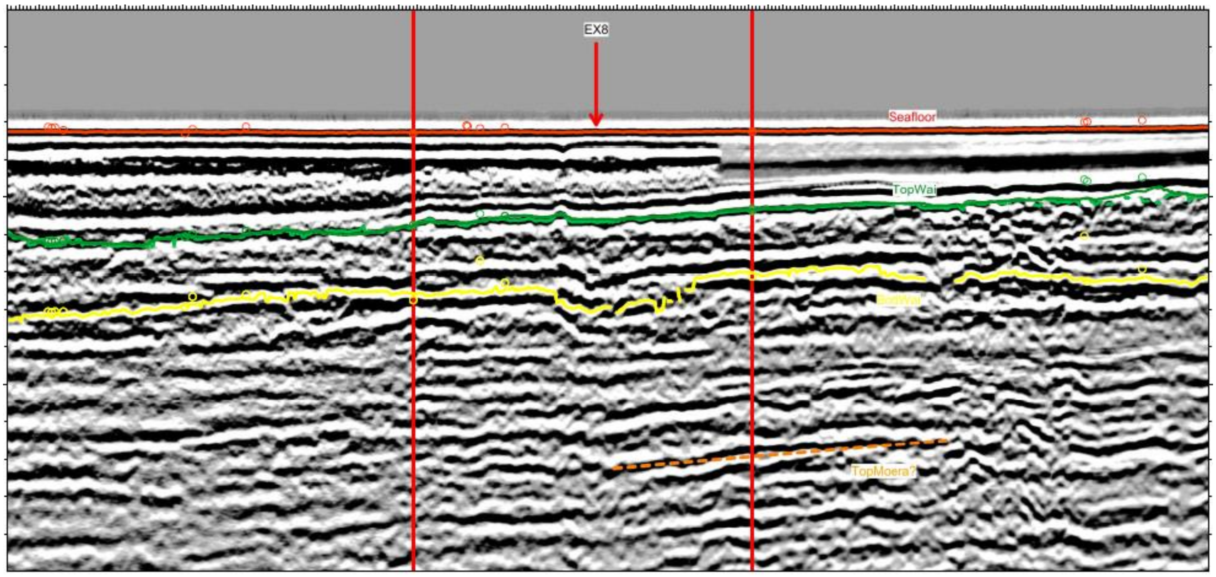
APPENDIX 1: Geological and geophysical summary, Te Whanganui a Tara/Wellington Harbour (NIWA)

Geological and geophysical summary, Te Whanganui a Tara/Wellington Harbour

Development of the Geological Model for hydrogeological investigations

Prepared for Stantec MWH/Wellington Water Ltd

May 2018



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Contents

Tables

Figures

Executive summary

In 2017-18, offshore boreholes were drilled to determine the potential efficacy of extracting groundwater from the Waiwhetu Artesian Gravels from sites in Te Whanganui a Tara/Wellington Harbour. The selection of the two borehole sites (E3/3A and E8) involved scrutiny of many features identified from previously collected marine geophysical seismic reflection lines, which were then integrated with the lithological logs from existing and new borehole observations. The end product is a revised conceptual geological model, summarised herein, for incorporation into the HAM (Hutt Aquifer Model) groundwater model, operated by Earth in Mind Ltd.

Historical marine seismic-reflection data, collected in the 1990's by GNS Science, and new offshore data acquired and interpreted by NIWA in 2015-16 for Stantec MWH and Wellington Water Ltd were the main datasets used in the current study. Interpretations of these data provide evidence that the Waiwhetu Artesian Gravels extends offshore from Petone-Seaview, on the northeastern side of the harbour, beneath the harbour floor towards Te Motu Kairangi/Miramar Peninsula and southwards towards the harbour entrance.

The new boreholes drilled through the surficial marine harbour muds (Petone Marine Beds, 0-10.5 ka, marine Isotope Stage (MIS) 1, Holocene) and confirmed the depth to the top of the aquifer at 22.9 m below the seafloor off Kau Bay (E3/3A) and 18.3 m south of Matiu/Somes Island (E8). The marine transgression was very rapid ~10,500 years ago at the end of the last glacial period, and flooded across the upper surface of the fluvial gravel beds of the upper Waiwhetu gravels (10.5-71 ka, MIS 2-4). The base of the upper Waiwhetu Artesian Gravels is at 27.75 m below the sea floor at E3/3A and at 29.3 m at E8. At E3/3A the upper Waiwhetu Artesian Gravels are underlain by 17.25 m of predominantly fine-grained materials (here referred to as intra-Waiwhetu silt) to a depth below the sea floor of 45 m. At E8, while present, this unit is only 3.5 m thick. This relative thickness of this unit at E3/3A suggests that the western part of the harbour basin was occupied by a swamp or lake during at least the middle part of the last glacial period. The lower Waiwhetu Artesian Gravel underlies the silt from 45 to 48 m at E3/3A and between 32.8 and 43.7 m below sea floor at E8. The Wilford Shell Bed underlies Waiwhetu Artesian Gravels at both sites, from 48-74.5 m below sea floor at E3/3A and from 43.7-61 m at E8. The unit is appreciably thinner at E8 than at E3/3A. The top of Moera Basal Gravels was intersected at 74.5 m below sea floor at E3/3A and at 61 m at E8.

From these new borehole data, we infer that the subsurface Waiwhetu Artesian Gravels is likely to be poorly represented east of Matiu/Somes Island, although there are insufficient data to fully confirm this interpretation. The Waiwhetu Artesian Gravels dips southwards (deepens) in the northern part of the basin but thins towards the harbour entrance. The overlying Holocene harbour muds become intercalated with gravels and sands that prograde northwards from the harbour entrance towards Falcon Shoals. There is evidence south of these shoals that subsurface units, including the Waiwhetu Artesian Gravels, become progressively shallower, suggesting the influence of recent faulting and regional tectonic uplift (essentially from east to west) across this area of the harbour.

In addition, lithological information from the boreholes better constrains the geophysical interpretations and ground-truths depth-conversions for the 2015-16 seismic reflection profiles. These interpretations are consolidated herein into a conceptual understanding of how the sedimentary systems developed within Te Whanganui a Tara/Wellington Harbour over the past ~130,000 years. This geological model informs the parameterisation of the HAM hydrogeological model, developed for the aquifer system throughout the harbour basin and adjacent Hutt Valley.

1 Introduction

Stantec MWH, on behalf of Wellington Water Ltd (WWL), are the project leaders for the offshore exploratory drilling component of WWL's Resilience project, which aims to mitigate the potential effects of earthquakes and other natural geological hazards on the groundwater resources and water reticulation infrastructure of the Wellington region.

Throughout 2017 and the first part of 2018, the National Institute of Water and Atmospheric Research Ltd (NIWA) and the Institute of Geological and Nuclear Sciences Ltd (GNS Science) provided geological and geophysical advice to the Stantec MWH-WWL project. We advised on the location of two new offshore exploratory boreholes in Te Whanganui a Tara/Wellington Harbour and the derivation of a new geological model for incorporation into the next phase of hydrogeological modelling (Hutt Aquifer Model version 4, HAM4), as operated by Earth In Mind Ltd.

The present report summarises the geological and geophysical data and interpretations derived over the course of the project.

2 Geological setting

2.1 Tectonic setting

New Zealand sits astride the active transpressional boundary zone between the Pacific and Australian crustal plates (Figure 2-1). This plate boundary is complex, with westward-directed subduction of the Pacific Plate beneath the Australian Plate under the North Island/Te Ika a Maui, and eastward directed subduction of the Australian Plate beneath the Pacific Plate to the south of the South Island/Te Waipounamu. These two subduction zones are linked through the South Island by the predominantly strike-slip Alpine Fault and Marlborough fault system. The surface expression of the tectonic boundary, the Hikurangi Trough, lies 85 km to the southwest of Wellington Harbour/Te Whanganui a Tara. However, the primary boundary between the plates is a gently west-dipping fault that underlies Wellington City itself at a depth of about 25 km. Plate convergence in the Wellington area is about 41 mm/year at an azimuth of c. 260˚ (DeMets et al. 1994).

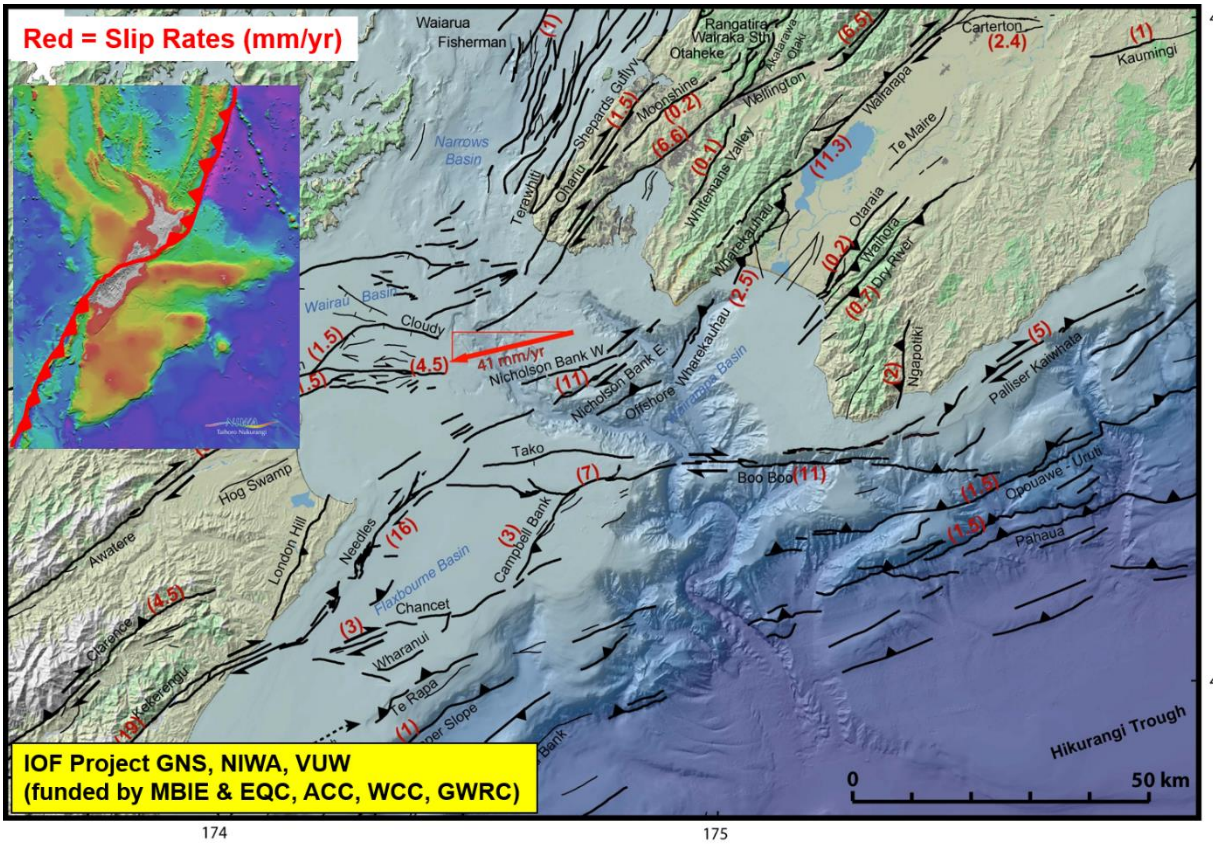

Figure 2-1: The Te Moana o Raukawa/Cook Strait region includes the surficial boundary between the Australian and Pacific plates. The rugged geomorphology (topography and bathymetry hillshades) is traversed by numerous active faults (after Barnes et al. 2008). The plate vector of the Pacific Plate relative to the Australian Plate of 41 mm/yr is shown in central Cook Strait (DeMets et al. 1994). Slip rates (mm/yr) for individual faults are shown in red brackets. Inset: The Australian Plate lies to the west and the Pacific Plate to the east of the toothed line that marks the position of the plate boundary through the New Zealand subcontinent. IOF = It's Our Fault, GNS = Institute of Geological and Nuclear Sciences (GNS Science), NIWA = National Institute of Water and Atmospheric Research, VUW = Victoria University of Wellington, MBIE = Ministry of Business, Innovation and Employment, EQC = Earthquake Commission, ACC = Accident Compensation Commission, WCC = Wellington City Council, GWRC = Greater Wellington Regional Council.

Over the past 20 years, geodetic and geophysical studies have more accurately located the plate interface and documented a slip deficit beneath the Wellington region (e.g., Barnes and Audru 1999; Wallace et al. 2004; Nicol and Wallace 2007; Nodder et al. 2007; Barnes et al. 2008; Wallace et al. 2009; Eberhart-Phillips and Reyners 2012; Reyners et al. 2017). This slip deficit indicates that the subduction interface is locked beneath the Wellington Peninsula and that it is a significant source of "great" earthquakes; i.e. > magnitude (M) 8.

Compounding the seismic hazard presented by this plate interface source are a series of southwest–northeast trending active faults that extend through the area. These faults propagate through the upper plate (the Australian Plate), many of which are likely to bottom out on the plate interface fault (Figure 2-1, Figure 2-2). These faults extend all the way to the surface, are mostly strike-slip in character (slip vector is sub-horizontal) and include the Shepherds Gully, Ohariu (Heron et al. 1998; Litchfield et al. 2006), Moonshine (Begg and Van Dissen 2000), Wellington (Berryman 1990; Little et al. 2010; Langridge et al. 2011) and Wairarapa faults (Little et al. 2009).

A second suite of faults in the Wellington Harbour area are orientated approximately north-south (Figure 2-2); a growing body of evidence indicates that a number of these faults are also active, although not capable of generating earthquakes of the same magnitude as the major strike-slip faults in the region. These secondary structures include the Whitemans Valley (Begg and Van Dissen 1998), Aotea (Barnes et al. 2014), Evans Bay (Lewis and Carter 1976; Lewis and Mildenhall 1985), Somes Island (Wood and Davy 1992; Davy and Wood 1993) and Ward Island faults (Wood and Davy 1992; Davy and Wood 1993).

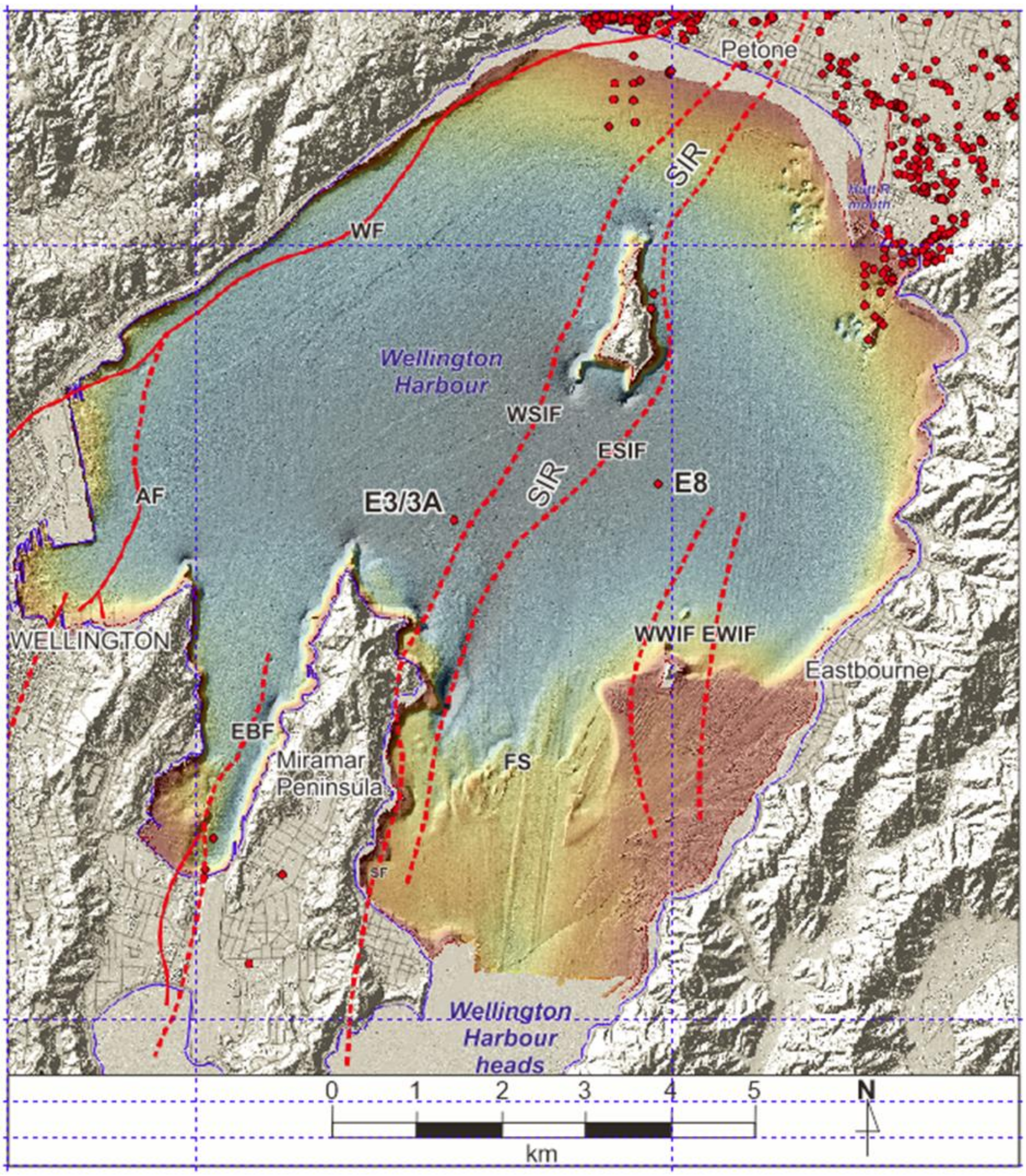

Figure 2-2: Known active faults and postulated faults (likely to be active) in Wellington Harbour. Known active faults (solid red lines) are from the Active Faults Database (held by GNS Science) and postulated active faults are compiled here (red dashed lines) from Wood and Davy (1992) and recent NIWA seismic reflection data (Barnes et al. 2014). Bathymetry is an elevation grid derived from NIWA point depth data. Boreholes in GNS Science's database are shown as red dots. FS=Falcon Shoals; SIR=Somes Island ridge; WF = Wellington Fault; AF=Aotea Fault; EBF=Evans Bay Fault; WSIF= Western Somes Island Fault; ESIF= Eastern Somes Island Fault; WWIF= Western Ward Island Fault; EWIF=eastern Ward Island fault; SF=Seatoun Fault.

With a few areas of exception, much of the Wellington region has been in an overall state of uplift over the last 4 million years (4 Ma) due to faulting activity related to the structural evolution of the Pacific-Australia plate boundary beneath the southern part of the North Island/Te Ika a Maui. The result of this uplift is that there are few areas where sediments younger than this are preserved onshore, having been progressively stripped away by terrestrial erosion. Some notable exceptions include the Upper Hutt (terrestrial sediments), Lower Hutt and Port Nicholson basins where terrestrial and shallow marine to swampy sediments and landslide colluvium and alluvial gravels are preserved overlying Mesozoic greywacke basement rocks.

2.2 Te Whanganui a Tara/Wellington Harbour

Te Whanganui a Tara/Wellington Harbour is a moderately sized (85 km^2), enclosed tidal embayment at the southernmost North Island/Te Ika a Maui, New Zealand (Figure 2-3). The harbour margins are steep and bounded on its western flank by the Wellington Fault. On its eastern extent is the steep, uplifted topography that form the hills on the western side of the Wainuiomata basin, representing the westernmost extent of the southern section of the Remutaka Range. The rugged coastline along the south coast of the Wellington peninsula, between Sinclair Head in the west to Turakirae Head in the east, is indented by many shallow, southward-facing embayments, of which Wellington Harbour is the largest and the most constrained. The continental shelf along the Wellington south coast is typically less than 10 km wide, descending southward to depths of more than 1 km in the Te Moana o Raukawa/Cook Strait canyon system (e.g., Mitchell 1996; Mackay et al. 2009).

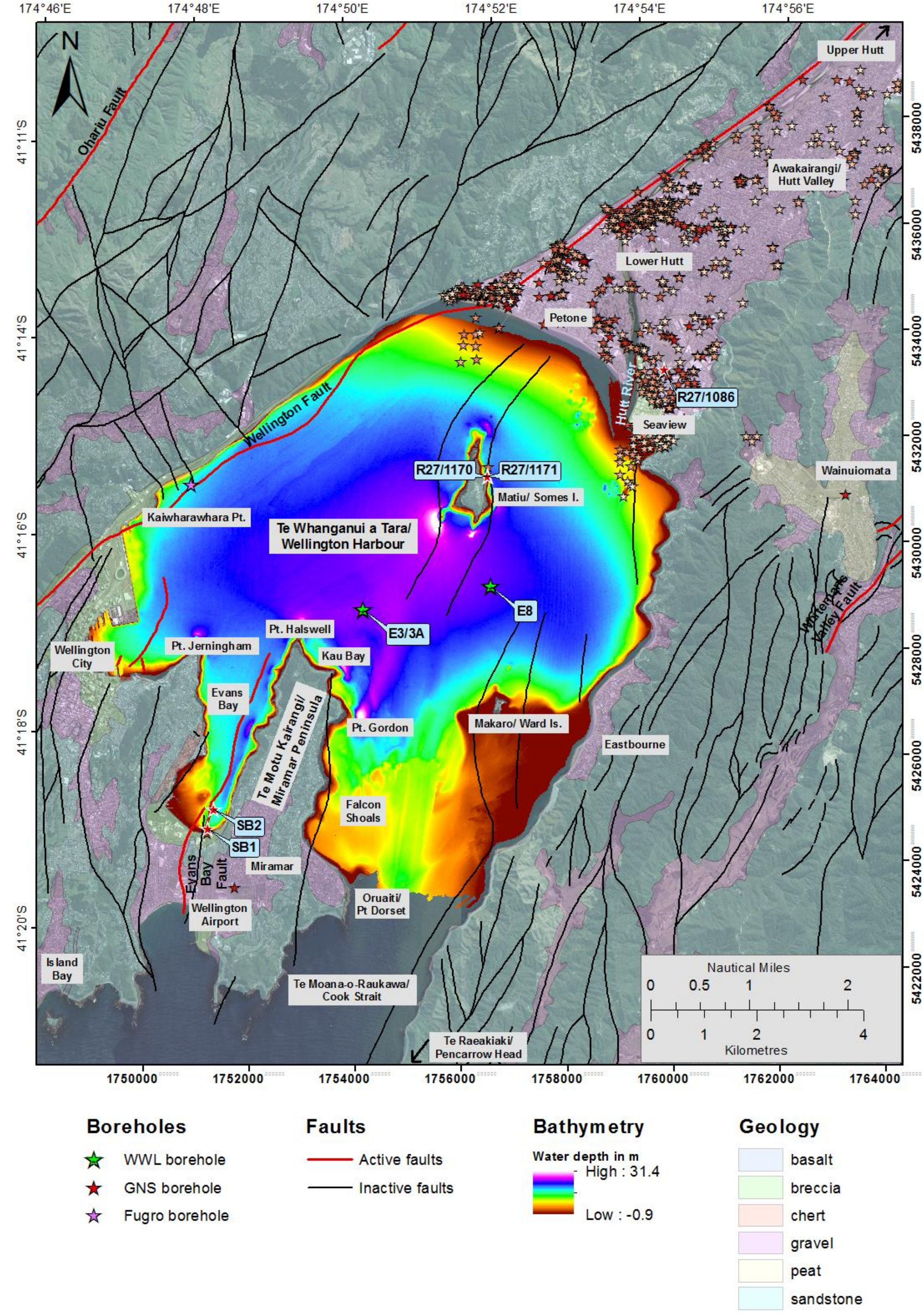

Figure 2-3: Locality map showing geology, faults, bathymetry and borehole locations in Te Whanganui a Tara/Wellington Harbour and Awakairangi/Hutt Valley. Surficial geology, faults and borehole locations from GNS Science; bathymetry (in metres) from NIWA (Pallentin et al. 2009).

The 20-30 m-deep, 8 km wide basin of Wellington Harbour, narrows to 2 km through the ~9 km-long harbour entrance (Pallentin et al. 2009) (Figure 2-3), where the greatest depth is < 15 m. A 1-2.5 km-wide shoal (<5 m-deep) fringes Makaro/Ward Island, which lie along the eastern margin of the harbour entrance from Te Raeakiaki/Pencarrow Head to Eastbourne. Matiu/Somes Island is a large block of uplifted greywacke basement rock in the central-western part of the harbour (Figure 2-3). Te Awa Kairangi/Hutt River flows into the northeastern margin of the harbour at the southeastern end of Petone Beach through a short reach of levees. On either side of the levees at the river mouth are several large seafloor depressions, where freshwater is expelled from subsurface gravels (Harding 2000). Similar depressions are also observed on the harbour floor offshore from prominent headlands of Orua-kai-kuru/Point Jerningham, Kaitawharo/ Point Halswell at the northern end of Te Motu Kairangi/Miramar Peninsula and off the northern and southern ends of Matiu/Somes Island.

The uplifted topography around the periphery of Te Whanganui a Tara/Wellington Harbour comprises Mesozoic greywacke rocks of Triassic-Jurassic age (Begg and Mazengarb 1996; Begg and Johnston 2000) (Figure 2-3). Pleistocene to Quaternary sediments (<2 million years old) are restricted to areas of low-lying topography, including Wellington City, Miramar, Island Bay, Wainuiomata and in the greatest extent up into the Hutt Valley (Lower and Upper Hutt). Such younger deposits include old colluvial/alluvial gravel fans that descending into the harbour basin from the surrounding steep topography, alluvial river gravels and sands, peat and swamp deposits, marine sands and muds and most recently materials used in the various reclamations around the harbour periphery in modern times.

The surficial sediments of central Wellington Harbour are predominantly silty muds (Van der Linden 1966; van der Linden 1967; Dunbar et al. 1997; Goff et al. 1998) that are intercalated with sands and gravels in the harbour entrance and around the periphery of Wellington Harbour (Matthews 1980b; Matthews 1980a; Carter and Lewis 1995) (Figure 2-4). The muddy sediments in the harbour basin are correlatives of the Petone Marine Beds identified onshore in boreholes in the Hutt Valley, which are predominantly derived from the deposition of suspended sediments discharged from the Hutt River. In high-resolution geophysical data, these surficial muddy sediments are characterised by continuous, parallel, weak-moderate amplitude reflectors (e.g., Lewis 1989). These unconsolidated uppermost harbour muds are also organic-rich and gassy, which reduces the ability to image deeper seismic reflectors (e.g., Davy and Wood 1993).

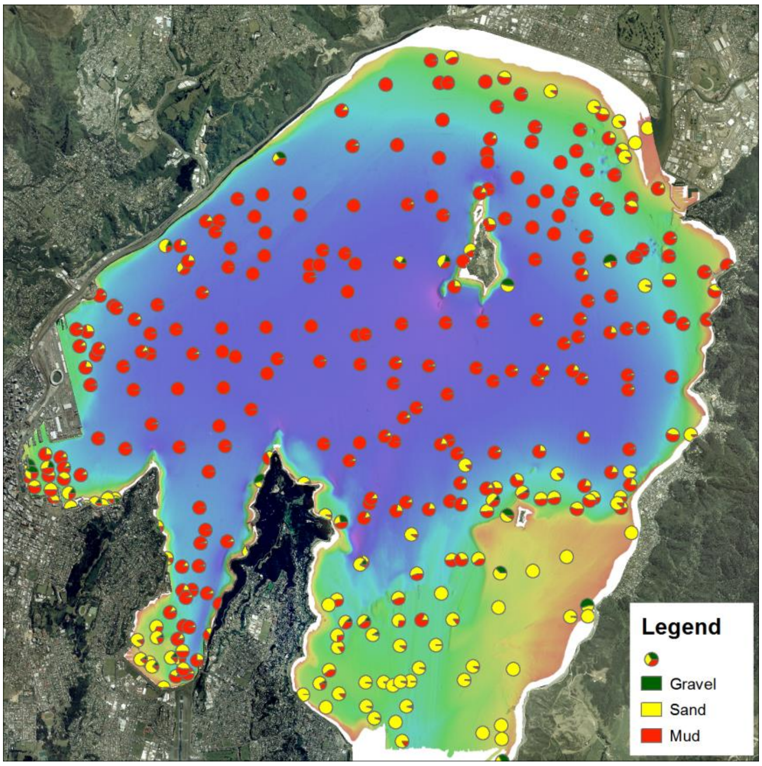

Figure 2-4: Sediment samples from Wellington Harbour and northern harbour entrance, superimposed on bathymetry (50 cm grid).

The sand cover on the inner shelf of the south coast comprises predominantly well-sorted fine-medium sands that commonly supports small (2-4 cm-high, 10-70 cm wavelength) symmetrical ripples with extensive patches of coarse sand-fine pebble gravel mega-ripples (20-50 cm high, 1-3 m wavelength) exposed through surficial sand cover. These are typically present around headlands and across the harbour entrance (e.g., Carter 1977; Arron and Lewis 1993; Carter and Lewis 1995; Wright, Mackay et al. 2006). Cobbles and boulders form aprons around rock outcrops that can protrude through the veneer of surficial sand and fine gravel, which is typically less than 5 cm to perhaps up to 1.5 m in thickness (Carter and Lewis 1995).

The sands and gravels in the harbour entrance extend in an apron towards the mud-filled basin of Wellington Harbour (Figure 2-4). In side-scan sonar and acoustic backscatter imagery, the sea-floor here is characterised by strongly reflective coarse nature of the substrate (Arron and Lewis 1993). Consequently, there are difficulties with imaging sub-surface features beneath the reflective sand/gravel veneer around the entrance using other geophysical techniques, such as seismic reflection sub-bottom profiling (e.g., Lewis et al. 1987). There, subsurface reflectors are typically, weak, diffuse to high amplitude, but may be very discontinuous, depending on the character of the sub-surface geology (i.e., alluvial river gravels, sand-filled tidal scours, gravel beach units, colluvium/alluvium, greywacke basement rock, etc).

3 Previous studies

Seismic reflection geophysical surveys across Wellington Harbour have provided a means to image and understand the structure and stratigraphy of materials beneath Wellington Harbour (Davey 1971; Hochstein and Davey 1974; Lewis, Davy et al. 1987; Lewis 1989; Wood and Davy 1992; Davy and Wood 1993; Barnes et al. 2014; Nodder et al. 2014; Nodder et al. 2015; Lamarche et al. 2016). These data also provide evidence for the existence of active faults around Matiu/Somes and Makaro/Ward islands and information on the impact/control of the Wellington Fault on Quaternary deposition. Much of these data are contained in commercial reports, and, in particular, NIWA provided WWL with new geophysical data and stratigraphic interpretations on the distribution and depth of the Waiwhetu Artesian Gravels in relation to the proposed pipeline route (Nodder et al. 2015) and in anticipation of the offshore borehole exploration phase (Lamarche et al. 2016). In the 2000s, multibeam echosounders were used to survey the bathymetry of the entire Wellington Harbour and generate 50 cm gridded Digital Elevation Model (DEM) of the harbour's seafloor and seafloor substrate (backscatter) data (Pallentin et al. 2009).

The work of Mildenhall (1994) and Mildenhall (1995) in establishing an overview of the palynostratigraphy of the region, particularly in the Petone area, was of great significance. This work provided a biostratigraphic framework that enabled chronostratigraphic correlation with the international sea-level curve (Imbrie et al. 1984; Antonioli et al. 2004; Lisiecki and Raymo 2005), which is based on oxygen isotopes as a proxy for high-frequency climatic fluctuations (particularly sea-level variations) over the last one million years.

Begg and Mazengarb (1996) summarised many disparate strands of geological investigation to create a surface geological map and conceptual analysis of subsurface Quaternary stratigraphy in the Wellington area.

Brown and Jones (2000) reported on the drilling of a groundwater investigation borehole on the Moera gravel aquifer, but teased out an important conceptual feature of sedimentation from the international sea-level curve. They reported on the presence of a laterally persistent, fine-grained unit within the Waiwhetu Artesian Gravels that they correlated with ameliorated climate during Marine Isotope Stage (MIS) 3, from c. 29 – 57 thousand years ago. Their work provides a firm basis for better understanding the stratigraphy of Wellington Harbour last glacial sediments.

Better understanding of rates of uplift and subsidence in the Lower Hutt valley (and by inference, Wellington Harbour) resulted from the work of Begg et al. (2002) and its refinement in Townsend et al. (2015). They concluded that subsidence of the Lower Hutt Valley is a result of an imbalance of uplift associated with Wairarapa Fault earthquakes (e.g., 1855 M8.2 Wairarapa Earthquake) and subsidence associated with Wellington Fault ruptures.

In 2012, following the recognition of damage wrought by the 2010-2011 Canterbury Earthquake Sequence, Greater Wellington Regional Council contracted GNS to evaluate the impact of a potential Wellington Fault rupture on the Waiwhetu Artesian Gravels (Zemansky et al. 2012). This work provides a useful foundation to assess the relation between Wellington/Hutt Valley water supply and earthquake hazard.

Following the 14 Nov. 2016 M_w 7.8 Kaikoura Earthquake, changes in water quality were detected in the Waiwhetu Artesian Gravels, and prompted work to better understand the nature of the aquitard separating unconfined groundwater and the confined Waiwhetu Artesian Gravels. This work was reported in Begg and Morgenstern (2017) and identified frailties in the aquitard due to lateral lithological changes that potentially result in water-quality issues in the Waiwhetu Artesian Gravels.

Since 2015, NIWA has completed several pieces of work for WWL and Stantec MWH outlining the subsurface character and extent of the Waiwhetu Artesian Gravels beneath Wellington Harbour (Lamarche et al. 2015; Nodder 2015; Nodder et al. 2015; Lamarche et al. 2016). These data and interpretations underpin further geophysical interpretations and the locations for the offshore exploratory boreholes, as summarised in the present report.

4 Methods

4.1 Marine geophysical data-sets

The marine-geophysical datasets herein were collected specifically for MWH Stantec and WWL, namely, from NIWA voyages KAH1505 in August 2015 (joint with CentrePort Ltd) (Lamarche et al. 2015; Nodder et al. 2015) and KAH1602 in February 2016 (Lamarche et al. 2016). These seismic reflection data were collected using a mini-GI air-gun source, with a 4 second firing rate, and 25 m-long 16 channel digital-hydrophone array, towed behind NIWA's Research Vessel *Kaharoa*. These new mini-GI gun geophysical data were integrated with shallow 'boomer' data recently collected by Applied Acoustics Ltd (voyage IKA1012) in 2010, and multi-channel data acquired for an *It's Our Fault* project (voyage IKA1303, Barnes et al., 2014) in 2013 on NIWA's coastal survey vessel *Ikatere*. Additional data were provided from raw and interpreted sections collected during much older GNS surveys by Wood and Davy (1992) and Davy and Wood (1993) using single and multi-channel airgun and 'boomer' data.

The NIWA geophysical data from KAH1505 and KAH1602 were processed using *Globe Claritas®*, with a processing sequence that included band-pass filtering, swell-wave removal, Common Depth Point gathers, Normal Move-out and stacking (Lamarche et al. 2015, 2016). These seismic data were interpreted stratigraphically using IHS *Kingdom Suite®*. All navigation data were projected in New Zealand Transverse Mercator.

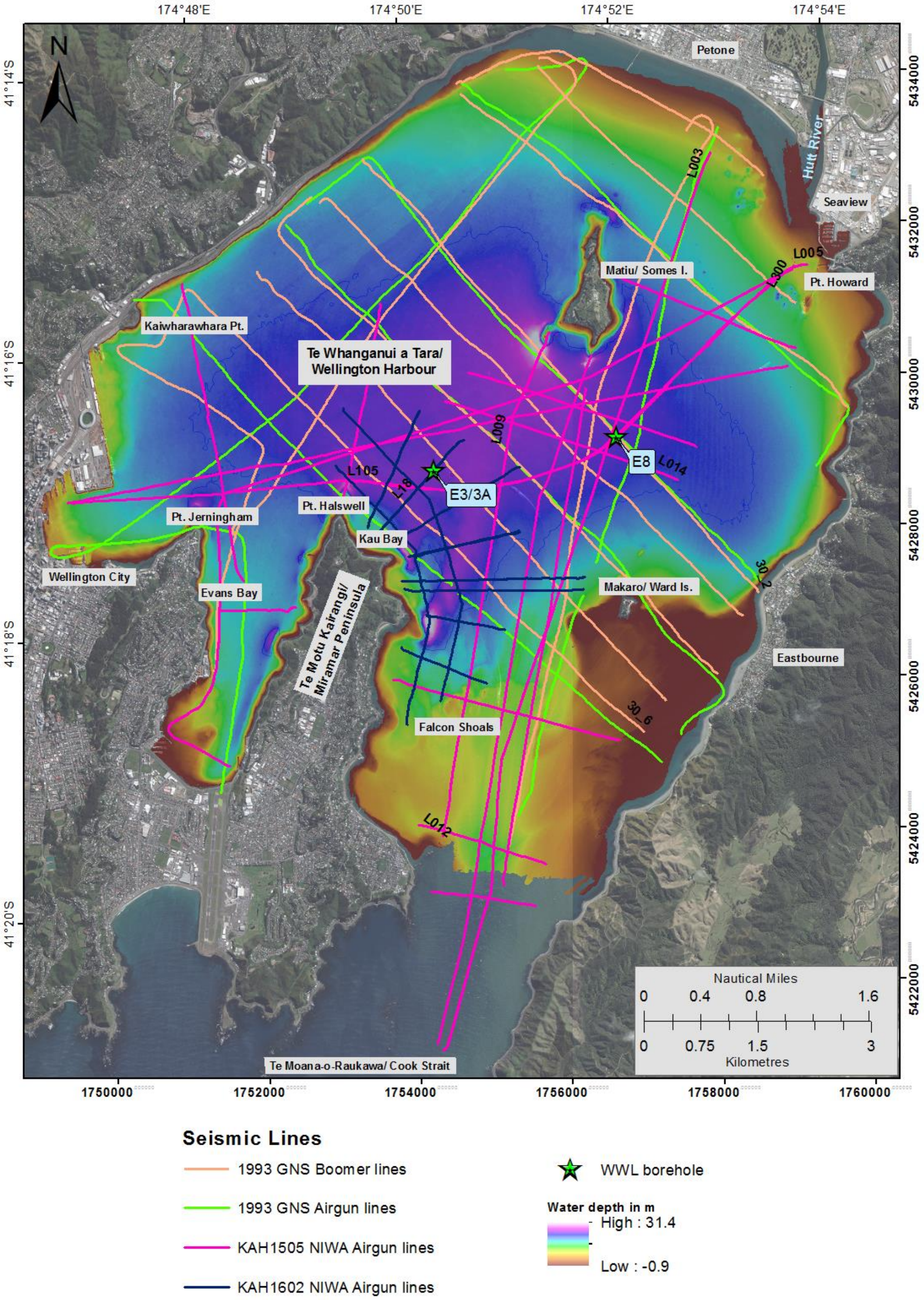

Figure 4-1: Marine geophysical-survey tracks collected by NIWA and GNS Science in Te Whanganui a Tara/Wellington Harbour. NIWA data from KAH1505 and KAH1602 (Nodder et al. 2015; Lamarche et al. 2016); GNS Science data from (Wood and Davy 1992; Davy and Wood 1993). NIWA bathymetry is in metres (Pallentin et al. 2009).

4.2 New offshore borehole data and site selection

Discovery of water within the Waiwhetu Artesian Gravels in exploratory borehole E3/3A was significant as it proves that the Waiwhetu gravel unit carries fresh water almost as far as the Te Motu Kairangi/Miramar Peninsula. However, when water-pump testing and chemical analysis indicated that the aquifer at the E3/3A site was unable to deliver adequate water volumes or quality, more favourable sites had to be explored and evaluated. The project team concluded that these unfavourable characteristics were a result of the site being marginal to the main Waiwhetu Artesian Gravels. A new site within thicker and better-defined gravels was sought.

Target areas for a new borehole were constrained by three principal limitations: (1) saline intrusion hazard; (2) a conceptual geological understanding of aquifer characteristics; and (3) seismic hazard related to known faults (Gyopari et al. 2017).

All areas of a potentially thin or fragile aquitard were located and excluded from selection to minimise the possibility of saline intrusion. Such fragilities in the aquitard may be present close to emergent points of basement rock along the Te Motu Kairangi/Miramar Peninsula (e.g., Point Halswell, Point Gordon, etc.), at Falcon Shoals, close to the rocky points around Matiu/Somes Island, and along contacts between bedrock and overlying younger (i.e., Quaternary) sediments.

Faults that had historically been identified in seismic profiles (Davy & Wood 1993) were digitised and previously mapped fault zones around Matiu/Somes and Makaro/Ward islands were excluded. In addition to fault zones, new seismic profiles indicate that the upper Waiwhetu gravels thin over the Somes Island ridge. Site E3/3A had tested one of the two areas outside these fault zones: the area west of the Somes Island ridge. The other fault-free area was on the east side of the Matiu/Somes Island ridge, in the channel between Matiu/Somes and Makaro/Ward islands.

The preferred new borehole location was well-covered by seismic profiles, maximising stratigraphic knowledge and correlation with the proven geology at E3/3A. Seismic reflection data were reviewed in the light of the E3/3A lithological log, which helped in better characterising deposits of last-glacial age; some last-glacial materials are characterised by a densely “stippled” seismic signature, others by a more stratified or “laminar” nature (Figure 5-4). The “stippled” signature is now interpreted as representing channelised alluvial gravels while the “laminar” signature correlates with the fine-grained deposits between the upper and lower Waiwhetu gravels. Using seismic profiles to map the upper Waiwhetu gravels identified a “stippled” belt of inferred alluvial gravels extending from close to the Hutt River mouth through the harbour on the eastern side of Matiu/Somes Island. This belt thins southwards but becomes seismically unresolved between 3 and 1 km north of Falcon Shoals.

The seismic data are supplemented by information from existing marine bores within and close to the harbour. Foremost are those exploratory bores from the old Gear Meat site (R27/0151; top of upper Waiwhetu gravels at 21.0 m below ground-level) and Parkside Road in Seaview (R27/1086; top of upper Waiwhetu gravels at 21.0 m). Logs from these deep bores constrain the depth of the base of each geological unit and their character, close to the Petone foreshore.

Other supplementary data includes borehole logs in the Petone Wharf area (10 logs, none deeper than 25 m below the seabed), the Ngāmatau/Point Howard Wharf area (15 logs, none deeper than 14.2 m below seabed), from Matiu/Somes Island (two logs, R27/1170 to a depth of -21.0 m below seabed and R27/1171 m to a depth of 23.2 m below seabed, with the top of the upper Waiwhetu gravels was at 15.8 m and 12.5 m below the seabed, respectively) and two bores in Evans Bay north of the end of

Wellington Airport runway (SB1 and SB2, with depths of 39.5 m and 35.0 m below the seabed, respectively).

Having spatially mapped and integrated these features, preference was given to sites inferred to have thicker aquitard and aquifer sequences. The new site (E8) was selected taking all these attributes into account, and is close to seismic profiles KAH1505_L003, KAH1505_L005, KAH1505_L105 (NIWA) and Line 30_2 (GNS Science).

E8 was drilled in January 2018. Here, the upper Waiwhetu gravels is considerably thicker than those encountered at E3/3A (11 m vs 4.5 m in E3/3A), as was the thickness of the lower Waiwhetu gravels (10.9 m vs 3 m in E3/3A). Both upper and lower Waiwhetu gravels are water-bearing at this site (see text in the main report for details about volumes and discharge rates).

4.3 Data integration

All existing data were integrated within specialist three-dimensional geological-modelling software, Leapfrog Geo (version 4.1). Topography was established using the NZ Transverse Mercator 2000 projection and the Greater Wellington Regional Council LiDAR-derived digital elevation model (DEM), GWRC_DTM_1m. Harbour bathymetry in the form of a NIWA DEM (version “wh250cm”), was projected to NZTM and entered into Leapfrog. The log for the first borehole, E3/3A, was digitised along with those from the historic borehole database for the Lower Hutt valley (hvdl17; Begg and Morgenstern 2017).

Images of all interpreted seismic profiles (from S. Woeltz, S. Nodder and G. Lamarche, NIWA; B. Davy, GNS Science) were entered to the Leapfrog Geo project as scale-corrected cross-sections. NIWA seismic profile KAH1602_L18 strikes north-east through E3/3A. The profile was rectified by aligning the interpreted seafloor seismic reflector, the NIWA multibeam bathymetry and measured depth to the borehole collar. The inferred base of the Holocene sequence was then aligned with the top of the uppermost gravel recorded in E3/3A. A similar exercise was completed for the historic GNS Science profile Line 30_6, although it is located c. 400 m southwest from the E3/3A borehole site. This calibration propagates through the network of NIWA and GNS Science seismic profiles using profile intersections.

Interpreted reflectors, marking the base of the Holocene sequence at the top of the Waiwhetu Artesian Gravels, were digitised as closely spaced points. These points were supplemented by other tie points where geologically required (e.g. including borehole data from the Lower Hutt valley) and this file was used to build a mesh representing the base of the Holocene (the base of the marine Holocene sequence, c. 10,300 years before present). A similar process was used to represent the base of the upper Waiwhetu gravels, the base of an intra-Waiwhetu silt, the base of the lower Waiwhetu gravels and the base of the Wilford Shellbed.

The digital terrain surfaces derived from this process were used to build volumes, each representing a particular stratigraphic unit. Grids were exported for use in HAM4 and for verification in *IHS Kingdom Suite®*.

The newly acquired geophysical lines were loaded into the *IHS Kingdom Suite®* software for interpretation and selected reflectors (Seafloor, Top Waiwhetu, Lower Waiwhetu and Top Moera) were picked and correlated around the seismic grid. The two borehole lithologic logs were integrated to these seismic reflection interpretations. Since the vertical unit of the seismic profiles is two-way travel-time (TWT, in seconds), conversion to depth (in metres) by tying the measured depth of the lithologic contacts in the boreholes to key seismic reflectors to derive an average sound speed in the sediments (seismic velocity) for each intervening unit. These seismic velocities were then applied to the time sections to convert them to depth, specifically: 1500 m/s was used from the sea-surface to the seafloor (water column), and 1600 m/s for the sub-seafloor sediment section.

5 Results and interpretation

5.1 Seismic character of subbottom units

The characteristics of the prominent geophysical features and seismic units identified (e.g. Figure 5-7) are outlined below:

5.1.1 Acoustic basement

"Acoustic basement" is defined as the depth at which seismic reflection energy decreases dramatically so that no or little coherent reflection is imaged below. The acoustic basement is generally related to a change in the substrate's characteristics (i.e., density, compactness). In the harbour data, "acoustic basement" was identified by strong upper reflections, with masked or discontinuous reflectivity beneath (Figure 5-1). Based on the geology of the area, especially around the harbour margins (Begg and Mazengarb 1996), it is assumed that acoustic basement represents greywacke basement rock, but this is not definitive until ground truthed with drill samples. Outcropping and subsurface contacts of various seismic units with the acoustic basement were mapped as part of the project. To the south of Matiu/Somes Island, irregular acoustic basement that is associated with the Somes Island ridge (Figure 2-2), progressively deepens beyond the penetration of the seismic sections, while on the Makaro/Ward Island platform, acoustic basement progressively shoals under the platform to eventually crop out along the Eastbourne coastline (Begg and Mazengarb 1996; Begg and Johnston 2000).

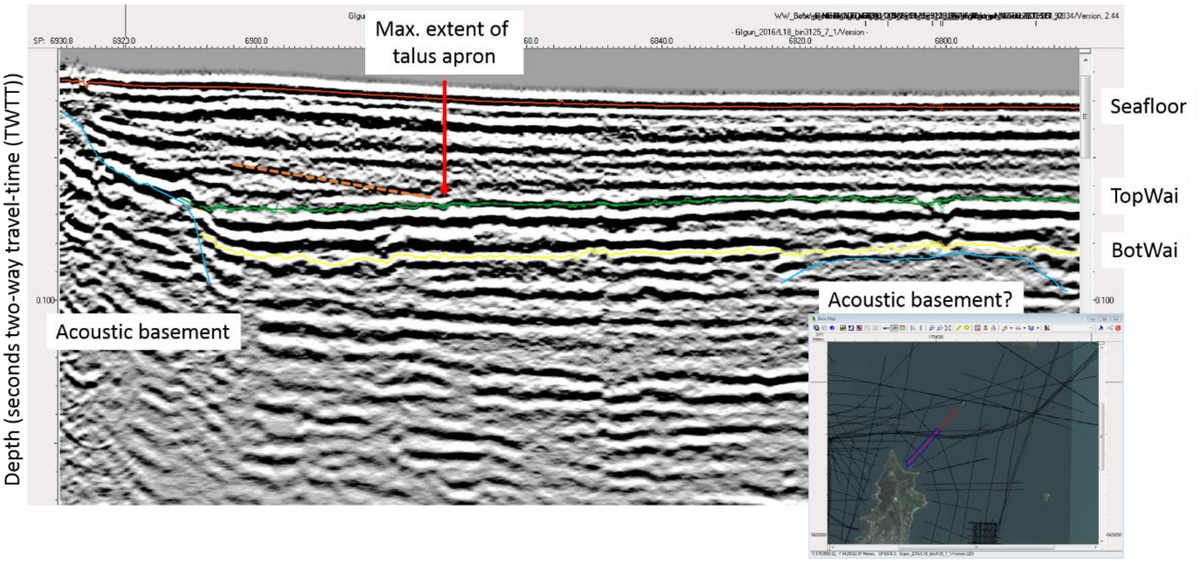

Figure 5-1: Seismic profile showing the acoustic basement (blue) and extent of talus aprons (orange (KAH1602_L18). Red = Seafloor, Green = Top Waiwhetu (TopWai), Yellow = Lower Waiwhetu (BotWai).

Decimetre-scale channels in acoustic basement are observed in historic (Lewis et al. 1987) and new geophysical data across the narrowest part of the Wellington Harbour entrance off Oruaiti/Point

Dorset (Lamarche et al. 2015) (Figure 5-2). This has implications for the distribution of the subsurface gravel layers which appear to shallow and onlap the acoustic basement, south of Falcon Shoals. This geometry suggests that there is relative uplift across this area, perhaps related to regional tectonism driven by the Wairarapa Fault (e.g., Little et al. 2009).

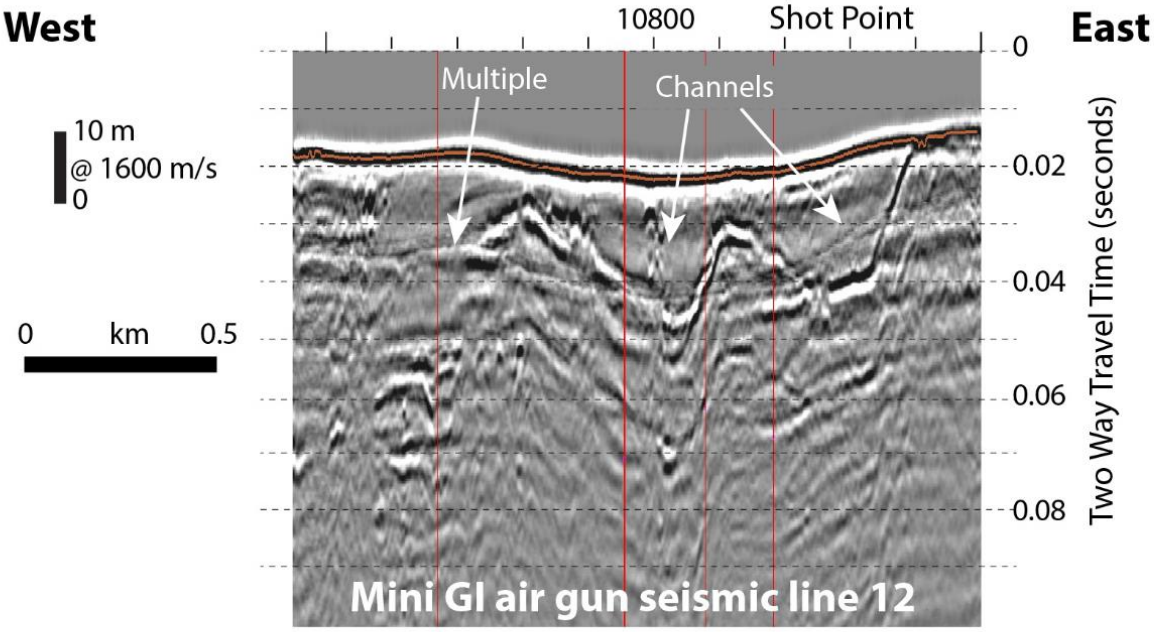

Figure 5-2: Seismic profile showing large-scale channel incision in the acoustic basement in the vicinity of the harbour entrance. Data from (KAH1505_L012) (Lamarche et al. 2015).

5.1.2 Talus aprons around greywacke promontories

Moderate amplitude, inclined reflectors typically at base of outcropping acoustic basement and at the bottom of the overlying semi-transparent marine muds (Figure 5-1). These features could be zones of potential groundwater leakage, especially where they are associated with known seafloor depressions off greywacke headlands (Harding 2000; Pallentin et al. 2009; Nodder 2015)

5.1.3 Gas/fluid masking in marine muds

This phenomenon is pervasive in many areas of the harbour, especially in water depths deeper than 18 m (Nodder 2015). It is believed to be related to biogenic gas accumulation due to the degradation of organic matter in the marine sediments (e.g., Judd and Hovland 2009). However, there is also the possibility it could be related to freshwater discharge, especially around structural discontinuities, such as faults (e.g., Lewis 1989), or at the contact of greywacke basement with less compact sediments (e.g., Harding 2000). In the latter case, the lateral extent would be much less than that for biogenic gas.

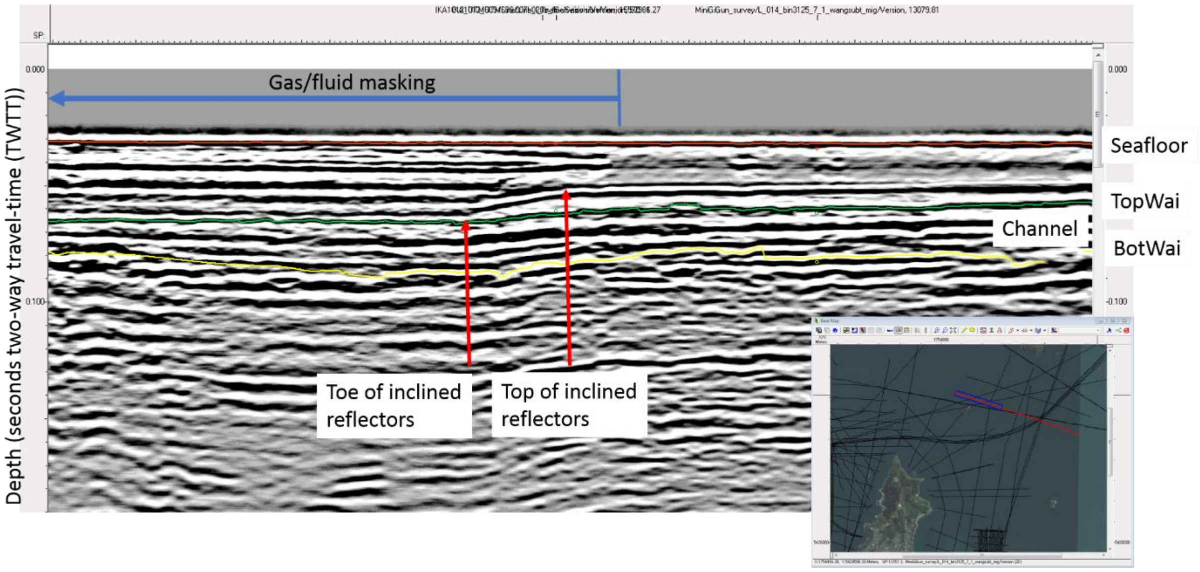

Figure 5-3: Seismic profile showing gas/fluid masking in upper muddy sediments and "ramp" feature west of Matiu/Somes Island (KAH1505_L014). Red = Seafloor, Green = Top Waiwhetu (TopWai), Yellow = Lower Waiwhetu (BotWai).

5.1.4 Sub-units with the Waiwhetu Artesian Gravels

Within the seismic unit defined by the Top and Lower Waiwhetu reflectors, two sub-units were subsequently identified in order to better characterise the lateral extent of gravel layers within the Waiwhetu Artesian Gravels. This further definition is based on recovered sediments from the first offshore exploratory borehole, E3/3A, where a 17 m-thick, possibly lacustrine muddy unit was encountered between the upper- and lowermost gravels associated with the Waiwhetu Artesian Gravels (see below).

Extending from the Petone-Seaview foreshore, a “stippled” sub-unit was identified, comprising many discontinuous, diffractive, moderate to weak reflections. This unit thins towards the west and south, wedging out upwards onto the uppermost Top Waiwhetu reflector. Based on the borehole lithologies in E3/3A and E8, it is inferred that this unit represents the upper water-bearing gravels of the Waiwhetu Artesian Gravels. Below this sub-unit, and extending further to the south towards Te Motu Kairangi/Miramar Peninsula, moderately strong reflections near the bottom of the Waiwhetu Artesian Gravels become more “laminar” and flat-lying. These are now thought to best represent the muddy intra-formational unit that is 17 m-thick at E3/3A and thins to 3.5 m to the northeast at E8. In the vicinity of E8 and north of here towards Petone/Seaview, the base of this sub-unit corresponds to the mapped Lower Waiwhetu reflector.

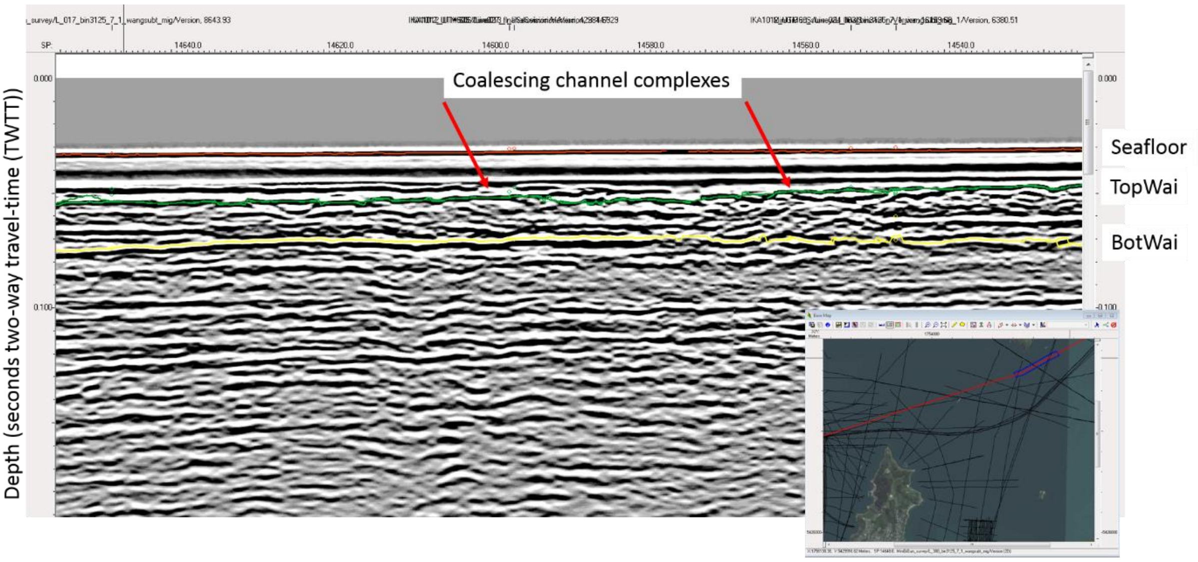

Figure 5-4: Seismic profile showing channels in upper "stippled" unit in the Waiwhetu Artesian Gravels (KAH1505_L300). The lower laminated sub-unit is seen at the very western (left) side of the profile, where the upper stippled unit lenses out against the TopWai reflector. Red = Seafloor, Green = Top Waiwhetu (TopWai), Yellow = Lower Waiwhetu (BotWai).

While the Base Waiwhetu reflector from Davy and Wood (1993) was not identified in the NIWA data-set, there is likely to be a relationship with a sequence of discontinuous, moderately reflective, irregular reflections below the mapped Lower Waiwhetu reflector. This package of reflectivity lies above a zone of much weaker reflectivity that is now inferred to represent the muddy marine sediments of the Wilford Shellbed above the Moera Gravels (i.e., Top Moera reflector).

5.1.5 Possible "Top Moera" reflector

This reflector was only identified after interpretations had been made based on the actual depth of this lithological unit in the two offshore exploratory boreholes, E3/3A and E8, and after comparisons were drawn with historical GNS seismic surveys (Wood and Davy 1992; Davy and Wood 1993). It comprises a moderately strong reflector that has some lateral continuity (Figure 5-6), but is difficult to trace around the seismic grid with confidence, especially without seismic profiles over the borehole site to act as ties to the ground-truthed stratigraphy.

5.1.6 Falcon Shoals

The lateral extent of Falcon Shoals near the harbour entrance off Point Gordon was delineated. Here, there is extensive anecdotal evidence for freshwater seepage from the seafloor and in the water column (Harding 2000). In the NIWA geophysical data, the northern edge of the shoals is characterised by very high amplitude reflectors that have strong multiple energy, which masks any subsurface horizons (Lamarche et al. 2015). This boundary is coincident with a slight step in the bathymetry (Pallentin et al. 2009), which marks the southern extent of where the harbour muds interfinger with marine sands and gravels that are prograding in through the harbour entrance from the inner shelf of Te Moana o Raukawa/Cook Strait (e.g., Carter and Lewis 1995).

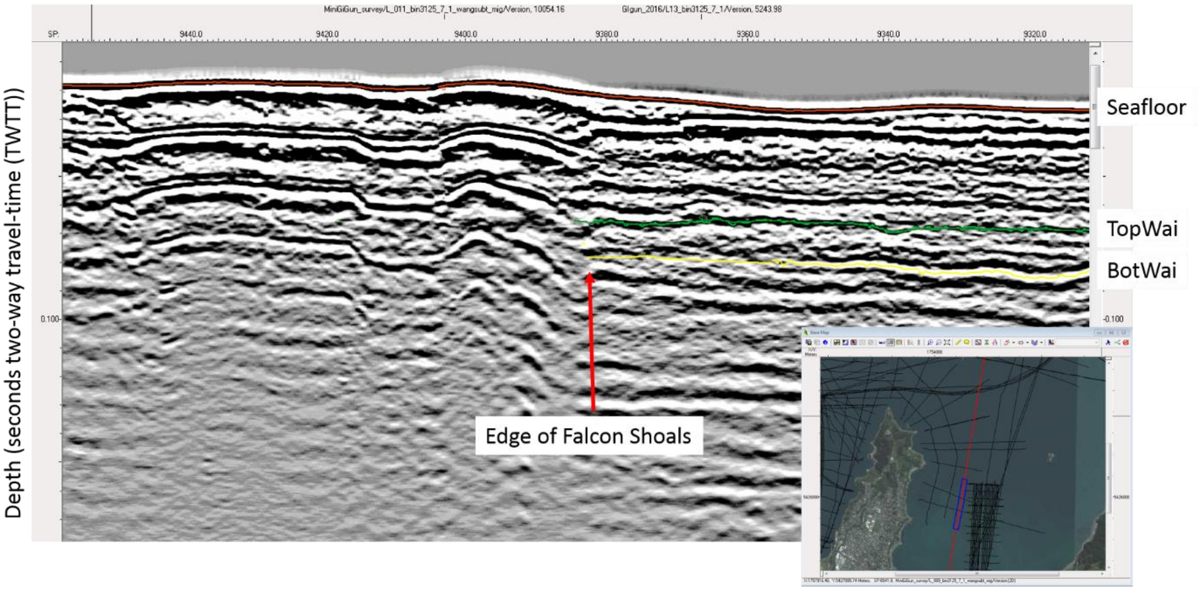

Figure 5-5: Seismic profile showing high reflection and multiple energy at Falcon Shoals (KAH1505_L009). North (to the right) of Falcon Shoals, there is evidence of diffuse progradational reflections, associated with marine sands and gravels. Red = Seafloor, Green = Top Waiwhetu (TopWai), Yellow = Lower Waiwhetu (BotWai)..

5.1.7 Prograding inner shelf marine sands and gravels

A series of moderate to low amplitude, semi-continuous, inclined reflectors that are inferred to interfinger with the harbour muds in the harbour entrance, extending northwards from Falcon Shoals (Figure 5-5). The actual contact with the harbour muds is difficult to identify definitively, but there appears to be a broad zone throughout the harbour entrance where this transition is likely to occur. This is also likely to be a zone where confining pressures from the harbour mud aquitard are reduced, as evidenced by diffuse freshwater leakage across this area of the harbour (Harding 2000).

5.1.8 Active faulting

An inclined reflector "ramp" was observed in the Top Waiwhetu and underlying reflectors (Figure 5-3). The ramp lies parallel to structural faults identified by Wood and Davy (1992) along the western side Matiu/Somes Island. This is suggestive of active deformation associated with the western horst-bounding fault that has facilitated the uplift of the island greywacke block. A similar relationship was not observed on the eastern side of the horst.

Other potentially active faults were identified along the western margin of the Makaro/Ward Island platform, where subsurface reflectors are offset or deformed by faulting. Similar faulting activity was identified in this region in the GNS geophysical data (Davy and Wood 1993).

There did not appear to be any evidence offshore along eastern Te Motu Kairangi/Miramar Peninsula of recent deformation on the inferred active Point Gordon Fault (Huber 1992; Pillans and Huber 1995).

5.2 Seismic stratigraphy and spatial extent of the gravel sequence

The NIWA marine geophysical data highlight two key subsurface reflectors: (1) an uppermost reflector located at the base of the overlying, seismically transparent marine muds, which corresponds to the unconformity at the top of the Waiwhetu Artesian Gravels, hence it's label in previous reports as "Top Waiwhetu" (Lamarche et al. 2015; Nodder, Lamarche et al. 2015; Lamarche et al. 2016); and, (2) a prominent deeper reflector that can be mapped with reasonable confidence around the seismic grid, interpreted as a "Lower Waiwhetu" reflector and considered to be an intra-formational horizon within the gravels rather than the base of this aquifer unit (Lamarche et al. 2016). The "Top Waiwhetu" reflector was correlated to offshore boreholes east of Matiu/Somes Island (Lamarche et al. 2015) and off Kaiwharawhara (Barnes et al. 2014) and corresponded to a transition from marine muds to terrestrial gravels, with an inferred age of 10,000 years (±1500 years) (Barnes et al. 2014). Acoustic basement was also identified on the network of seismic profiles. These interpretations were corroborated and strengthened by integrating previous surveys that identified the Base Holocene (equivalent to Top Waiwhetu), Base Waiwhetu and Base Wilford (= Top Moera) from earlier studies (Wood and Davy 1992; Davy and Wood 1993).

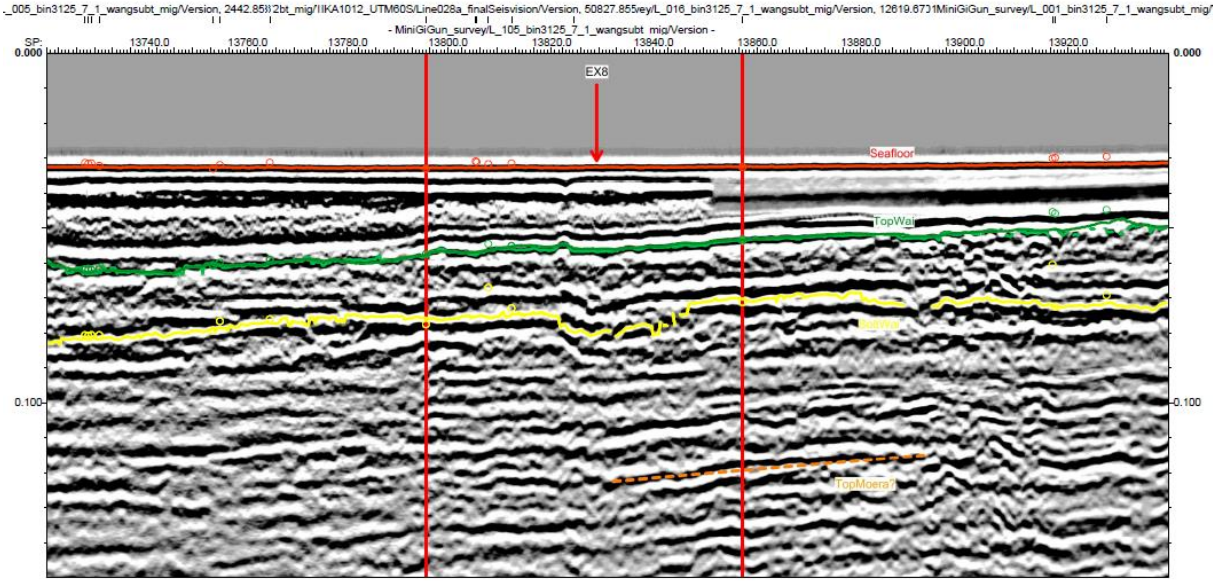

Figure 5-6: Example of prominent reflectors identified in Wellington Harbour geophysical survey data (Seismic line KAH1505_L105). Red = Seafloor, Green = Top Waiwhetu (TopWai), Yellow = Lower Waiwhetu (BotWai), Orange (dashed) = Top Moera. The planned location of exploratory borehole E8 is shown (EX8).

The mapped unit between the Top Waiwhetu and Lower Waiwhetu reflectors represents the upper part of the Waiwhetu Artesian Gravels sequence (Figure 5-6). This unit deepens in the stratigraphic section from off Petone-Seaview as it enters the harbour basin. It thins to the southwest, between Matiu/Somes Island and Te Motu Kairangi/Miramar Peninsula, and eventually tapers to less than a metre thickness across the northern entrance to Evans Bay (Nodder et al. 2015; Lamarche et al. 2016). In the subsurface, the upper part of the Waiwhetu Artesian Gravels thins over areas of the acoustic basement and thins slightly as it approaches the harbour coastline where it appears to abut acoustic basement, presumably associated with outcropping greywacke rock. Southwards through the harbour entrance, the unit becomes more inclined and deepens markedly to more than 30-40 m below the seafloor as the overlying harbour muds thicken concomitantly, and eventually pinches out towards the lower contact. At Falcon Shoals (see below), where seismic correlations have proved to be problematic (Lamarche et al. 2015), the Waiwhetu Artesian Gravel unit is interpreted as shallowing up the stratigraphic section, and probably thins onto or intersects channelised/incised "acoustic basement" south of Oruaiti/Point Dorset. These earlier surveys infer that the gravel sequence associated with the Waiwhetu Artesian Gravels does not extend beyond the harbour entrance and onto the inner continental shelf of Te Moana o Raukawa/Cook Strait. However, faint but coherent reflectors below the “acoustic basement” are possibly continuous with the gravel units imaged within the harbour, suggestive of further lateral continuity onto the shelf.

New geophysical interpretations over the course of the borehole drilling phase of the project are summarised in Figure 5-7.

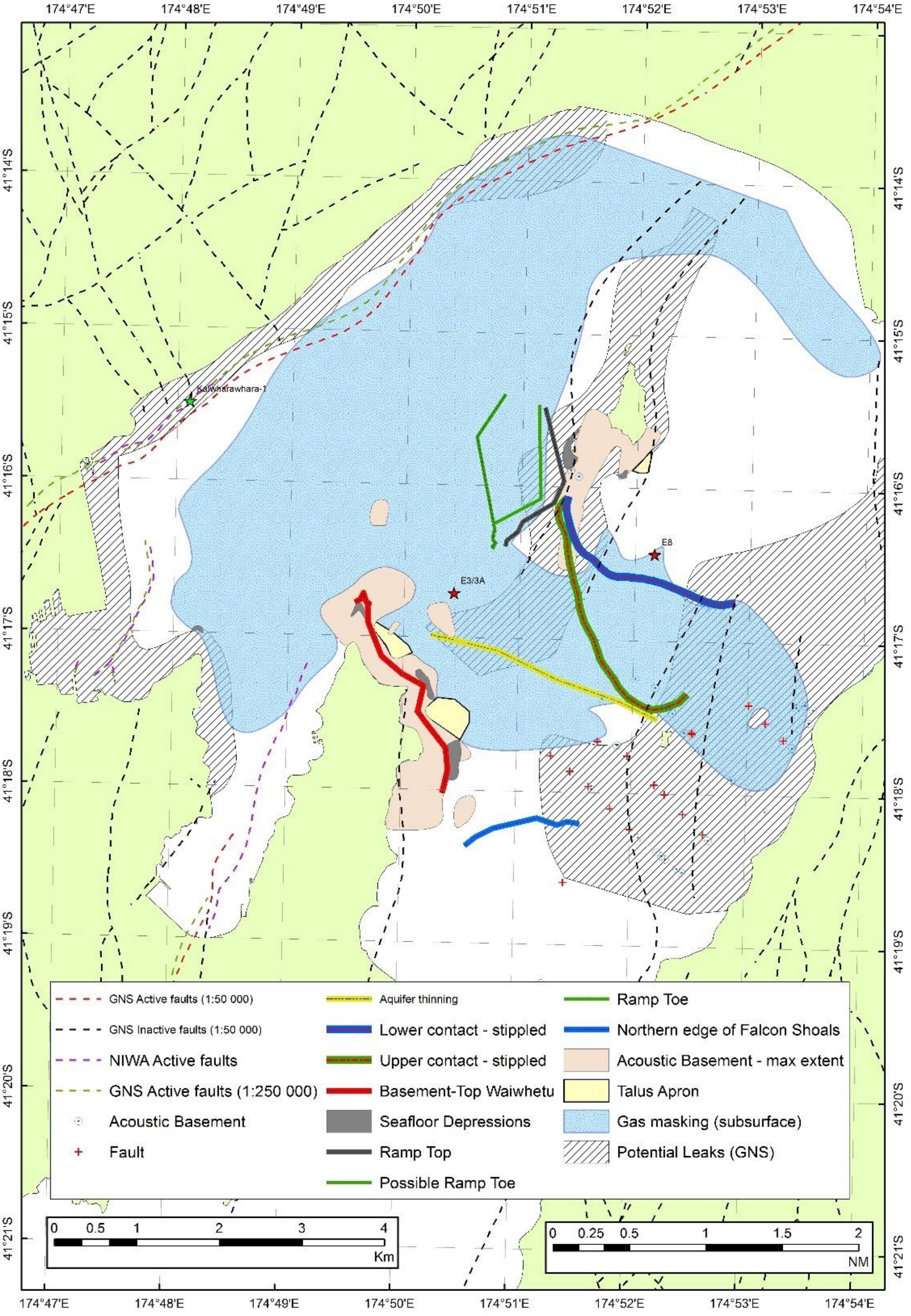

Figure 5-7: Summary of geophysical features identified and mapped in seismic section by NIWA in Te Whanganui a Tara/Wellington Harbour.

5.3 Geological data from boreholes

Borehole core and logs from E3/3A and E8 provide the most reliable ground-truth data on the Quaternary stratigraphy beneath the harbour. In general, core recovery was exceptionally good. Two limitations of these data are: (1) the bore at E3 had to be abandoned due to poor weather at a depth of c. 15 m; a new site within a few metres (E3A) was used for the remainder of the record, but the first 15 m of E3A was not cored. We rely on the lateral homogeneity of materials in this top 15 m to provide confidence that the sequence is fully cored; and, (2) no core was recovered from the top 12.2 m of E8. Stantec provide high quality geological logs for the boreholes, with supplementary engineering geological information and neutron and dual density electric logs.

Sediment recovered in cores from both sites are predominantly gravel and sandy gravel. Minor differences in lithology between the sites include the presence of minor sand, silt and clay components in the unit at E8, and in gravel clast roundness, which is recorded as subrounded to rounded at E3/3A and subrounded to subangular at E8.

Recovered Holocene marine sediments are dominated by soft to firm silt and clayey silt materials, although they become sandier near the base. In general, firmness increases at c. 10 m depth. These silty sediments are 22.9 m thick at E3/3A and 18.3 m thick at E8. Across most of the harbour basin, Holocene marine deposits mantle all underlying units. In shallower parts of the harbour (e.g. Petone Beach, Days Bay, Eastbourne and beneath the harbour heads), laterally equivalent Holocene marine materials may be sandy or even gravelly. These materials are equivalent to the Petone Marine Beds found in the Lower Hutt valley.

The two harbour borehole logs indicate that the Waiwhetu Artesian Gravels can be sub-divided into three units, an upper Waiwhetu gravel unit, an intervening fine-grained unit and a lower Waiwhetu gravel unit. At E3/3A the upper Waiwhetu gravels are only 4.85 m thick, while at E8 they are 11 m thick. The intra-Waiwhetu fine-grained unit is 17.25 m thick at E3/3A and only 3.5 m thick at E8. The underlying lower Waiwhetu gravels are 3 m thick at E3/3A and 10.9 m thick at E8 (Table 5-1).

Table 5-1: Summary stratigraphic information from the two offshore exploratory boreholes, E3/3A and E8. bsf = below seafloor; RL = relative level in relation to sealevel.

Wellington Harbour borehole		**E3/3A**		**E8**	
	Sea floor	**-23.37**		**-22.62**	
Stratigraphy		**depth bsf (m)**	**RL (m)**	**bsf (m)**	**RL (m)**
Petone Marine Beds	Thickness	22.9		18.3	
upper Waiwhetu gravels	Top	22.9	-46.27	18.3	-40.92
	Base	27.75	-51.12	29.3	-51.92
	Thickness	4.85		11	
intra-Waiwhetu fine-grained unit	Thickness	17.25		3.5	
lower Waiwhetu gravels	Top	45	-68.37	32.8	-55.42
	Base	48	-71.37	43.7	-66.32
	Thickness	3		10.9	
Total Waiwhetu gravels	Thickness	25.1		25.4	
Wilford Shellbed	Top	48	-71.37	43.7	-66.32
	Base	74.5	-97.87	61	-83.62
	Thickness	26.5		17.3	
Moera gravels	Top	74.5	-97.87	61	-83.62
	Bottom of borehole	80.06	-103.43	71.15	-93.77
	Thickness drilled	5.56		10.15	

Overall, E8 has a thinner sequence than E3/3A (61 m vs 74.5 m, respectively, to the base of the Wilford Shellbed) although the thickness of the Waiwhetu Artesian Gravels is comparable. The two boreholes show contrasting thicknesses amongst the three Waiwhetu sub-units, with the upper Waiwhetu gravels at E8 almost 2.3 times thicker than at E3/3A; the intra-Waiwhetu fine-grained unit at E3/3A is almost five times thicker than at E8; and the lower Waiwhetu gravels are more than 3.5 times thicker in E8.

At E3/3A the upper Waiwhetu gravels comprise mostly clayey gravel, sandy gravel and sand, with gravel clasts mostly rounded to sub-rounded. At E8 similar lithologies are present, but gravel clasts are recorded as largely sub-rounded to sub-angular.

The intra-Waiwhetu fine-grained unit at E3/3A comprises predominantly silt and silty sand, with minor gravel and clay, but its most important difference is its significant thickness at 17.3 m. This contrasts with its thickness of only 3.5 m and finer texture (clay and sand) at E8. The tapering of this sequence between E3/3A and E8 is one of the most significant differences between the two sequences. The elevation of its upper contact is broadly comparable, as is the thickness of the entire last-glacial sequence.

As with the upper Waiwhetu gravels, the lower Waiwhetu gravel unit is substantially thinner at E3/3A (3 m) than at E8 (10.9 m).

Wilford Shellbed materials sometimes contain shell fragments and comprise silt, silty clay and clayey silt, with a minor sand component, particularly near its base at E8. The unit is substantially thicker at E3/3A (26.5 m) than at E8 (17.3 m).

Only the uppermost section of the Moera Basal Gravels was drilled in the boreholes. Lithologies recorded are sandy, silty and/or clayey gravel, but at E3/3A the basal 2 m of the thin interval sampled (5.6 m) comprised clayey silt. At E8 the unit was much thicker (10.2 m), which also included a thin (0.7 m) gravelly clay layer. The driller (Pat Cooper, pers. comm.) considered that materials were distinctive at E8 and differed from alluvial gravels in the poor sorting and the presence of abundant angular to subangular clasts. Porewater was conspicuous in E3/3A, but not in E8.

5.4 Conceptual seismic stratigraphic model

Figure 5-8 andFigure 5-9 summarise the geometries and lithological units that make a conceptual model seismic-stratigraphic model for Te Whanganui a Tara/Wellington Harbour drawn from the geophysical data collected and re-integrated in the current study. The basic stratigraphic units are outlined below:

- Fine-grained Holocene sediment (age: 10.5 ka to 0 years; Marine Isotope Stage (MIS) 1) encountered in boreholes are entirely marine, mostly deposited under low energy (> 15 m water depth; see Lewis and Carter (1976)) conditions.
- Marine transgression was at c. 10,300 years BP (shell and rootlets radiocarbon dates; NZA64440 & NZA64456 respectively) and very rapid, as suggested by similar conventional radiocarbon ages derived from Evans Bay (Lewis and Mildenhall 1985) and Kaiwharawhara samples (c. 4-5 km away).
- Between Falcon Shoals and Wellington Harbour heads, materials of the Petone Marine Beds are probably largely sandy and gravelly, having been deposited within the storm wave-zone (Carter and Lewis 1995); they probably provide a poor seal on any underlying porous gravel.
- Before the marine transgression at the start of the Holocene, the western part of the Wellington Harbour basin was low-lying, and occupied by a long-lived swamp and/or a lake (MIS4-2).
- The upper Waiwhetu gravels (probable age: 29-14 ka; MIS 2) represent a alluvial delta that propagates across this swampy or lacustrine plain, thickest on the eastern side of Somes Island ridge. They probably did not propagate all the way to Falcon Shoals prior to the early Holocene sea level rise.
- A fine-grained intra-Waiwhetu unit was deposited within the basin and is thicker in the west and thins to the east, and is possibly absent in places. This unit is likely to be diachronous (probably during the entire period from 71–10.5 ka; MIS 4-2), displacing the volume occupied by the lower and upper Waiwhetu gravels present in the east. The silt is of swamp and/or lake origin.

- The fine-grained intra-Waiwhetu silt probably thins or lenses out close to Wellington harbour heads. The upper Waiwhetu gravels probably thin to zero thickness a few kilometres north of the harbour heads, but if present in the south, are probably in hydraulic contact with lower Waiwhetu gravels.
- Lower Waiwhetu gravels propagate across older marine deposits, and were lain down when the sea retreated from Wellington Harbour following the last interglacial (c. 71 ka; MIS 4). They are thickest on the eastern side of the Somes Island ridge.
- Wilford Shellbed represents a marine incursion during the high sea level stands of the last interglacial period (130–71 ka; MIS 5). This marine incursion is analogous to that of the Holocene but has been tilted by subsequent tectonic deformation along and across the axis of the basin.
- The Wilford Shellbed probably thins towards Wellington Harbour heads, and may coarsen as well, as they were probably deposited in an analogous environmental setting (within the zone of bottom resuspension by storm-waves) to that of the Holocene Petone Marine Beds.

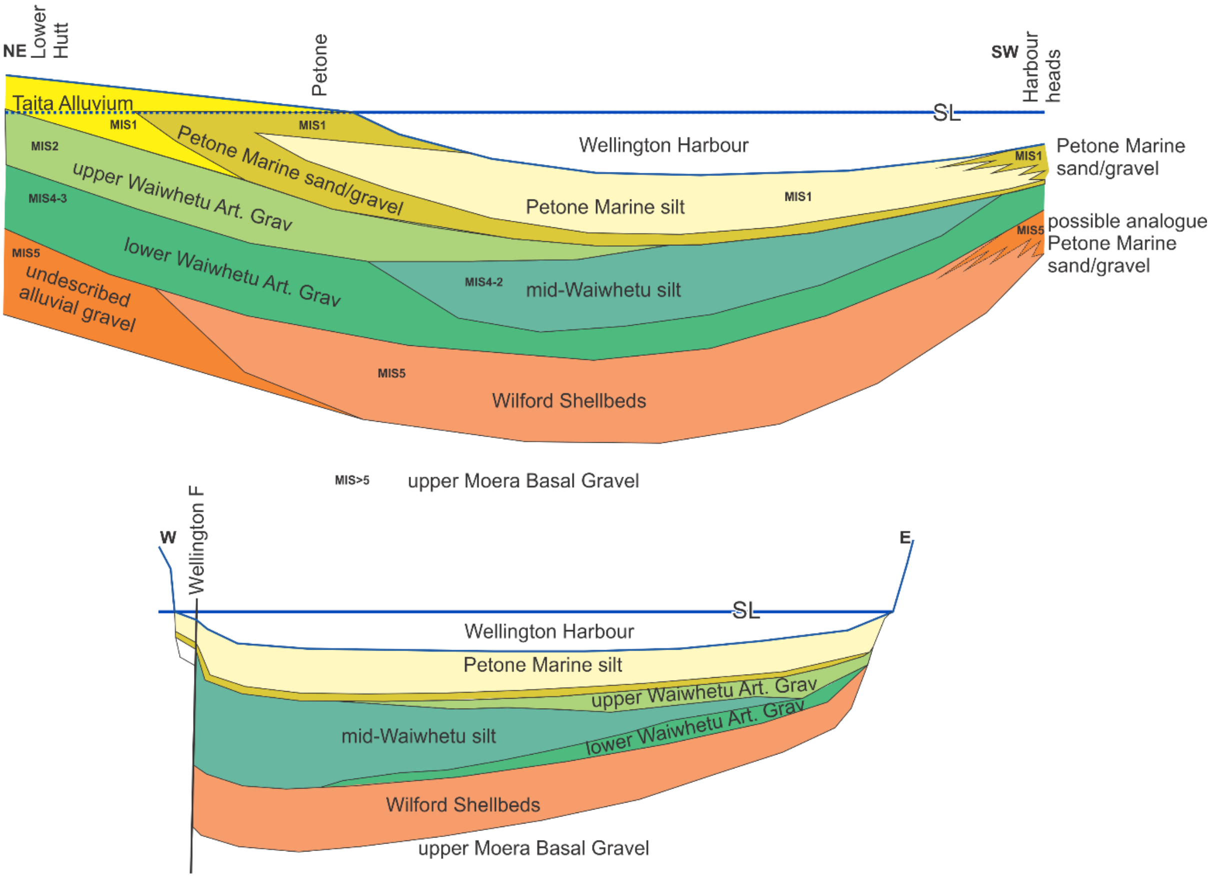

Figure 5-8: A conceptual stratigraphic model for upper Quaternary units beneath Wellington Harbour illustrating ages and geometric relationships. The upper diagram illustrates the conceptual stratigraphic model down the NE-SW axis of the basin, while the lower image provides a conceptual E-W cross section. Note tapering of sedimentary units towards Wellington Harbour heads. This is manifest as a coarsening of marine

units of the Petone Marine Beds and Wilford Shellbed close to the harbour heads, and thinning of the intra-Waiwhetu silt to the east and flanks of the harbour heads.

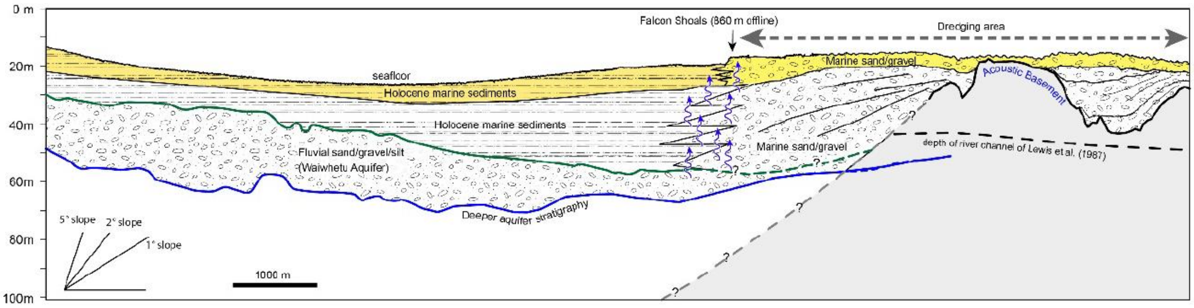

Figure 5-9: Conceptual model for the NE-SW geometry of the Waiwhetu Artesian Gravels towards the Wellington Harbour entrance (right-hand side of figure). Areas of uncertainty are shown by dashed lines and question marks. Note the extreme vertical exaggeration of this section, employed to emphasise the stratigraphic relationships (from Lamarche et al. 2015).

6 Summary and recommendations

Newly acquired lithologic information from offshore boreholes is used to better constrain previous marine geophysical interpretations in Te Whanganui a Tara/Wellington. A conceptual model was developed to show how the sedimentary units and their stratigraphic geometries developed within Te Whanganui a Tara/Wellington Harbour over the past ~130,000 years. This geological model was then used to inform the parameterisation of the HAM hydrogeological model, developed for the aquifer system throughout the harbour basin and Hutt Valley to the north.

Recommendations for future work that could contribute to our current data and understanding of the gravel aquifer sequence include:

(1) Acquisition of new seismic reflection data to the west of Matiu/Somes Island to better constrain the lateral extent of the Waiwhetu Artesian Gravels within the Wellington Harbour basin, especially as there are insufficient data to verify the occurrence of the aquifer east of Matiu/Somes Island. Future geophysical data acquired using the same system as employed on KAH1502 and KAH1602 will provide high resolution data in areas with gas masking, especially in the vicinity of the Wellington Fault between Kaiwharawhara and Petone, and in central parts of the harbour basin.

(2) Consideration should be given to borehole drilling further offshore to confirm the geological model interpretations, especially in the vicinity of Falcon Shoals, and to the west of Matiu/Somes Island.

(3) Detailed geological investigations (e.g., grain-size, texture, composition, palynology, ^{14}C aging) on sediment recovered from the boreholes would greatly improve our understanding of the stratigraphy of the Wellington basin, and how the sedimentary system developed in response to climatic (glacial-interglacial) and environmental change (e.g., land clearances by humans) over the past ~130,000 years.

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APPENDIX 2: Field investigation methodology

Drilling

The exploration bores were drilled by the Griffiths McMillan Joint Venture (GMJV) using a Fraste Sonic Rig mounted on the Tuhara jack-up barge, which was provided by Heron Construction. A more detailed description of the drilling methods is presented in the Geotechnical Factual Report (Stantec, 2018) but the general process used was as follows:

- Installation of an 8” sea riser to between 14 and 22 m below sea floor;
- Advancement of bore using 6” casing advance and PQ sonic coring techniques;
- Core samples were collected by GMJV and logged by a Stantec Engineering Geologist;
- Geophysical logs were run from surface to the base of the bore once it had reached full depth. These comprised gamma and neutron density logs;
- The bore was sealed and backfilled to ensure that the aquifer units were not connected and all casing was removed from the bore.

Open hole sampling and testing

The majority of the core sample was taken in 3m runs, but when gravel units were encountered the runs were shortened to 1.5m to allow for a more detailed assessment of the potential water bearing capacity of these units. At the end of each run within the gravel horizons the water level was allowed to stabilise and where appropriate constant rate or falling/rising head tests were undertaken within the casing.

In the majority of the units, the water quality was assessed by pumping the open bore using a 3” surface pump and measuring the electrical conductivity, pH value and temperature of the groundwater until this started to stabilise. It was frequently necessary to pump for several hours to ensure that the majority of the drilling fluid and saline water used for the constant/falling head tests was sufficiently removed so the results were representative of aquifer conditions.

Once the groundwater field parameters started to stabilise a grab sample was taken using the methods detailed below and sent to the laboratory for analysis to provide an initial assessment of the potential groundwater quality.

Installation and development

Once a gravel unit had been drilled through in its entirety, the best location for the temporary screen was identified based on the core samples and the results of the constant/falling head tests. Areas of clean, well washed gravels with higher indicative permeability were considered to be preferable. When a larger thickness of good gravels was present, the screen was located nearer the base of this unit to ensure the best flow from the aquifer and to maximise the chances of picking up higher salinity water should pumping result in any significant changes to the water quality. Once the screen was installed the temporary casing was pulled back to the top of the aquifer to allow flow into the bore whilst maintaining the seal between the aquifer units.

If the gravel unit was not considered to be water bearing the temporary screen was not installed and not additional testing was undertaken. This proved to be the case for two thin gravelly horizons within the Lower Waiwhetu in E3a and the clay bound gravel units encountered within the Moera in E8.

For the first test on E3a, within the Upper Waiwhetu, a 1.5m length of 4” stainless steel wire-wound screen with 2.0mm aperture was used with a 0.5 m steel sump. For all the other tests a 3.0 m length of 4” stainless steel wire-wound screen with 2.0mm aperture was used with a 0.5 m steel sump at the base. The screen was cleaned between uses to ensure there was no cross-contamination of the aquifer units.

The temporary screen was installed within the casing at the depths summarised in Table A2.1 below. Once installed the outer 6” casing was pulled back to expose the formation and the bore was developed using a combination of pumping, surging and airlifting until the water was clear of significant sediment and the aquifer parameters were stable. A compressor was used for the airlifting and 2” and 3” surface pumps were used during development and surging.

Table A2.1: Temporary installation details

Bore	Aquifer	Screen Depth (mbsf)	Development	Static Water Level (mamsl)
E3a	Upper Waiwhetu	24.0 – 25.5	1 day pumping and surging	3.77 (24/07/2017)
E3a	Upper Waiwhetu	25.0 – 28.0	1.5 days pumping, airlifting and surging	3.79 (22/08/2017)
E3a	Moera	74.0 – 77.0	1 day 2 hrs pumping, airlifting and surging	4.08 (8/08/2017)
E8	Upper Waiwhetu	25.0 – 28.0	1.5 days pumping, airlifting and surging	2.95 (14/01/2018)
E8	Lower Waiwhetu	38.8 – 41.8	1.5 days pumping, airlifting and surging	3.09 (21/01/2018)

During the later stages of development, regular measurements of the flow, electrical conductivity, pH and volume of sediment were undertaken to assess whether the bore was fully developed. Flow measurements were estimated by measuring the time taken to fill a 1000L water container (bucket test). Water quality estimates were taken using a calibrated YSI Water Quality Sonde and the sediment quantity was estimated by filling a 20L bucket and inspecting the volume of sediment which settled to the base.

Only once all these parameters had stabilised and the sediment within the abstracted groundwater was minimised was the bore declared to be sufficiently developed. A groundwater sample was generally collected for laboratory analysis at the end of development to provide more accurate water quality information than obtained from the grab samples collected from the open bore.

Monitoring Equipment

Following development, the following monitoring equipment was installed to provide accurate information on variations in the groundwater levels and quality:

- In bore instrumentation;

    - Vented pressure transducer (0-20 m depth range) to measure the water level, which also measured the electrical conductivity and temperature of the groundwater, which was linked to the real time telemetered system (BSMART) managed by NIWA;
    - Sealed back-up pressure transducer requiring manual download, which measured the water level and temperature at regular intervals in case the telemetered system failed;
- NIWA's Portable Underway Flow Through System (PUFTS) which comprised a small pump and flow through cell which measured the following water quality parameters and was linked to the BSMART system;
    - Electrical Conductivity;
    - pH value;
    - Temperature;
    - Salinity;
    - Turbidity;
    - Dissolved oxygen;
- Flow meter to record the pumping rate, which was also linked to the BSMART system. However, there were issued with getting the flow meter to work accurately so this was not used in all the tests (see below for details);
- Tidal gauge comprising a vented pressure transducer installed within a steel tube bolted to the side of the barge.

In addition the BSMART system also included a weather station on the barge which ran full time and measured the following information:

- Barometric pressure;
- Wind speed and direction;
- Temperatures;
- Humidity; and
- Sunlight.

To ensure that data would not be lost if the BSMART system failed at a critical moment, the following back-ups and manual checks were used:

- Unvented pressure transducer (0-30 m depth range) was installed within the bore during the testing to provide water level information;
- Manual readings with an electronic dip meter were taken to calibrate the water level data;
- GWRC records for the tidal levels at Queens Wharf were available should the tidal gauge fail (which did occur);
- Basic electrical conductivity readings were duplicated within the PUFTS and in hole monitoring systems;
- Water quality measurements were also taken manually using a flow through cell and YSI water quality meter;
- Flow rate measurements were cross-checked by regular "bucket test" estimates using the 1000L water tank.

In general the monitoring equipment functioned well but there were a few issues that needed to be addressed during the testing. Sediment was present within the groundwater when the pump was started during the tests undertaken in the Upper Waiwhetu at E3a. Whilst it did clear up after several hours of pumping, it was necessary to install a sediment trap to ensure that the sediment did not damage the sensors within PUFTS (see photos in Appendix 9). This sediment trap was open to the air and as such the dissolved oxygen data from these tests is not considered to be accurate.

Additionally the sediment led to the initial flow meter jamming and providing inconsistent flow readings. These were cross-checked by doing regular bucket tests and the flow meter was switched out for an electronic version for the later tests to ensure more accurate data was available.

Variable amounts of degassing were noted during the pumping tests. The PUFTS set-up was designed to cope with some gas and included a flow cell which pulled out gas bubbles before the groundwater was fed into the flow through cell with the sondes (see photos in Appendix 9). Within the flow through cell a brush rotated around all the sensors every five minutes, clearing them of air bubbles. Whilst these measures were sufficient for most of the tests, there was significant degassing during the test on the Lower Waiwhetu Aquifer at E8 which could not be managed by this system. It was therefore necessary to set up a degassing tank before the water was fed through PUFTS during this test (see photos in Appendix 9).

The vigorous degassing seen in this test meant that the electronic flow meter was not able to accurately read the flow due to the volume of bubbles present within the groundwater. It was therefore necessary to rely solely on regular bucket test measurements to assess the pump rate during the test on the Lower Waiwhetu Aquifer at E8.

There was an issue with the tidal logger for the final test on E3a. The logger failed just prior to the test and it was not possible to obtain a replacement in time for the pumping test. It was necessary to use the GWRC data for the tidal levels at Queens Wharf to correct the data for tidal affects. A replacement logger was installed and functioning throughout the program at E8.

Wellfield Flow Regulation and Background Monitoring

The Waiwhetu Aquifer is known to be highly tranmissive on shore in the Hutt Valley. The effects of pumping at the Gear Island and Waterloo Wellfields are seen at the Petone foreshore (McEwans Park Bore) and at the monitoring bore located at Somes Island, see Figure 1 for locations. Proving whether the aquifers encountered in E3a and E8 are connected to the onshore aquifer was a critical part of the project.

Wellington Water managed their wellfield abstractions so that generally even flows were achieved during the monitoring and testing undertaken at the exploration bores. This was to ensure that the drawdown during the pumping tests was not unduly influenced by onshore abstraction. It was not always possible for the wellfield flow to remain steady for the full duration of the test, but where possible the abstraction rates were kept constant for several hours before changing to a new stable rate.

Additionally Wellington Water arranged for the wellfields to be switched off overnight for between 3.5 and 6 hours, whilst the water level was being monitored within the exploration bores, before switching the pumps back on at a high rate for at least 2 hours. This allowed the water level within the cone of influence of the wellfields to start to recover before being drawn down again when the wellfields were switched back on. This regulated flow pattern resulted in a signature water level change seen on shore, which was used to assess whether the aquifers were connected to the main Waiwhetu Aquifer onshore. Where recovery was noted within the aquifers in the exploration bores (e.g. Upper and Lower Waiwhetu), this data also provided a means of estimating regional transmissivity values.

Baseline monitoring of the water levels within the bore was undertaken overnight, generally both before and after the pumping test. This information was used, in conjunction with the water level variations at Somes Island and McEwan Park and the abstraction rates for the wellfields, to assess whether the aquifers were in continuity. Additionally the information from the overnight monitoring periods was used to assess the impacts of tidal variations, barometric pressure changes and variations in the wellfield pumping rates on the water levels measured within the boreholes. This information was essential to ensure that the data from the pumping tests was corrected accurately and also provided information on the static water levels within the aquifers under the harbour.

Pump Testing Methodology

The pumping tests and baseline monitoring periods for each bore and aquifer unit are summarised in Table A2.2 below.

Table A2.2: Monitoring and testing details

Bore	Aquifer	Screened Zone (mbsf)	Testing undertaken
E3	N/A	N/A	Terminated in Petone Marine Beds so no testing undertaken
E3a	Upper Waiwhetu	24.0 – 25.5	• Overnight monitoring on the 24 and 25 July 2017 • CRT for 7hr at 5.5 L/s using submersible pump on 25 July 2017 • SRT as step down test at end of CRT as three 30 minute steps of 4.2, 3.5 and 2.0 L/s followed by 30 minutes recovery
		25.0 – 28.0	• SRT of four 30 minute steps of 13.5, 15.5, 16.7 and 19.6 L/s, followed by 30 minutes recovery on 18 August 2017 • 48 hour CRT at 17 L/s from 18 to 20 August 2017 • 38.5 hours recovery and baseline monitoring from 20 to 22 August 2017
	Lower Waiwhetu	N/A	Gravel units were thin and not water bearing so no testing was undertaken
	Moera	74.0 – 77.0	• Overnight monitoring in the open hole on 4 August 2017 • Overnight monitoring on the 8, 9 and 10 August 2017 • SRT as three 30 minute steps at 4.1, 5.6 and 7.0 L/s using the submersible pump on 9th August 2017 • CRT continued on from SRT at 7.0 L/s for a further 6.5 hours using submersible pump, followed by 30 minutes recovery

			• Short term CRTs (up to 2hrs in length) using the surface pump at rates of 16, 14, 13 and 12.3 L/s on10 August 2017
E8	Upper Waiwhetu	25.0 – 28.0	• Overnight monitoring on 13, 14 and 15 January 2018 • SRT of five 30 minutes steps of 5.1, 7.0, 8.7, 10.8 and 13.5 L/s on 14 January 2018 using the surface pump • CRT of 2 hours duration at 12.3 L/s followed by 10 minutes recovery on 15 January 2018 using the surface pump • CRT of 7 hours duration at 12.7 L/s followed by 30 minutes recovery, also on 15 January 2018 with the surface pump
	Lower Waiwhetu	38.8 – 41.8	• Overnight monitoring on 20 and 21 January 2018 • SRT of 4 30 minute steps at 5.9, 8.0, 10.0 and 11.5 L/s on 21 January 2018 using the surface pump • CRT continued on from SRT for 7 hours at 11.5 L/s with flow rates decreasing to 10 L/s by the end of the test, followed by 30 minutes recovery
	Moera	N/A	Gravels were claybound and not water bearing so no testing was undertaken

The tests were set up to maximise the flow and drawdown using the available equipment in order to adequately characterise the water quality of the aquifer and provide information on the potential aquifer parameters of the various units. The surface pump was used to provide greater flow where the casing configuration did not allow for a large enough submersible pump to stress the aquifer.

Prior to each test the pump rates were trialled to ensure that all the equipment was working effectively and to work out the flow rates for the SRTs and CRTs in advance so steps in flow rate could be managed smoothly and accurately. Once all the trials were complete the water level was allowed to recover until monitoring indicated that the levels were representative of static water levels before the actual testing commenced.

During each test the following measurements were undertaken in addition to the telemetered data collected by the BSMART system (summarised above):

- Manual depth to water measurements from the top of the casing using an electronic dip tape at the following intervals;
    - Baseline monitoring periods – start and finish of monitoring interval,
    - SRTs – every minute for 10 minutes, then two minute intervals for the remainder of the step, with these monitoring intervals repeated for each step,
    - CRTs - same intervals as the SRTs for the first 30 minutes, followed by readings at 35, 40, 50, 60, 80, 100, 120, 150, 180, 210 and 240 minutes and then hourly readings thereafter,
    - Recovery – same intervals as the SRTs. Recovery monitoring of more than 30 minutes was not required.
- Bucket test estimates of the pump rate by timing how long it took to fill a 1000L drum at 30 minute intervals during the SRTs and at hourly intervals during the CRTs.

- Bucket test estimates of the flow through PUFTS using a 20L bucket at regular intervals throughout the test to ensure that the flow rate remains constant.
- Water quality field parameters were recorded at regular intervals (15 to 30 minutes) throughout all SRTs and CRTs using a YSI water quality meter connected to a flow through cell. These parameters comprised;
    - Electrical conductivity,
    - pH value,
    - Temperature, and
    - Dissolved oxygen (when the system was sealed).

The flow rate was maintained as constant as much as possible, but the tidal variations did mean that there was some variation in the flow rate when running the pump at maximum. This is most clearly seen in the results for the Lower Waiwhetu in E8. On completion of each test the bore was left to recover overnight before the temporary casing was removed.

Water sampling

Regular estimates of field water quality parameters were taken through development and the pumping tests using a YSI water quality probe installed in a flow through cell. The probe was calibrated on a daily basis and on the two occasions that the probe refused to calibrate, the back-up probe was successfully calibrated and used as an alternative.

A summary of the water quality samples taken for laboratory analysis is presented in Table A2.3 below.

Table A2.3: Water quality samples collected

Bore	Aquifer	Sample Name	Date Collected	Reasoning
E3a	Upper Waiwhetu	E3a 25m Drill	19/07/2017 16:00	Grab sample from formation
		E3a 24-25.5 DEV	24/07/2017 11:45	End of development
		E3aPT1 1hr	25/07/2017 09:00	Beginning of CRT PT1
		E3a PT1 3.5hr	25/07/2017 11:30	Middle of CRT PT1
		E3a PT1 7hr	25/07/2017 15:00	End of CRT PT1
		E3a PT3 19hr	19/08/2017 11:30	Middle of 48hr CRT PT3
		E3a PT3 4pm	20/08/2017 16:00	End of 48hr CRT PT3
		E3a PT3 (2)	22/08/2017 10:30	For breakpoint chlorination testing
	Moera	E3a 74.4m	04/08/2017 16:00	Grab sample from formation
		E3a 74-77m DEV	08/08/2017 13:30	End of development

		E3a PT2 1.5hr	09/08/2017 09:30	Beginning of CRT PT2
		E3a PT2 4.5hr	09/08/2017 12:30	Middle of CRT PT2
		E3a PT2 7.5hr	09/08/2017 15:30	End of CRT PT2
E8	Upper Waiwhetu	E8 GRAB 25.7m	10/01/2018 15:30	Grab sample from formation
		E8 UWA SRT1	14/01/2018 13:45	Middle of SRT
		E8 UWA PT1A	15/01/2018 08:30	Beginning of CRT PT1
		E8 UWA PT2B	15/01/2018 12:00	Middle of CRT PT2
		E8 UWA PT2C	15/01/2018 15:30	End of CRT PT2
	Lower Waiwhetu	E8 LWA DEV	20/01/2018 16:45	End of development
		E8 LWA PT3A	21/01/2018 09:00	Beginning of CRT PT3
		E8 LWA PT3B	21/01/2018 12:30	Middle of CRT PT3
		E8 LWA PT3C	21/01/2018 16:00	End of CRT PT3

All the samples were collected after the bores had been purged sufficiently to ensure that the results reflected the groundwater in the aquifer and were not contaminated by drilling fluids. For the grab samples the open bore was pumped continuously for at least four hours using the surface pump. During this period the field water quality parameters were measured using the YSI water quality meter at regular intervals to ensure that the majority of the drilling fluid had been removed from the groundwater before sampling was undertaken.

The samples from development and pumping were taken from a tap affixed to the discharge pipe and were collected after the pump had been running for a minimum of one hour and generally after a significantly longer period. Field water quality parameters were also monitored to ensure that the samples were representative.

The samples were collected within sterile containers, with preservatives where necessary, and stored in the fridge on the barge before being transported to the laboratory in sealed chilly bins chilled with ice packs under full chain of custody protocols. Where possible the samples were delivered to the laboratory within 24hours of sampling. However, when sampling occurred at the weekend the samples were kept in the fridge on the barge until they could be delivered to the laboratory.

Twenty litre bulk samples were collected from the Upper and Lower Waiwhetu Aquifers in E3a and E8 at the end of the pumping tests in case additional samples were required. These were initially stored on the barge before being transferred into a long term storage freezer.

For quality assurance and control purposes duplicate samples were taken from each bore from each aquifer unit tested. The samples from E3a were sent to a back-up laboratory to cross-check the results provided by the main laboratory used. The duplicate samples from E8 were sent to the main laboratory. Details of the duplicate samples are presented below.

- E3a 25m Drill (2) was collected as a duplicate grab sample from the Upper Waiwhetu aquifer from the open bore E3a. It was not analysed and was stored in the fridge as a spare in case it was required.
- E3a PT1 7hr (2) was collected from the Upper Waiwhetu Aquifer in E3a at the end of the pump test on 25 July 2017 at 3pm.
- E3a PT2 7.5hr (2) was collected from the Moera Aquifer in E3a at the end of the pump test on 9 August 2017 at 3:30pm.
- E8-DUP was collected from the Upper Waiwhetu Aquifer in E8 during the pumping test on the 15 January 2018 at 12pm.
- E8-DUP2 was collected from the Lower Waiwhetu Aquifer in E8 during the pumping test on the 21 January 2018 at 9am.

Water quality laboratory analysis

The samples were sent to two laboratories for chemical analysis. The main laboratory was Eurofins ELS which is an IANZ accredited laboratory based in Wellington which specialised in potable water testing and environmental analysis. The second laboratory was CFA laboratory based in Ashburton which is an IANZ accredited laboratory specialising in drinking water testing, which was previously associated with McMillan Drilling. This laboratory was used as a back-up and for quality assurance purposes.

All the samples were analysed for the following parameters:

- General parameters, including pH, TSS, TDS, TOC, EC, alkalinity, turbidity, hardness, salinity, dissolved and total Ca, Mg, K and Na, dissolved Si, fluoride, chloride, bromide, sulphate and colour;
- Nutrients, including nitrate, nitrite and ammonia;
- Dissolved metals, including Al, Sb, As, Ba, Be, B, Cd, Cr, Cu, Fe, Pb, Li, Mn, Hg, Mo, Ni, Se, Ag, Sn, Zn and U;
- Total metals, including Al, As, B, Cd, Cr, Cu, Fe, Pb, Mn, Ni and Zn; and
- Total Coliforms and E. Coli.

An additional sample from the Upper Waiwhetu Aquifer at E3a was also analysed for breakpoint chlorination, although the results of that testing are not included within this report.

Age dating

The following samples were taken for age dating analysis:

- E3a PT1 7hr (Upper Waiwhetu Aquifer at E3a)
- E3a PT2 7.5hr (Moera Aquifer at E3a)
- E8 UWA PT2C (Upper Waiwhetu Aquifer at E8)

- E8 LWA PT3C (Lower Waiwhetu Aquifer at E8)

The samples were collected using the methodology provided by GNS which involved submerging the sterile containers in the sample water and then filling the containers from the base up with fresh sample water at least three times before sealing. Any air bubbles were knocked out and the containers were sealed whilst still submerged to ensure that no air could get into the samples. The lids were then taped up with Teflon tape and covered with insulation tape to minimise the chances of air getting into the samples.

The samples were stored in a cool chilly bin without any ice or ice packs to reduce the chances of modern water contaminating the samples. They were transported to GNS within 24 hours, where possible, to ensure that the radon tests were effective. GNS carried out the laboratory testing and tested for the following parameters:

- Tritium,
- CFCs,
- SF6,
- Stable isotopes, and
- Radon.

APPENDIX 3: Data analysis methodology

Correction of Water Levels

The water levels measured within all the aquifer units encountered within the exploratory bores were influenced by the following factors:

- Seasonal changes caused by variations in recharge and abstraction,
- Tidal effects caused by pressure changes in the groundwater as the tide ebbs and flows over the aquifer,
- Changes in barometric pressure, which causes changes in the water pressure within the aquifer,
- Settlement of the barge, which altered the level of the survey point all the measurements were taken from;
- Drawdown from pumping at the Waterloo and Gear Island wellfields, which varied with the abstraction rates from these wellfields, and
- Effects of pumping tests at the bores.

In order to assess the baseline conditions and to use the pumping test data to attempt to estimate representative aquifer parameters, it was necessary to consider the effects of the tide, barge settlement, barometric pressure and wellfield abstraction. An example of the uncorrected data for the 48hr pumping test on the Upper Waiwhetu Aquifer in E3a is presented in Figure A3.1 below as an example.

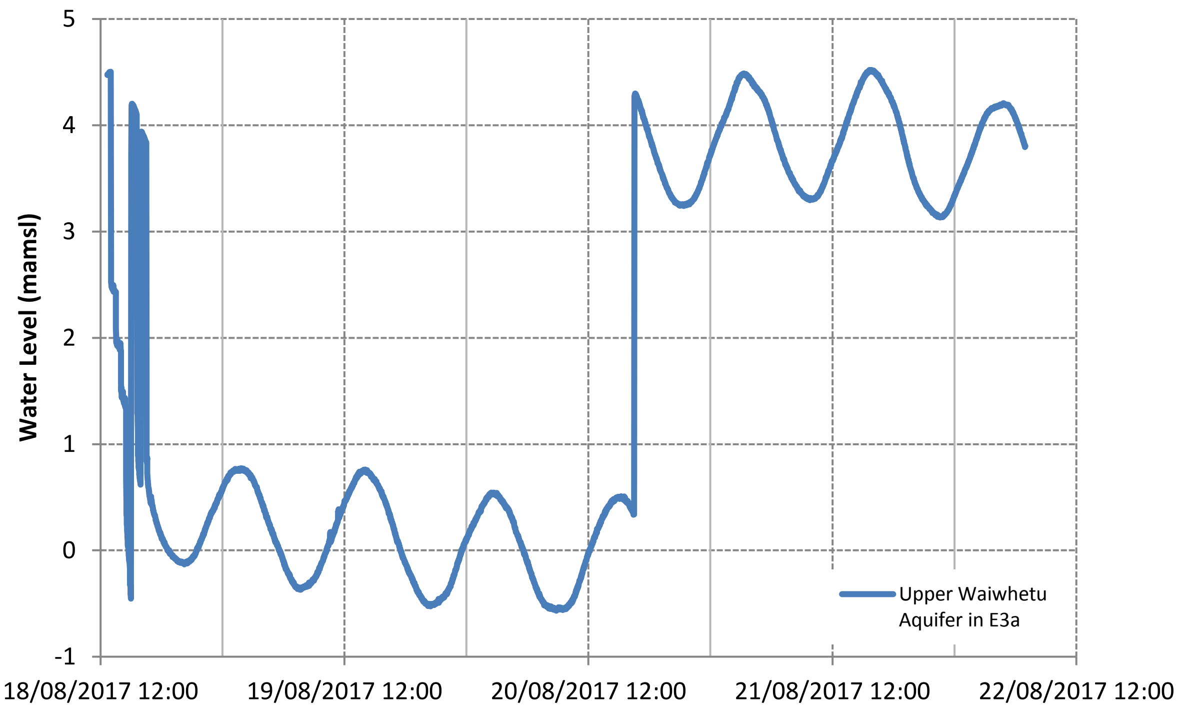


Figure A3.1: Measured Water Levels

The following data correction processes was applied to all the data:

- Converted manual groundwater level measurements from metres below top of casing to metres above mean sea level using the half hourly surveyed barge levels and the measured casing stickup;
- Corrected the groundwater level data from the unvented back-up logger for barometric effects, when this data was used. This is not necessary for the vented logger data used for most of the analysis because it is not influenced by these effects;
- Converted the logger data into groundwater level in metres above mean sea level by using the manual dip measurements of the resting water level to calibrate against. This was cross checked by considering multiple points and the depth of the data logger was installed at;
- Any sharp changes associated with a noted change in logger depth (e.g. when the pump was moved) were corrected;
- The tidal effects were removed by analysing the change in the baseline water level caused by the tide and removing this effect based on the following factors;
    - Tidal efficiency, the ratio of the water level change in bore and the tidal range,
    - Tidal time lag, the time offset of the tidal effect. This generally increases with distance from the coast, although aquifer transmissivity is also a factor,
- The tidal efficiency (as a percentage) and the tidal lag developed from the baseline data were then used to correct the pump test data as well (see Figure A3.2 for an example and Table A3.1 for the tidal correction factors);
- An assessment was then made to address the impacts of changing pumping rates at Waterloo and Gear Island wellfields on the water levels within the bore. The water levels were compared to those seen in equivalent monitoring bores closer to the wellfields (e.g. Somes Island bore) and to the changing abstraction rates for the wellfields. Where necessary the data was corrected for these effects but generally the changes were limited and the time lag was significant so, given that the wellfields were held at relatively consistent pumping rates during the testing, correction was mostly unnecessary;
- Changes in water levels were compared with the trends in barometric pressure to assess whether there was any correlation so the data could be corrected for barometric efficiency effects if required. No discernible relationship was detected and as such barometric efficiency corrections were not undertaken.

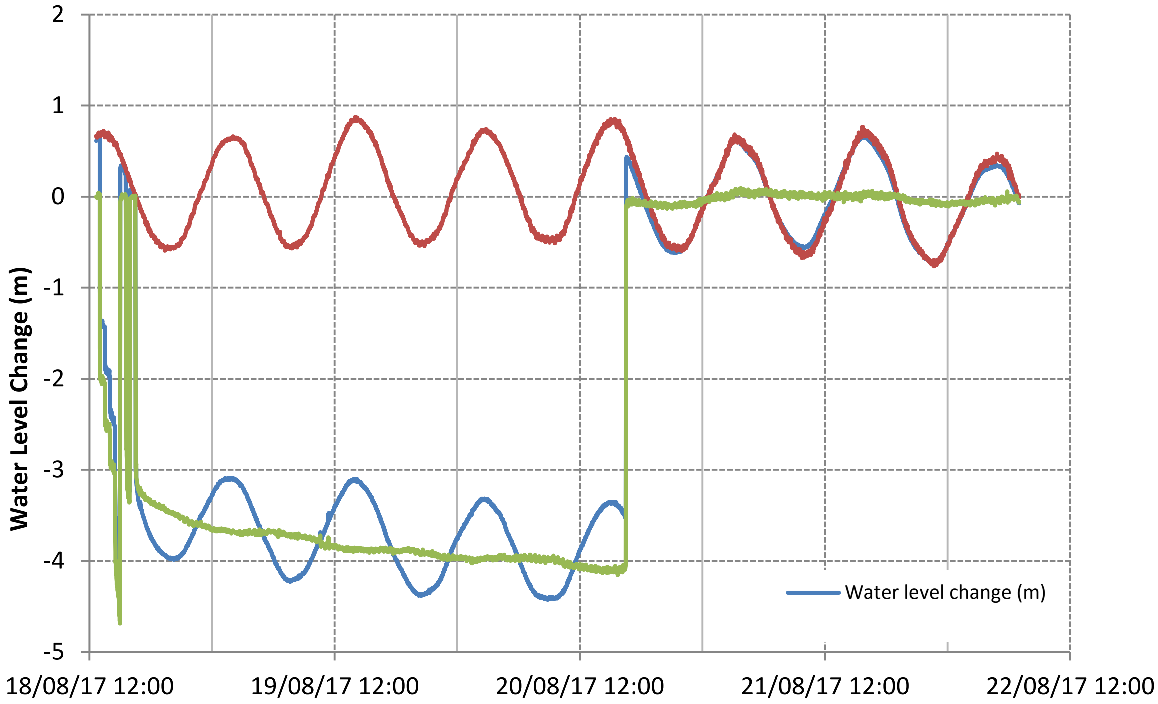


Figure A3.2: Correcting Water Levels for Tidal Effects for Upper Waiwhetu Aquifer in E3a

Table A3.1: Tidal efficiency and lag correction factors

Bore	Aquifer	Tidal Efficiency (%)	Tidal Lag (minutes)
E3a	Upper Waiwhetu	90	-10
	Moera	80	-10
E8	Upper Waiwhetu	90	-10
	Lower Waiwhetu	90	-10
Somes Island	Upper Waiwhetu	80	-10 to -15
McEwan Park	Upper Waiwhetu	50	0
	Lower Waiwhetu	50	0
Randwick	Upper Waiwhetu	13	180
Hutt Rec	Upper Waiwhetu	30	135
UWA3	Moera	44	15 to 20

In addition to these corrections consideration was given to the changes in the surveyed levels of the barge. The barge level was monitored on a regular 30 minute interval during the days when pumping tests were undertaken. There could be significant variation minor short term variation due to the swaying of the barge caused by changing pressure on the structure from the wind and swell (see Figure A3.3). However this “noise” did not significantly affect the water level measurements but the longer term differences had to be accounted for and the data was corrected to the average value for the test period to account for this settlement of the barge.

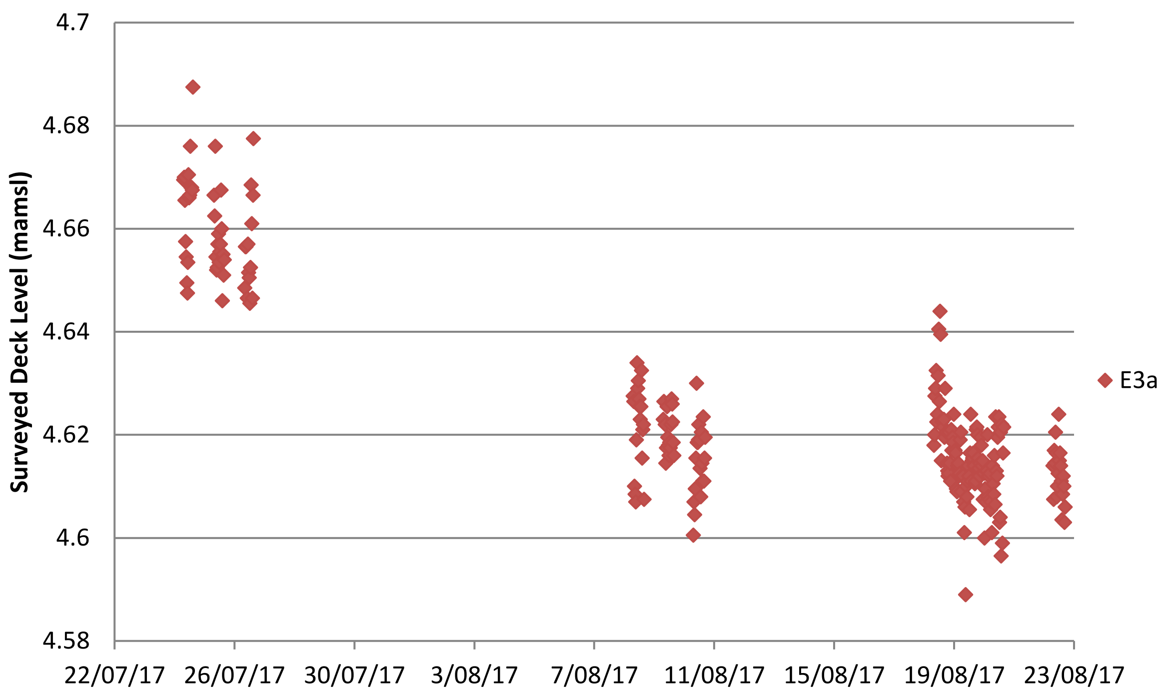


Figure A3.3: Variation in surveyed deck levels during tests at E3a

An additional consideration during the data correction was the salinity of the water. Groundwater level loggers use the water pressure and density to calculate the height of the water column above the logger. Increases in salinity lead to an increase in the water density which can change the estimated water level. For the majority of the tests the water was fresh, but the water encountered in the Lower Waiwhetu Aquifer was more brackish. An assessment of the potential difference in recorded water level due to the differing salinity indicated that there would be less than 2mm difference per metre of head based on the total dissolved solid results for the different aquifers. This was within the error of the previous corrections and was therefore considered to be insignificant.

To ensure that the data corrections were effective, prior to the field investigation, the long term monitoring data from the Somes Island and McEwan Park bores were analysed using the methodology outlined above. This longer term analysis was used to assess the potential error associated with the data correction and ensure that it was minimised.

Pump test analysis

The corrected data from the overnight monitoring and the various pumping tests was used to estimate the following aquifer and bore parameters:

- Bore losses,
- Aquifer losses,
- Transmissivity, and
- Storativity.

The Hantush-Birschenk and Eden-Hazel Methods (Kruseman and de Ridder, 1994) were used on the step rate test drawdown data to assess the proportion of bore and aquifer losses and the efficiency of the temporary bore installation. These assessment methods are based on the following assumptions:

1. The aquifer is confined, leaky, or unconfined;
2. The aquifer has an infinite extent;
3. The aquifer is homogeneous, isotropic, and of uniform thickness over the area influenced by pumping;
4. The piezometric surface is horizontal prior to pumping;
5. The aquifer is pumped in a series of uniform steps with increasing discharge rates;
6. The well is fully penetrating;
7. The flow to the well is in an unsteady state;
8. Non-linear well losses are appreciable and vary according to the expression CQ2; and
9. $u < 0.01$.

The majority of these assumptions are reasonable based on the aquifer conditions encountered during the tests. However, the wells were not always fully penetrating and the alluvial nature of the aquifers means that they are not naturally isotropic or homogeneous. There is insufficient data to assess whether there are significant variations in the thickness, although the seismic information indicates that the aquifer thickness is likely to be relatively uniform in the immediate vicinity of each bore.

The results of the constant rate pumping tests were analysed using the Cooper-Jacob Straight Line Method for confined aquifers to estimate the transmissivity of the aquifer unit. This method is based on similar assumptions to those detailed above, although assumptions 5 and 8 do not apply. This method relies on a constant pumping rate being applied for the whole test. Where there was a significant change in pumping rate during the test the analysis focussed on the part of the data associated with the constant pumping rate.

The recovery of the water levels within the bores once the pumping tests were completed was also analysed. When the recovery rate was suitable the Theis Recovery Method was used to analyse the data (Krusemann and de Ridder, 1994). This method is based on similar assumptions to those listed above, but uses the residual against drawdown to estimate the transmissivity of the aquifer. Residual drawdown is the time since the start of the pump test divided by the time since the pump was switched off.

In some cases the recovery was too rapid for the Theis Recovery Method to be effective. In these cases, particularly the Moera Aquifer in E3a and the Upper Waiwhetu Aquifer in E8, an underdamped oscillatory response was seen within the bore when the pump was switched off. This type of response is generally only seen in highly permeable aquifers and the Van der Kamp Method (1978) was used to analyse this data. This method assumes that:

- The aquifer is homogenous;
- The well is fully penetrating; and
- The damping coefficient and period of oscillation remain constant.

Whilst these assumptions are generally reasonable, it should be noted that this method is designed to assess the response within a bore to a slug test, i.e. an instantaneous change in water level and the associated recovery. A prolonged pumping test would have a different effect, pulling water from further away in the aquifer and changing the water pressure across the whole radius of influence. Therefore this assessment method is not strictly applicable to the recovery from pumping tests. However, the highly transmissive nature of the aquifer, the fact that the aquifer is confined and the relatively low flow rates of the pumping tests mean that the method can be used to provide an estimate of the transmissivity provided that the limitations are considered.

The above methods were used to estimate the bore efficiency and transmissivity of the aquifer in the vicinity of the bores. However the bore diameter and temporary nature of the installation meant that it was difficult to significantly stress the aquifer and the majority of the drawdown seen during the testing was associated with bore losses rather than aquifer losses. The bore installation was designed to obtain representative water quality samples and the limitations of this set-up for accurate estimates of the aquifer parameters were acknowledged prior to the drilling program and were apparent throughout the testing.

Furthermore it is not possible to accurately estimate the storage of the aquifer from drawdown within the pumped bore due to the effects of well losses. In order to obtain more accurate transmissivity estimates and assess the storativity the changes in water level associated with the wellfield switch-off were analysed using the Theis Method for confined aquifers. This method is based on similar assumptions to those listed above.

The response when the wellfields were shutdown was analysed using this method by assuming the pump rate was the average value it was before the shutdown and the displacement associated with the recovery was the equivalent drawdown. These assumptions are reasonable when the principles of radial flow into wells are considered.

When the wellfields were switched back on the drawdown data was analysed using the pumping rates following the switch-on and the associated drawdown response. This data was used to estimate the average transmissivity and storage of the aquifer between the wellfield and the bore. It should be noted that during the tests on E3a pumping was occurring at both the Waterloo and Gear Island wellfields so the average distance from these bores was used, whereas during the tests on E8 only Waterloo wellfield was in use so the distance for this wellfield only was used for the analysis.

In order to assess the variation in the transmissivity across the aquifer the response to the wellfield switch off on the night of the 14th January 2018 was also analysed for the regional monitoring bores at Somes Island, McEwan Park and Randwick. An attempt was also made to analyse the data from the bore at the Hutt Recreation Ground, but its proximity to the Waterloo wellfield meant that it was difficult to accurately correct the data for tidal variations and as such there was a reduced confidence the results.

Water quality assessment

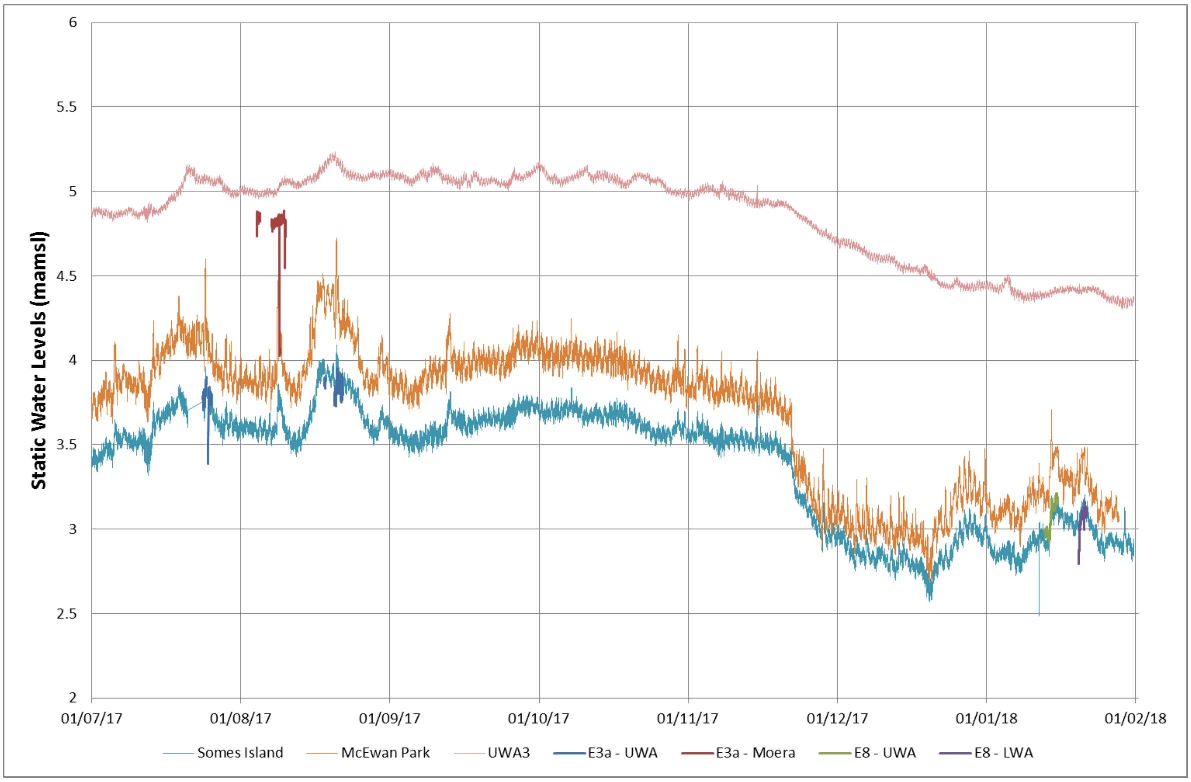
In order to assess the validity of the water quality information the duplicate samples were analysed and the relative percentage difference values were calculated.

In general the RPD values were less than 5% indicating a high level of sample consistency. Where the RPD values were higher the concentrations were extremely low, meaning that a slight difference causes a high RPD which is not a reflection of a significant difference between the samples. The laboratory also undertakes their own quality control and quality assurance tests to ensure the results are accurate where possible.

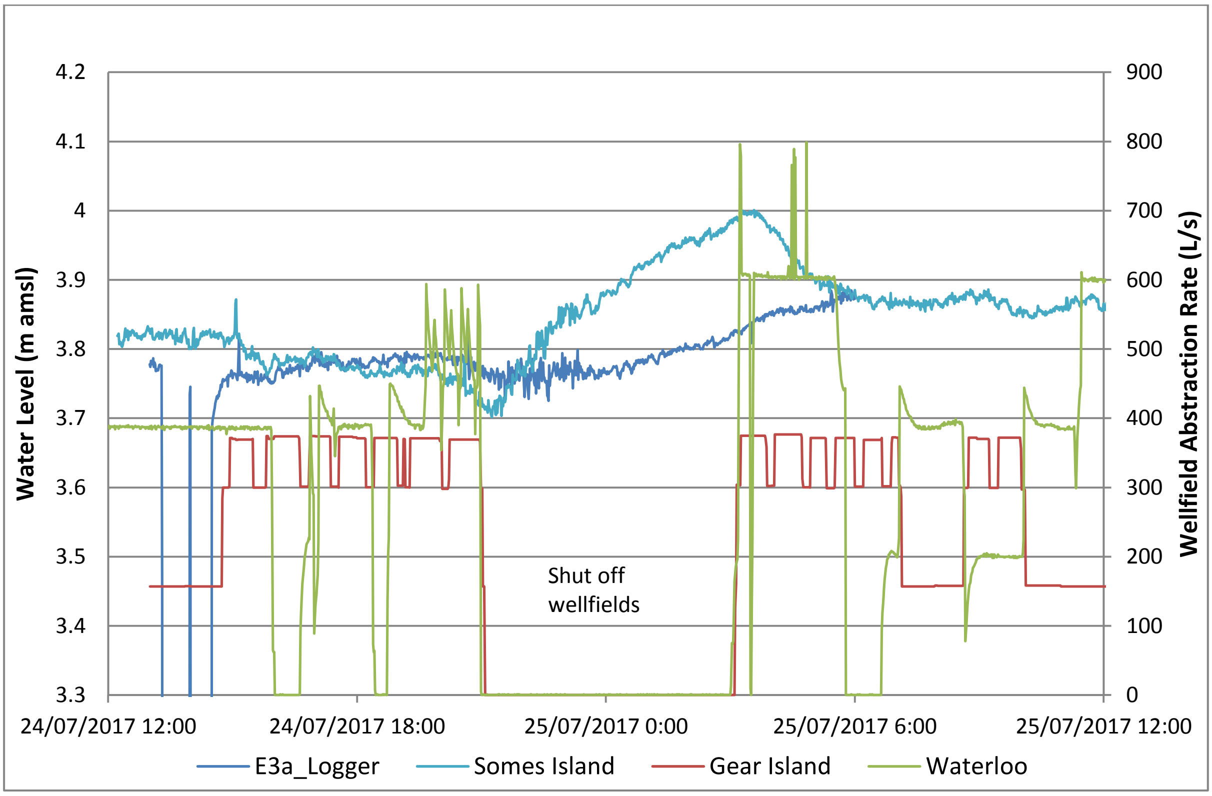
Based on the quality assurance testing undertaken, the results are considered likely to be representative of aquifer conditions.

APPENDIX 4: Groundwater monitoring hydrographs

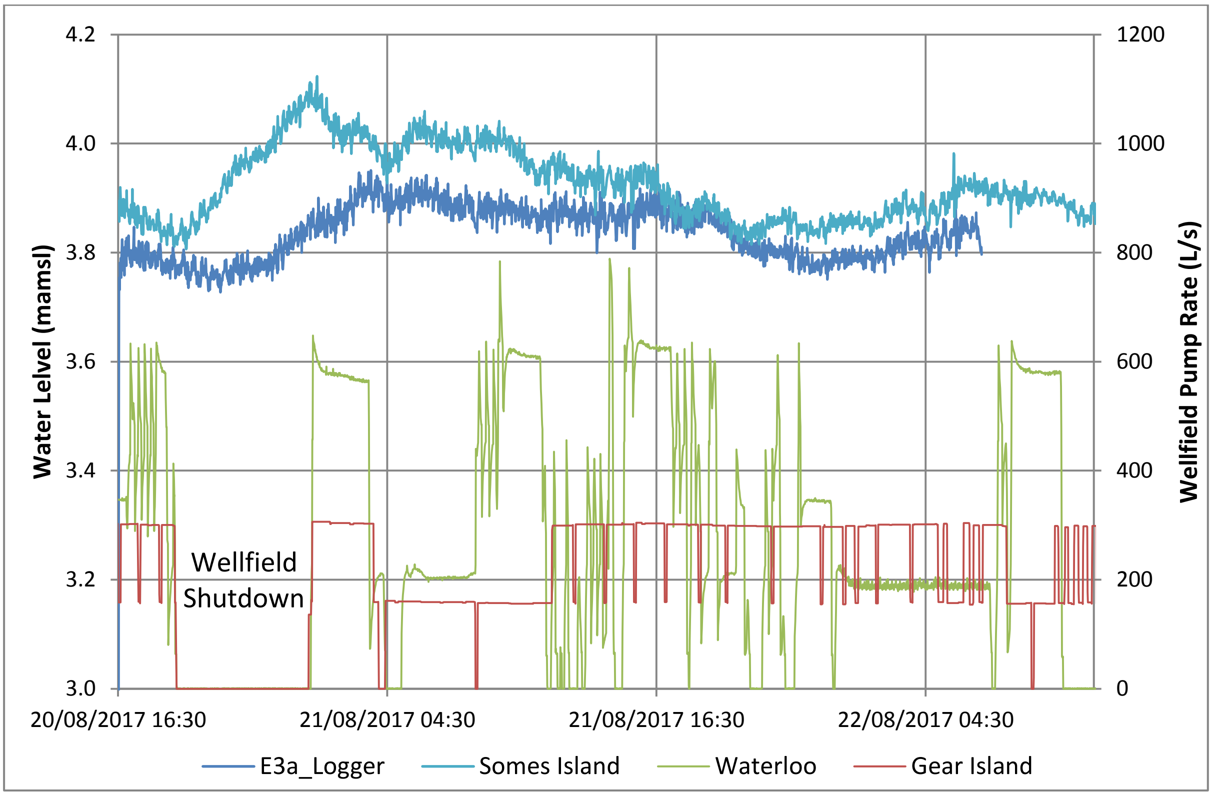
Static water level monitoring compared with long term groundwater level records.



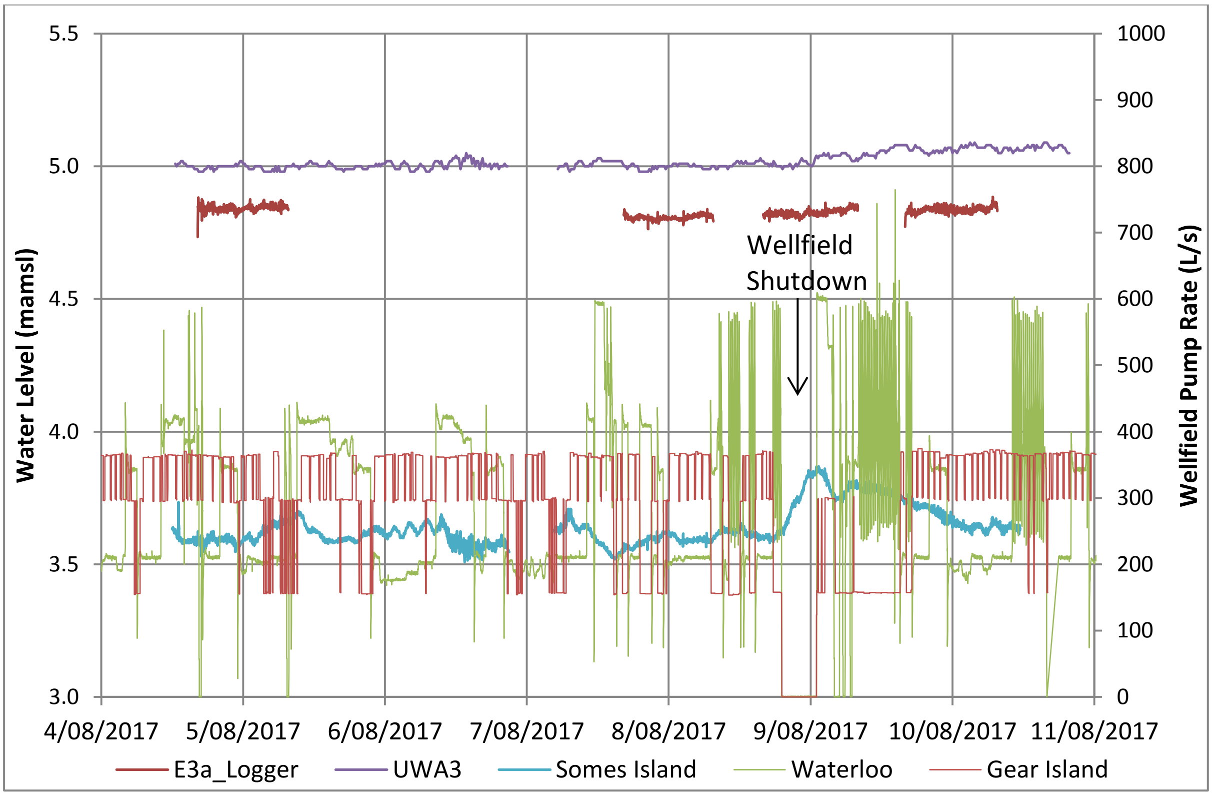
E3a – Upper Waiwhetu Aquifer Hydrograph 24th to 25th July 2017



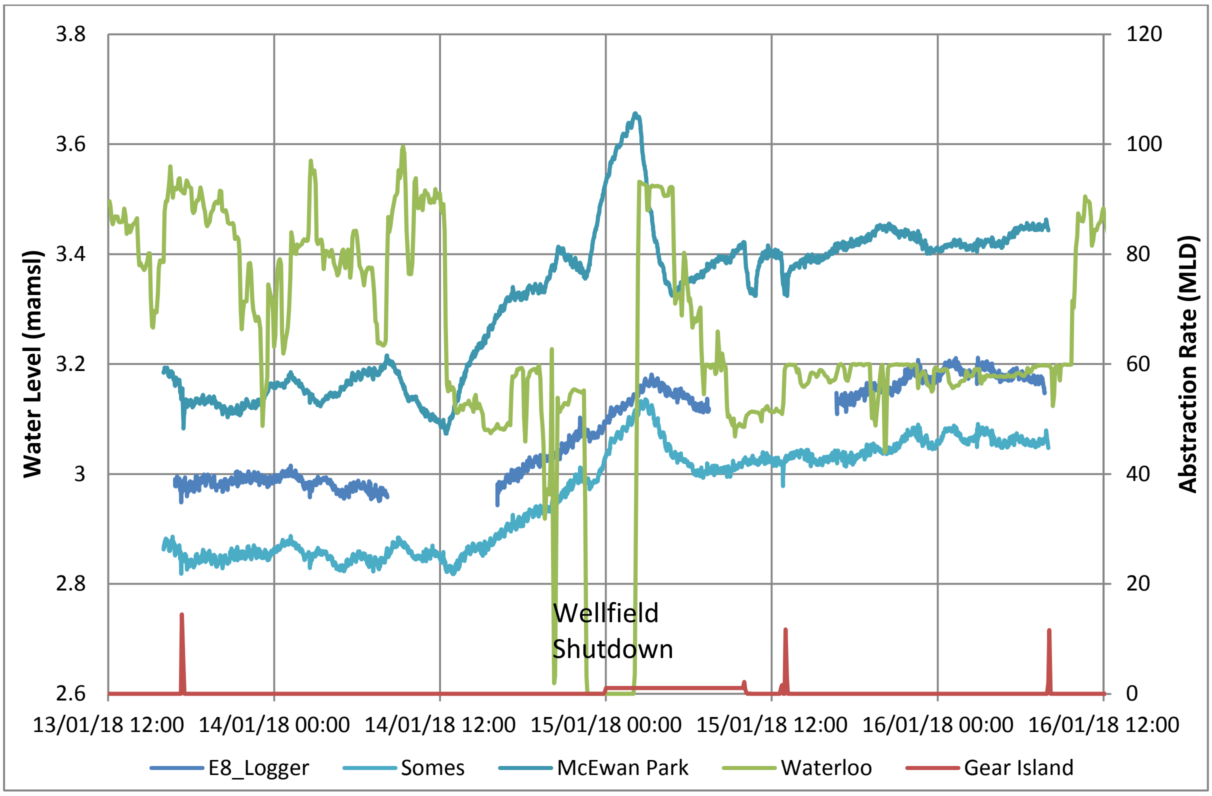
E3a – Upper Waiwhetu Aquifer Hydrograph 20th to 22nd August 2017



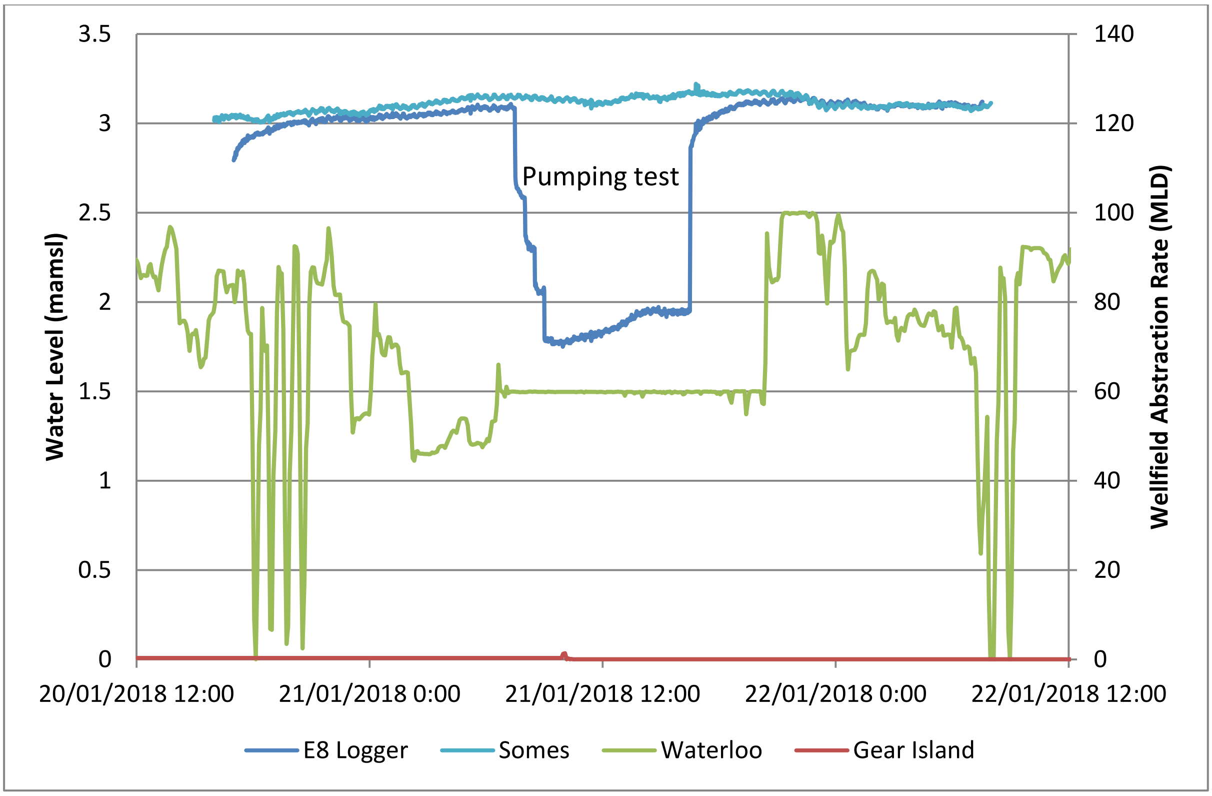
E3a – Moera Aquifer Hydrograph 4th to 11th August 2017



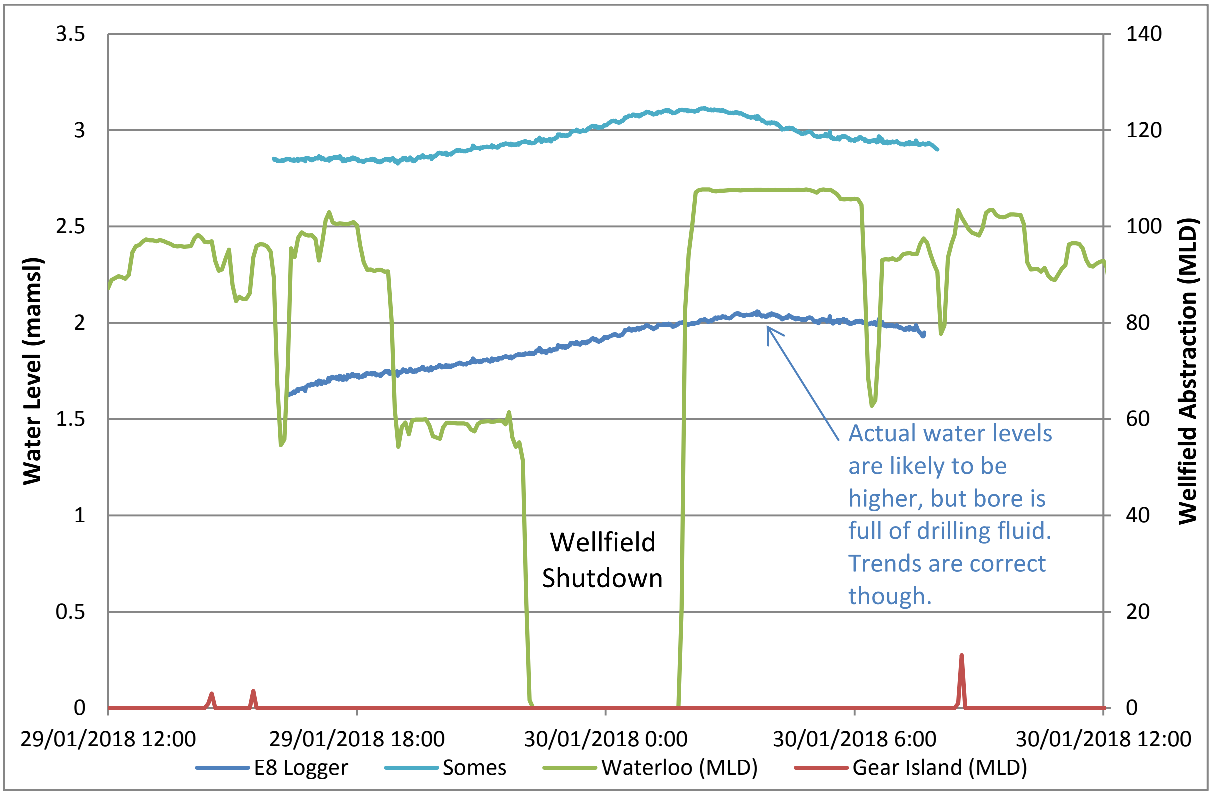
E8 – Upper Waiwhetu Aquifer Hydrograph 13th to 16th January 2018



E8 – Lower Waiwhetu Aquifer Hydrograph 20th to 22nd January 2018



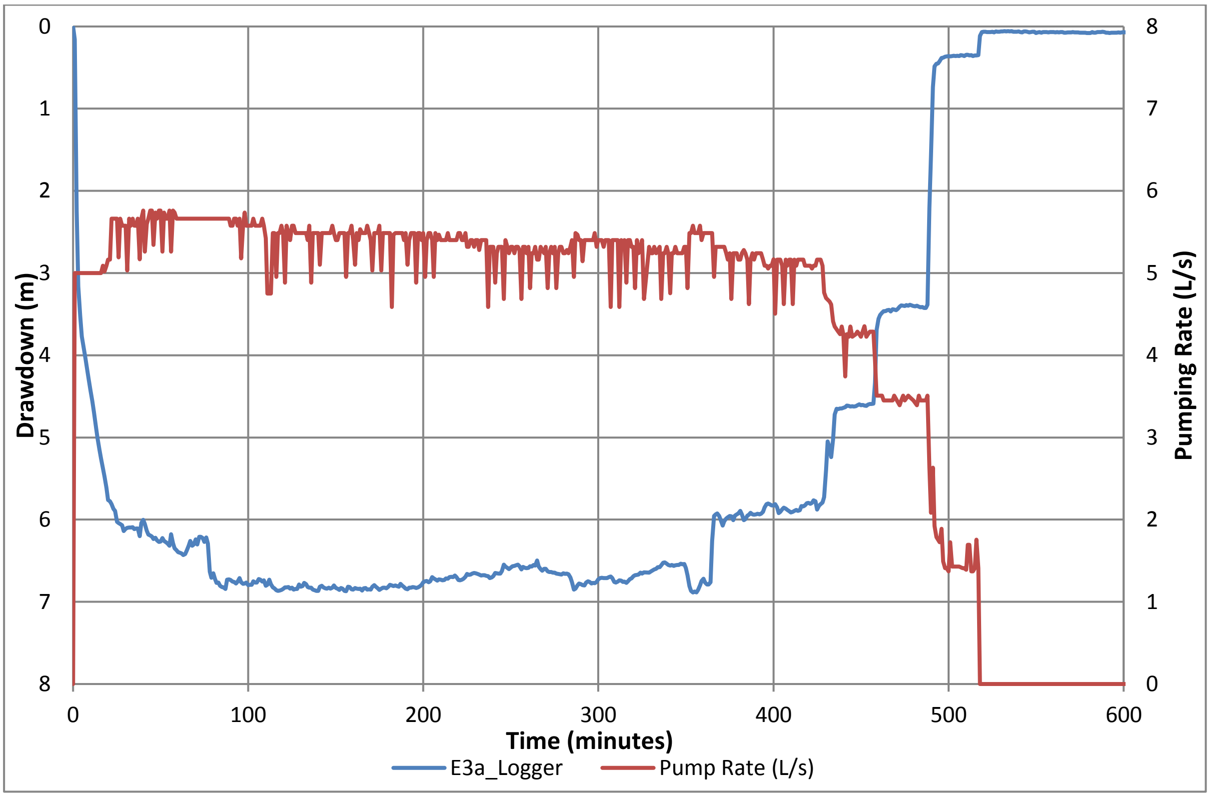
E8 – Lower Waiwhetu Aquifer (drilling fluid in open hole) Hydrograph 29th to 20th January 2018



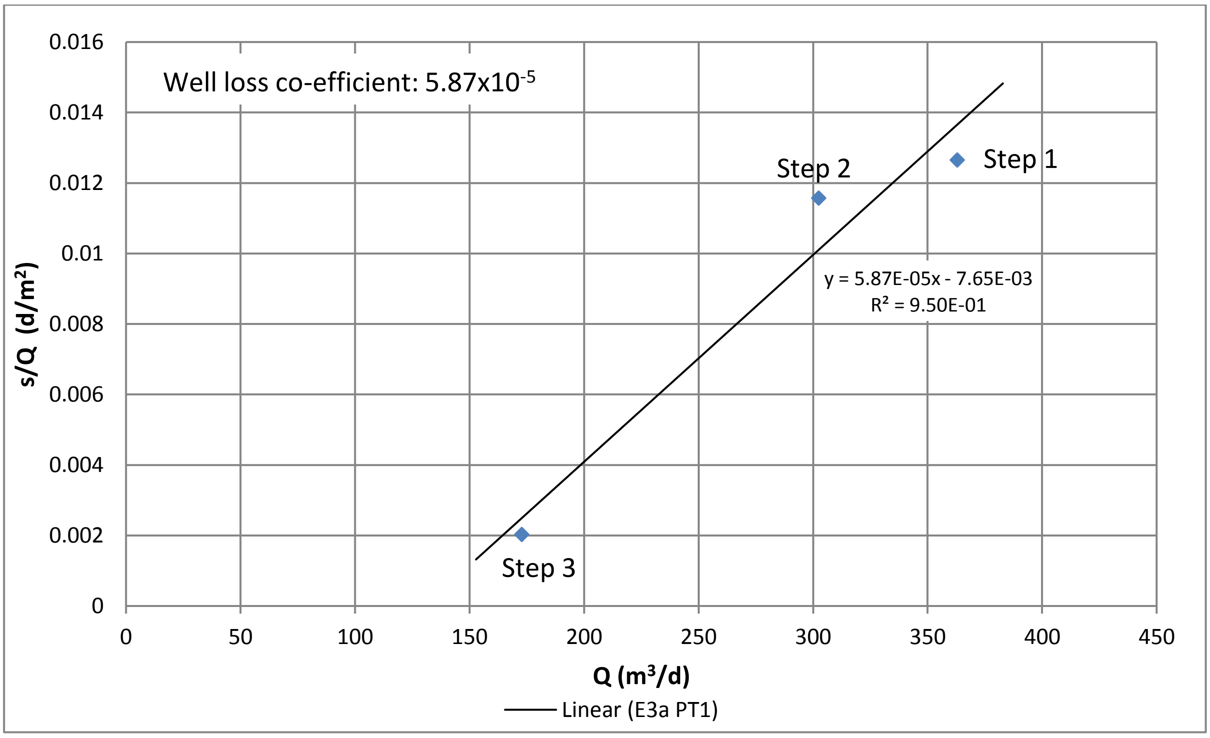
APPENDIX 5: Pumping test results

E3a – Upper Waiwhetu

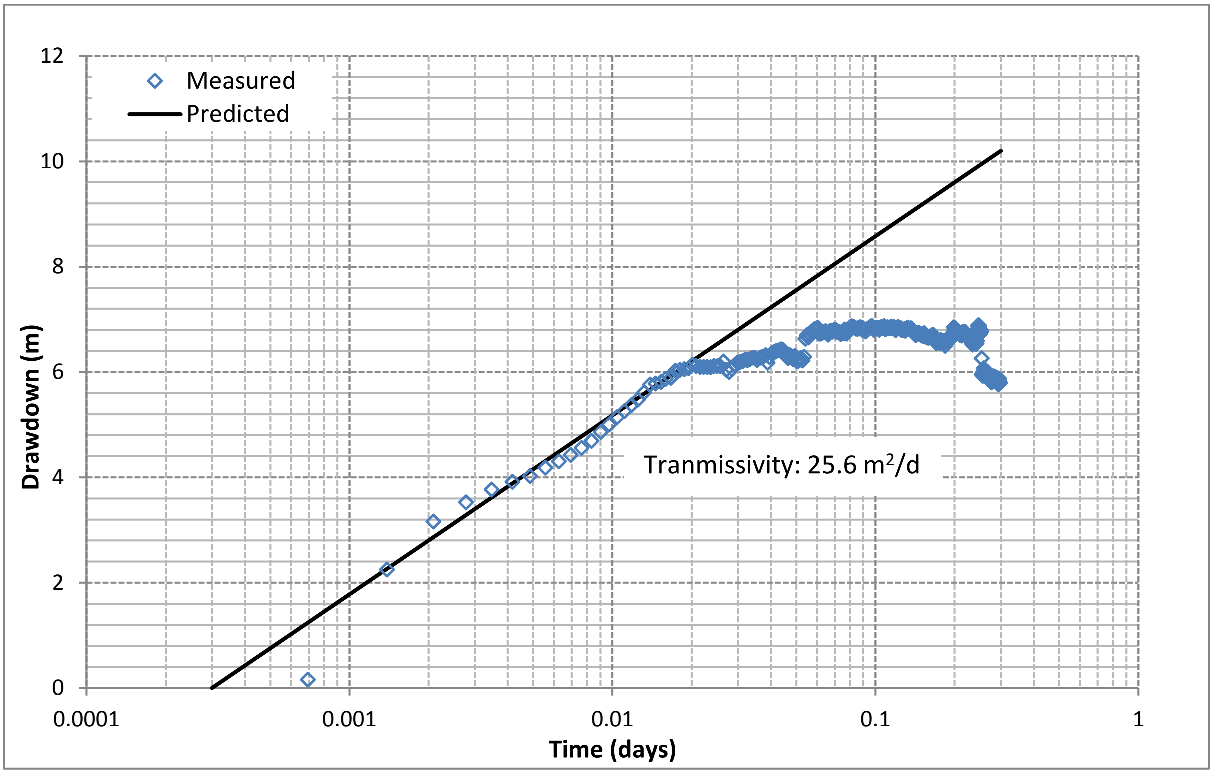
Pumping test on 25th July 2017. Bore screened 24.0 – 25.5 below sea floor.



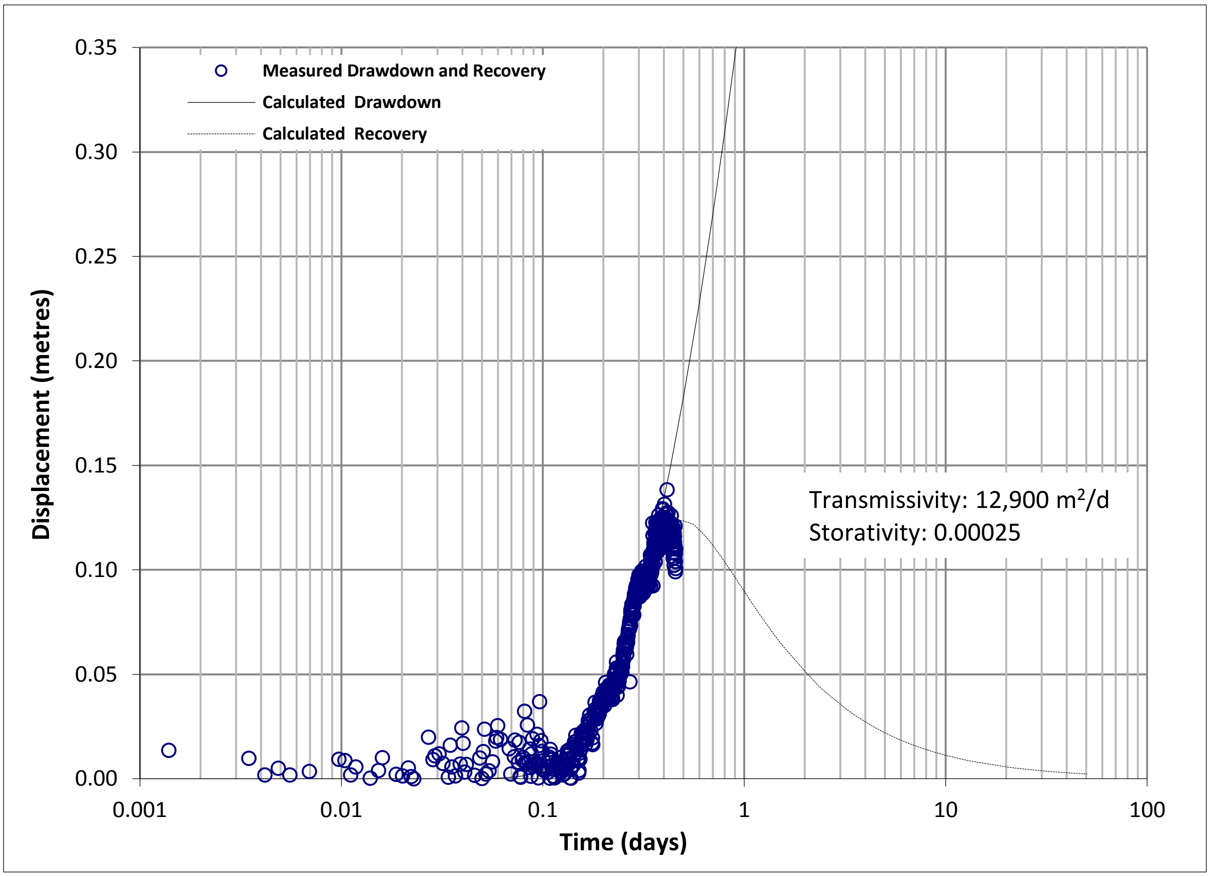
Step Rate Test Analysis – s/q vs Q (for step down test at end of pumping test)



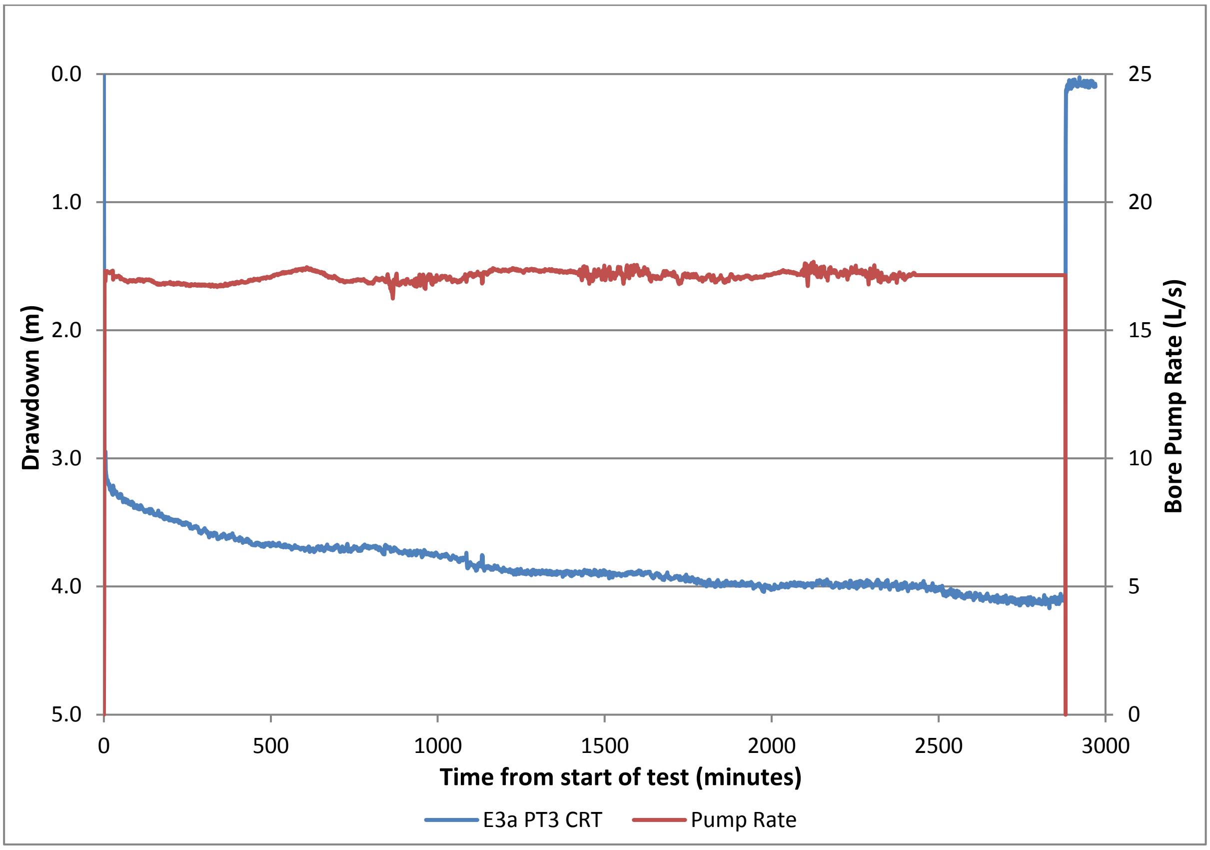
Cooper-Jacob Analysis of CRT results



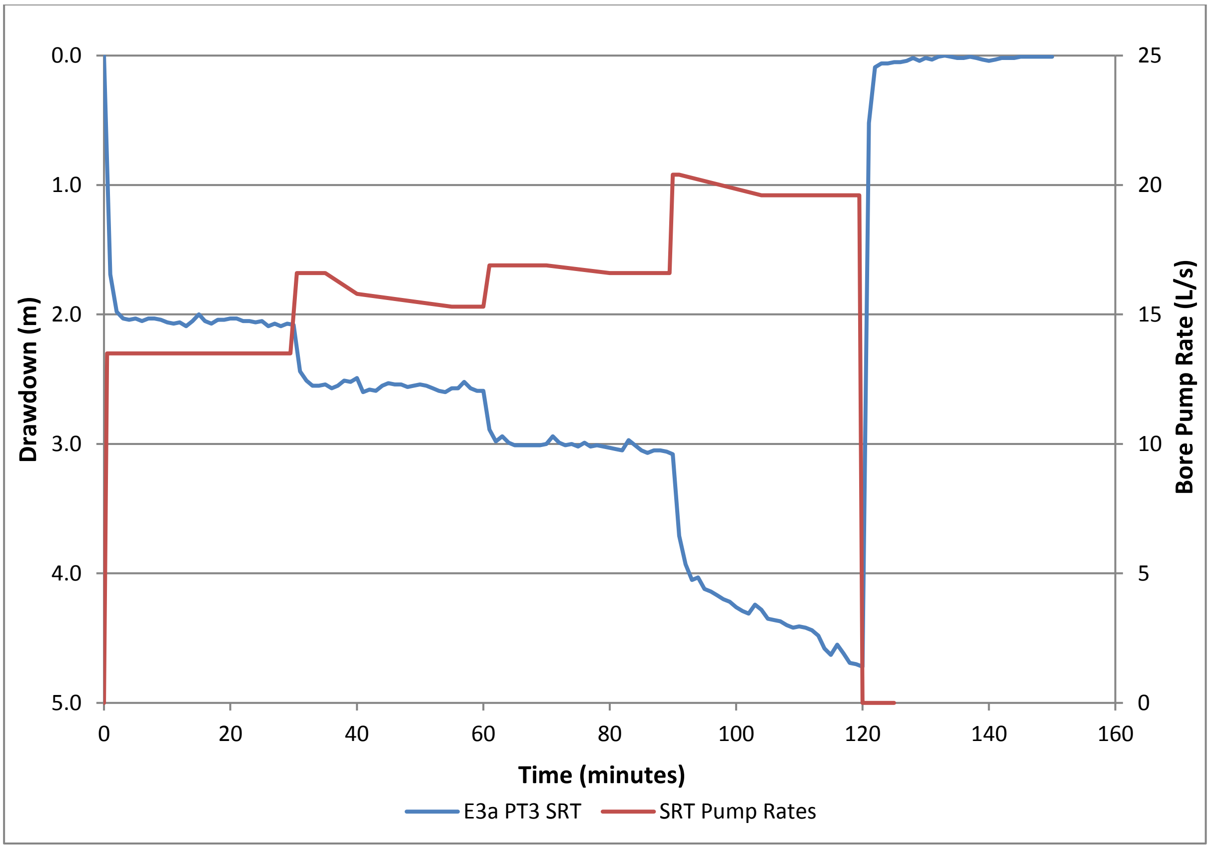
Theis Analysis of water level changes associated with the wellfield shutdown



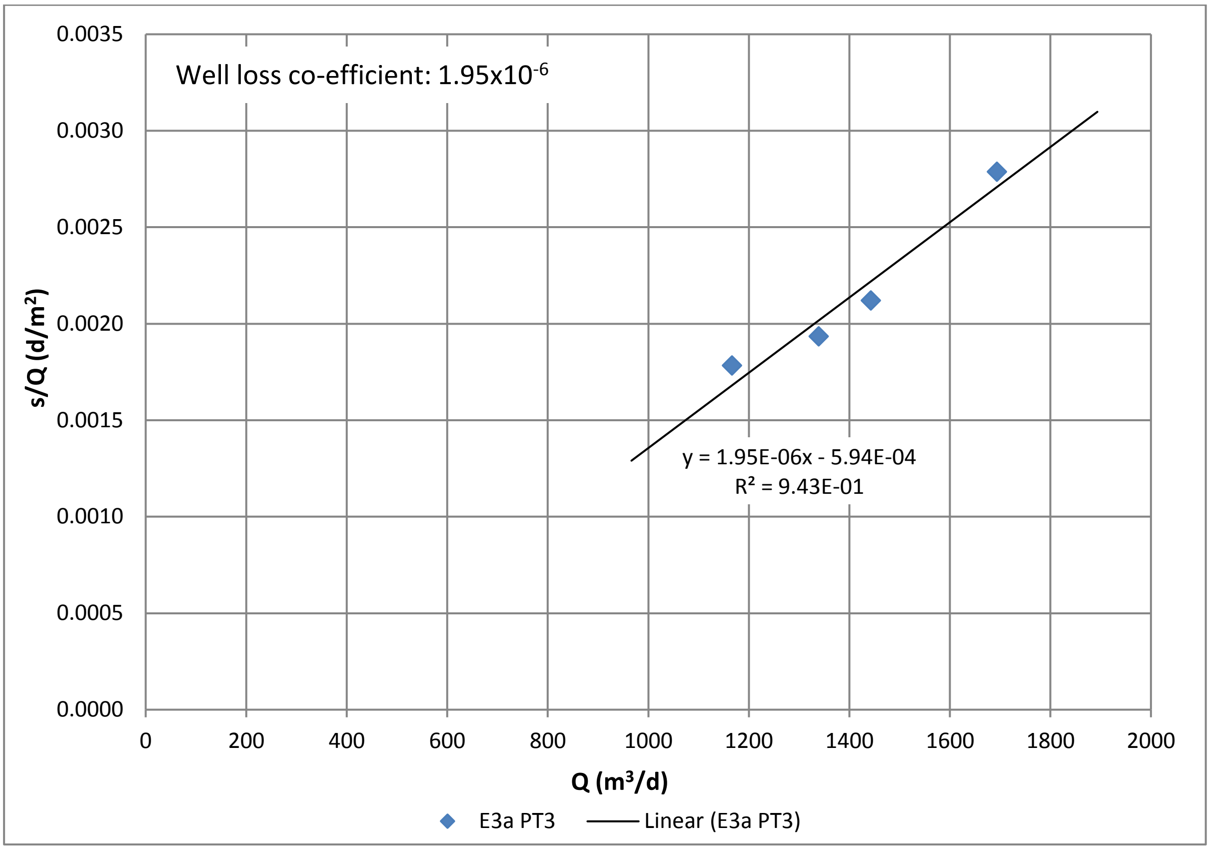
Pumping test on 18th to 20th August 2017. Bore screened 25.0 – 28.0 below sea floor.



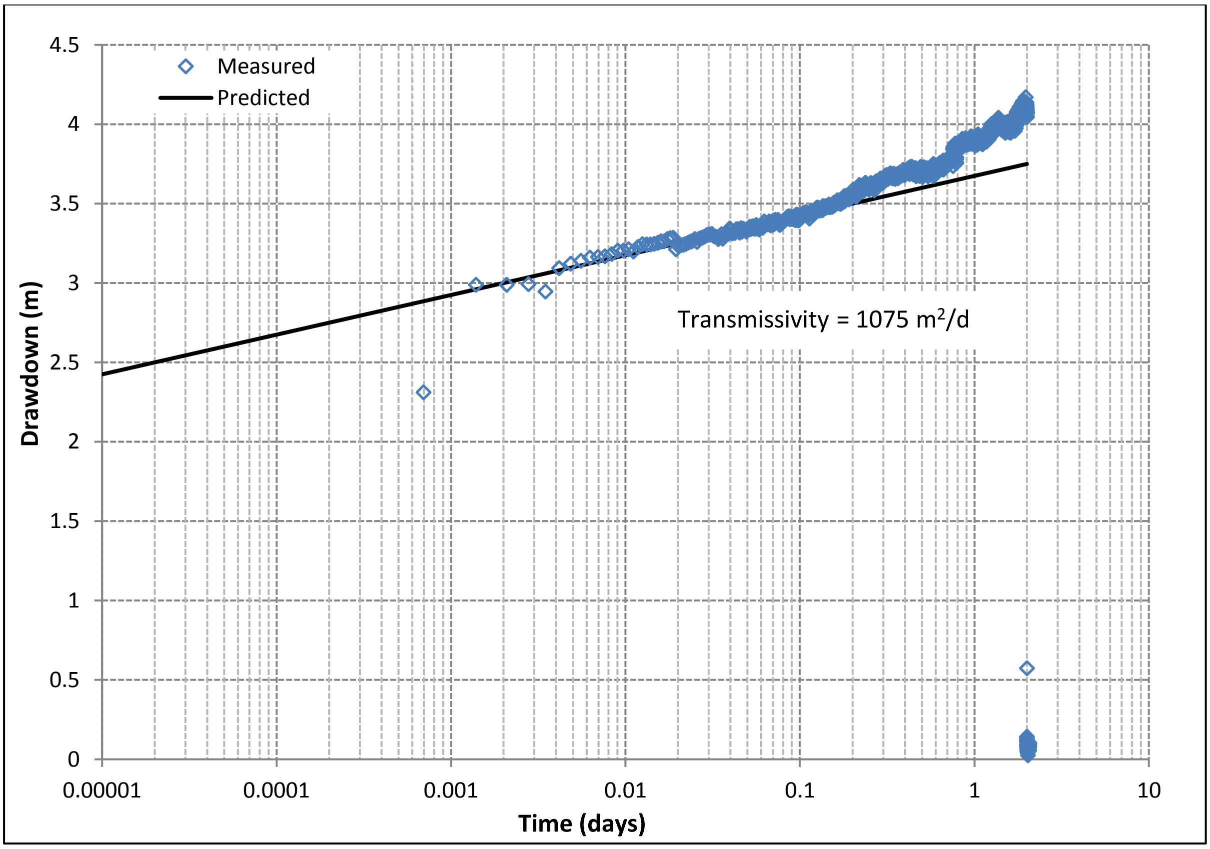
Step rate test on 18th August 2017. Bore screened 25.0 – 28.0 below sea floor.



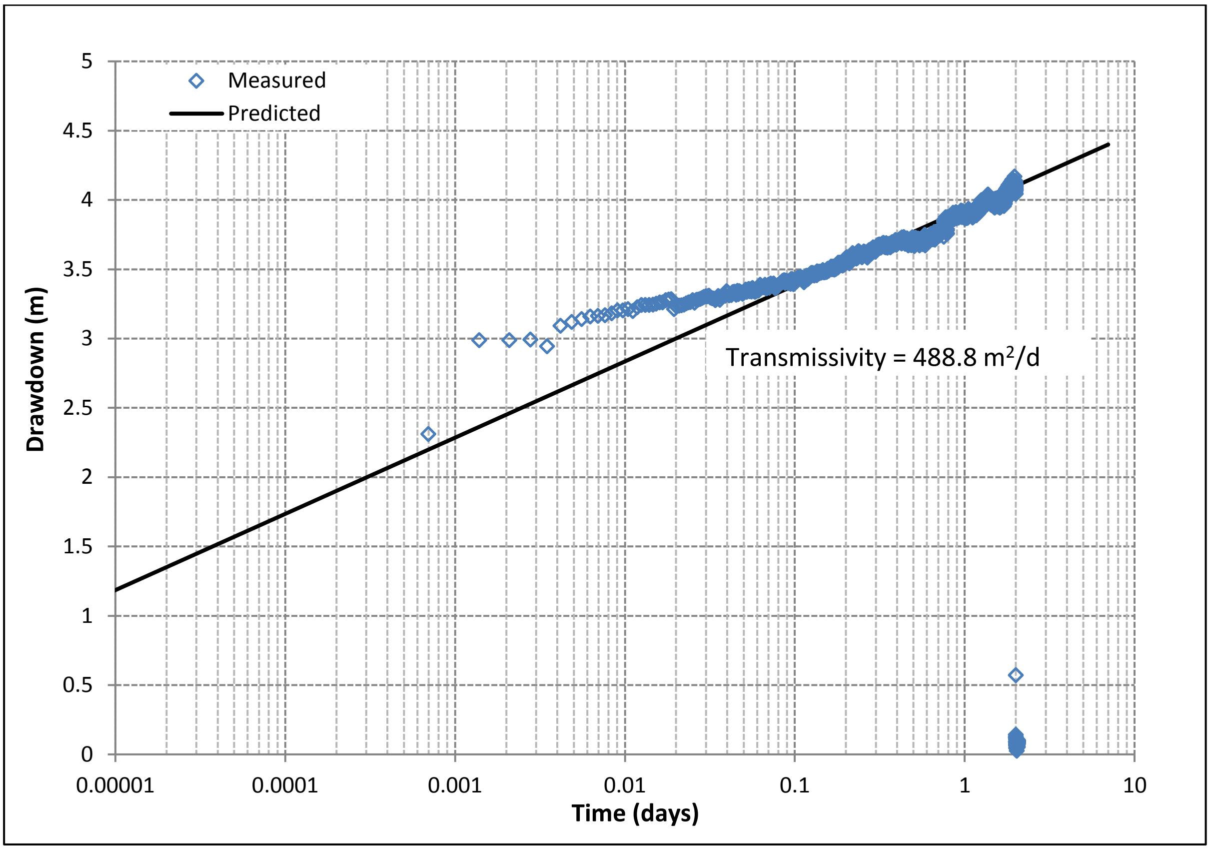
Step Rate Test Analysis – s/q vs Q



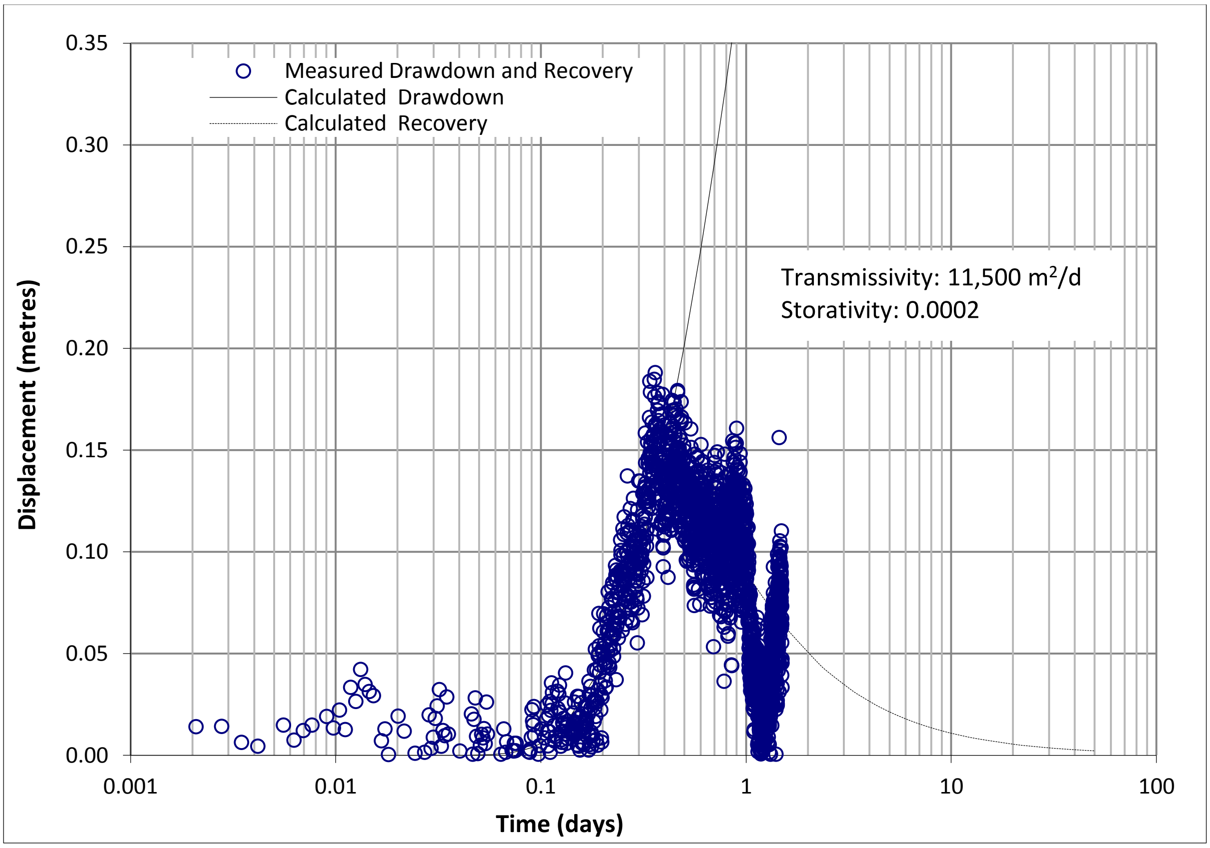
Cooper-Jacob Analysis of CRT Results (fit to early time data)



Cooper-Jacob Analysis of CRT Results (fit to later time data)

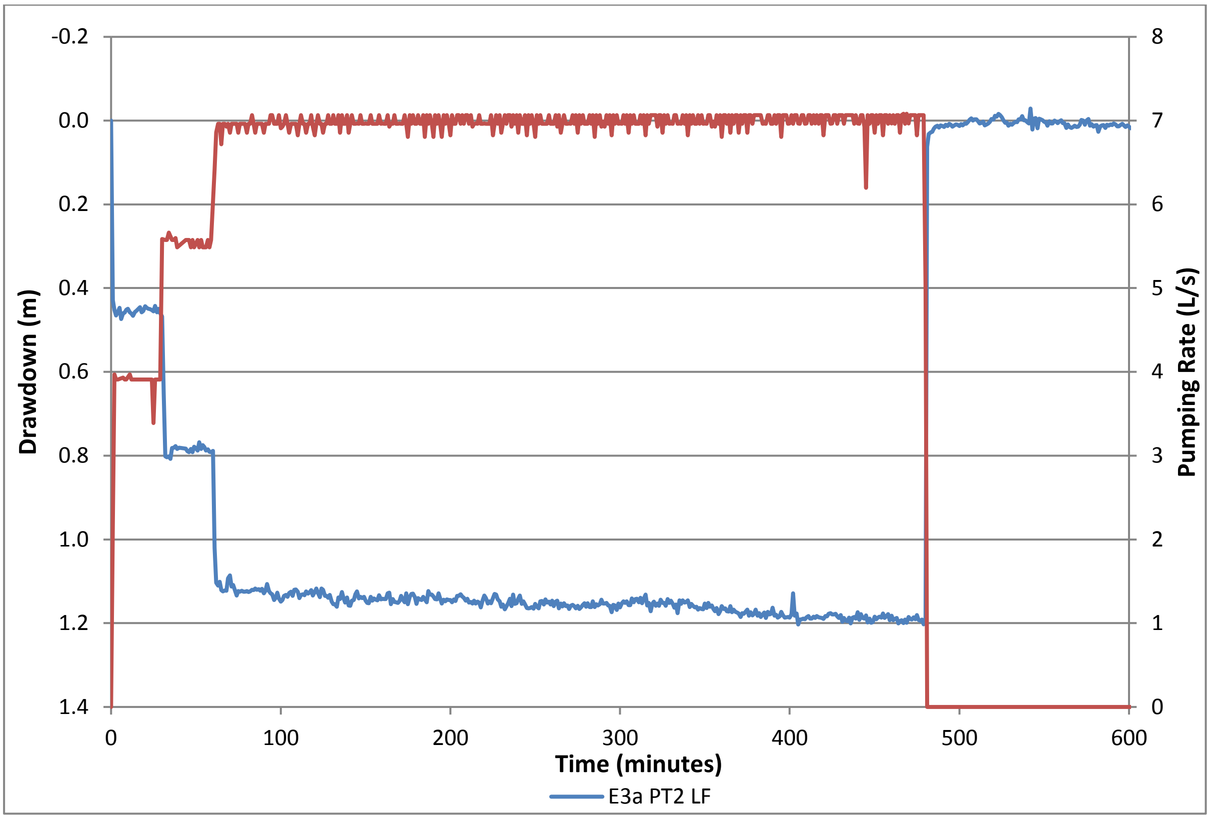


Theis Analysis of water level changes associated with the wellfield shutdown

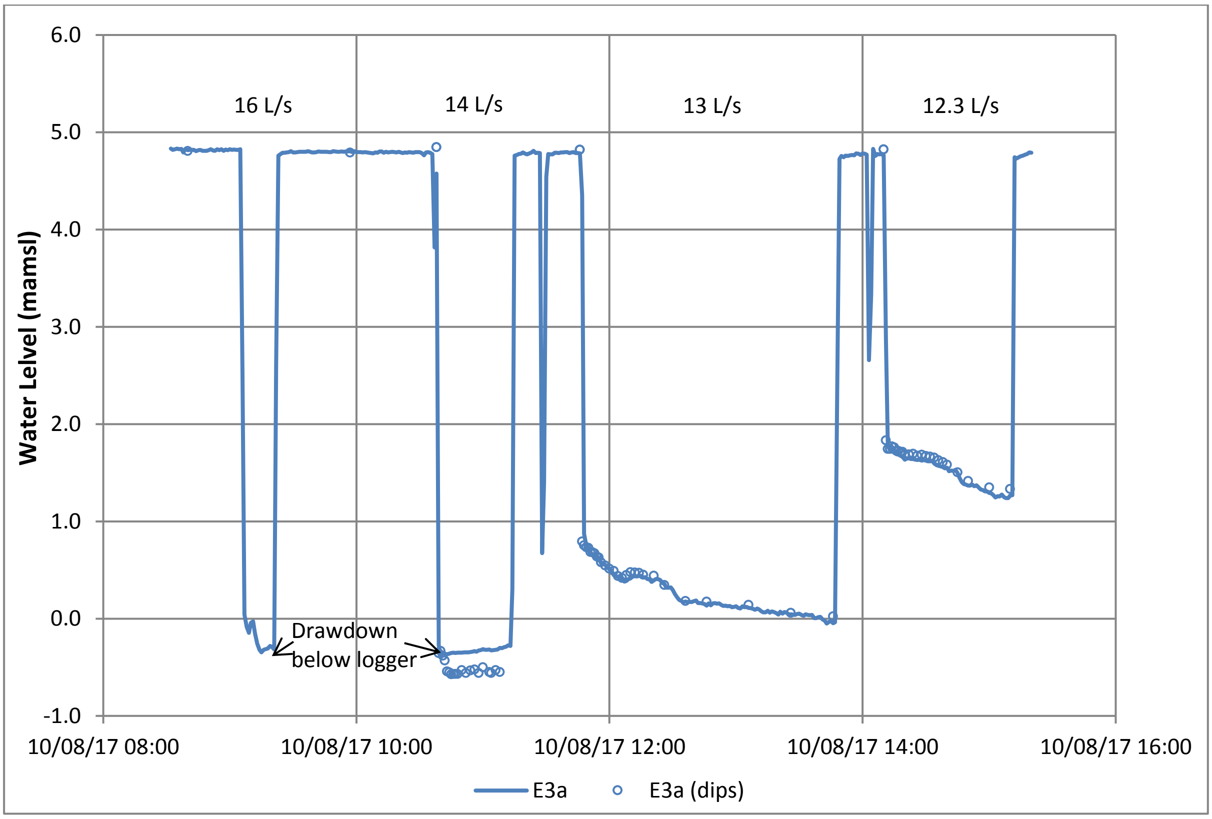


E3a – Moera

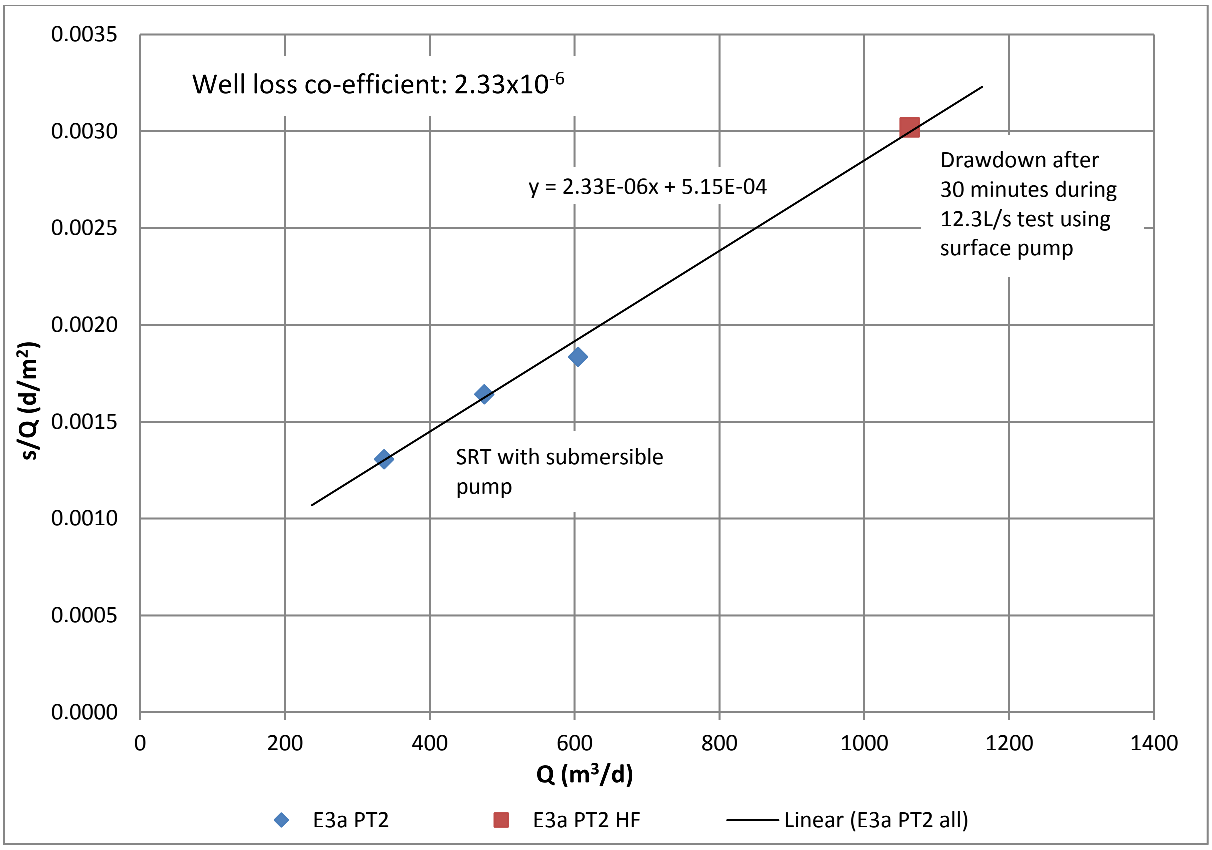
Pumping test on 9th August 2017. Bore screened 74.0 – 77.0 m below sea floor.



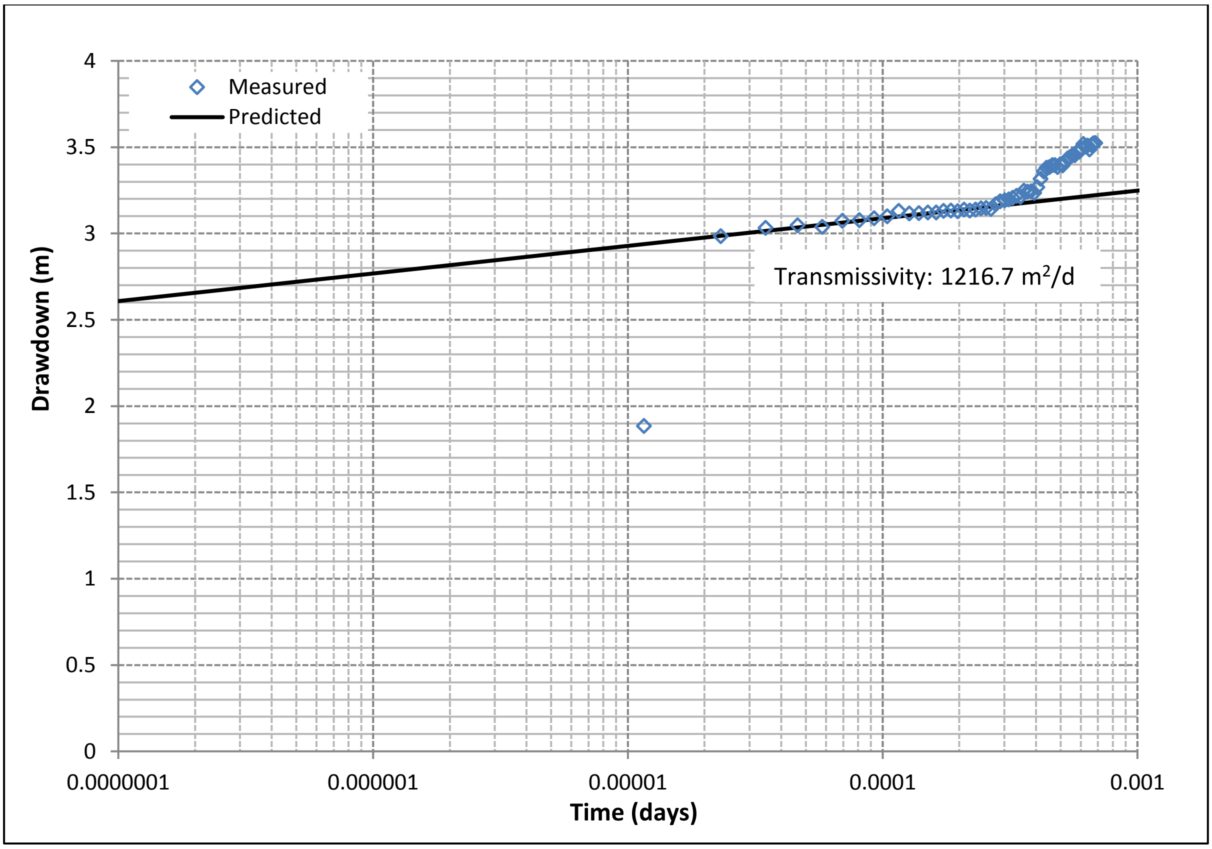
High flow pumping tests on 10th August 2017. Bore screened 74.0 – 77.0 m below sea floor.



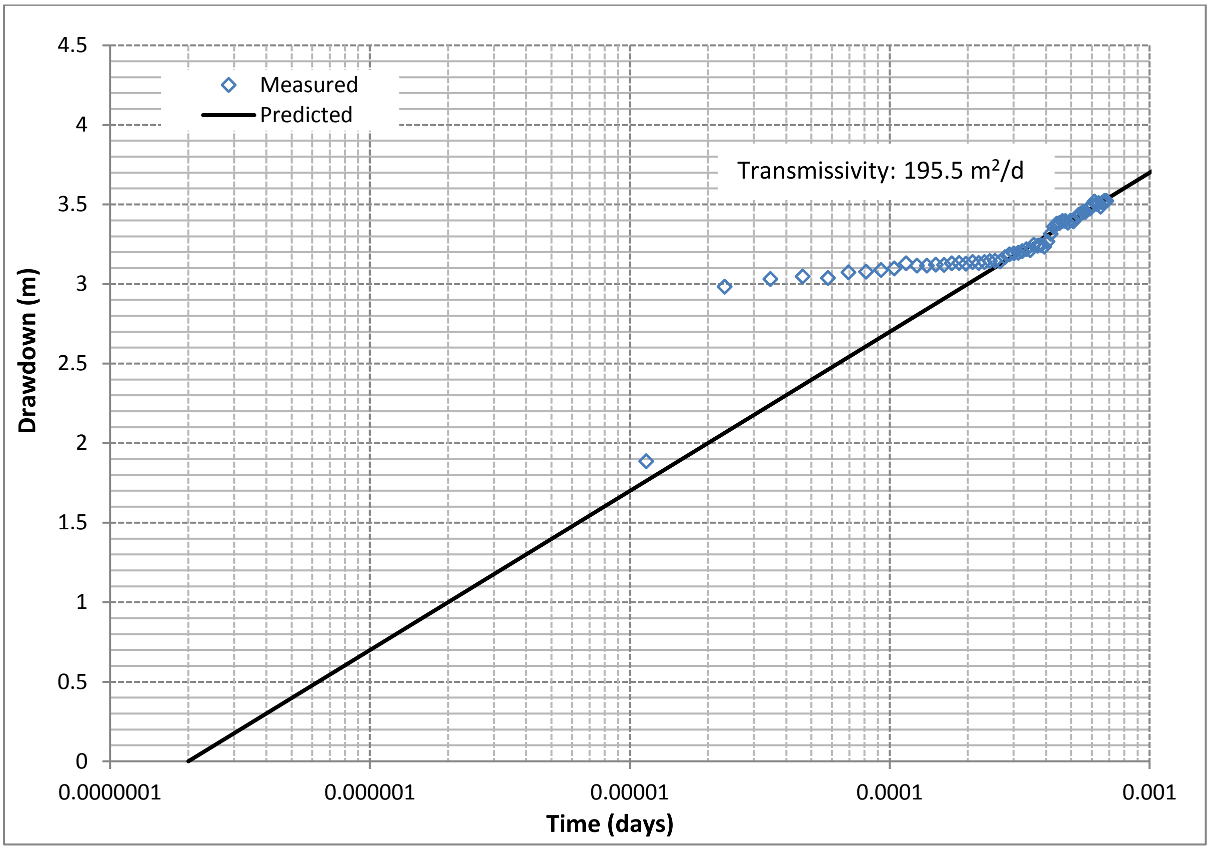
Step Rate Test Analysis – s/q vs Q



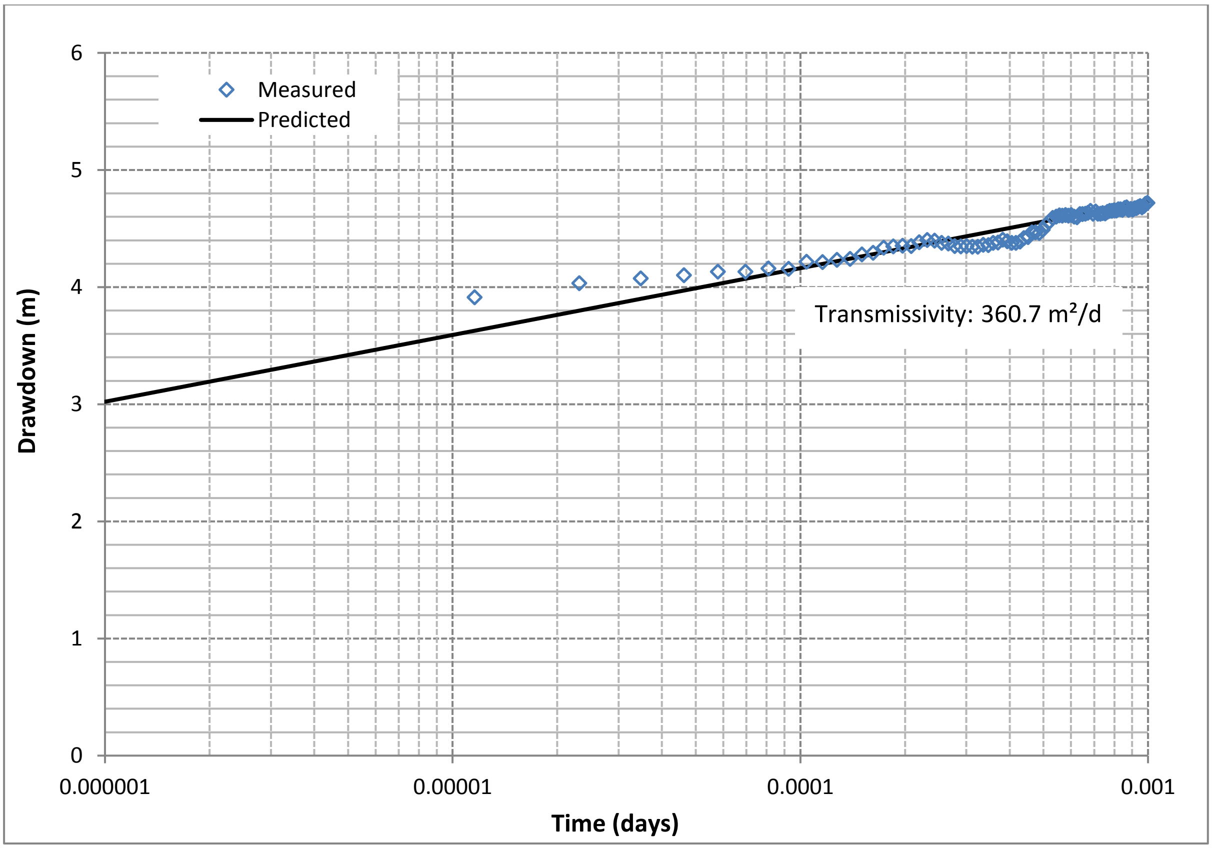
Cooper Jacob Analysis of 12.3 L/s pumping test (early time data)



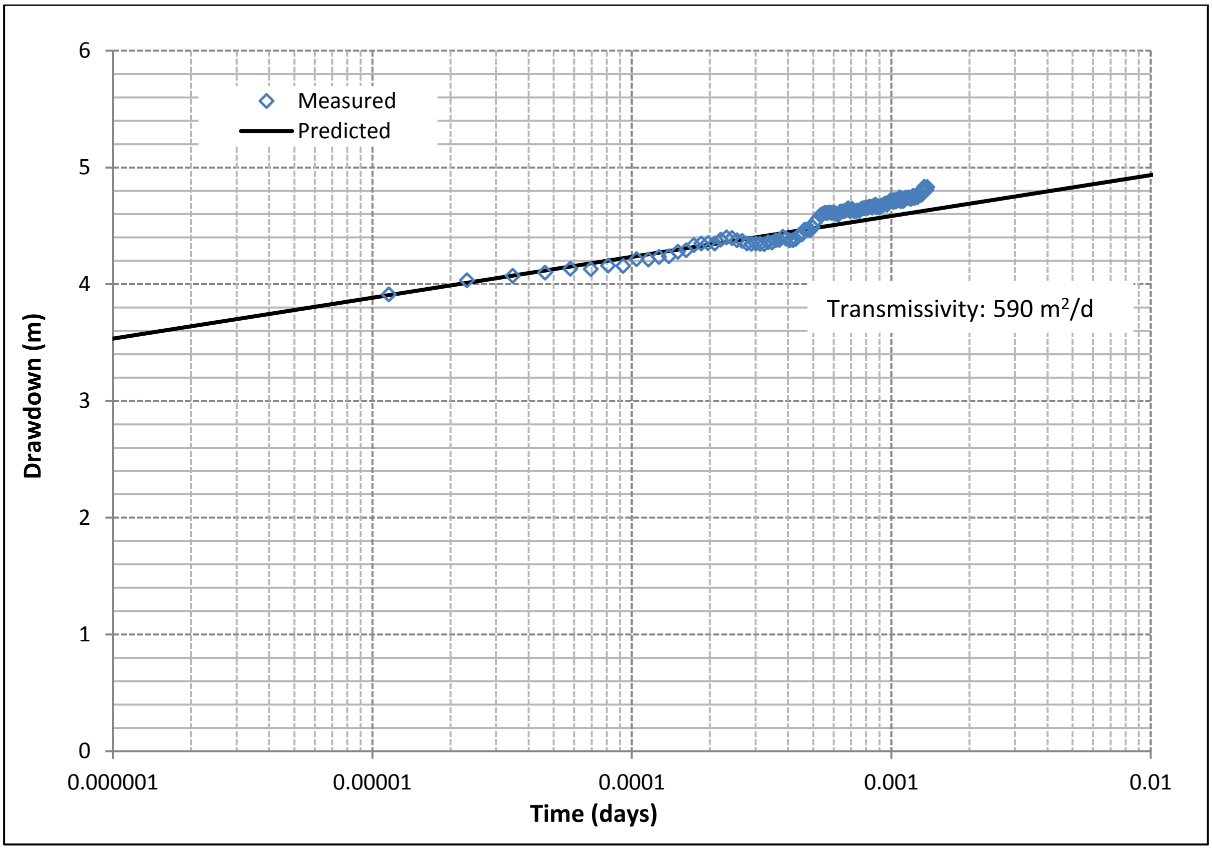
Cooper Jacob Analysis of 12.3 L/s pumping test (late time data)



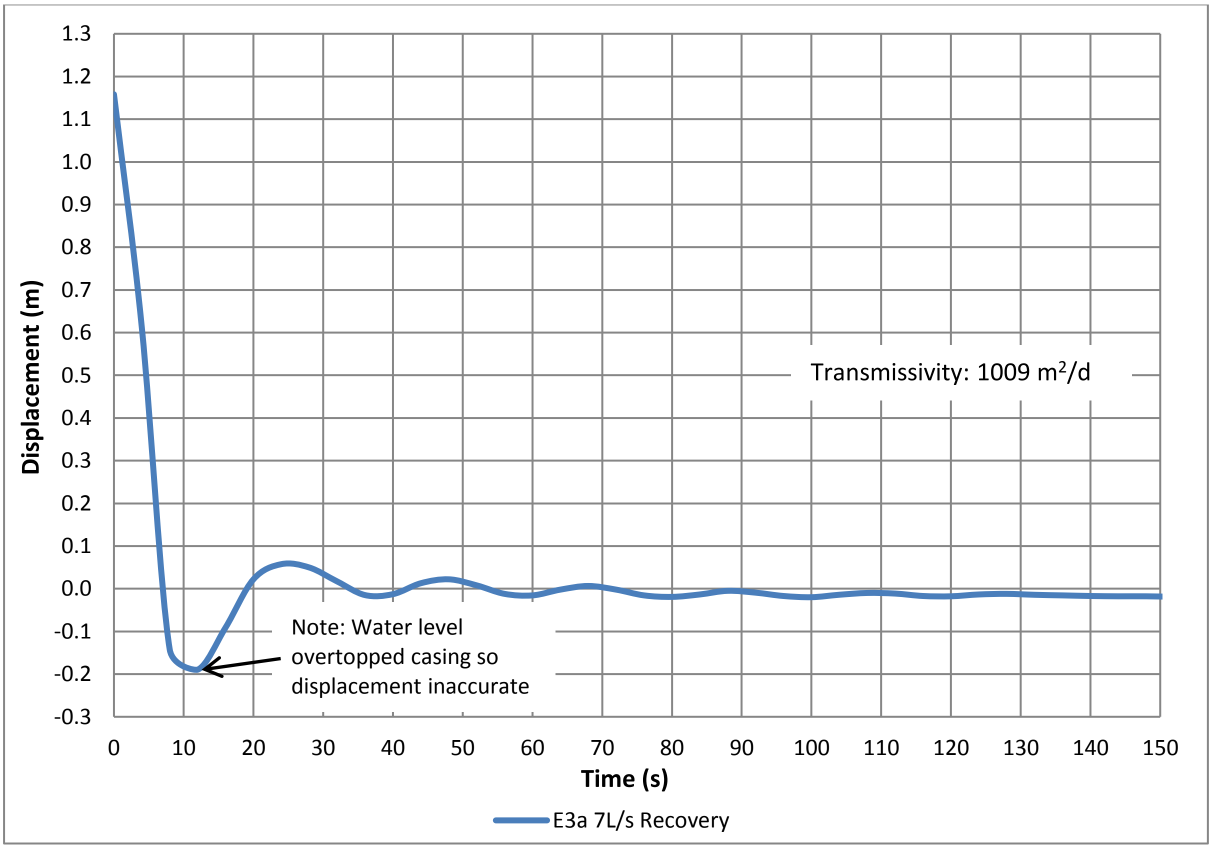
Cooper Jacob Analysis of 13 L/s pumping test (early and late time data)



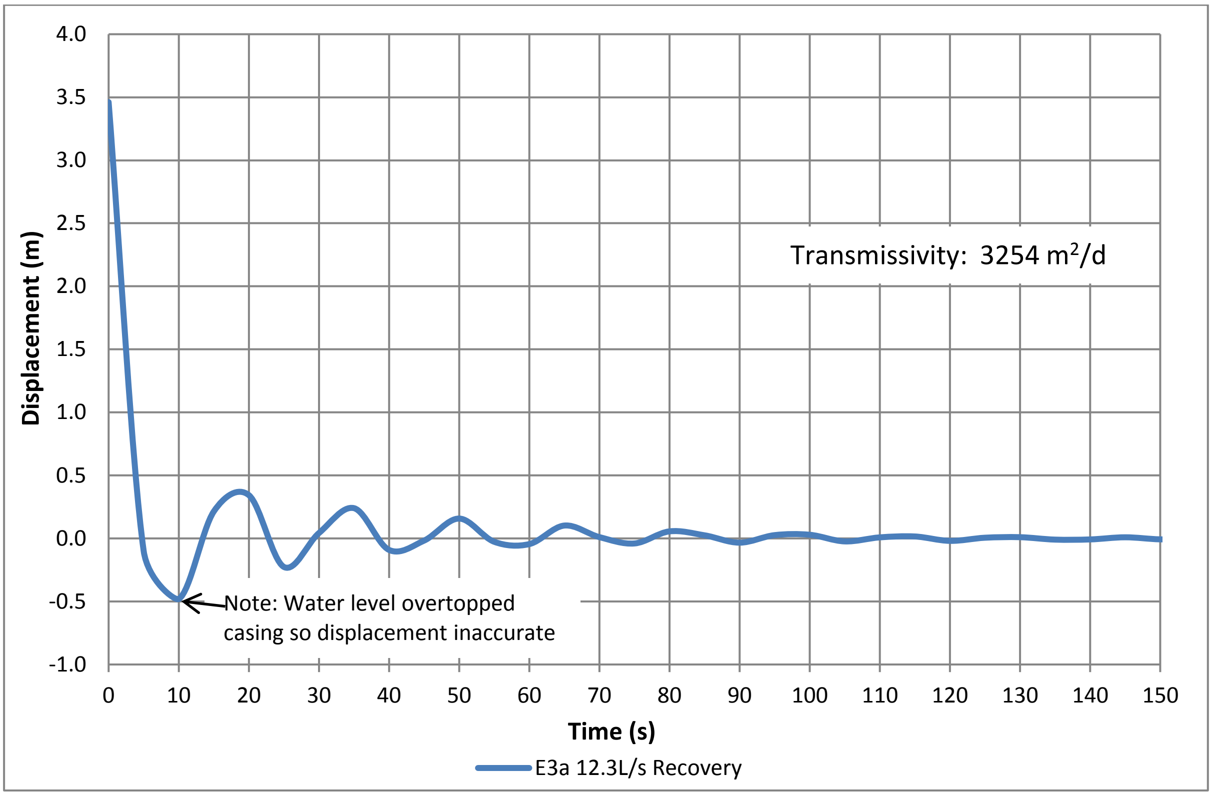
Cooper Jacob Analysis of 13 L/s pumping test (early and middle time data)



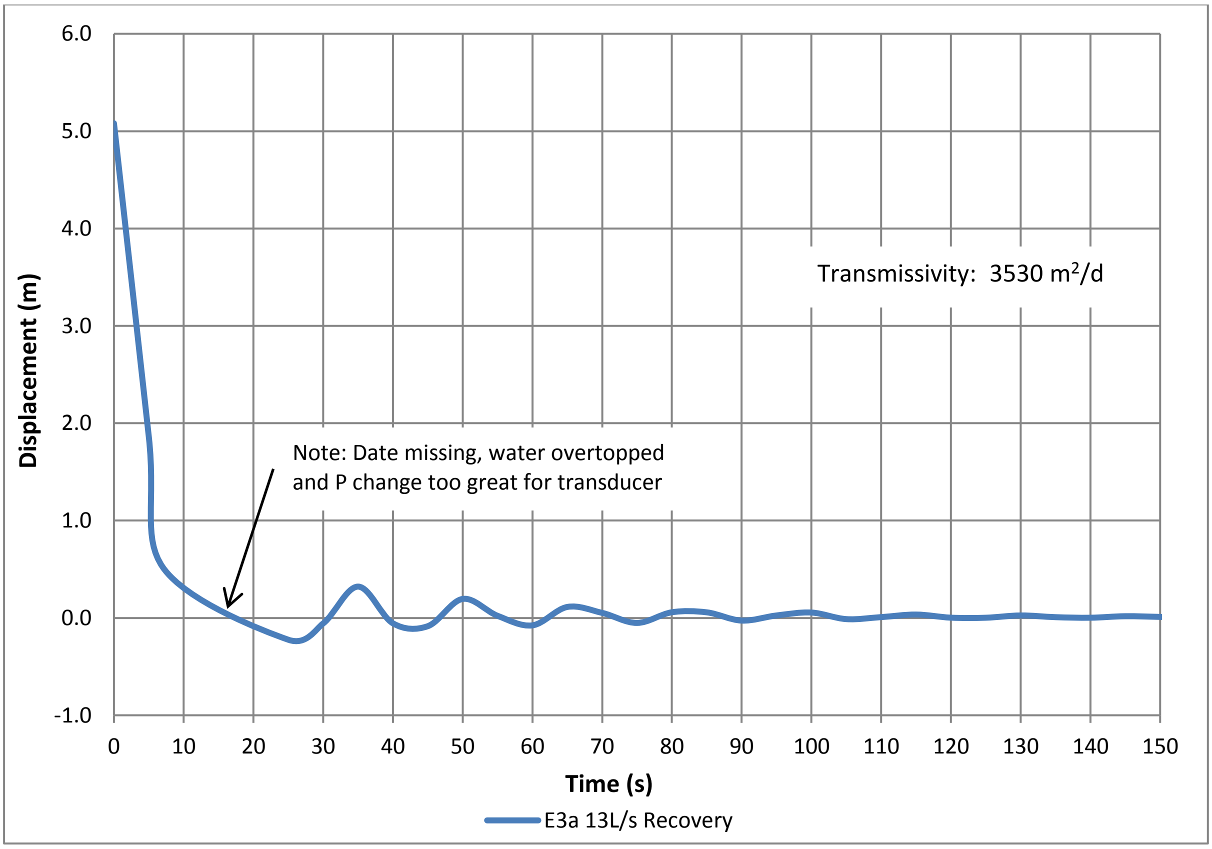
Van der Kamp Analysis of recovery (7 L/s pumping test)



Van der Kamp Analysis of recovery (12.3 L/s pumping test)

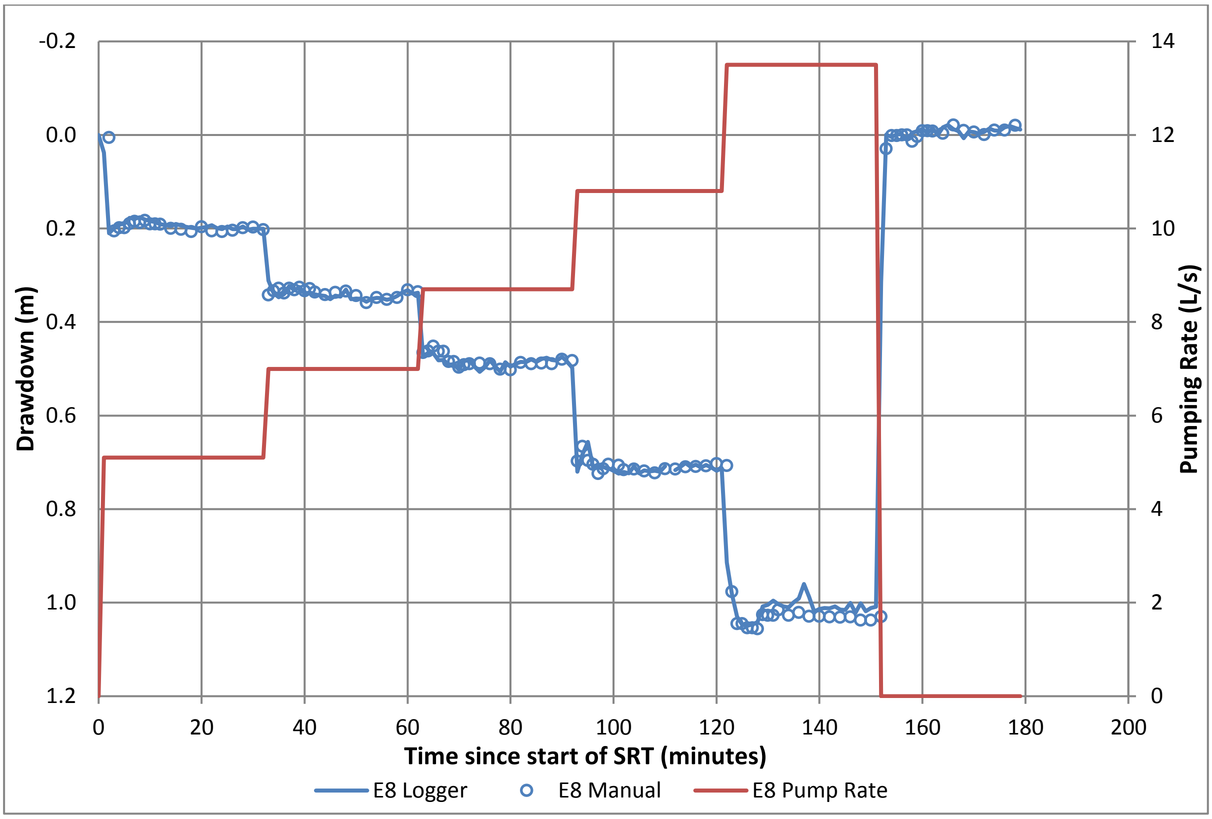


Van der Kamp Analysis of recovery (13 L/s pumping test)

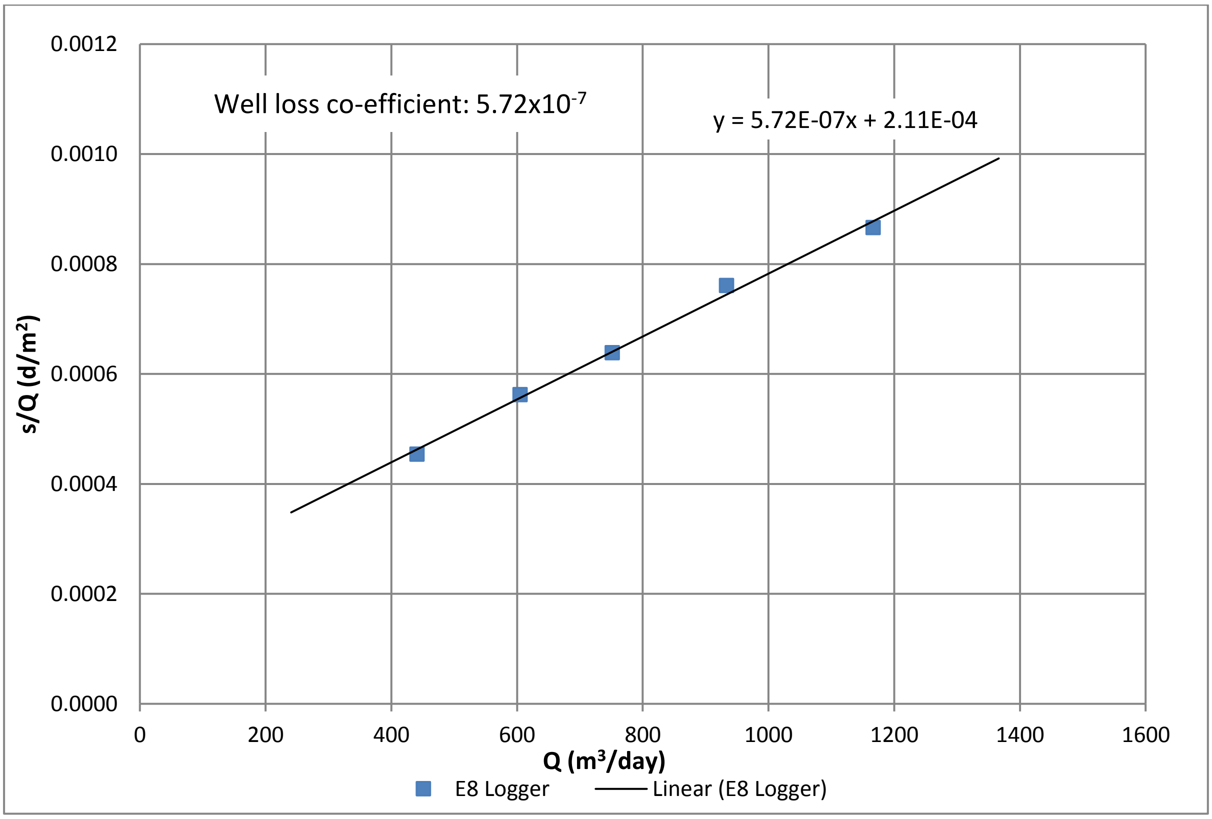


E8 – Upper Waiwhetu

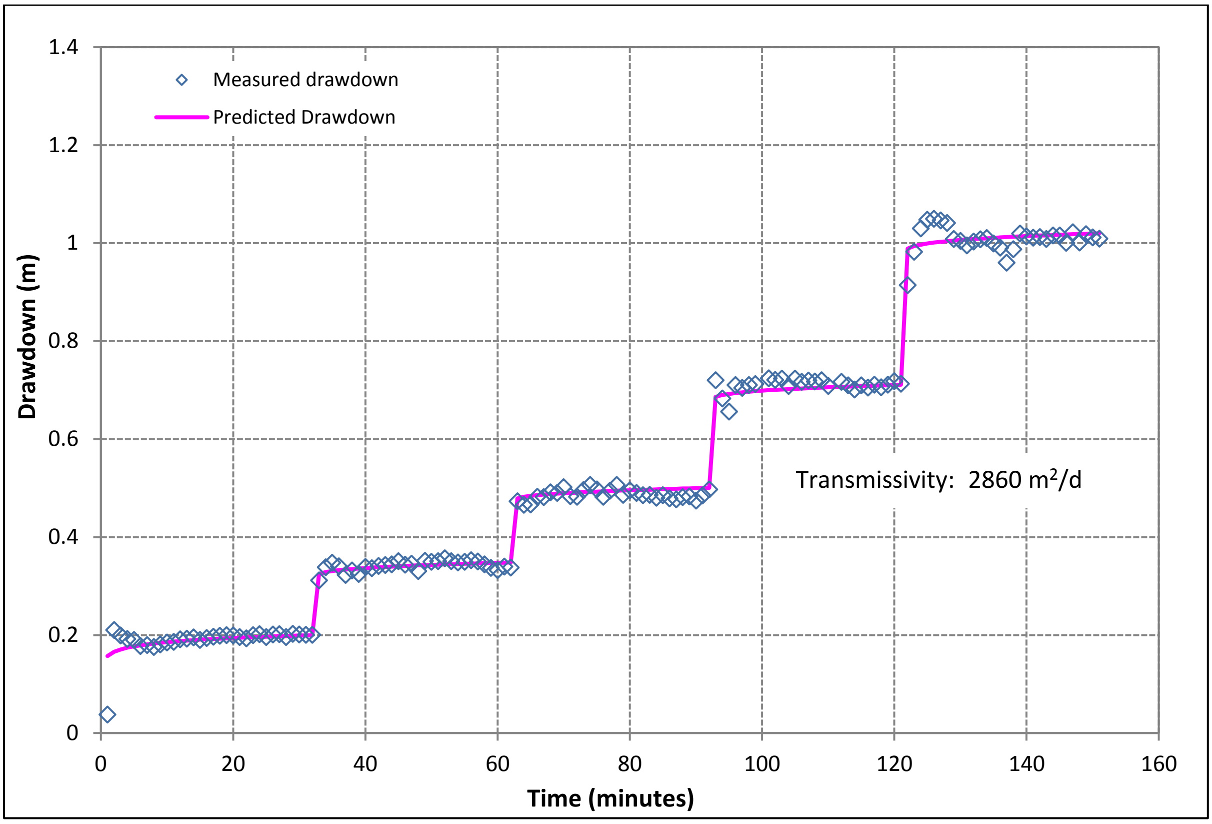
Step Rate Test on 14th January 2018. Bore screened 25.0 – 28.0 m below sea floor.



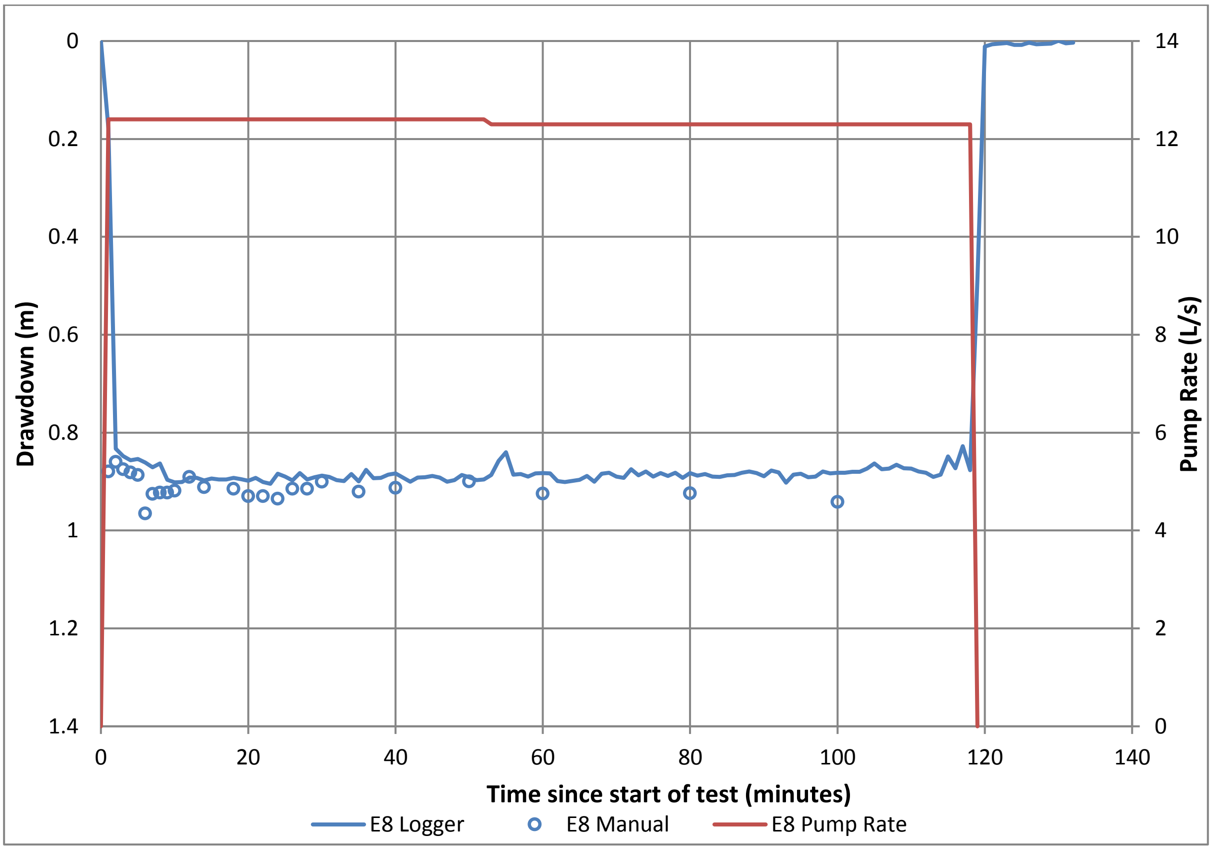
Step Rate Test Analysis – s/q vs Q



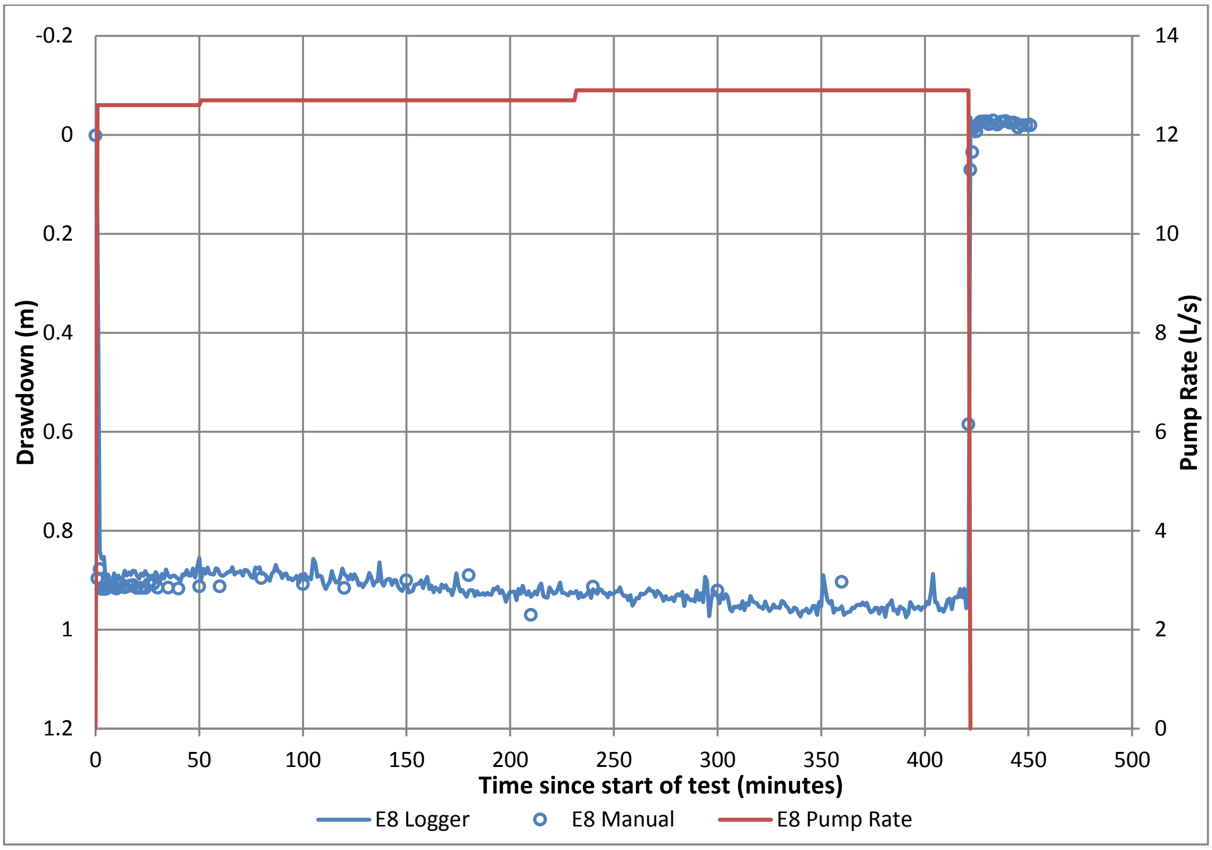
Eden Hazel Analysis of SRT data



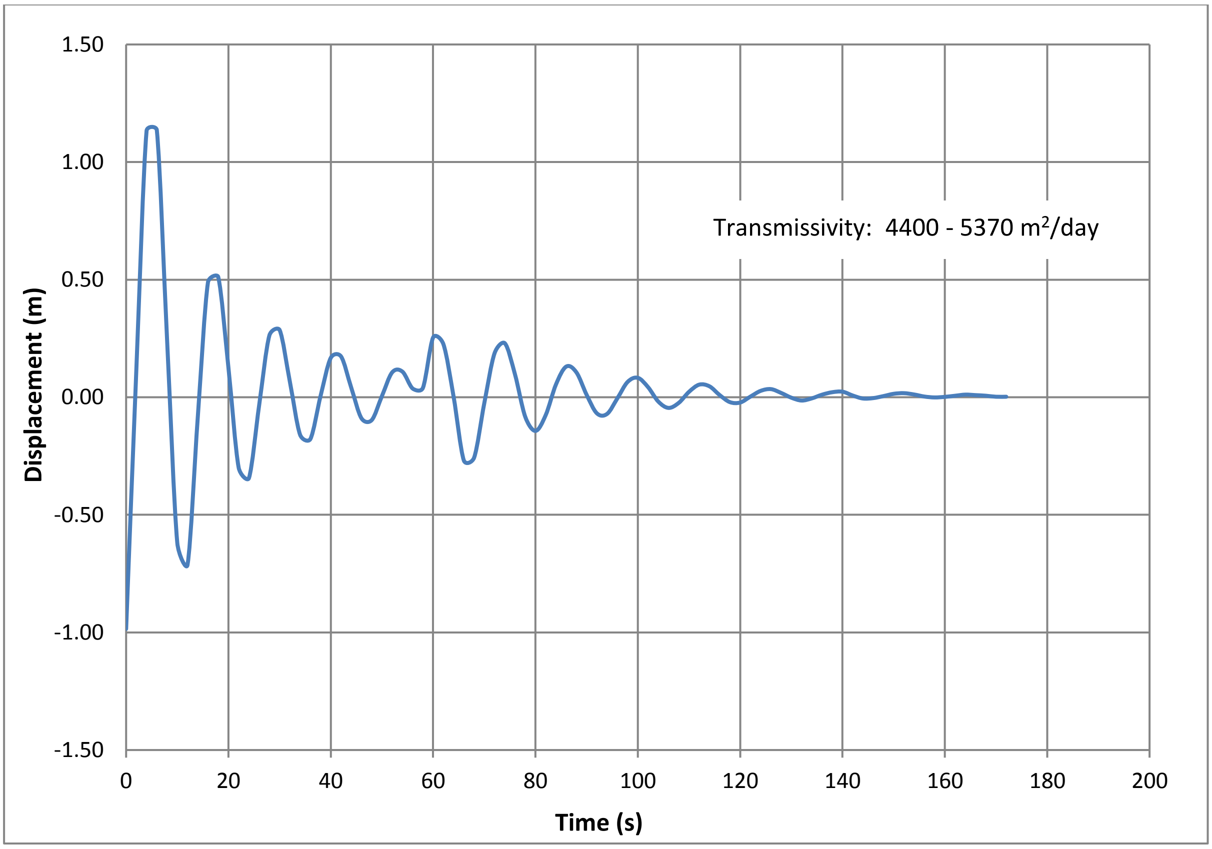
Pumping test on 15th January 2018. Bore screened 25.0 – 28.0 m below sea floor.



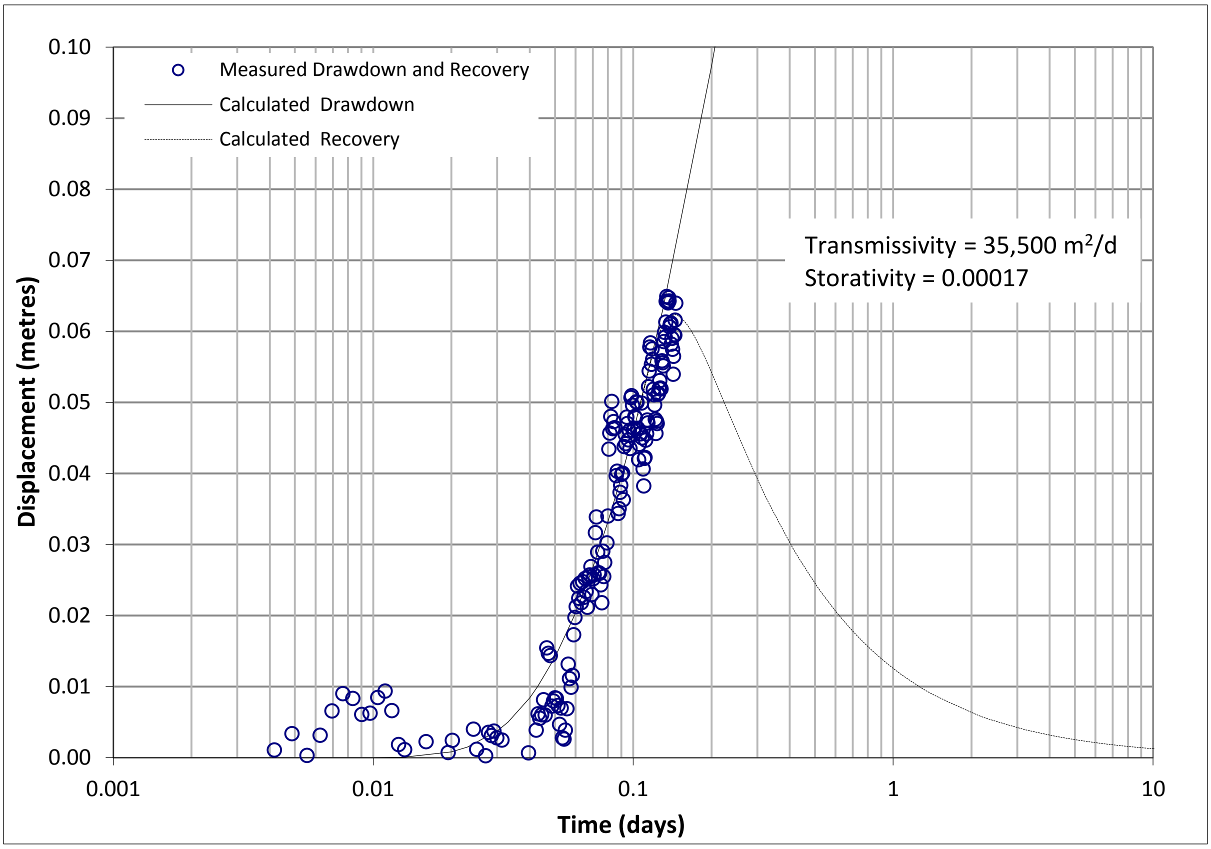
Second pumping test on 15th January 2018. Bore screened 25.0 – 28.0 m below sea floor.



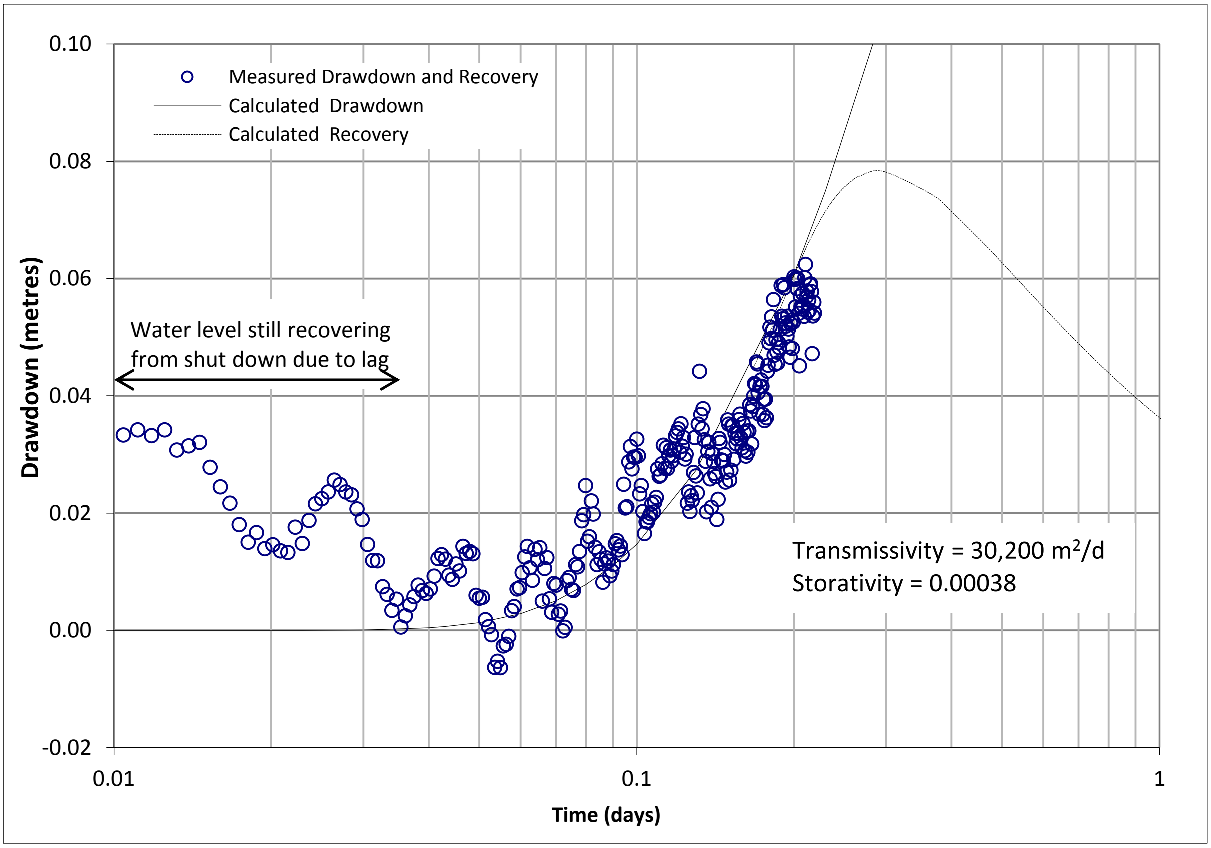
Van der Kamp Analysis of recovery (second pumping test)



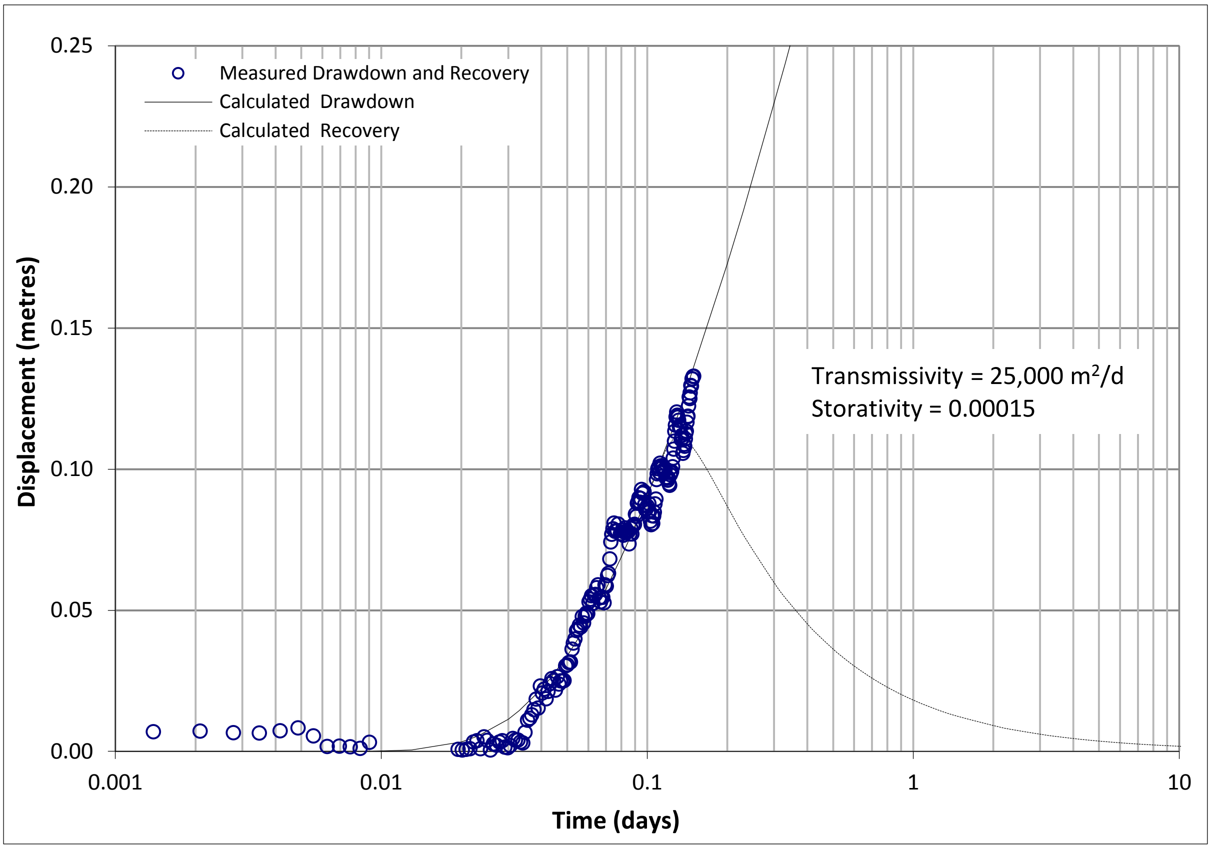
Theis Analysis of water level changes in E8 associated with the wellfield shutdown



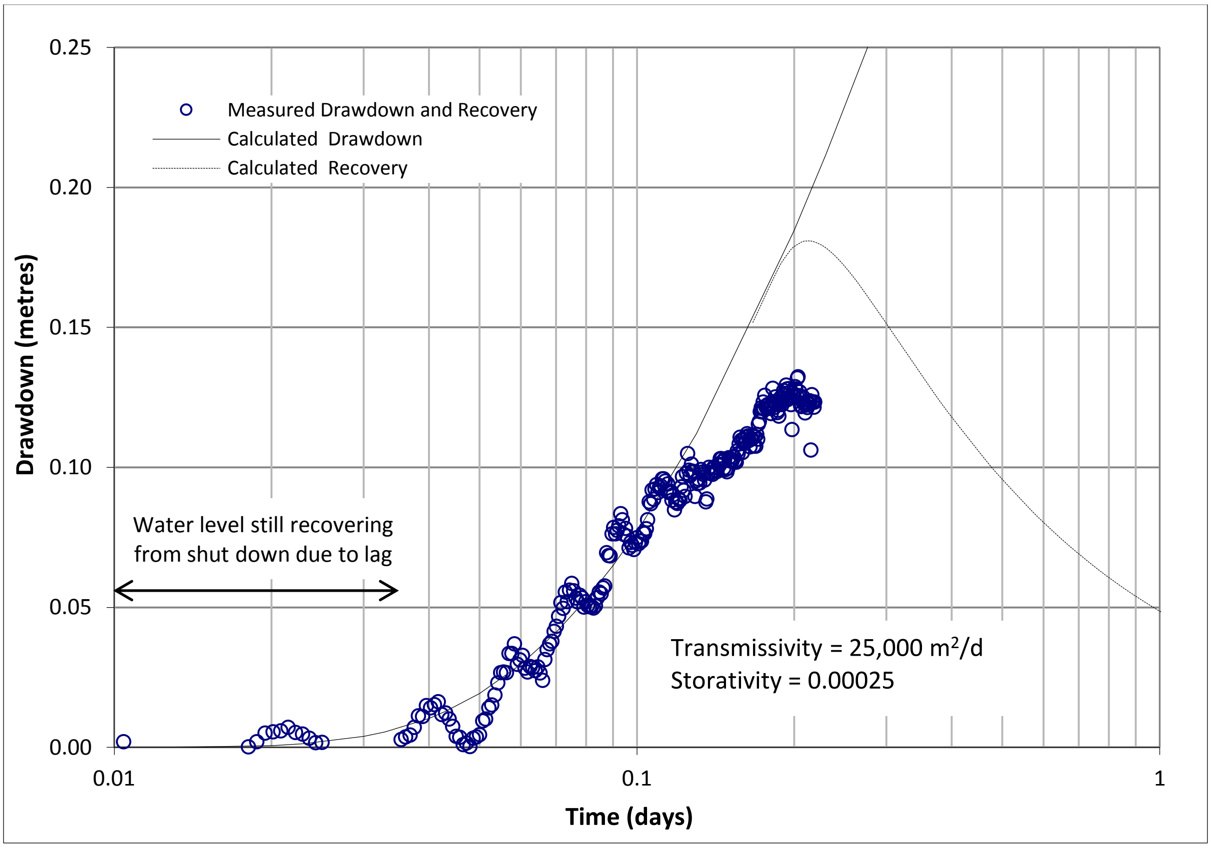
Theis Analysis of water level changes in E8 associated with the wellfield restart



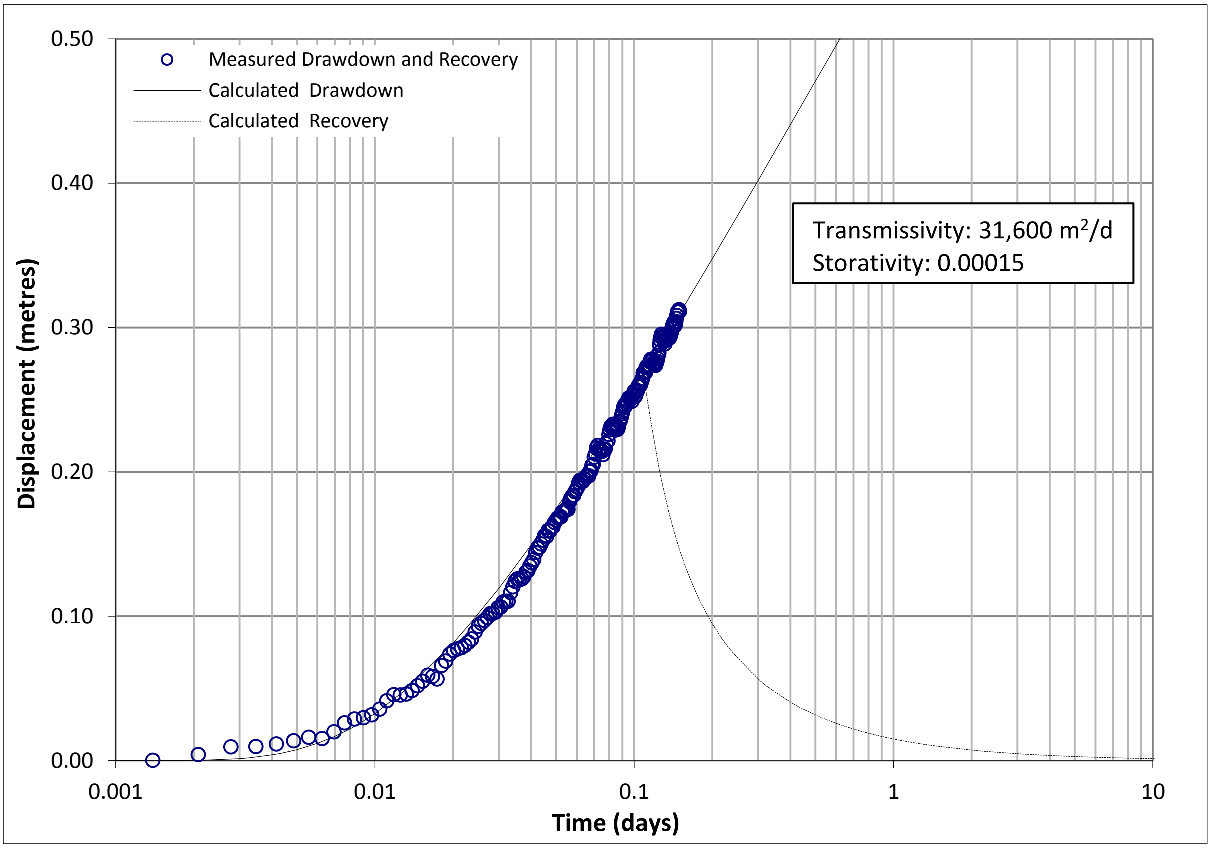
Theis Analysis of water level changes in Somes Island bore associated with the wellfield shutdown



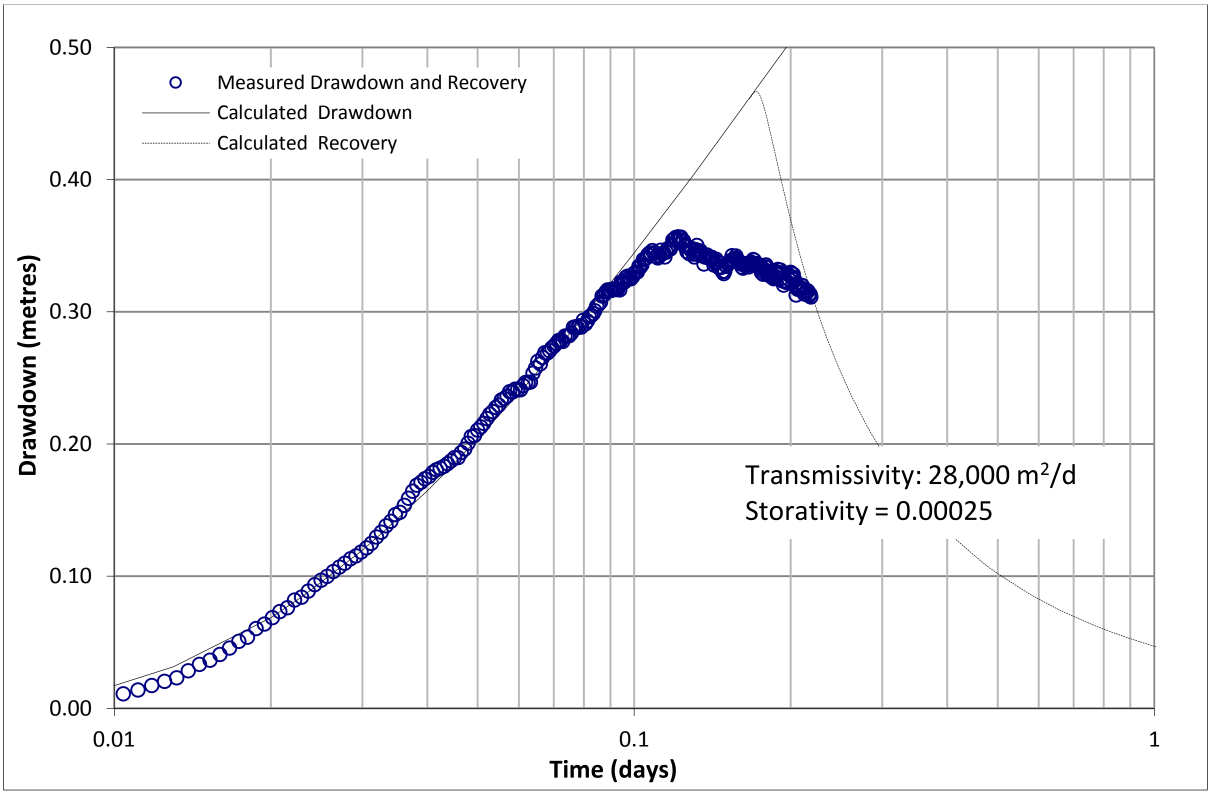
Theis Analysis of water level changes in Somes Island bore associated with the wellfield restart



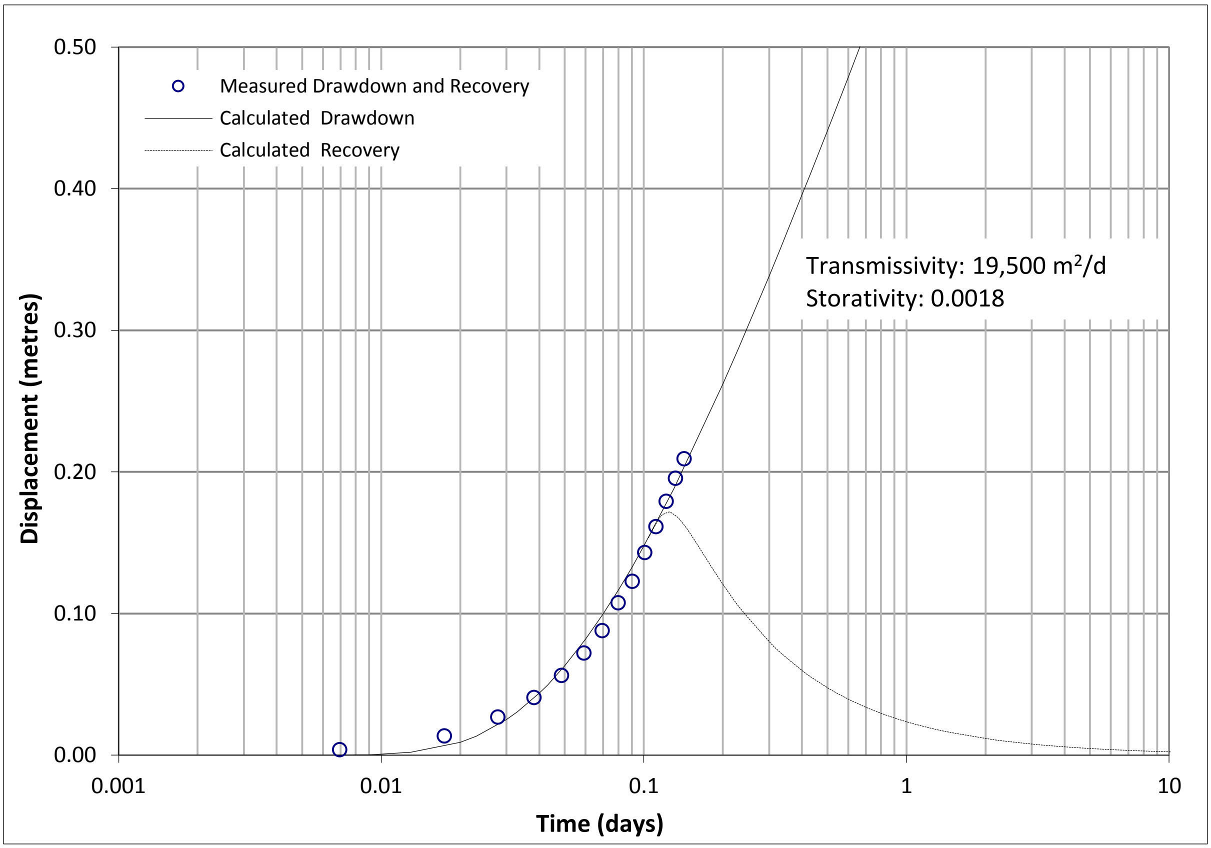
Theis Analysis of water level changes in McEwan Park bore associated with the wellfield shutdown



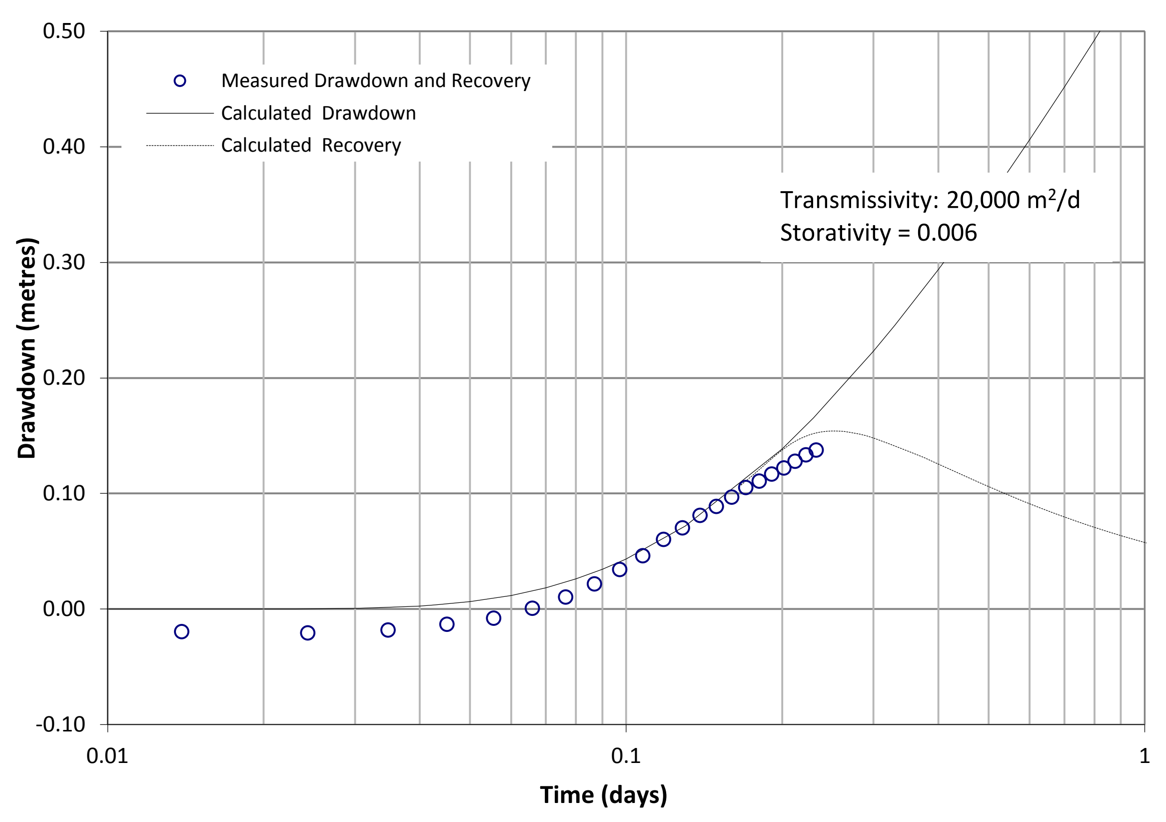
Theis Analysis of water level changes in McEwan Park bore associated with the wellfield restart



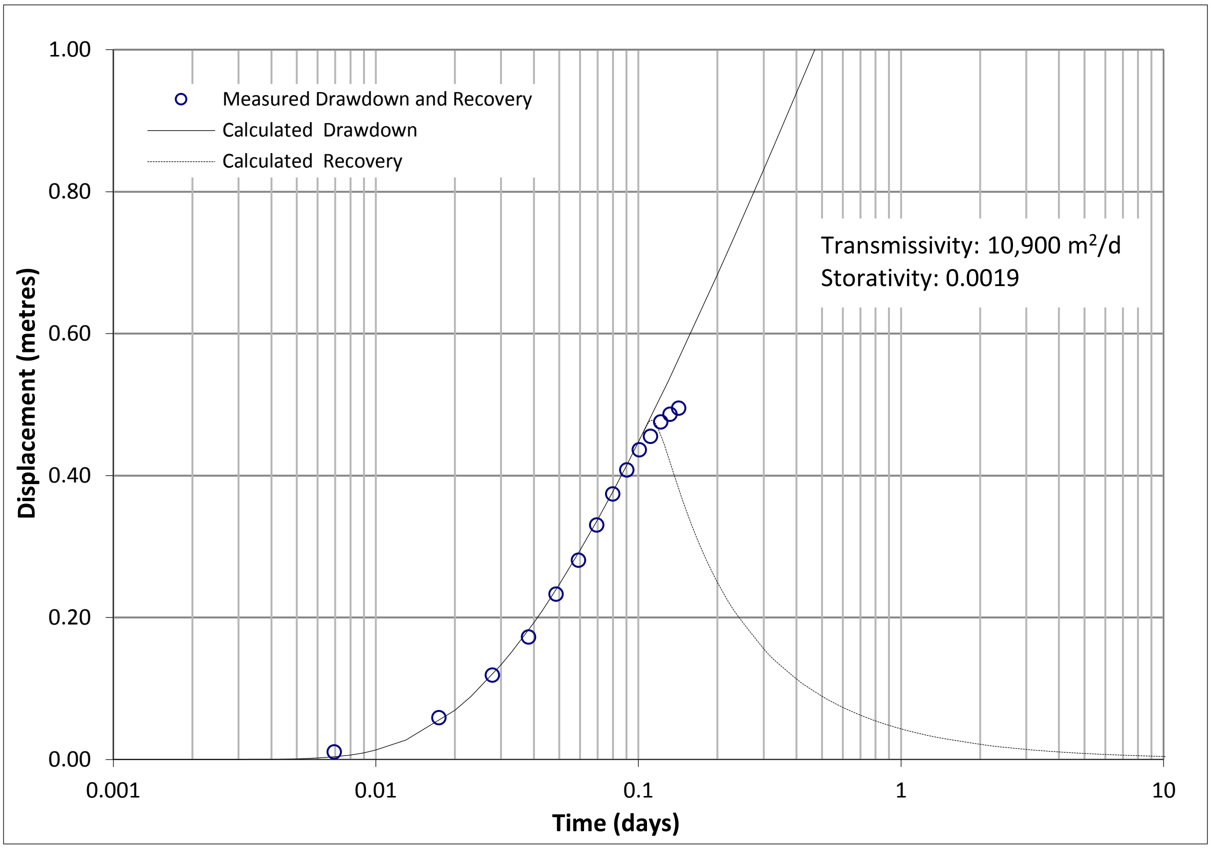
Theis Analysis of water level changes in Randwick bore associated with the wellfield shutdown



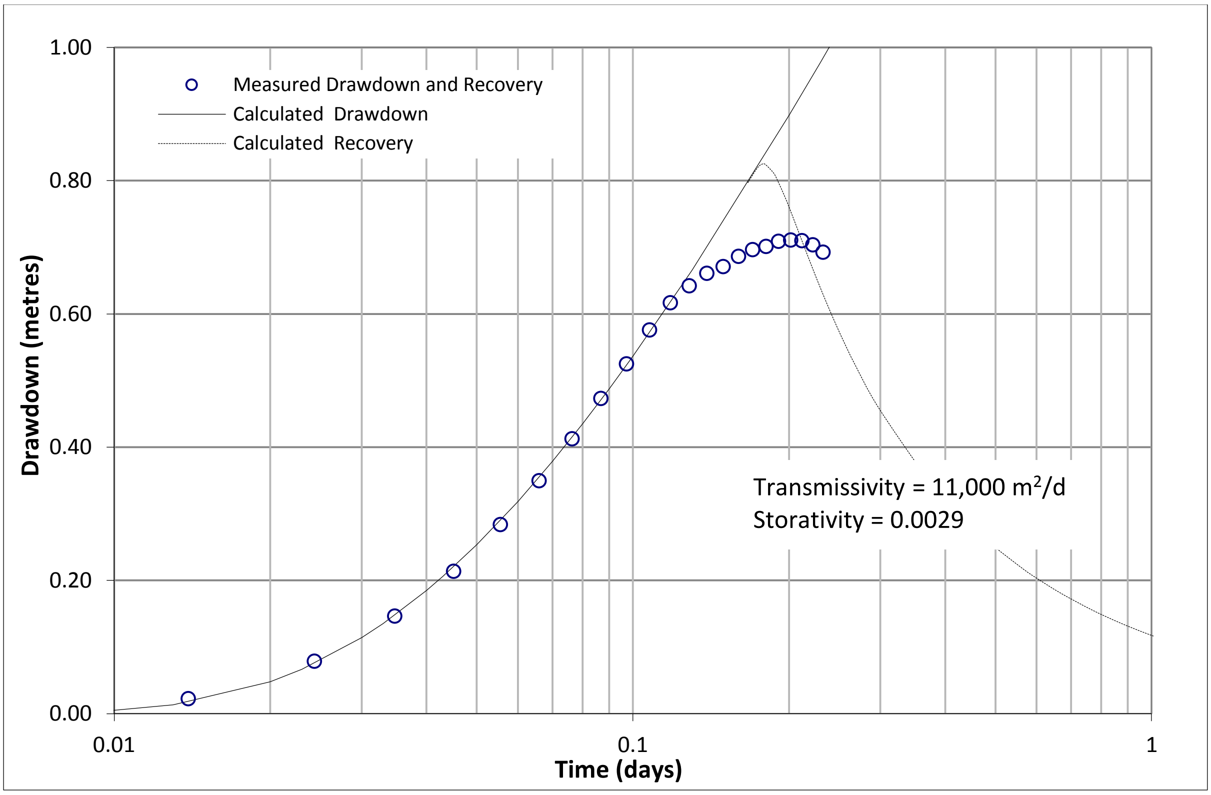
Theis Analysis of water level changes in Randwick bore associated with the wellfield restart



Theis Analysis of water level changes in Hutt Rec bore associated with the wellfield shutdown

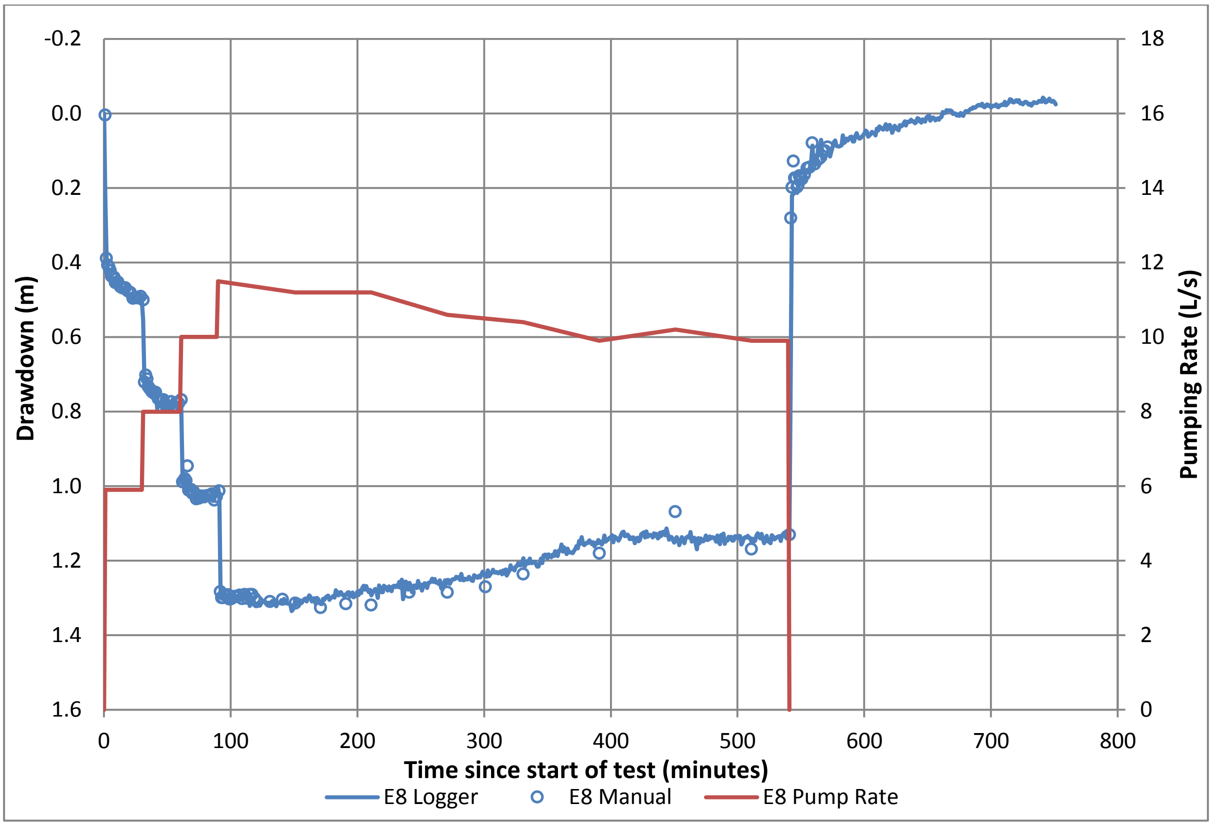


Theis Analysis of water level changes in Hutt Rec bore associated with the wellfield restart

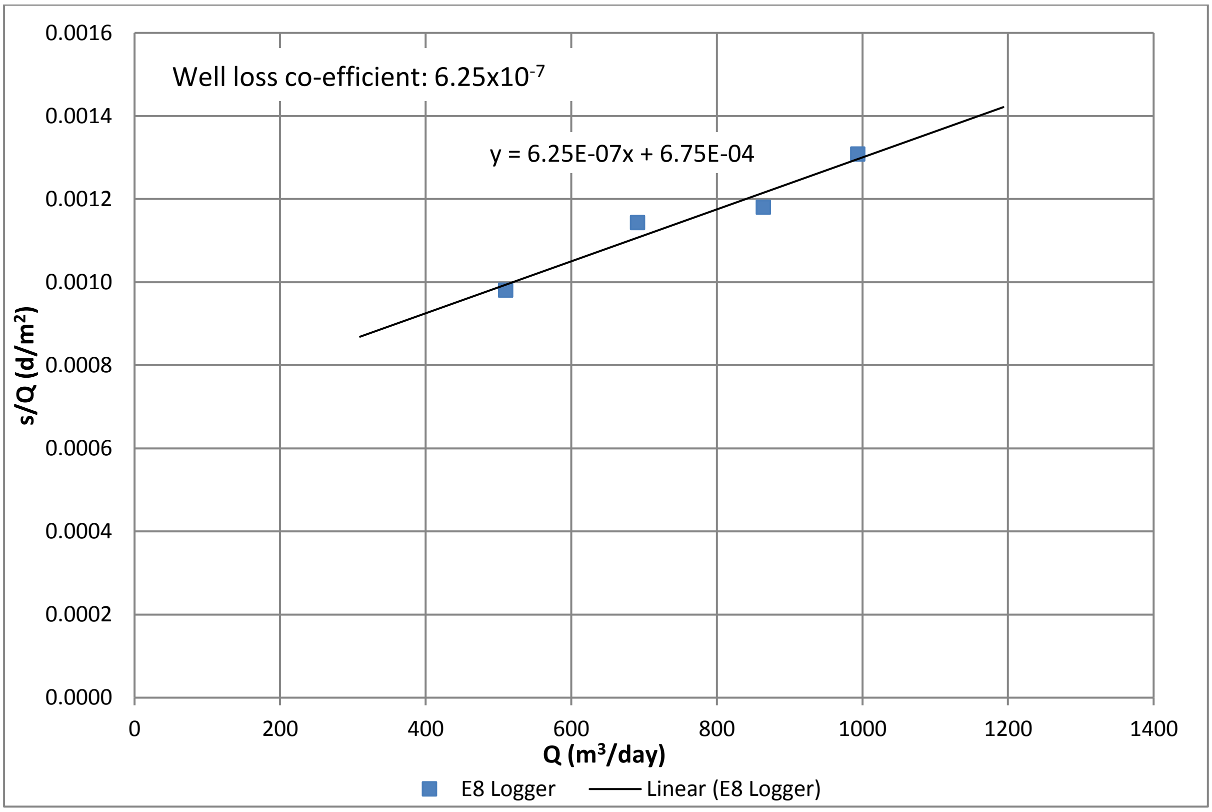


E8 – Lower Waiwhetu

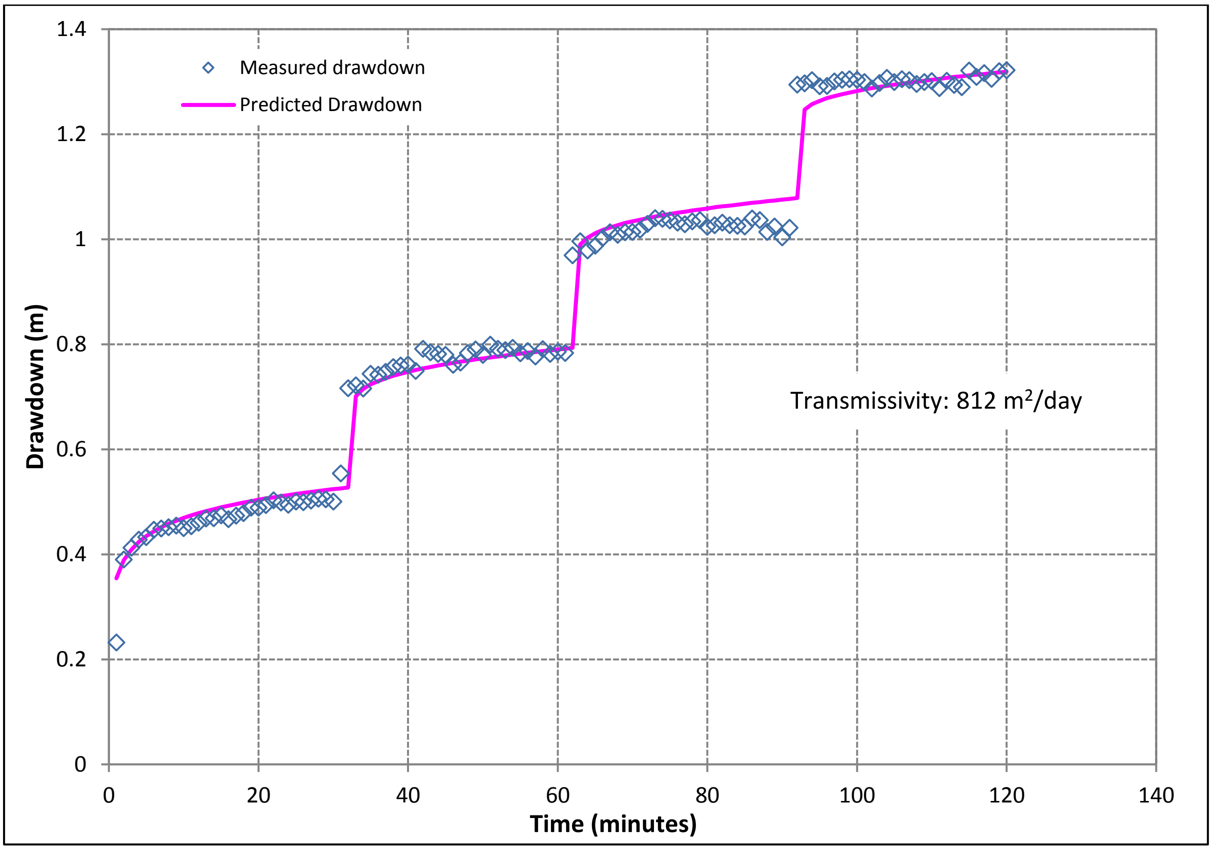
Pumping test on 21st January 2018. Bore screened 38.8 – 41.8 m below sea floor.



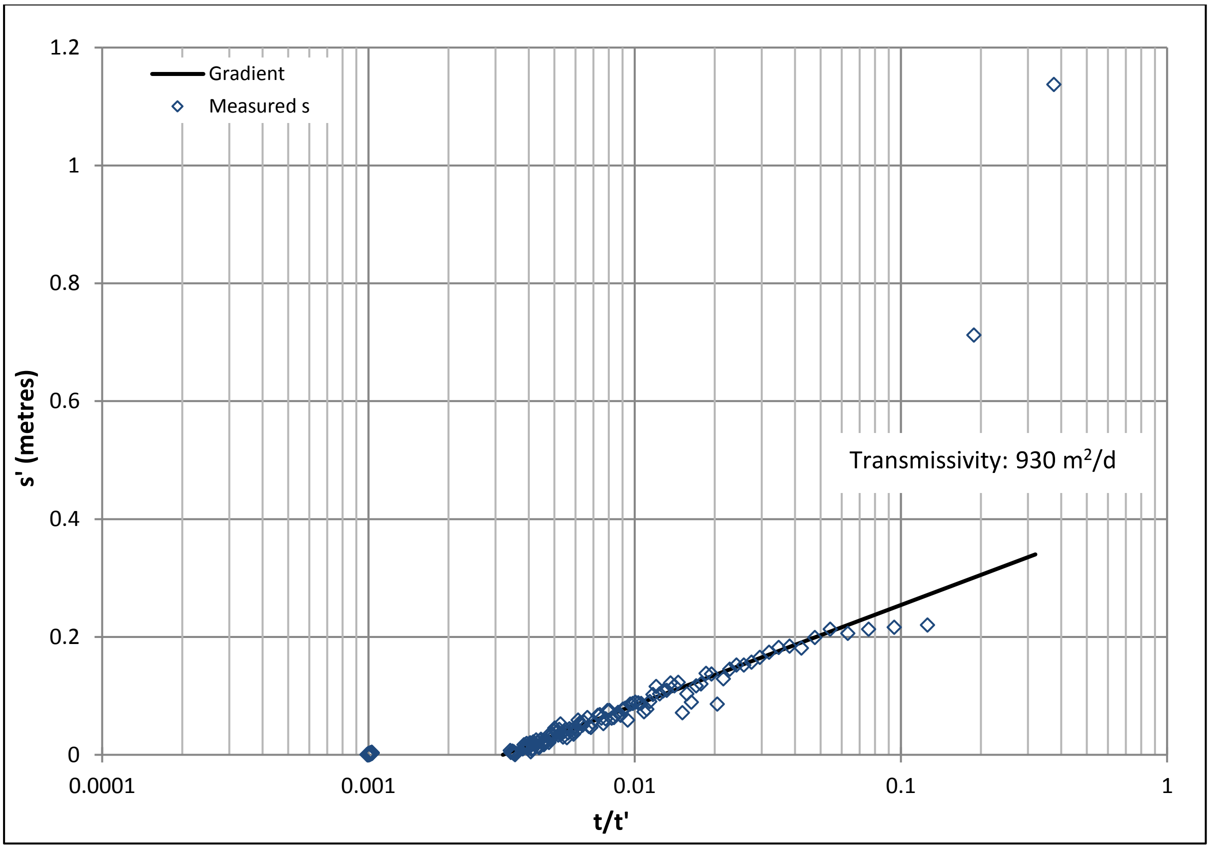
Step Rate Test Analysis – s/q vs Q



Eden Hazel Analysis of SRT data



Theis Recovery Analysis of CRT recovery



APPENDIX 6: Water quality laboratory test results

Eurofins ELS Limited

Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045

Attention: Nick Urlich

Analytical Report

Report Number: 17/43908

Issue: 2
21 July 2017

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
17/43908-01	Miscellaneous Sample		19/07/2017 16:00	20/07/2017 12:05	0

Notes: E3a 25m Drill

	Test	**Result**	**Units**	**Signatory**
0001	pH	7.0		Gordon McArthur KTP
0002	Suspended Solids - Total	21	g/m^3	Marylou Cabral KTP
0040	Total (NP) Organic Carbon	25.1	g/m^3	Tracy Morrison KTP
0052	Alkalinity - Total	92	g CaCO3/m^3	Gordon McArthur KTP
0055	Conductivity at 25°C	95.3	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Marylou Cabral KTP
0072	Bicarbonate Alkalinity	92	g CaCO3/m^3	Gordon McArthur KTP
0084	Turbidity	29.0	NTU	Gordon McArthur KTP
0590	Anion Sum	7.54	meq/L	Sharon van Soest KTP
0591	Cation Sum	7.76	meq/L	Divina Lagazon KTP
0601	Fluoride	0.48	g/m^3	Wayne Edgerley KTP
0602	Chloride	205	g/m^3	Wayne Edgerley KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Wayne Edgerley KTP
0604	Bromide	0.80	g/m^3	Wayne Edgerley KTP
0605	Nitrate - Nitrogen	< 0.01	g/m^3	Wayne Edgerley KTP
0607	Sulphate	12.0	g/m^3	Wayne Edgerley KTP
0677	Colour	2.5	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	3.55	g/m^3	Divina Lagazon KTP
1024	Total Dissolved Solids	481	g/m^3	Marylou Cabral KTP
1250	Transmissivity @ 253.7nm	62.9	%	Gordon McArthur KTP
1275	Transmissivity after filtration	92.9	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	12.1	g/m^3	Rob Deacon KTP
1622	Magnesium - Acid Soluble	11.7	g/m^3	Rob Deacon KTP
1629	Potassium - Acid Soluble	9.23	g/m^3	Rob Deacon KTP
1634	Sodium - Acid Soluble	127	g/m^3	Rob Deacon KTP
1642	Total Hardness	79	g CaCO3/m^3	Rob Deacon KTP
1810	Calcium - Dissolved	12.0	g/m^3	Rob Deacon KTP
1822	Magnesium - Dissolved	11.8	g/m^3	Rob Deacon KTP
1829	Potassium - Dissolved	8.85	g/m^3	Rob Deacon KTP
1834	Sodium - Dissolved	129	g/m^3	Rob Deacon KTP
1843	Silica - Dissolved	24.0	g/m^3	Rob Deacon KTP
6001	Aluminium - Acid Soluble	0.725	g/m^3	Sharon van Soest KTP
6003	Arsenic - Acid Soluble	0.008	g/m^3	Sharon van Soest KTP
6007	Boron - Acid Soluble	0.11	g/m^3	Sharon van Soest KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/43908-01	Miscellaneous Sample		19/07/2017 16:00	20/07/2017 12:05	0

Notes: E3a 25m Drill

	Test	Result	Units	Signatory
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Sharon van Soest KTP
6013	Copper - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6017	Iron - Acid Soluble	2.90	g/m³	Sharon van Soest KTP
6018	Lead - Acid Soluble	0.0006	g/m³	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.475	g/m³	Sharon van Soest KTP
6024	Nickel - Acid Soluble	0.0007	g/m³	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.003	g/m³	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.007	g/m³	Sharon van Soest KTP
6704	Barium - Dissolved	0.014	g/m³	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6707	Boron - Dissolved	0.11	g/m³	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6717	Iron - Dissolved	0.67	g/m³	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6719	Lithium - Dissolved	0.003	g/m³	Sharon van Soest KTP
6721	Manganese - Dissolved	0.466	g/m³	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6723	Molybdenum - Dissolved	0.0010	g/m³	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6738	Zinc - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

This report cancels and replaces report 17/43908-1. Please dispose of all previous versions.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m³
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m³
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³

Test	Methodology	Detection Limit
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m³
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m³
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³

Test	Methodology	Detection Limit
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012	1 MPN/100mL

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Deacon

Report Released By
Rob Deacon

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Eurofins ELS Limited

Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045
Attention: Nick Urlich

Analytical Report

Report Number: 17/44644

Issue: 2
26 July 2017

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/44644-01	Miscellaneous Sample		24/07/2017 11:45	25/07/2017 09:31	P0003408

Notes: E3a 24-25.5 DEV

	Test	Result	Units	Signatory
0001	pH	7.1		Marylou Cabral KTP
0002	Suspended Solids - Total	8	g/m³	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	0.9	g/m³	Tracy Morrison KTP
0052	Alkalinity - Total	89	g CaCO3/m³	Marylou Cabral KTP
0055	Conductivity at 25°C	64.2	mS/m	Marylou Cabral KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m³	Marylou Cabral KTP
0072	Bicarbonate Alkalinity	89	g CaCO3/m³	Marylou Cabral KTP
0084	Turbidity	10.2	NTU	Gordon McArthur KTP
0590	Anion Sum	4.98	meq/L	Sharon van Soest KTP
0591	Cation Sum	6.06	meq/L	Sharon van Soest KTP
0592	Ion Balance	9.75	%	Sharon van Soest KTP
0601	Fluoride	0.48	g/m³	Wayne Edgerley KTP
0602	Chloride	124	g/m³	Wayne Edgerley KTP
0603	Nitrite - Nitrogen	< 0.01	g/m³	Wayne Edgerley KTP
0604	Bromide	0.50	g/m³	Wayne Edgerley KTP
0605	Nitrate - Nitrogen	0.05	g/m³	Wayne Edgerley KTP
0607	Sulphate	0.50	g/m³	Wayne Edgerley KTP
0677	Colour	4.5	TCU	Marylou Cabral KTP
0760	Ammonia Nitrogen	3.42	g/m³	Divina Lagazon KTP
1024	Total Dissolved Solids	338	g/m³	Marylou Cabral KTP
1250	Transmissivity @ 253.7nm	69.6	%	Marylou Cabral KTP
1275	Transmissivity after filtration	84.7	%	Marylou Cabral KTP
1301	Salinity	< 2.0 *	ppt	Marylou Cabral KTP
1610	Calcium - Acid Soluble	11.5	g/m³	Wayne Edgerley KTP
1622	Magnesium - Acid Soluble	9.61	g/m³	Wayne Edgerley KTP
1629	Potassium - Acid Soluble	6.48	g/m³	Wayne Edgerley KTP
1634	Sodium - Acid Soluble	95.2	g/m³	Wayne Edgerley KTP
1642	Total Hardness	68	g CaCO3/m³	Wayne Edgerley KTP
1810	Calcium - Dissolved	10.2	g/m³	Wayne Edgerley KTP
1822	Magnesium - Dissolved	9.37	g/m³	Wayne Edgerley KTP
1829	Potassium - Dissolved	6.28	g/m³	Wayne Edgerley KTP
1834	Sodium - Dissolved	92.8	g/m³	Wayne Edgerley KTP
1843	Silica - Dissolved	24.2	g/m³	Wayne Edgerley KTP
6001	Aluminium - Acid Soluble	0.105	g/m³	Sharon van Soest KTP
6003	Arsenic - Acid Soluble	0.005	g/m³	Sharon van Soest KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
17/44644-01	Miscellaneous Sample		24/07/2017 11:45	25/07/2017 09:31	P0003408

Notes: E3a 24-25.5 DEV

	Test	**Result**	**Units**	**Signatory**
6007	Boron - Acid Soluble	0.08	g/m^3	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m^3	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m^3	Sharon van Soest KTP
6013	Copper - Acid Soluble	< 0.0005	g/m^3	Sharon van Soest KTP
6017	Iron - Acid Soluble	2.67	g/m^3	Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m^3	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.463	g/m^3	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m^3	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.012	g/m^3	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m^3	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.004	g/m^3	Sharon van Soest KTP
6704	Barium - Dissolved	0.016	g/m^3	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6707	Boron - Dissolved	0.06	g/m^3	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m^3	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6717	Iron - Dissolved	1.60	g/m^3	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6719	Lithium - Dissolved	0.002	g/m^3	Sharon van Soest KTP
6721	Manganese - Dissolved	0.406	g/m^3	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0008	g/m^3	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m^3	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6738	Zinc - Dissolved	0.007	g/m^3	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m^3	Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

This report cancels and replaces report 17/44644-1. Please dispose of all previous versions.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m^3
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m^3
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m^3
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m

Test	Methodology	Detection Limit
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m³
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m³

Test	Methodology	Detection Limit
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012	1 MPN/100mL

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Deacon

Report Released By
Rob Deacon

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Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045

Attention: Nick Urlich

Analytical Report

Report Number: 17/44925

Issue: 2
28 July 2017

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/44925-01	Drinking Water		25/07/2017 09:00	26/07/2017 08:30	P0003408

Notes: E3a PT1 1hr

	Test	Result	Units	Signatory
0001	pH	7.1		Gordon McArthur KTP
0002	Suspended Solids - Total	79	g/m^3	Marylou Cabral KTP
0040	Total (NP) Organic Carbon	1.3	g/m^3	Tracy Morrison KTP
0052	Alkalinity - Total	91	g CaCO3/m^3	Gordon McArthur KTP
0055	Conductivity at 25°C	64.2	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	91	g CaCO3/m^3	Gordon McArthur KTP
0084	Turbidity	51.0	NTU	Gordon McArthur KTP
0590	Anion Sum	5.05	meq/L	Sharon van Soest KTP
0591	Cation Sum	6.01	meq/L	Sharon van Soest KTP
0592	Ion Balance	8.68	%	Sharon van Soest KTP
0601	Fluoride	0.49	g/m^3	Wayne Edgerley KTP
0602	Chloride	126	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Wayne Edgerley KTP
0604	Bromide	0.69	g/m^3	Wayne Edgerley KTP
0605	Nitrate - Nitrogen	< 0.01	g/m^3	Wayne Edgerley KTP
0607	Sulphate	0.44	g/m^3	Wayne Edgerley KTP
0677	Colour	2.8	TCU	Marylou Cabral KTP
0760	Ammonia Nitrogen	3.46	g/m^3	Divina Lagazon KTP
1004	Temperature on arrival	8.8	Deg C	Tegan Slater
1024	Total Dissolved Solids	307	g/m^3	Marylou Cabral KTP
1250	Transmissivity @ 253.7nm	48.3	%	Marylou Cabral KTP
1275	Transmissivity after filtration	91.6	%	Marylou Cabral KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	10.7	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	9.18	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	6.78	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	95.3	g/m^3	Shanel Kumar KTP
1642	Total Hardness	65	g CaCO3/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	10.4	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	9.08	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	6.85	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	97.6	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	25.3	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	1.35	g/m^3	Sharon van Soest KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/44925-01	Drinking Water		25/07/2017 09:00	26/07/2017 08:30	P0003408

Notes: E3a PT1 1hr

	Test	Result	Units	Signatory
6003	Arsenic - Acid Soluble	0.005	g/m³	Sharon van Soest KTP
6007	Boron - Acid Soluble	0.07	g/m³	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Sharon van Soest KTP
6011	Chromium - Acid Soluble	0.001	g/m³	Sharon van Soest KTP
6013	Copper - Acid Soluble	0.0013	g/m³	Sharon van Soest KTP
6017	Iron - Acid Soluble	3.01	g/m³	Sharon van Soest KTP
6018	Lead - Acid Soluble	0.0013	g/m³	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.491	g/m³	Sharon van Soest KTP
6024	Nickel - Acid Soluble	0.0012	g/m³	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.147	g/m³	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.005	g/m³	Sharon van Soest KTP
6704	Barium - Dissolved	0.008	g/m³	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6707	Boron - Dissolved	0.08	g/m³	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6717	Iron - Dissolved	0.63	g/m³	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6719	Lithium - Dissolved	0.002	g/m³	Sharon van Soest KTP
6721	Manganese - Dissolved	0.459	g/m³	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0005	g/m³	Sharon van Soest KTP
6724	Nickel - Dissolved	0.0005	g/m³	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6738	Zinc - Dissolved	0.066	g/m³	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/44925-02	Drinking Water		25/07/2017 11:30	26/07/2017 08:30	P0003408

Notes: E3a PT1 3.5hr

	Test	Result	Units	Signatory
0001	pH	7.3		Gordon McArthur KTP
0002	Suspended Solids - Total	36	g/m³	Marylou Cabral KTP
0040	Total (NP) Organic Carbon	1.3	g/m³	Tracy Morrison KTP
0052	Alkalinity - Total	91	g CaCO3/m³	Gordon McArthur KTP
0055	Conductivity at 25°C	62.5	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m³	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	91	g CaCO3/m³	Gordon McArthur KTP
0084	Turbidity	22.3	NTU	Gordon McArthur KTP
0590	Anion Sum	4.94	meq/L	Sharon van Soest KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
17/44925-02	Drinking Water		25/07/2017 11:30	26/07/2017 08:30	P0003408

Notes: E3a PT1 3.5hr

	Test	**Result**	**Units**	**Signatory**
0591	Cation Sum	6.18	meq/L	Sharon van Soest KTP
0592	Ion Balance	11.1	%	Sharon van Soest KTP
0601	Fluoride	0.48	g/m^3	Wayne Edgerley KTP
0602	Chloride	122	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Wayne Edgerley KTP
0604	Bromide	0.48	g/m^3	Wayne Edgerley KTP
0605	Nitrate - Nitrogen	0.02	g/m^3	Wayne Edgerley KTP
0607	Sulphate	0.21	g/m^3	Wayne Edgerley KTP
0677	Colour	2.6	TCU	Marylou Cabral KTP
0760	Ammonia Nitrogen	3.51	g/m^3	Divina Lagazon KTP
1024	Total Dissolved Solids	319	g/m^3	Marylou Cabral KTP
1250	Transmissivity @ 253.7nm	59.6	%	Marylou Cabral KTP
1275	Transmissivity after filtration	91.4	%	Marylou Cabral KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	10.9	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	9.34	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	7.09	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	98.4	g/m^3	Shanel Kumar KTP
1642	Total Hardness	66	g $CaCO_3$/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	10.5	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	9.06	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	6.82	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	96.9	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	25.4	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.440	g/m^3	Sharon van Soest KTP
6003	Arsenic - Acid Soluble	0.005	g/m^3	Sharon van Soest KTP
6007	Boron - Acid Soluble	0.07	g/m^3	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m^3	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m^3	Sharon van Soest KTP
6013	Copper - Acid Soluble	0.0023	g/m^3	Sharon van Soest KTP
6017	Iron - Acid Soluble	2.90	g/m^3	Sharon van Soest KTP
6018	Lead - Acid Soluble	0.0025	g/m^3	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.510	g/m^3	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m^3	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.096	g/m^3	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m^3	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.005	g/m^3	Sharon van Soest KTP
6704	Barium - Dissolved	0.012	g/m^3	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6707	Boron - Dissolved	0.07	g/m^3	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m^3	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6717	Iron - Dissolved	1.31	g/m^3	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/44925-02	Drinking Water		25/07/2017 11:30	26/07/2017 08:30	P0003408

Notes: E3a PT1 3.5hr

	Test	Result	Units	Signatory
6719	Lithium - Dissolved	0.002	g/m³	Sharon van Soest KTP
6721	Manganese - Dissolved	0.493	g/m³	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6723	Molybdenum - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6738	Zinc - Dissolved	0.044	g/m³	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/44925-03	Drinking Water		25/07/2017 15:00	26/07/2017 08:30	P0003408

Notes: E3a PT1 7hr

	Test	Result	Units	Signatory
0001	pH	7.6		Gordon McArthur KTP
0002	Suspended Solids - Total	11	g/m³	Marylou Cabral KTP
0040	Total (NP) Organic Carbon	1.1	g/m³	Tracy Morrison KTP
0052	Alkalinity - Total	92	g CaCO3/m³	Gordon McArthur KTP
0055	Conductivity at 25°C	62.2	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m³	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	92	g CaCO3/m³	Gordon McArthur KTP
0084	Turbidity	7.61	NTU	Gordon McArthur KTP
0590	Anion Sum	5.03	meq/L	Sharon van Soest KTP
0591	Cation Sum	6.16	meq/L	Sharon van Soest KTP
0592	Ion Balance	10.1	%	Sharon van Soest KTP
0601	Fluoride	0.48	g/m³	Wayne Edgerley KTP
0602	Chloride	124	g/m³	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m³	Wayne Edgerley KTP
0604	Bromide	0.49	g/m³	Wayne Edgerley KTP
0605	Nitrate - Nitrogen	0.06	g/m³	Wayne Edgerley KTP
0607	Sulphate	0.13	g/m³	Wayne Edgerley KTP
0677	Colour	2.7	TCU	Marylou Cabral KTP
0760	Ammonia Nitrogen	3.55	g/m³	Divina Lagazon KTP
1024	Total Dissolved Solids	308	g/m³	Marylou Cabral KTP
1250	Transmissivity @ 253.7nm	82.8	%	Marylou Cabral KTP
1275	Transmissivity after filtration	92.1	%	Marylou Cabral KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	11.0	g/m³	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	9.27	g/m³	Shanel Kumar KTP
1629	Potassium - Acid Soluble	6.76	g/m³	Shanel Kumar KTP
1634	Sodium - Acid Soluble	98.3	g/m³	Shanel Kumar KTP
1642	Total Hardness	66	g CaCO3/m³	Shanel Kumar KTP
1810	Calcium - Dissolved	10.4	g/m³	Shanel Kumar KTP
1822	Magnesium - Dissolved	8.79	g/m³	Shanel Kumar KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/44925-03	Drinking Water		25/07/2017 15:00	26/07/2017 08:30	P0003408

Notes: E3a PT1 7hr

	Test	Result	Units	Signatory
1829	Potassium - Dissolved	6.44	g/m³	Shanel Kumar KTP
1834	Sodium - Dissolved	91.8	g/m³	Shanel Kumar KTP
1843	Silica - Dissolved	23.7	g/m³	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.149	g/m³	Sharon van Soest KTP
6003	Arsenic - Acid Soluble	0.005	g/m³	Sharon van Soest KTP
6007	Boron - Acid Soluble	0.08	g/m³	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Sharon van Soest KTP
6013	Copper - Acid Soluble	0.0023	g/m³	Sharon van Soest KTP
6017	Iron - Acid Soluble	2.77	g/m³	Sharon van Soest KTP
6018	Lead - Acid Soluble	0.0012	g/m³	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.524	g/m³	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.052	g/m³	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.005	g/m³	Sharon van Soest KTP
6704	Barium - Dissolved	0.023	g/m³	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6707	Boron - Dissolved	0.07	g/m³	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6713	Copper - Dissolved	0.0015	g/m³	Sharon van Soest KTP
6717	Iron - Dissolved	2.09	g/m³	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6719	Lithium - Dissolved	0.002	g/m³	Sharon van Soest KTP
6721	Manganese - Dissolved	0.515	g/m³	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0005	g/m³	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6738	Zinc - Dissolved	0.053	g/m³	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

This report cancels and replaces report 17/44925-1. Please dispose of all previous versions.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m³
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m³
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³

Test	Methodology	Detection Limit
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m^3
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012	1 MPN/100mL

Onsite Observation Methodology:

Test	Methodology	Detection Limit
Temperature on arrival	The temperature of the microbiological samples, upon arrival at the laboratory must not be below 0'C or exceed 10'C.	Deg C

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Deacon

Report Released By
Rob Deacon

This laboratory is accredited by International Accreditation New Zealand and its reports are recognised in all countries affiliated to the International Laboratory Accreditation Co-operation Mutual Recognition Arrangement (ILAC-MRA). The tests reported have been performed in accordance with our terms of accreditation, with the exception of tests marked "not IANZ", which are outside the scope of this laboratory's accreditation.

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Eurofins ELS Limited

Analytical Report

Interim

Wellington Water Ltd - WCC
Non Routine H2O

Report Number: 17/47080

Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045

Issue: 1
08 August 2017

Attention: David Cameron

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/47080-01	Drinking Water		04/08/2017 16:00	07/08/2017 10:25	P1010105

Notes: E3a 74.4 m

	Test	Result	Units	Signatory
0001	pH	7.4		Gordon McArthur KTP
0002	Suspended Solids - Total	35	g/m^3	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	Not Available	g/m^3	
0052	Alkalinity - Total	159	g CaCO3/m^3	Gordon McArthur KTP
0055	Conductivity at 25°C	137	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	159	g CaCO3/m^3	Gordon McArthur KTP
0084	Turbidity	25.5	NTU	Jennifer dela Rama KTP
0590	Anion Sum	11.6	meq/L	Sharon van Soest KTP
0591	Cation Sum	11.4	meq/L	Sharon van Soest KTP
0592	Ion Balance	0.96	%	Sharon van Soest KTP
0601	Fluoride	0.09	g/m^3	Shanel Kumar KTP
0602	Chloride	319	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0604	Bromide	1.33	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	0.06	g/m^3	Shanel Kumar KTP
0607	Sulphate	1.32	g/m^3	Shanel Kumar KTP
0677	Colour	2.2	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	5.08	g/m^3	Divina Lagazon KTP
1024	Total Dissolved Solids	695	g/m^3	Marylou Cabral KTP
1250	Transmissivity @ 253.7nm	67.8	%	Gordon McArthur KTP
1275	Transmissivity after filtration	92.7	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	38.3	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	21.2	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	12.5	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	161	g/m^3	Shanel Kumar KTP
1642	Total Hardness	183	g CaCO3/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	37.6	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	19.9	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	11.9	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	158	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	26.3	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.368	g/m^3	Shanel Kumar KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
17/47080-01	Drinking Water		04/08/2017 16:00	07/08/2017 10:25	P1010105

Notes: E3a 74.4 m

	Test	**Result**	**Units**	**Signatory**
6003	Arsenic - Acid Soluble	0.001	g/m³	Shanel Kumar KTP
6007	Boron - Acid Soluble	0.10	g/m³	Shanel Kumar KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Shanel Kumar KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Shanel Kumar KTP
6013	Copper - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6017	Iron - Acid Soluble	1.79	g/m³	Shanel Kumar KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6021	Manganese - Acid Soluble	0.271	g/m³	Shanel Kumar KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6038	Zinc - Acid Soluble	0.013	g/m³	Shanel Kumar KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Shanel Kumar KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6703	Arsenic - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6704	Barium - Dissolved	0.104	g/m³	Shanel Kumar KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6707	Boron - Dissolved	0.11	g/m³	Shanel Kumar KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Shanel Kumar KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6717	Iron - Dissolved	0.02	g/m³	Shanel Kumar KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6719	Lithium - Dissolved	0.003	g/m³	Shanel Kumar KTP
6721	Manganese - Dissolved	0.288	g/m³	Shanel Kumar KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0006	g/m³	Shanel Kumar KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Shanel Kumar KTP
6730	Silver - Dissolved	< 0.0020	g/m³	Shanel Kumar KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6738	Zinc - Dissolved	0.006	g/m³	Shanel Kumar KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Shanel Kumar KTP
M0403	Total Coliforms	< 1	MPN/100ml	Yuemei Yu KTP
M0404	E. coli	< 1	MPN/100mL	Yuemei Yu KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

All samples analysed as we receive them. Delivery was within the correct time and temperature conditions.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m³
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m³
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³

Test	Methodology	Detection Limit
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m³

Test	Methodology	Detection Limit
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012	1 MPN/100mL

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Deacon

Report Released By
Rob Deacon

Eurofins ELS Limited

Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045

Attention: Nick Urlich

Analytical Report

Report Number: 17/47465

Issue: 1
10 August 2017

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/47465-01	Drinking Water		08/08/2017 13:30	09/08/2017 08:40	P1010105

Notes: E3a 74-77m DEV

	Test	Result	Units	Signatory
0001	pH	7.5		Marylou Cabral KTP
0002	Suspended Solids - Total	3	g/m^3	Marylou Cabral KTP
0040	Total (NP) Organic Carbon	0.9	g/m^3	Tracy Morrison KTP
0052	Alkalinity - Total	162	g CaCO3/m^3	Marylou Cabral KTP
0055	Conductivity at 25°C	134	mS/m	Marylou Cabral KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Marylou Cabral KTP
0072	Bicarbonate Alkalinity	162	g CaCO3/m^3	Marylou Cabral KTP
0084	Turbidity	10.1	NTU	Jennifer dela Rama KTP
0590	Anion Sum	11.4	meq/L	Sharon van Soest KTP
0591	Cation Sum	11.2	meq/L	Sharon van Soest KTP
0592	Ion Balance	1.02	%	Sharon van Soest KTP
0601	Fluoride	0.08	g/m^3	Shanel Kumar KTP
0602	Chloride	310	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0604	Bromide	1.25	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0607	Sulphate	0.33	g/m^3	Shanel Kumar KTP
0677	Colour	1.3	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	5.06	g/m^3	Divina Lagazon KTP
1004	Temperature on arrival	6.4	Deg C	Alex Eustace
1024	Total Dissolved Solids	598	g/m^3	Marylou Cabral KTP
1250	Transmissivity @ 253.7nm	76.0	%	Gordon McArthur KTP
1275	Transmissivity after filtration	94.5	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Marylou Cabral KTP
1610	Calcium - Acid Soluble	38.7	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	19.7	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	11.8	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	158	g/m^3	Shanel Kumar KTP
1642	Total Hardness	178	g CaCO3/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	37.7	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	19.5	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	10.8	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	160	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	26.3	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.008	g/m^3	Sharon van Soest KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/47465-01	Drinking Water		08/08/2017 13:30	09/08/2017 08:40	P1010105

Notes: E3a 74-77m DEV

	Test	Result	Units	Signatory
6003	Arsenic - Acid Soluble	0.001	g/m³	Sharon van Soest KTP
6007	Boron - Acid Soluble	0.11	g/m³	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Sharon van Soest KTP
6013	Copper - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6017	Iron - Acid Soluble	1.82	g/m³	Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.304	g/m³	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.003	g/m³	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.001	g/m³	Sharon van Soest KTP
6704	Barium - Dissolved	0.120	g/m³	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6707	Boron - Dissolved	0.09	g/m³	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6717	Iron - Dissolved	0.84	g/m³	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6719	Lithium - Dissolved	0.003	g/m³	Sharon van Soest KTP
6721	Manganese - Dissolved	0.281	g/m³	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6723	Molybdenum - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0020	g/m³	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6738	Zinc - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
M0403	Total Coliforms	1	MPN/100ml	Sunita Raju KTP
M0404	E. coli	< 1	MPN/100mL	Sunita Raju KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m³
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m³
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m

Test	Methodology	Detection Limit
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m^3
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m^3
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m^3
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m^3
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m^3
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m^3
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m^3
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m^3
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m^3
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m^3
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m^3
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m^3
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m^3
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m^3
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m^3
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m^3
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m^3
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m^3
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m^3
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m^3
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m^3
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3

Test	Methodology	Detection Limit
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012	1 MPN/100mL

Onsite Observation Methodology:

Test	Methodology	Detection Limit
Temperature on arrival	The temperature of the microbiological samples, upon arrival at the laboratory must not be below 0'C or exceed 10'C.	Deg C

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Report Released By
Sunita Raju

This laboratory is accredited by International Accreditation New Zealand and its reports are recognised in all countries affiliated to the International Laboratory Accreditation Co-operation Mutual Recognition Arrangement (ILAC-MRA). The tests reported have been performed in accordance with our terms of accreditation, with the exception of tests marked "not IANZ", which are outside the scope of this laboratory's accreditation.

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Eurofins ELS Limited

Analytical Report

Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045

Attention: Nick Urlich

Report Number: 17/47664

Issue: 1
11 August 2017

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
17/47664-01	Drinking Water		09/08/2017 09:30	10/08/2017 08:40	P1010105

Notes: E3a PT2 1.5hr

	Test	**Result**	**Units**	**Signatory**
0001	pH	7.5		Marylou Cabral KTP
0002	Suspended Solids - Total	4	g/m^3	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	0.9	g/m^3	Sharon van Soest KTP
0052	Alkalinity - Total	159	g CaCO3/m^3	Marylou Cabral KTP
0055	Conductivity at 25°C	133	mS/m	Marylou Cabral KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Marylou Cabral KTP
0072	Bicarbonate Alkalinity	159	g CaCO3/m^3	Marylou Cabral KTP
0084	Turbidity	12.7	NTU	Jennifer dela Rama KTP
0590	Anion Sum	11.6	meq/L	Amit Kumar
0591	Cation Sum	11.1	meq/L	Shanel Kumar KTP
0592	Ion Balance	2.14	%	Shanel Kumar KTP
0601	Fluoride	0.06	g/m^3	Shanel Kumar KTP
0602	Chloride	318	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0604	Bromide	1.29	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0607	Sulphate	0.20	g/m^3	Shanel Kumar KTP
0677	Colour	1.5	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	5.12	g/m^3	Divina Lagazon KTP
1004	Temperature on arrival	4.6	Deg C	Tegan Slater
1024	Total Dissolved Solids	602	g/m^3	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	76.7	%	Gordon McArthur KTP
1275	Transmissivity after filtration	94.2	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	39.1	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	20.7	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	11.6	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	153	g/m^3	Shanel Kumar KTP
1642	Total Hardness	183	g CaCO3/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	38.8	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	20.6	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	11.3	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	157	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	25.8	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.006	g/m^3	Shanel Kumar KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/47664-01	Drinking Water		09/08/2017 09:30	10/08/2017 08:40	P1010105

Notes: E3a PT2 1.5hr

	Test	Result	Units	Signatory
6003	Arsenic - Acid Soluble	< 0.001	g/m³	Shanel Kumar KTP
6007	Boron - Acid Soluble	0.10	g/m³	Shanel Kumar KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Shanel Kumar KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Shanel Kumar KTP
6013	Copper - Acid Soluble	0.0010	g/m³	Shanel Kumar KTP
6017	Iron - Acid Soluble	1.67	g/m³	Shanel Kumar KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6021	Manganese - Acid Soluble	0.291	g/m³	Shanel Kumar KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6038	Zinc - Acid Soluble	0.153	g/m³	Shanel Kumar KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Shanel Kumar KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6703	Arsenic - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6704	Barium - Dissolved	0.103	g/m³	Shanel Kumar KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6707	Boron - Dissolved	0.09	g/m³	Shanel Kumar KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Shanel Kumar KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6717	Iron - Dissolved	0.44	g/m³	Shanel Kumar KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6719	Lithium - Dissolved	0.003	g/m³	Shanel Kumar KTP
6721	Manganese - Dissolved	0.271	g/m³	Shanel Kumar KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6723	Molybdenum - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Shanel Kumar KTP
6730	Silver - Dissolved	< 0.0020	g/m³	Shanel Kumar KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6738	Zinc - Dissolved	0.084	g/m³	Shanel Kumar KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Shanel Kumar KTP
M0403	Total Coliforms	< 1	MPN/100ml	Juana Tamayo KTP
M0404	E. coli	< 1	MPN/100mL	Juana Tamayo KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/47664-02	Drinking Water		09/08/2017 12:30	10/08/2017 08:40	P1010105

Notes: E3a PT2 4.5hr

	Test	Result	Units	Signatory
0001	pH	7.5		Gordon McArthur KTP
0002	Suspended Solids - Total	3	g/m³	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	0.7	g/m³	Sharon van Soest KTP
0052	Alkalinity - Total	158	g CaCO3/m³	Marylou Cabral KTP
0055	Conductivity at 25°C	133	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m³	Marylou Cabral KTP
0072	Bicarbonate Alkalinity	158	g CaCO3/m³	Marylou Cabral KTP
0084	Turbidity	12.4	NTU	Jennifer dela Rama KTP
0590	Anion Sum	11.5	meq/L	Amit Kumar

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/47664-02	Drinking Water		09/08/2017 12:30	10/08/2017 08:40	P1010105

Notes: E3a PT2 4.5hr

	Test	Result	Units	Signatory
0591	Cation Sum	11.3	meq/L	Shanel Kumar KTP
0592	Ion Balance	0.65	%	Shanel Kumar KTP
0601	Fluoride	0.06	g/m³	Shanel Kumar KTP
0602	Chloride	315	g/m³	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m³	Shanel Kumar KTP
0604	Bromide	1.28	g/m³	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m³	Shanel Kumar KTP
0607	Sulphate	0.08	g/m³	Shanel Kumar KTP
0677	Colour	1.4	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	5.10	g/m³	Divina Lagazon KTP
1024	Total Dissolved Solids	593	g/m³	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	79.5	%	Gordon McArthur KTP
1275	Transmissivity after filtration	94.1	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	39.4	g/m³	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	20.7	g/m³	Shanel Kumar KTP
1629	Potassium - Acid Soluble	11.5	g/m³	Shanel Kumar KTP
1634	Sodium - Acid Soluble	159	g/m³	Shanel Kumar KTP
1642	Total Hardness	184	g CaCO3/m³	Shanel Kumar KTP
1810	Calcium - Dissolved	39.0	g/m³	Shanel Kumar KTP
1822	Magnesium - Dissolved	20.4	g/m³	Shanel Kumar KTP
1829	Potassium - Dissolved	11.1	g/m³	Shanel Kumar KTP
1834	Sodium - Dissolved	157	g/m³	Shanel Kumar KTP
1843	Silica - Dissolved	25.7	g/m³	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.003	g/m³	Shanel Kumar KTP
6003	Arsenic - Acid Soluble	< 0.001	g/m³	Shanel Kumar KTP
6007	Boron - Acid Soluble	0.10	g/m³	Shanel Kumar KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Shanel Kumar KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Shanel Kumar KTP
6013	Copper - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6017	Iron - Acid Soluble	1.63	g/m³	Shanel Kumar KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6021	Manganese - Acid Soluble	0.295	g/m³	Shanel Kumar KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6038	Zinc - Acid Soluble	0.047	g/m³	Shanel Kumar KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Shanel Kumar KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6703	Arsenic - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6704	Barium - Dissolved	0.118	g/m³	Shanel Kumar KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6707	Boron - Dissolved	0.10	g/m³	Shanel Kumar KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Shanel Kumar KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6717	Iron - Dissolved	0.82	g/m³	Shanel Kumar KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/47664-02	Drinking Water		09/08/2017 12:30	10/08/2017 08:40	P1010105

Notes: E3a PT2 4.5hr

	Test	Result	Units	Signatory
6719	Lithium - Dissolved	0.003	g/m^3	Shanel Kumar KTP
6721	Manganese - Dissolved	0.294	g/m^3	Shanel Kumar KTP
6722	Mercury - Dissolved	< 0.0005	g/m^3	Shanel Kumar KTP
6723	Molybdenum - Dissolved	< 0.0005	g/m^3	Shanel Kumar KTP
6724	Nickel - Dissolved	< 0.0005	g/m^3	Shanel Kumar KTP
6728	Selenium - Dissolved	< 0.005	g/m^3	Shanel Kumar KTP
6730	Silver - Dissolved	< 0.0020	g/m^3	Shanel Kumar KTP
6734	Tin - Dissolved	< 0.0005	g/m^3	Shanel Kumar KTP
6738	Zinc - Dissolved	0.036	g/m^3	Shanel Kumar KTP
6747	Uranium - Dissolved	< 0.0002	g/m^3	Shanel Kumar KTP
M0403	Total Coliforms	< 1	MPN/100ml	Juana Tamayo KTP
M0404	E. coli	< 1	MPN/100mL	Juana Tamayo KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/47664-03	Drinking Water		09/08/2017 15:30	10/08/2017 08:40	P1010105

Notes: E3a PT2 7.5hr

	Test	Result	Units	Signatory
0001	pH	7.7		Gordon McArthur KTP
0002	Suspended Solids - Total	< 3	g/m^3	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	0.7	g/m^3	Sharon van Soest KTP
0052	Alkalinity - Total	159	g CaCO3/m^3	Marylou Cabral KTP
0055	Conductivity at 25°C	133	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Marylou Cabral KTP
0072	Bicarbonate Alkalinity	159	g CaCO3/m^3	Marylou Cabral KTP
0084	Turbidity	6.61	NTU	Jennifer dela Rama KTP
0590	Anion Sum	11.4	meq/L	Amit Kumar
0591	Cation Sum	11.2	meq/L	Shanel Kumar KTP
0592	Ion Balance	0.68	%	Shanel Kumar KTP
0601	Fluoride	0.06	g/m^3	Shanel Kumar KTP
0602	Chloride	312	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0604	Bromide	1.27	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0607	Sulphate	0.05	g/m^3	Shanel Kumar KTP
0677	Colour	1.6	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	5.17	g/m^3	Divina Lagazon KTP
1024	Total Dissolved Solids	598	g/m^3	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	82.6	%	Gordon McArthur KTP
1275	Transmissivity after filtration	92.8	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	39.1	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	20.5	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	11.4	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	158	g/m^3	Shanel Kumar KTP
1642	Total Hardness	182	g CaCO3/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	38.8	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	20.4	g/m^3	Shanel Kumar KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
17/47664-03	Drinking Water		09/08/2017 15:30	10/08/2017 08:40	P1010105

Notes: E3a PT2 7.5hr

	Test	**Result**	**Units**	**Signatory**
1829	Potassium - Dissolved	11.2	g/m³	Shanel Kumar KTP
1834	Sodium - Dissolved	154	g/m³	Shanel Kumar KTP
1843	Silica - Dissolved	25.8	g/m³	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.003	g/m³	Shanel Kumar KTP
6003	Arsenic - Acid Soluble	< 0.001	g/m³	Shanel Kumar KTP
6007	Boron - Acid Soluble	0.10	g/m³	Shanel Kumar KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Shanel Kumar KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Shanel Kumar KTP
6013	Copper - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6017	Iron - Acid Soluble	1.54	g/m³	Shanel Kumar KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6021	Manganese - Acid Soluble	0.302	g/m³	Shanel Kumar KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Shanel Kumar KTP
6038	Zinc - Acid Soluble	0.036	g/m³	Shanel Kumar KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Shanel Kumar KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6703	Arsenic - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6704	Barium - Dissolved	0.112	g/m³	Shanel Kumar KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6707	Boron - Dissolved	0.10	g/m³	Shanel Kumar KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Shanel Kumar KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Shanel Kumar KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6717	Iron - Dissolved	0.61	g/m³	Shanel Kumar KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6719	Lithium - Dissolved	0.003	g/m³	Shanel Kumar KTP
6721	Manganese - Dissolved	0.290	g/m³	Shanel Kumar KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6723	Molybdenum - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Shanel Kumar KTP
6730	Silver - Dissolved	< 0.0020	g/m³	Shanel Kumar KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6738	Zinc - Dissolved	0.030	g/m³	Shanel Kumar KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Shanel Kumar KTP
M0403	Total Coliforms	10	MPN/100ml	Juana Tamayo KTP
M0404	E. coli	< 1	MPN/100mL	Juana Tamayo KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

All samples analysed as we receive them. Delivery was within the correct time and temperature conditions.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m³
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m³
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³

Test	Methodology	Detection Limit
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m^3
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012	1 MPN/100mL

Onsite Observation Methodology:

Test	Methodology	Detection Limit
Temperature on arrival	The temperature of the microbiological samples, upon arrival at the laboratory must not be below 0'C or exceed 10'C.	Deg C

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Deacon

Report Released By
Rob Deacon

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Eurofins ELS Limited

Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045

Attention: Nick Urlich

Analytical Report

Report Number: 17/49633

Issue: 1
23 August 2017

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/49633-01	Ground Water		19/08/2017 11:30	22/08/2017 12:10	P1010105

Notes: E3a PT3 19hr

	Test	Result	Units	Signatory
0001	pH	7.0		Marylou Cabral KTP
0002	Suspended Solids - Total	< 3	g/m^3	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	0.9	g/m^3	Sharon van Soest KTP
0052	Alkalinity - Total	91	g CaCO3/m^3	Marylou Cabral KTP
0055	Conductivity at 25°C	63.0	mS/m	Marylou Cabral KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Marylou Cabral KTP
0072	Bicarbonate Alkalinity	91	g CaCO3/m^3	Marylou Cabral KTP
0084	Turbidity	12.8	NTU	Marylou Cabral KTP
0590	Anion Sum	5.10	meq/L	Amit Kumar
0591	Cation Sum	5.96	meq/L	Graham Waghorn KTP
0592	Ion Balance	7.72	%	Graham Waghorn KTP
0601	Fluoride	0.46	g/m^3	Shanel Kumar KTP
0602	Chloride	127	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0604	Bromide	0.49	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	0.11	g/m^3	Shanel Kumar KTP
0607	Sulphate	0.59	g/m^3	Shanel Kumar KTP
0677	Colour	6.4	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	3.41	g/m^3	Rob Deacon KTP
1004	Temperature on arrival	9.7	Deg C	Tegan Slater
1024	Total Dissolved Solids	324	g/m^3	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	69.2	%	Gordon McArthur KTP
1275	Transmissivity after filtration	86.2	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Marylou Cabral KTP
1610	Calcium - Acid Soluble	10.3	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	9.42	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	6.41	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	94.6	g/m^3	Shanel Kumar KTP
1642	Total Hardness	65	g CaCO3/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	10.4	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	9.48	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	6.32	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	94.6	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	24.7	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.035	g/m^3	Sharon van Soest KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/49633-01	Ground Water		19/08/2017 11:30	22/08/2017 12:10	P1010105

Notes: E3a PT3 19hr

	Test	Result	Units	Signatory
6003	Arsenic - Acid Soluble	0.006	g/m^3	Sharon van Soest KTP
6007	Boron - Acid Soluble	0.07	g/m^3	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m^3	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m^3	Sharon van Soest KTP
6013	Copper - Acid Soluble	0.0012	g/m^3	Sharon van Soest KTP
6017	Iron - Acid Soluble	2.69	g/m^3	Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m^3	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.560	g/m^3	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m^3	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.049	g/m^3	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m^3	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.005	g/m^3	Sharon van Soest KTP
6704	Barium - Dissolved	0.008	g/m^3	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6707	Boron - Dissolved	0.07	g/m^3	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m^3	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6717	Iron - Dissolved	0.67	g/m^3	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6719	Lithium - Dissolved	0.003	g/m^3	Sharon van Soest KTP
6721	Manganese - Dissolved	0.467	g/m^3	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0006	g/m^3	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m^3	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6738	Zinc - Dissolved	0.025	g/m^3	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m^3	Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml	Sunita Raju KTP
M0404	E. coli	< 1	MPN/100mL	Sunita Raju KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

Sample(s) received outside the correct time and/or temperature conditions and was analysed at your request. Results for these tests can be considered approximate only.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m^3
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m^3

Test	Methodology	Detection Limit
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³

Test	Methodology	Detection Limit
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m^3
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012	1 MPN/100mL

Onsite Observation Methodology:

Test	Methodology	Detection Limit
Temperature on arrival	The temperature of the microbiological samples, upon arrival at the laboratory must not be below 0'C or exceed 10'C.	Deg C

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Report Released By
Rob Deacon

This laboratory is accredited by International Accreditation New Zealand and its reports are recognised in all countries affiliated to the International Laboratory Accreditation Co-operation Mutual Recognition Arrangement (ILAC-MRA). The tests reported have been performed in accordance with our terms of accreditation, with the exception of tests marked "not IANZ", which are outside the scope of this laboratory's accreditation.

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Eurofins ELS Limited

Analytical Report

Report Number: 17/49634

Issue: 1
23 August 2017

Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045

Attention: Nick Urlich

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
17/49634-01	Ground Water		22/08/2017 10:30	22/08/2017 12:10	P1010105

Notes: E3a PT3 (2)

	Test	**Result**	**Units**	**Comments**	**Signatory**
0001	pH	7.0			Marylou Cabral KTP
0002	Suspended Solids - Total	10	g/m^3		Gordon McArthur KTP
0040	Total (NP) Organic Carbon	0.9	g/m^3		Sharon van Soest KTP
0052	Alkalinity - Total	93	g CaCO3/m^3		Marylou Cabral KTP
0055	Conductivity at 25°C	62.7	mS/m		Marylou Cabral KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3		Marylou Cabral KTP
0072	Bicarbonate Alkalinity	93	g CaCO3/m^3		Marylou Cabral KTP
0084	Turbidity	3.77	NTU		Marylou Cabral KTP
0590	Anion Sum	5.06	meq/L		Amit Kumar
0591	Cation Sum	6.03	meq/L		Graham Waghorn KTP
0592	Ion Balance	8.68	%		Graham Waghorn KTP
0601	Fluoride	0.47	g/m^3		Shanel Kumar KTP
0602	Chloride	125	g/m^3		Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3		Shanel Kumar KTP
0604	Bromide	0.48	g/m^3		Shanel Kumar KTP
0605	Nitrate - Nitrogen	0.01	g/m^3		Shanel Kumar KTP
0607	Sulphate	0.28	g/m^3		Shanel Kumar KTP
0677	Colour	4.9	TCU		Gordon McArthur KTP
0760	Ammonia Nitrogen	3.40	g/m^3		Rob Deacon KTP
1004	Temperature on arrival	9.7	Deg C	Complies	Tracy Morrison .
1024	Total Dissolved Solids	285	g/m^3		Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	79.3	%		Gordon McArthur KTP
1275	Transmissivity after filtration	88.0	%		Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt		Marylou Cabral KTP
1610	Calcium - Acid Soluble	10.6	g/m^3		Shanel Kumar KTP
1622	Magnesium - Acid Soluble	9.51	g/m^3		Shanel Kumar KTP
1629	Potassium - Acid Soluble	6.60	g/m^3		Shanel Kumar KTP
1634	Sodium - Acid Soluble	95.7	g/m^3		Shanel Kumar KTP
1642	Total Hardness	66	g CaCO3/m^3		Shanel Kumar KTP
1810	Calcium - Dissolved	10.4	g/m^3		Shanel Kumar KTP
1822	Magnesium - Dissolved	9.34	g/m^3		Shanel Kumar KTP
1829	Potassium - Dissolved	6.33	g/m^3		Shanel Kumar KTP
1834	Sodium - Dissolved	93.7	g/m^3		Shanel Kumar KTP
1843	Silica - Dissolved	24.8	g/m^3		Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.143	g/m^3		Sharon van Soest KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/49634-01	Ground Water		22/08/2017 10:30	22/08/2017 12:10	P1010105

Notes: E3a PT3 (2)

	Test	Result	Units	Comments	Signatory
6003	Arsenic - Acid Soluble	0.006	g/m³		Sharon van Soest KTP
6007	Boron - Acid Soluble	< 0.03	g/m³		Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³		Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³		Sharon van Soest KTP
6013	Copper - Acid Soluble	< 0.0005	g/m³		Sharon van Soest KTP
6017	Iron - Acid Soluble	2.73	g/m³		Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³		Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.546	g/m³		Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³		Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.054	g/m³		Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m³		Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³		Sharon van Soest KTP
6703	Arsenic - Dissolved	0.005	g/m³		Sharon van Soest KTP
6704	Barium - Dissolved	0.028	g/m³		Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³		Sharon van Soest KTP
6707	Boron - Dissolved	0.06	g/m³		Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³		Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³		Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6717	Iron - Dissolved	1.96	g/m³		Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6719	Lithium - Dissolved	0.003	g/m³		Sharon van Soest KTP
6721	Manganese - Dissolved	0.450	g/m³		Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0005	g/m³		Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³		Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6738	Zinc - Dissolved	0.049	g/m³		Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³		Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml		Sunita Raju KTP
M0404	E. coli	< 1	MPN/100mL		Sunita Raju KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

All samples analysed as we receive them. Delivery was within the correct time and temperature conditions.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m³
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m³
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³

Test	Methodology	Detection Limit
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m³

Test	Methodology	Detection Limit
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012	1 MPN/100mL

Onsite Observation Methodology:

Test	Methodology	Detection Limit
Temperature on arrival	The temperature of the microbiological samples, upon arrival at the laboratory must not be below 0'C or exceed 10'C.	Deg C

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Deacon

Report Released By
Rob Deacon

This laboratory is accredited by International Accreditation New Zealand and its reports are recognised in all countries affiliated to the International Laboratory Accreditation Co-operation Mutual Recognition Arrangement (ILAC-MRA). The tests reported have been performed in accordance with our terms of accreditation, with the exception of tests marked "not IANZ", which are outside the scope of this laboratory's accreditation.

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Eurofins ELS Limited

Analytical Report

Report Number: 17/49635

Issue: 1
23 August 2017

Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045

Attention: Nick Urlich

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
17/49635-01	Ground Water		20/08/2017 16:00	22/08/2017 12:10	P1010105

Notes: E3a PT3 4pm

	Test	Result	Units	Comments	Signatory
0001	pH	7.0			Marylou Cabral KTP
0002	Suspended Solids - Total	5	g/m³		Gordon McArthur KTP
0040	Total (NP) Organic Carbon	0.9	g/m³		Sharon van Soest KTP
0052	Alkalinity - Total	93	g CaCO3/m³		Marylou Cabral KTP
0055	Conductivity at 25°C	62.1	mS/m		Marylou Cabral KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m³		Marylou Cabral KTP
0072	Bicarbonate Alkalinity	93	g CaCO3/m³		Marylou Cabral KTP
0084	Turbidity	8.79	NTU		Marylou Cabral KTP
0590	Anion Sum	5.03	meq/L		Amit Kumar
0591	Cation Sum	5.89	meq/L		Graham Waghorn KTP
0592	Ion Balance	7.90	%		Graham Waghorn KTP
0601	Fluoride	0.46	g/m³		Shanel Kumar KTP
0602	Chloride	124	g/m³		Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m³		Shanel Kumar KTP
0604	Bromide	0.48	g/m³		Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m³		Shanel Kumar KTP
0607	Sulphate	0.19	g/m³		Shanel Kumar KTP
0677	Colour	7.1	TCU		Gordon McArthur KTP
0760	Ammonia Nitrogen	3.41	g/m³		Rob Deacon KTP
1004	Temperature on arrival	9.7	Deg C	Complies	Tracy Morrison .
1024	Total Dissolved Solids	281	g/m³		Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	68.4	%		Gordon McArthur KTP
1275	Transmissivity after filtration	83.3	%		Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt		Marylou Cabral KTP
1610	Calcium - Acid Soluble	10.6	g/m³		Shanel Kumar KTP
1622	Magnesium - Acid Soluble	9.54	g/m³		Shanel Kumar KTP
1629	Potassium - Acid Soluble	6.53	g/m³		Shanel Kumar KTP
1634	Sodium - Acid Soluble	92.7	g/m³		Shanel Kumar KTP
1642	Total Hardness	66	g CaCO3/m³		Shanel Kumar KTP
1810	Calcium - Dissolved	10.3	g/m³		Shanel Kumar KTP
1822	Magnesium - Dissolved	9.32	g/m³		Shanel Kumar KTP
1829	Potassium - Dissolved	6.28	g/m³		Shanel Kumar KTP
1834	Sodium - Dissolved	92.0	g/m³		Shanel Kumar KTP
1843	Silica - Dissolved	24.6	g/m³		Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.023	g/m³		Sharon van Soest KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
17/49635-01	Ground Water		20/08/2017 16:00	22/08/2017 12:10	P1010105

Notes: E3a PT3 4pm

	Test	**Result**	**Units**	**Comments**	**Signatory**
6003	Arsenic - Acid Soluble	0.005	g/m³		Sharon van Soest KTP
6007	Boron - Acid Soluble	0.07	g/m³		Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³		Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³		Sharon van Soest KTP
6013	Copper - Acid Soluble	0.0018	g/m³		Sharon van Soest KTP
6017	Iron - Acid Soluble	2.56	g/m³		Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³		Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.528	g/m³		Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³		Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.045	g/m³		Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m³		Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³		Sharon van Soest KTP
6703	Arsenic - Dissolved	0.006	g/m³		Sharon van Soest KTP
6704	Barium - Dissolved	0.014	g/m³		Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³		Sharon van Soest KTP
6707	Boron - Dissolved	0.08	g/m³		Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³		Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³		Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6717	Iron - Dissolved	1.10	g/m³		Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6719	Lithium - Dissolved	0.004	g/m³		Sharon van Soest KTP
6721	Manganese - Dissolved	0.554	g/m³		Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0006	g/m³		Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³		Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³		Sharon van Soest KTP
6738	Zinc - Dissolved	0.028	g/m³		Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³		Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml		Sunita Raju KTP
M0404	E. coli	< 1	MPN/100mL		Sunita Raju KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

Sample(s) received outside the correct time and/or temperature conditions and was analysed at your request. Results for these tests can be considered approximate only.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m³
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m³

Test	Methodology	Detection Limit
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³

Test	Methodology	Detection Limit
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m^3
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012	1 MPN/100mL

Onsite Observation Methodology:

Test	Methodology	Detection Limit
Temperature on arrival	The temperature of the microbiological samples, upon arrival at the laboratory must not be below 0'C or exceed 10'C.	Deg C

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Report Released By
Rob Deacon

This laboratory is accredited by International Accreditation New Zealand and its reports are recognised in all countries affiliated to the International Laboratory Accreditation Co-operation Mutual Recognition Arrangement (ILAC-MRA). The tests reported have been performed in accordance with our terms of accreditation, with the exception of tests marked "not IANZ", which are outside the scope of this laboratory's accreditation.

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Eurofins ELS Limited

Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045
Attention: Nick Urlich

Analytical Report

Report Number: 18/1480

Issue: 2
12 January 2018

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/1480-01	Miscellaneous Sample		10/01/2018 15:30	10/01/2018 16:55	4606

Notes: E8-GRAB 25.7m

	Test	Result	Units	Signatory
0001	pH	7.4		Gordon McArthur KTP
0002	Suspended Solids - Total	6	g/m^3	Marylou Cabral KTP
0040	Total (NP) Organic Carbon	1.4	g/m^3	Sharon van Soest KTP
0052	Alkalinity - Total	67	g CaCO3/m^3	Gordon McArthur KTP
0055	Conductivity at 25°C	154	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	67	g CaCO3/m^3	Gordon McArthur KTP
0084	Turbidity	4.30	NTU	Gordon McArthur KTP
0590	Anion Sum	13.1	meq/L	Marylou Cabral KTP
0591	Cation Sum	13.0	meq/L	Shanel Kumar KTP
0592	Ion Balance	0.22	%	Marylou Cabral KTP
0601	Fluoride	0.33	g/m^3	Shanel Kumar KTP
0602	Chloride	386	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0604	Bromide	1.39	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0607	Sulphate	51.7	g/m^3	Shanel Kumar KTP
0677	Colour	3.3	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	2.03	g/m^3	Divina Lagazon KTP
1024	Total Dissolved Solids	832	g/m^3	Marylou Cabral KTP
1250	Transmissivity @ 253.7nm	80.0	%	Gordon McArthur KTP
1275	Transmissivity after filtration	85.3	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	29.3	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	31.0	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	13.5	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	195	g/m^3	Shanel Kumar KTP
1642	Total Hardness	196	g CaCO3/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	29.2	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	31.2	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	13.4	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	194	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	22.0	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.029	g/m^3	Sharon van Soest KTP
6003	Arsenic - Acid Soluble	0.014	g/m^3	Sharon van Soest KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
18/1480-01	Miscellaneous Sample		10/01/2018 15:30	10/01/2018 16:55	4606

Notes: E8-GRAB 25.7m

	Test	**Result**	**Units**	**Signatory**
6007	Boron - Acid Soluble	0.12	g/m³	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Sharon van Soest KTP
6013	Copper - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6017	Iron - Acid Soluble	0.60	g/m³	Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.485	g/m³	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.033	g/m³	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.013	g/m³	Sharon van Soest KTP
6704	Barium - Dissolved	0.061	g/m³	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6707	Boron - Dissolved	0.12	g/m³	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6717	Iron - Dissolved	0.05	g/m³	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6719	Lithium - Dissolved	0.003	g/m³	Sharon van Soest KTP
6721	Manganese - Dissolved	0.460	g/m³	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6723	Molybdenum - Dissolved	0.0037	g/m³	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6738	Zinc - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

This report cancels and replaces report 18/1480-1. Please dispose of all previous versions.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m³
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m³
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m

Test	Methodology	Detection Limit
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m³
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m³

Test	Methodology	Detection Limit
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012 by Colilert Quantitray	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012 by Colilert Quantitray	1 MPN/100mL

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Deacon

Report Released By

Rob Deacon

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Eurofins ELS Limited

Analytical Report

Report Number: 18/2343

Issue: 3
24 January 2018

Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045

Attention: Nick Urlich

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/2343-01	Miscellaneous Sample		15/01/2018 12:00	16/01/2018 08:15	P1010105

Notes: E8-UWA-PT2B

	Test	Result	Units	Signatory
0001	pH	7.4		Gordon McArthur KTP
0002	Suspended Solids - Total	< 3	g/m^3	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	2.2	g/m^3	Tracy Morrison KTP
0052	Alkalinity - Total	89	g CaCO3/m^3	Gordon McArthur KTP
0055	Conductivity at 25°C	46.1	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	89	g CaCO3/m^3	Gordon McArthur KTP
0084	Turbidity	0.98	NTU	Gordon McArthur KTP
0590	Anion Sum	3.71	meq/L	Sharon van Soest KTP
0591	Cation Sum	4.35	meq/L	Sharon van Soest KTP
0592	Ion Balance	7.99	%	Sharon van Soest KTP
0601	Fluoride	0.48	g/m^3	Shanel Kumar KTP
0602	Chloride	77.2	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0604	Bromide	0.31	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0607	Sulphate	3.42	g/m^3	Shanel Kumar KTP
0677	Colour	6.7	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	1.09	g/m^3	Divina Lagazon KTP
1024	Total Dissolved Solids	258	g/m^3	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	77.3	%	Gordon McArthur KTP
1275	Transmissivity after filtration	80.4	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	6.98	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	5.08	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	5.94	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	76.6	g/m^3	Shanel Kumar KTP
1642	Total Hardness	38	g CaCO3/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	7.05	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	5.08	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	6.06	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	76.0	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	22.8	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.007	g/m^3	Sharon van Soest KTP
6003	Arsenic - Acid Soluble	0.023	g/m^3	Sharon van Soest KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
18/2343-01	Miscellaneous Sample		15/01/2018 12:00	16/01/2018 08:15	P1010105

Notes: E8-UWA-PT2B

	Test	**Result**	**Units**	**Signatory**
6007	Boron - Acid Soluble	0.09	g/m³	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Sharon van Soest KTP
6013	Copper - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6017	Iron - Acid Soluble	0.51	g/m³	Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.122	g/m³	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.009	g/m³	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.022	g/m³	Sharon van Soest KTP
6704	Barium - Dissolved	0.015	g/m³	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6707	Boron - Dissolved	0.09	g/m³	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6717	Iron - Dissolved	0.13	g/m³	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6719	Lithium - Dissolved	0.002	g/m³	Sharon van Soest KTP
6721	Manganese - Dissolved	0.118	g/m³	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0055	g/m³	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6738	Zinc - Dissolved	0.006	g/m³	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
18/2343-02	Miscellaneous Sample		15/01/2018 15:30	16/01/2018 08:15	P1010105

Notes: E8-UWA-PT2C

	Test	**Result**	**Units**	**Signatory**
0001	pH	7.5		Gordon McArthur KTP
0002	Suspended Solids - Total	< 3	g/m³	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	2.2	g/m³	Tracy Morrison KTP
0052	Alkalinity - Total	87	g CaCO3/m³	Gordon McArthur KTP
0055	Conductivity at 25°C	44.3	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m³	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	87	g CaCO3/m³	Gordon McArthur KTP
0084	Turbidity	0.72	NTU	Gordon McArthur KTP
0590	Anion Sum	3.54	meq/L	Sharon van Soest KTP
0591	Cation Sum	4.24	meq/L	Sharon van Soest KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
18/2343-02	Miscellaneous Sample		15/01/2018 15:30	16/01/2018 08:15	P1010105

Notes: E8-UWA-PT2C

	Test	**Result**	**Units**	**Signatory**
0592	Ion Balance	8.99	%	Sharon van Soest KTP
0601	Fluoride	0.49	g/m³	Shanel Kumar KTP
0602	Chloride	72.1	g/m³	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m³	Shanel Kumar KTP
0604	Bromide	0.30	g/m³	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m³	Shanel Kumar KTP
0607	Sulphate	3.26	g/m³	Shanel Kumar KTP
0677	Colour	6.3	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	1.07	g/m³	Divina Lagazon KTP
1024	Total Dissolved Solids	231	g/m³	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	76.8	%	Gordon McArthur KTP
1275	Transmissivity after filtration	81.2	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	6.84	g/m³	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	4.83	g/m³	Shanel Kumar KTP
1629	Potassium - Acid Soluble	6.02	g/m³	Shanel Kumar KTP
1634	Sodium - Acid Soluble	74.6	g/m³	Shanel Kumar KTP
1642	Total Hardness	37	g CaCO3/m³	Shanel Kumar KTP
1810	Calcium - Dissolved	6.47	g/m³	Shanel Kumar KTP
1822	Magnesium - Dissolved	4.65	g/m³	Shanel Kumar KTP
1829	Potassium - Dissolved	5.73	g/m³	Shanel Kumar KTP
1834	Sodium - Dissolved	71.3	g/m³	Shanel Kumar KTP
1843	Silica - Dissolved	21.8	g/m³	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.007	g/m³	Sharon van Soest KTP
6003	Arsenic - Acid Soluble	0.022	g/m³	Sharon van Soest KTP
6007	Boron - Acid Soluble	0.09	g/m³	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Sharon van Soest KTP
6013	Copper - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6017	Iron - Acid Soluble	0.50	g/m³	Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.118	g/m³	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.007	g/m³	Sharon van Soest KTP
6701	Aluminium - Dissolved	0.005	g/m³	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.022	g/m³	Sharon van Soest KTP
6704	Barium - Dissolved	0.016	g/m³	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6707	Boron - Dissolved	0.09	g/m³	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6717	Iron - Dissolved	0.12	g/m³	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6719	Lithium - Dissolved	0.002	g/m³	Sharon van Soest KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
18/2343-02	Miscellaneous Sample		15/01/2018 15:30	16/01/2018 08:15	P1010105

Notes: E8-UWA-PT2C

	Test	**Result**	**Units**	**Signatory**
6721	Manganese - Dissolved	0.114	g/m³	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0054	g/m³	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6738	Zinc - Dissolved	0.004	g/m³	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
M0403	Total Coliforms	1	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
18/2343-03	Miscellaneous Sample		15/01/2018 08:30	16/01/2018 08:15	P1010105

Notes: E8-UWA-PT1A

	Test	**Result**	**Units**	**Signatory**
0001	pH	7.5		Gordon McArthur KTP
0002	Suspended Solids - Total	< 3	g/m³	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	2.3	g/m³	Tracy Morrison KTP
0052	Alkalinity - Total	90	g CaCO3/m³	Gordon McArthur KTP
0055	Conductivity at 25°C	49.9	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m³	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	90	g CaCO3/m³	Gordon McArthur KTP
0084	Turbidity	0.94	NTU	Gordon McArthur KTP
0590	Anion Sum	4.05	meq/L	Sharon van Soest KTP
0591	Cation Sum	4.61	meq/L	Sharon van Soest KTP
0592	Ion Balance	6.49	%	Sharon van Soest KTP
0601	Fluoride	0.47	g/m³	Shanel Kumar KTP
0602	Chloride	87.5	g/m³	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m³	Shanel Kumar KTP
0604	Bromide	0.35	g/m³	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m³	Shanel Kumar KTP
0607	Sulphate	4.73	g/m³	Shanel Kumar KTP
0677	Colour	7.3	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	1.13	g/m³	Divina Lagazon KTP
1024	Total Dissolved Solids	254	g/m³	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	75.5	%	Gordon McArthur KTP
1275	Transmissivity after filtration	78.8	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	7.64	g/m³	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	5.63	g/m³	Shanel Kumar KTP
1629	Potassium - Acid Soluble	6.21	g/m³	Shanel Kumar KTP
1634	Sodium - Acid Soluble	80.4	g/m³	Shanel Kumar KTP
1642	Total Hardness	42	g CaCO3/m³	Shanel Kumar KTP
1810	Calcium - Dissolved	7.70	g/m³	Shanel Kumar KTP
1822	Magnesium - Dissolved	5.71	g/m³	Shanel Kumar KTP
1829	Potassium - Dissolved	6.35	g/m³	Shanel Kumar KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/2343-03	Miscellaneous Sample		15/01/2018 08:30	16/01/2018 08:15	P1010105

Notes: E8-UWA-PT1A

	Test	Result	Units	Signatory
1834	Sodium - Dissolved	81.1	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	22.9	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.008	g/m^3	Sharon van Soest KTP
6003	Arsenic - Acid Soluble	0.024	g/m^3	Sharon van Soest KTP
6007	Boron - Acid Soluble	0.10	g/m^3	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m^3	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m^3	Sharon van Soest KTP
6013	Copper - Acid Soluble	< 0.0005	g/m^3	Sharon van Soest KTP
6017	Iron - Acid Soluble	0.57	g/m^3	Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m^3	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.140	g/m^3	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m^3	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.020	g/m^3	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m^3	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.024	g/m^3	Sharon van Soest KTP
6704	Barium - Dissolved	0.020	g/m^3	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6707	Boron - Dissolved	0.10	g/m^3	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m^3	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m^3	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6717	Iron - Dissolved	0.30	g/m^3	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6719	Lithium - Dissolved	0.002	g/m^3	Sharon van Soest KTP
6721	Manganese - Dissolved	0.132	g/m^3	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0058	g/m^3	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m^3	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6738	Zinc - Dissolved	0.007	g/m^3	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m^3	Sharon van Soest KTP
M0403	Total Coliforms	5	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/2343-04	Miscellaneous Sample		14/01/2018 00:00	16/01/2018 08:15	P1010105

Notes: E8-UWA-SRT1

	Test	Result	Units	Signatory
0001	pH	7.5		Gordon McArthur KTP
0002	Suspended Solids - Total	< 3	g/m^3	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	2.5	g/m^3	Tracy Morrison KTP
0052	Alkalinity - Total	92	g CaCO3/m^3	Gordon McArthur KTP
0055	Conductivity at 25°C	51.2	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Gordon McArthur KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/2343-04	Miscellaneous Sample		14/01/2018 00:00	16/01/2018 08:15	P1010105

Notes: E8-UWA-SRT1

	Test	Result	Units	Signatory
0072	Bicarbonate Alkalinity	92	g CaCO3/m³	Gordon McArthur KTP
0084	Turbidity	0.92	NTU	Gordon McArthur KTP
0590	Anion Sum	4.24	meq/L	Sharon van Soest KTP
0591	Cation Sum	4.72	meq/L	Sharon van Soest KTP
0592	Ion Balance	5.41	%	Sharon van Soest KTP
0601	Fluoride	0.47	g/m³	Shanel Kumar KTP
0602	Chloride	93.1	g/m³	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m³	Shanel Kumar KTP
0604	Bromide	0.37	g/m³	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m³	Shanel Kumar KTP
0607	Sulphate	4.98	g/m³	Shanel Kumar KTP
0677	Colour	7.2	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	1.14	g/m³	Divina Lagazon KTP
1024	Total Dissolved Solids	261	g/m³	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	76.7	%	Gordon McArthur KTP
1275	Transmissivity after filtration	78.5	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	7.81	g/m³	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	5.84	g/m³	Shanel Kumar KTP
1629	Potassium - Acid Soluble	6.28	g/m³	Shanel Kumar KTP
1634	Sodium - Acid Soluble	82.3	g/m³	Shanel Kumar KTP
1642	Total Hardness	44	g CaCO3/m³	Shanel Kumar KTP
1810	Calcium - Dissolved	7.68	g/m³	Shanel Kumar KTP
1822	Magnesium - Dissolved	5.81	g/m³	Shanel Kumar KTP
1829	Potassium - Dissolved	6.19	g/m³	Shanel Kumar KTP
1834	Sodium - Dissolved	81.2	g/m³	Shanel Kumar KTP
1843	Silica - Dissolved	22.1	g/m³	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.005	g/m³	Sharon van Soest KTP
6003	Arsenic - Acid Soluble	0.024	g/m³	Sharon van Soest KTP
6007	Boron - Acid Soluble	0.10	g/m³	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Sharon van Soest KTP
6013	Copper - Acid Soluble	0.0006	g/m³	Sharon van Soest KTP
6017	Iron - Acid Soluble	0.56	g/m³	Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.138	g/m³	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.014	g/m³	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.024	g/m³	Sharon van Soest KTP
6704	Barium - Dissolved	0.015	g/m³	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6707	Boron - Dissolved	0.10	g/m³	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/2343-04	Miscellaneous Sample		14/01/2018 00:00	16/01/2018 08:15	P1010105

Notes: E8-UWA-SRT1

	Test	Result	Units	Signatory
6713	Copper - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6717	Iron - Dissolved	0.02	g/m^3	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6719	Lithium - Dissolved	0.002	g/m^3	Sharon van Soest KTP
6721	Manganese - Dissolved	0.132	g/m^3	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0059	g/m^3	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m^3	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m^3	Sharon van Soest KTP
6738	Zinc - Dissolved	0.008	g/m^3	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m^3	Sharon van Soest KTP
M0403	Total Coliforms	1	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/2343-05	Miscellaneous Sample		15/01/2018 00:00	16/01/2018 08:15	P1010105

Notes: E8-DUP

	Test	Result	Units	Signatory
0001	pH	7.5		Gordon McArthur KTP
0002	Suspended Solids - Total	< 3	g/m^3	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	2.3	g/m^3	Tracy Morrison KTP
0052	Alkalinity - Total	88	g CaCO3/m^3	Gordon McArthur KTP
0055	Conductivity at 25°C	46.2	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	88	g CaCO3/m^3	Gordon McArthur KTP
0084	Turbidity	0.95	NTU	Gordon McArthur KTP
0590	Anion Sum	3.71	meq/L	Sharon van Soest KTP
0591	Cation Sum	4.32	meq/L	Sharon van Soest KTP
0592	Ion Balance	7.54	%	Sharon van Soest KTP
0601	Fluoride	0.48	g/m^3	Shanel Kumar KTP
0602	Chloride	77.5	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0604	Bromide	0.31	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	0.03	g/m^3	Shanel Kumar KTP
0607	Sulphate	3.59	g/m^3	Shanel Kumar KTP
0677	Colour	6.6	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	1.09	g/m^3	Divina Lagazon KTP
1024	Total Dissolved Solids	240	g/m^3	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	75.9	%	Gordon McArthur KTP
1275	Transmissivity after filtration	77.7	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	7.03	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	5.05	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	6.04	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	75.8	g/m^3	Shanel Kumar KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/2343-05	Miscellaneous Sample		15/01/2018 00:00	16/01/2018 08:15	P1010105

Notes: E8-DUP

	Test	Result	Units	Signatory
1642	Total Hardness	38	g CaCO3/m³	Shanel Kumar KTP
1810	Calcium - Dissolved	6.76	g/m³	Shanel Kumar KTP
1822	Magnesium - Dissolved	4.99	g/m³	Shanel Kumar KTP
1829	Potassium - Dissolved	5.79	g/m³	Shanel Kumar KTP
1834	Sodium - Dissolved	73.7	g/m³	Shanel Kumar KTP
1843	Silica - Dissolved	21.8	g/m³	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.006	g/m³	Sharon van Soest KTP
6003	Arsenic - Acid Soluble	0.024	g/m³	Sharon van Soest KTP
6007	Boron - Acid Soluble	0.10	g/m³	Sharon van Soest KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Sharon van Soest KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Sharon van Soest KTP
6013	Copper - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6017	Iron - Acid Soluble	0.53	g/m³	Sharon van Soest KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6021	Manganese - Acid Soluble	0.128	g/m³	Sharon van Soest KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Sharon van Soest KTP
6038	Zinc - Acid Soluble	0.007	g/m³	Sharon van Soest KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Sharon van Soest KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6703	Arsenic - Dissolved	0.023	g/m³	Sharon van Soest KTP
6704	Barium - Dissolved	0.025	g/m³	Sharon van Soest KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6707	Boron - Dissolved	0.10	g/m³	Sharon van Soest KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Sharon van Soest KTP
6713	Copper - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6717	Iron - Dissolved	0.47	g/m³	Sharon van Soest KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6719	Lithium - Dissolved	0.002	g/m³	Sharon van Soest KTP
6721	Manganese - Dissolved	0.123	g/m³	Sharon van Soest KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6723	Molybdenum - Dissolved	0.0051	g/m³	Sharon van Soest KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Sharon van Soest KTP
6730	Silver - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Sharon van Soest KTP
6738	Zinc - Dissolved	0.006	g/m³	Sharon van Soest KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Sharon van Soest KTP
M0403	Total Coliforms	< 1	MPN/100ml	Maria Norris KTP
M0404	E. coli	< 1	MPN/100mL	Maria Norris KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

This report cancels and replaces report 18/2343-2. Please dispose of all previous versions.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m³
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m³
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³

Test	Methodology	Detection Limit
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m^3
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012 by Colilert Quantitray	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012 by Colilert Quantitray	1 MPN/100mL

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Report Released By
Rob Deacon

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Eurofins ELS Limited

Analytical Report

Wellington Water Ltd - WCC
Non Routine H2O
Wellington City Council
c/- Wellington Water
PO Box 39-804
WELLINGTON MAIL CENTRE
5045

Attention: Nick Urlich

Report Number: 18/3498

Issue: 2
26 January 2018

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/3498-01	Miscellaneous Sample		20/01/2018 16:45	23/01/2018 07:45	0

Notes: E8-LWA-DEV

	Test	Result	Units	Signatory
0001	pH	7.1		Gordon McArthur KTP
0002	Suspended Solids - Total	11	g/m^3	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	5.7	g/m^3	Tracy Morrison KTP
0052	Alkalinity - Total	343	g $CaCO_3$/m^3	Gordon McArthur KTP
0055	Conductivity at 25°C	334	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g $CaCO_3$/m^3	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	343	g $CaCO_3$/m^3	Gordon McArthur KTP
0084	Turbidity	23.7	NTU	Gordon McArthur KTP
0590	Anion Sum	29.7	meq/L	Tracy Morrison KTP
0591	Cation Sum	30.2	meq/L	Andrew Van Schaik
0592	Ion Balance	0.70	%	Andrew Van Schaik
0601	Fluoride	< 0.20	g/m^3	Shanel Kumar KTP
0602	Chloride	855	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.10	g/m^3	Shanel Kumar KTP
0604	Bromide	3.70	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	0.02	g/m^3	Shanel Kumar KTP
0607	Sulphate	1.26	g/m^3	Shanel Kumar KTP
0677	Colour	15.2	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	7.61	g/m^3	Divina Lagazon KTP
1024	Total Dissolved Solids	1,750	g/m^3	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	47.8	%	Gordon McArthur KTP
1275	Transmissivity after filtration	64.3	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	72.1	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	37.4	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	23.9	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	511	g/m^3	Shanel Kumar KTP
1642	Total Hardness	334	g $CaCO_3$/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	69.9	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	36.3	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	23.8	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	501	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	40.0	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.002	g/m^3	Tracy Morrison KTP
6003	Arsenic - Acid Soluble	< 0.001	g/m^3	Tracy Morrison KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/3498-01	Miscellaneous Sample		20/01/2018 16:45	23/01/2018 07:45	0

Notes: E8-LWA-DEV

	Test	Result	Units	Signatory
6007	Boron - Acid Soluble	0.19	g/m^3	Tracy Morrison KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m^3	Tracy Morrison KTP
6011	Chromium - Acid Soluble	< 0.001	g/m^3	Tracy Morrison KTP
6013	Copper - Acid Soluble	0.0059	g/m^3	Tracy Morrison KTP
6017	Iron - Acid Soluble	2.57	g/m^3	Tracy Morrison KTP
6018	Lead - Acid Soluble	< 0.0005	g/m^3	Tracy Morrison KTP
6021	Manganese - Acid Soluble	0.382	g/m^3	Tracy Morrison KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m^3	Tracy Morrison KTP
6038	Zinc - Acid Soluble	0.024	g/m^3	Tracy Morrison KTP
6701	Aluminium - Dissolved	< 0.002	g/m^3	Tracy Morrison KTP
6702	Antimony - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6703	Arsenic - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6704	Barium - Dissolved	0.169	g/m^3	Tracy Morrison KTP
6705	Beryllium - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6707	Boron - Dissolved	0.18	g/m^3	Tracy Morrison KTP
6708	Cadmium - Dissolved	< 0.0002	g/m^3	Tracy Morrison KTP
6711	Chromium - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6713	Copper - Dissolved	0.0033	g/m^3	Tracy Morrison KTP
6717	Iron - Dissolved	< 0.01	g/m^3	Tracy Morrison KTP
6718	Lead - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6719	Lithium - Dissolved	0.021	g/m^3	Tracy Morrison KTP
6721	Manganese - Dissolved	0.370	g/m^3	Tracy Morrison KTP
6722	Mercury - Dissolved	< 0.0005	g/m^3	Shanel Kumar KTP
6723	Molybdenum - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6724	Nickel - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6728	Selenium - Dissolved	< 0.005	g/m^3	Tracy Morrison KTP
6730	Silver - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6734	Tin - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6738	Zinc - Dissolved	0.018	g/m^3	Tracy Morrison KTP
6747	Uranium - Dissolved	< 0.0002	g/m^3	Tracy Morrison KTP
M0403	Total Coliforms	68	MPN/100ml	Juana Tamayo KTP
M0404	E. coli	< 1	MPN/100mL	Juana Tamayo KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/3498-02	Miscellaneous Sample		21/01/2018 09:00	23/01/2018 07:45	0

Notes: E8-LWA-PT3A

	Test	Result	Units	Signatory
0001	pH	7.1		Gordon McArthur KTP
0002	Suspended Solids - Total	12	g/m^3	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	5.7	g/m^3	Tracy Morrison KTP
0052	Alkalinity - Total	346	g CaCO3/m^3	Gordon McArthur KTP
0055	Conductivity at 25°C	337	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	346	g CaCO3/m^3	Gordon McArthur KTP
0084	Turbidity	21.9	NTU	Gordon McArthur KTP
0590	Anion Sum	30.6	meq/L	Tracy Morrison KTP
0591	Cation Sum	30.7	meq/L	Andrew Van Schaik

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
18/3498-02	Miscellaneous Sample		21/01/2018 09:00	23/01/2018 07:45	0

Notes: E8-LWA-PT3A

	Test	**Result**	**Units**	**Signatory**
0592	Ion Balance	0.22	%	Andrew Van Schaik
0601	Fluoride	< 0.20	g/m³	Shanel Kumar KTP
0602	Chloride	883	g/m³	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.10	g/m³	Shanel Kumar KTP
0604	Bromide	3.71	g/m³	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m³	Shanel Kumar KTP
0607	Sulphate	2.06	g/m³	Shanel Kumar KTP
0677	Colour	14.9	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	7.81	g/m³	Divina Lagazon KTP
1024	Total Dissolved Solids	1,770	g/m³	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	48.6	%	Gordon McArthur KTP
1275	Transmissivity after filtration	64.7	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	70.2	g/m³	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	38.4	g/m³	Shanel Kumar KTP
1629	Potassium - Acid Soluble	24.1	g/m³	Shanel Kumar KTP
1634	Sodium - Acid Soluble	524	g/m³	Shanel Kumar KTP
1642	Total Hardness	334	g CaCO3/m³	Shanel Kumar KTP
1810	Calcium - Dissolved	71.2	g/m³	Shanel Kumar KTP
1822	Magnesium - Dissolved	37.9	g/m³	Shanel Kumar KTP
1829	Potassium - Dissolved	24.4	g/m³	Shanel Kumar KTP
1834	Sodium - Dissolved	518	g/m³	Shanel Kumar KTP
1843	Silica - Dissolved	41.2	g/m³	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.002	g/m³	Tracy Morrison KTP
6003	Arsenic - Acid Soluble	< 0.001	g/m³	Tracy Morrison KTP
6007	Boron - Acid Soluble	0.20	g/m³	Tracy Morrison KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Tracy Morrison KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Tracy Morrison KTP
6013	Copper - Acid Soluble	0.0060	g/m³	Tracy Morrison KTP
6017	Iron - Acid Soluble	2.64	g/m³	Tracy Morrison KTP
6018	Lead - Acid Soluble	0.0009	g/m³	Tracy Morrison KTP
6021	Manganese - Acid Soluble	0.392	g/m³	Tracy Morrison KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Tracy Morrison KTP
6038	Zinc - Acid Soluble	0.030	g/m³	Tracy Morrison KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Tracy Morrison KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Tracy Morrison KTP
6703	Arsenic - Dissolved	< 0.001	g/m³	Tracy Morrison KTP
6704	Barium - Dissolved	0.166	g/m³	Tracy Morrison KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Tracy Morrison KTP
6707	Boron - Dissolved	0.19	g/m³	Tracy Morrison KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Tracy Morrison KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Tracy Morrison KTP
6713	Copper - Dissolved	0.0072	g/m³	Tracy Morrison KTP
6717	Iron - Dissolved	< 0.01	g/m³	Tracy Morrison KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6719	Lithium - Dissolved	0.021	g/m³	Tracy Morrison KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/3498-02	Miscellaneous Sample		21/01/2018 09:00	23/01/2018 07:45	0

Notes: E8-LWA-PT3A

	Test	Result	Units	Signatory
6721	Manganese - Dissolved	0.374	g/m^3	Tracy Morrison KTP
6722	Mercury - Dissolved	< 0.0005	g/m^3	Shanel Kumar KTP
6723	Molybdenum - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6724	Nickel - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6728	Selenium - Dissolved	< 0.005	g/m^3	Tracy Morrison KTP
6730	Silver - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6734	Tin - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6738	Zinc - Dissolved	0.052	g/m^3	Tracy Morrison KTP
6747	Uranium - Dissolved	< 0.0002	g/m^3	Tracy Morrison KTP
M0403	Total Coliforms	99	MPN/100ml	Juana Tamayo KTP
M0404	E. coli	< 1	MPN/100mL	Juana Tamayo KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/3498-03	Miscellaneous Sample		21/01/2018 12:30	23/01/2018 07:45	0

Notes: E8-LWA-PT3B

	Test	Result	Units	Signatory
0001	pH	7.2		Gordon McArthur KTP
0002	Suspended Solids - Total	10	g/m^3	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	5.6	g/m^3	Tracy Morrison KTP
0052	Alkalinity - Total	343	g CaCO3/m^3	Gordon McArthur KTP
0055	Conductivity at 25°C	334	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m^3	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	343	g CaCO3/m^3	Gordon McArthur KTP
0084	Turbidity	24.0	NTU	Gordon McArthur KTP
0590	Anion Sum	29.1	meq/L	Tracy Morrison KTP
0591	Cation Sum	29.9	meq/L	Andrew Van Schaik
0592	Ion Balance	1.38	%	Andrew Van Schaik
0601	Fluoride	< 0.20	g/m^3	Shanel Kumar KTP
0602	Chloride	832	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.10	g/m^3	Shanel Kumar KTP
0604	Bromide	3.68	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0607	Sulphate	0.89	g/m^3	Shanel Kumar KTP
0677	Colour	14.9	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	7.83	g/m^3	Divina Lagazon KTP
1024	Total Dissolved Solids	1,750	g/m^3	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	49.7	%	Gordon McArthur KTP
1275	Transmissivity after filtration	64.9	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	70.9	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	37.6	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	23.8	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	506	g/m^3	Shanel Kumar KTP
1642	Total Hardness	332	g CaCO3/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	72.6	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	38.1	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	24.1	g/m^3	Shanel Kumar KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
18/3498-03	Miscellaneous Sample		21/01/2018 12:30	23/01/2018 07:45	0

Notes: E8-LWA-PT3B

	Test	**Result**	**Units**	**Signatory**
1834	Sodium - Dissolved	514	g/m³	Shanel Kumar KTP
1843	Silica - Dissolved	42.0	g/m³	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	< 0.002	g/m³	Tracy Morrison KTP
6003	Arsenic - Acid Soluble	< 0.001	g/m³	Tracy Morrison KTP
6007	Boron - Acid Soluble	0.18	g/m³	Tracy Morrison KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m³	Tracy Morrison KTP
6011	Chromium - Acid Soluble	< 0.001	g/m³	Tracy Morrison KTP
6013	Copper - Acid Soluble	0.0010	g/m³	Tracy Morrison KTP
6017	Iron - Acid Soluble	2.07	g/m³	Tracy Morrison KTP
6018	Lead - Acid Soluble	< 0.0005	g/m³	Tracy Morrison KTP
6021	Manganese - Acid Soluble	0.362	g/m³	Tracy Morrison KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m³	Tracy Morrison KTP
6038	Zinc - Acid Soluble	0.012	g/m³	Tracy Morrison KTP
6701	Aluminium - Dissolved	< 0.002	g/m³	Tracy Morrison KTP
6702	Antimony - Dissolved	< 0.001	g/m³	Tracy Morrison KTP
6703	Arsenic - Dissolved	< 0.001	g/m³	Tracy Morrison KTP
6704	Barium - Dissolved	0.161	g/m³	Tracy Morrison KTP
6705	Beryllium - Dissolved	< 0.001	g/m³	Tracy Morrison KTP
6707	Boron - Dissolved	0.18	g/m³	Tracy Morrison KTP
6708	Cadmium - Dissolved	< 0.0002	g/m³	Tracy Morrison KTP
6711	Chromium - Dissolved	< 0.001	g/m³	Tracy Morrison KTP
6713	Copper - Dissolved	0.0007	g/m³	Tracy Morrison KTP
6717	Iron - Dissolved	< 0.01	g/m³	Tracy Morrison KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6719	Lithium - Dissolved	0.020	g/m³	Tracy Morrison KTP
6721	Manganese - Dissolved	0.368	g/m³	Tracy Morrison KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6723	Molybdenum - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Tracy Morrison KTP
6730	Silver - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6738	Zinc - Dissolved	0.019	g/m³	Tracy Morrison KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Tracy Morrison KTP
M0403	Total Coliforms	64	MPN/100ml	Juana Tamayo KTP
M0404	E. coli	< 1	MPN/100mL	Juana Tamayo KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
18/3498-04	Miscellaneous Sample		21/01/2018 16:00	23/01/2018 07:45	0

Notes: E8-LWA-PT3C

	Test	**Result**	**Units**	**Signatory**
0001	pH	7.1		Gordon McArthur KTP
0002	Suspended Solids - Total	10	g/m³	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	5.8	g/m³	Tracy Morrison KTP
0052	Alkalinity - Total	343	g CaCO3/m³	Gordon McArthur KTP
0055	Conductivity at 25°C	334	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m³	Gordon McArthur KTP

Sample	**Site**	**Map Ref.**	**Date Sampled**	**Date Received**	**Order No.**
18/3498-04	Miscellaneous Sample		21/01/2018 16:00	23/01/2018 07:45	0

Notes: E8-LWA-PT3C

	Test	**Result**	**Units**	**Signatory**
0072	Bicarbonate Alkalinity	343	g CaCO3/m^3	Gordon McArthur KTP
0084	Turbidity	25.0	NTU	Gordon McArthur KTP
0590	Anion Sum	30.3	meq/L	Tracy Morrison KTP
0591	Cation Sum	30.1	meq/L	Andrew Van Schaik
0592	Ion Balance	0.43	%	Andrew Van Schaik
0601	Fluoride	< 0.20	g/m^3	Shanel Kumar KTP
0602	Chloride	876	g/m^3	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.10	g/m^3	Shanel Kumar KTP
0604	Bromide	3.70	g/m^3	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m^3	Shanel Kumar KTP
0607	Sulphate	0.65	g/m^3	Shanel Kumar KTP
0677	Colour	14.9	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	7.67	g/m^3	Divina Lagazon KTP
1024	Total Dissolved Solids	1,740	g/m^3	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	52.0	%	Gordon McArthur KTP
1275	Transmissivity after filtration	64.1	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	70.5	g/m^3	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	37.7	g/m^3	Shanel Kumar KTP
1629	Potassium - Acid Soluble	23.9	g/m^3	Shanel Kumar KTP
1634	Sodium - Acid Soluble	509	g/m^3	Shanel Kumar KTP
1642	Total Hardness	331	g CaCO3/m^3	Shanel Kumar KTP
1810	Calcium - Dissolved	70.8	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	37.0	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	23.8	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	503	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	41.2	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.004	g/m^3	Tracy Morrison KTP
6003	Arsenic - Acid Soluble	< 0.001	g/m^3	Tracy Morrison KTP
6007	Boron - Acid Soluble	0.20	g/m^3	Tracy Morrison KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m^3	Tracy Morrison KTP
6011	Chromium - Acid Soluble	< 0.001	g/m^3	Tracy Morrison KTP
6013	Copper - Acid Soluble	0.0009	g/m^3	Tracy Morrison KTP
6017	Iron - Acid Soluble	2.82	g/m^3	Tracy Morrison KTP
6018	Lead - Acid Soluble	< 0.0005	g/m^3	Tracy Morrison KTP
6021	Manganese - Acid Soluble	0.416	g/m^3	Tracy Morrison KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m^3	Tracy Morrison KTP
6038	Zinc - Acid Soluble	0.019	g/m^3	Tracy Morrison KTP
6701	Aluminium - Dissolved	< 0.002	g/m^3	Tracy Morrison KTP
6702	Antimony - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6703	Arsenic - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6704	Barium - Dissolved	0.181	g/m^3	Tracy Morrison KTP
6705	Beryllium - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6707	Boron - Dissolved	0.20	g/m^3	Tracy Morrison KTP
6708	Cadmium - Dissolved	< 0.0002	g/m^3	Tracy Morrison KTP
6711	Chromium - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/3498-04	Miscellaneous Sample		21/01/2018 16:00	23/01/2018 07:45	0

Notes: E8-LWA-PT3C

	Test	Result	Units	Signatory
6713	Copper - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6717	Iron - Dissolved	0.01	g/m³	Tracy Morrison KTP
6718	Lead - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6719	Lithium - Dissolved	0.022	g/m³	Tracy Morrison KTP
6721	Manganese - Dissolved	0.396	g/m³	Tracy Morrison KTP
6722	Mercury - Dissolved	< 0.0005	g/m³	Shanel Kumar KTP
6723	Molybdenum - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6724	Nickel - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6728	Selenium - Dissolved	< 0.005	g/m³	Tracy Morrison KTP
6730	Silver - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6734	Tin - Dissolved	< 0.0005	g/m³	Tracy Morrison KTP
6738	Zinc - Dissolved	0.014	g/m³	Tracy Morrison KTP
6747	Uranium - Dissolved	< 0.0002	g/m³	Tracy Morrison KTP
M0403	Total Coliforms	79	MPN/100ml	Juana Tamayo KTP
M0404	E. coli	< 1	MPN/100mL	Juana Tamayo KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/3498-05	Miscellaneous Sample		21/01/2018 00:00	23/01/2018 07:45	0

Notes: E8-DUP2

	Test	Result	Units	Signatory
0001	pH	7.2		Gordon McArthur KTP
0002	Suspended Solids - Total	10	g/m³	Gordon McArthur KTP
0040	Total (NP) Organic Carbon	5.6	g/m³	Tracy Morrison KTP
0052	Alkalinity - Total	345	g CaCO3/m³	Gordon McArthur KTP
0055	Conductivity at 25°C	338	mS/m	Gordon McArthur KTP
0071	Carbonate Alkalinity	< 2	g CaCO3/m³	Gordon McArthur KTP
0072	Bicarbonate Alkalinity	345	g CaCO3/m³	Gordon McArthur KTP
0084	Turbidity	22.6	NTU	Gordon McArthur KTP
0590	Anion Sum	30.3	meq/L	Tracy Morrison KTP
0591	Cation Sum	30.6	meq/L	Andrew Van Schaik
0592	Ion Balance	0.44	%	Andrew Van Schaik
0601	Fluoride	< 0.20	g/m³	Shanel Kumar KTP
0602	Chloride	873	g/m³	Shanel Kumar KTP
0603	Nitrite - Nitrogen	< 0.10	g/m³	Shanel Kumar KTP
0604	Bromide	3.71	g/m³	Shanel Kumar KTP
0605	Nitrate - Nitrogen	< 0.01	g/m³	Shanel Kumar KTP
0607	Sulphate	1.88	g/m³	Shanel Kumar KTP
0677	Colour	15.3	TCU	Gordon McArthur KTP
0760	Ammonia Nitrogen	7.85	g/m³	Divina Lagazon KTP
1024	Total Dissolved Solids	1,740	g/m³	Gordon McArthur KTP
1250	Transmissivity @ 253.7nm	49.5	%	Gordon McArthur KTP
1275	Transmissivity after filtration	64.6	%	Gordon McArthur KTP
1301	Salinity	< 2.0 *	ppt	Gordon McArthur KTP
1610	Calcium - Acid Soluble	70.8	g/m³	Shanel Kumar KTP
1622	Magnesium - Acid Soluble	38.5	g/m³	Shanel Kumar KTP
1629	Potassium - Acid Soluble	24.4	g/m³	Shanel Kumar KTP
1634	Sodium - Acid Soluble	519	g/m³	Shanel Kumar KTP

Sample	Site	Map Ref.	Date Sampled	Date Received	Order No.
18/3498-05	Miscellaneous Sample		21/01/2018 00:00	23/01/2018 07:45	0

Notes: E8-DUP2

	Test	Result	Units	Signatory
1642	Total Hardness	335	g $CaCO_3/m^3$	Shanel Kumar KTP
1810	Calcium - Dissolved	71.1	g/m^3	Shanel Kumar KTP
1822	Magnesium - Dissolved	38.1	g/m^3	Shanel Kumar KTP
1829	Potassium - Dissolved	24.1	g/m^3	Shanel Kumar KTP
1834	Sodium - Dissolved	518	g/m^3	Shanel Kumar KTP
1843	Silica - Dissolved	41.2	g/m^3	Shanel Kumar KTP
6001	Aluminium - Acid Soluble	0.002	g/m^3	Tracy Morrison KTP
6003	Arsenic - Acid Soluble	< 0.001	g/m^3	Tracy Morrison KTP
6007	Boron - Acid Soluble	0.18	g/m^3	Tracy Morrison KTP
6008	Cadmium - Acid Soluble	< 0.0002	g/m^3	Tracy Morrison KTP
6011	Chromium - Acid Soluble	< 0.001	g/m^3	Tracy Morrison KTP
6013	Copper - Acid Soluble	0.0012	g/m^3	Tracy Morrison KTP
6017	Iron - Acid Soluble	2.57	g/m^3	Tracy Morrison KTP
6018	Lead - Acid Soluble	< 0.0005	g/m^3	Tracy Morrison KTP
6021	Manganese - Acid Soluble	0.378	g/m^3	Tracy Morrison KTP
6024	Nickel - Acid Soluble	< 0.0005	g/m^3	Tracy Morrison KTP
6038	Zinc - Acid Soluble	0.023	g/m^3	Tracy Morrison KTP
6701	Aluminium - Dissolved	< 0.002	g/m^3	Tracy Morrison KTP
6702	Antimony - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6703	Arsenic - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6704	Barium - Dissolved	0.175	g/m^3	Tracy Morrison KTP
6705	Beryllium - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6707	Boron - Dissolved	0.19	g/m^3	Tracy Morrison KTP
6708	Cadmium - Dissolved	< 0.0002	g/m^3	Tracy Morrison KTP
6711	Chromium - Dissolved	< 0.001	g/m^3	Tracy Morrison KTP
6713	Copper - Dissolved	0.0005	g/m^3	Tracy Morrison KTP
6717	Iron - Dissolved	0.01	g/m^3	Tracy Morrison KTP
6718	Lead - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6719	Lithium - Dissolved	0.021	g/m^3	Tracy Morrison KTP
6721	Manganese - Dissolved	0.369	g/m^3	Tracy Morrison KTP
6722	Mercury - Dissolved	< 0.0005	g/m^3	Shanel Kumar KTP
6723	Molybdenum - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6724	Nickel - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6728	Selenium - Dissolved	< 0.005	g/m^3	Tracy Morrison KTP
6730	Silver - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6734	Tin - Dissolved	< 0.0005	g/m^3	Tracy Morrison KTP
6738	Zinc - Dissolved	0.016	g/m^3	Tracy Morrison KTP
6747	Uranium - Dissolved	< 0.0002	g/m^3	Tracy Morrison KTP
M0403	Total Coliforms	61	MPN/100ml	Juana Tamayo KTP
M0404	E. coli	< 1	MPN/100mL	Juana Tamayo KTP

Comments:

* Not an accredited test.

Sampled by customer using ELS approved containers.

This report cancels and replaces report 18/3498-1. Please dispose of all previous versions.

Test Methodology:

Test	Methodology	Detection Limit
pH	Dedicated pH meter following APHA 22nd Edition Method 4500 H.	0.1
Suspended Solids - Total	APHA 22nd Edition Method 2540 D	3 g/m³
Total (NP) Organic Carbon	Total Non-Purgeable Organic Carbon using TOC analyser. APHA 22nd Edition 5310B,C, ASTM D2579, D4839.	0.1 g/m³
Alkalinity - Total	APHA 22nd Edition Method 2320 B	1 g CaCO3/m³
Conductivity at 25°C	APHA 22nd Edition Method 2510 B.	0.1 mS/m
Carbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Bicarbonate Alkalinity	APHA 22nd Edition Method 2320 B	2 g CaCO3/m³
Turbidity	Turbidity Meter following APHA 22nd Edition Method 2130 B.	0.01 NTU
Anion Sum	Calculation of the anion sum in miliequivalents per litre. Tests used are Alkalinity, Chloride, Nitrate, Boron and Sulphate.	0.001 meq/L
Cation Sum	Calculation of the cation sum in miliequivalents per litre. Tests used are Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.001 meq/L
Ion Balance	Calculation following APHA 22nd edition 1030E.1: (Cation Sum - Anion Sum) / (Anion Sum + Cation Sum). For this calculation the anions = Alkalinity, Chloride, Nitrate, Boron and Sulphate and the cations = Ammonia, Iron, Sodium, Potassium, Calcium, and Magnesium.	0.01 %
Fluoride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Chloride	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Nitrite - Nitrogen	Ion Chromatography following USEPA 300.0 (modified)	0.01 g/m³
Bromide	Ion Chromatography following USEPA 300.0 (modified)	0.02 g/m³
Nitrate - Nitrogen	Ion Chromatography following USEPA 300.0 (modified).	0.01 g/m³
Sulphate	Ion Chromatography following USEPA 300.0 (modified).	0.02 g/m³
Colour	Calculated from Absorbance @ 270nm.	0.1 TCU
Ammonia Nitrogen	Flow Injection Autoanalyser following APHA 22nd Edition Method 4500 NH3-H.	0.01 g/m³
Total Dissolved Solids	APHA 22nd Edition Method 2540 C, by Gravimetric Evaporation @ 180°C	10 g/m³
Transmissivity @ 253.7nm	UV-VIS spectrophotometer	0.1 %
Transmissivity after filtration	UV-VIS spectrophotometer, after 0.25u filtration.	0.1 %
Salinity	Based on APHA 22nd Edition method 2510 - Conductivity meter calibrated to synthetic seawater samples. Result reported as parts per thousand.	2 ppt
Calcium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Magnesium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Sodium - Acid Soluble	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.05 g/m³
Total Hardness	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	1 g CaCO3/m³
Calcium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Magnesium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Potassium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.01 g/m³
Sodium - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified).	0.02 g/m³
Silica - Dissolved	ICP-OES following APHA 22nd Edition Method 3120 B (modified)	0.02 g/m³
Aluminium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m³
Arsenic - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Boron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m³
Cadmium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m³
Chromium - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m³
Copper - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Iron - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m³
Lead - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³
Manganese - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m³

Test	Methodology	Detection Limit
Nickel - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Zinc - Acid Soluble	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Aluminium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Antimony - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Arsenic - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Barium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.002 g/m^3
Beryllium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Boron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.03 g/m^3
Cadmium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0002 g/m^3
Chromium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.001 g/m^3
Copper - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Iron - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.01 g/m^3
Lead - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Lithium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.001 g/m^3
Manganese - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Mercury - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Molybdenum - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Nickel - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.0005 g/m^3
Selenium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.005 g/m^3
Silver - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Tin - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0005 g/m^3
Zinc - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified).	0.002 g/m^3
Uranium - Dissolved	ICP-MS following APHA 22nd edition method 3125 (modified)	0.0002 g/m^3
Total Coliforms	APHA 22nd Edition, 9223B:2012 by Colilert Quantitray	1 MPN/100ml
E. coli	APHA 22nd Edition,9223B:2012 by Colilert Quantitray	1 MPN/100mL

"<" means that no analyte was found in the sample at the level of detection shown. Detection limits are based on a clean matrix and may vary according to individual sample.

g/m3 is the equivalent to mg/L and ppm.

Samples will be retained for a period of time, in suitable conditions appropriate to the analyses requested.

All test methods and confidence limits are available on request. This report must not be reproduced except in full, without the written consent of the laboratory.

Deacon

Report Released By
Rob Deacon

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APPENDIX 7: Chemistry Review of Wellington Harbour Exploratory Bores E3a and E8 (GNS)

4 April 2018

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Attention: Hayden Pipe

Dear Hayden

Chemistry review of Wellington Harbour exploratory bores E3a and E8

1. INTRODUCTION

Stantec New Zealand has commissioned GNS Science to review the water quality analyses from the E3a and E8 exploratory bores located in Wellington Harbour, New Zealand. The purpose of the review was to examine whether, and to what extent, the bores may be contaminated with sea water as well as to compare the water chemistry of bores with that of established wells within the Waiwhetu and Moera aquifers. The chemistry of E3a has been reported previously (van der Raaij 2017) and the findings have been repeated in this report.

1.1 SCOPE OF WORK

The scope of the GNS Science study is outlined below:

1. Assess the E3a and E8 water chemistry data in the context of the Somes Island bore and Petone foreshore groundwater chemistry data as well as in relation to the chemical characteristics of the sub-harbour Waiwhetu Aquifer and Moera Aquifer (evolution/trends, potential seawater mixing evidence) – with particular emphasis on Fe, Mn, NH_4 and Cl;
2. Provide views/evaluation on whether there is evidence for seawater mixing at E3a and E8.

□. DATA ANALYSIS

Water chemistry data for exploratory bores E3a and E8 were provided by Stantec New Zealand for the review. A summary of sample details is given in Table 1.

Table 1 Sample details.

Laboratory report ID	Sample time	Pump Test ID	Pumping test time (hours)	Depth below sea floor (m)	Aquifer
17/44□25-01	25/07/2017 0□:00	E3a PT1	1	23.4 – 27.8 m	Waiwhetu
17/44□25-02	25/07/2017 11:30	E3a PT1	3.5	23.4 – 27.8 m	Waiwhetu
17/44□25-03	26/07/2017 15:00	E3a PT1	7	23.4 – 27.8 m	Waiwhetu
17-47664-01	□/08/2017 0□:30	E3a PT2	1.5	74 – 77 m	Moera
17-47664-02	□/08/2017 12:30	E3a PT2	4.5	74 – 77 m	Moera
17-47664-03	10/08/2017 15:30	E3a PT2	7.5	74 – 77 m	Moera
17-4□633-01	1□/08/2017 11:30	E3a PT3	1□	23.4 – 27.8 m	Waiwhetu
17-4□635-01	20/08/2017 16:00	E3a PT3	48	23.4 – 27.8 m	Waiwhetu
17-4□634-01	22/08/2017 10:30	E3a PT3 (2)	3	23.4 – 27.8 m	Waiwhetu
18/2343-01	15/01/2018 12:00	E8-UWA-PT2□	-	25 – 28 m	Upper Waiwhetu
18/34□8-01	20/01/2018 16:45	E8-LWA-DE□	-	38.8 – 41.8 m	Lower Waiwhetu

For the comparison of the exploratory bores to groundwater from the Hutt Valley aquifer system, chemistry data from several groundwater wells have been used (Table 2). Seven of the twelve wells are part of the Greater Wellington Regional Council Groundwater Quality State of the Environment (G□SoE) monitoring network. A summary of the G□SoE data can be found in Tidswell et al. (2012). The council groundwater quality database also holds data for other wells of interest. For this study, data from one water supply well located at Gear Island, and four other wells located at the Petone foreshore have also been used. The locations of all wells in relation to the test wells are shown on Figure 1.

Table 2 Well details. The first seven wells are G□SoE wells.

Well ID	Name	E [1]	N	Depth (m)	Aquifer
R27/0320	I□M1	1756□□6	5434508	114.6	Moera
R27/1086	UWA3	175□813	5433246	181.4	Moera
R27/1171	Somes Island	17564□3	5431227	21.2	Waiwhetu
R27/1180	Willoughby St Well 8	1760435	54356□8	3□	Waiwhetu
R27/1182	Seaview Wools	175□274	5432161	24.7	Waiwhetu
R27/1183	Avalon Studios	1763084	54386□1	25	Waiwhetu
R27/1265	I□M2	1756□□8	5434516	48.3	Waiwhetu
R27/0122	McEwan shallow	1758748	5433546	26.2	Waiwhetu
R27/7153	McEwan deep	1758681	5433523	34.0	Waiwhetu
R27/7154	Tamatoa shallow	1757020	54342□4	45.1	Waiwhetu
R27/7215	Tamatoa deep	1757022	54342□8	56.□	Waiwhetu
□□32/0034	Gear Island Well 2	1758720	5434132	36.1	Waiwhetu

[1] Coordinates are NZTM.

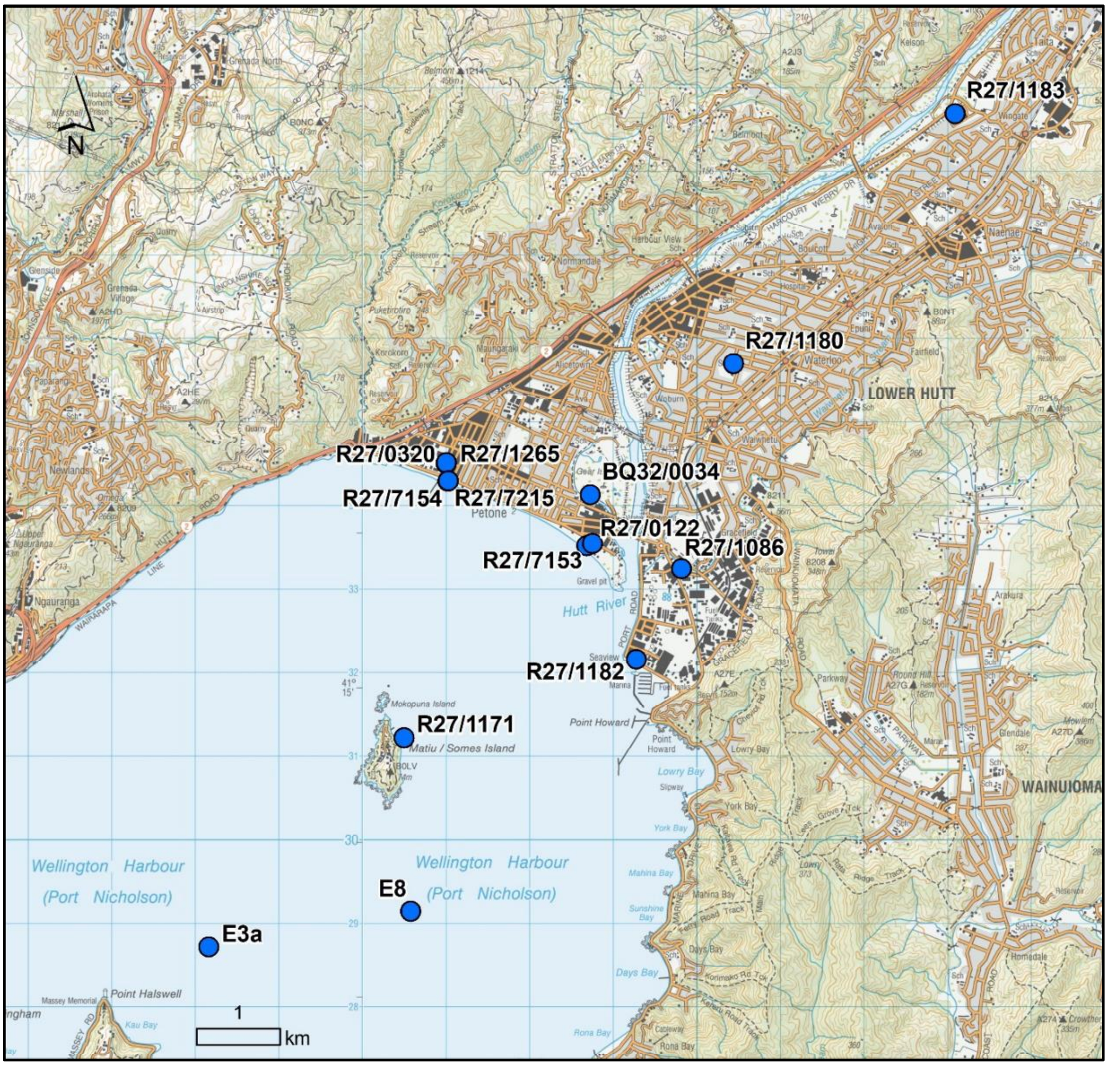

Figure 1 Well locations.

The geochemical modelling software NETPATH (Plummer et al. 1□□4) was used to undertake mass balance modelling of the chemical evolution of the groundwater observed at E3a and E8 from the groundwater of the upgradient wells such as those located at Somes Island and the Petone foreshore. Additional geochemical modelling was performed using Geochemists Workbench (version 10) software (□eth□e and □ea□el 2015).

3. DISCUSSION

3.1 GENERAL AQUIFER CHEMISTRY

Groundwater in the Hutt Valley aquifer system is predominantly Na-Ca-HCO_3-Cl type water, with smaller proportions of magnesium and sulphate (Figure 2). Groundwater from most wells in the Waiwhetu Aquifer have similar chemistry to that of the Hutt River, although somewhat higher in dissolved solids. Wells in the Moera Aquifer have slightly different chemistry, with a higher proportion of sodium (Na) over calcium (Ca) (Figure 2).

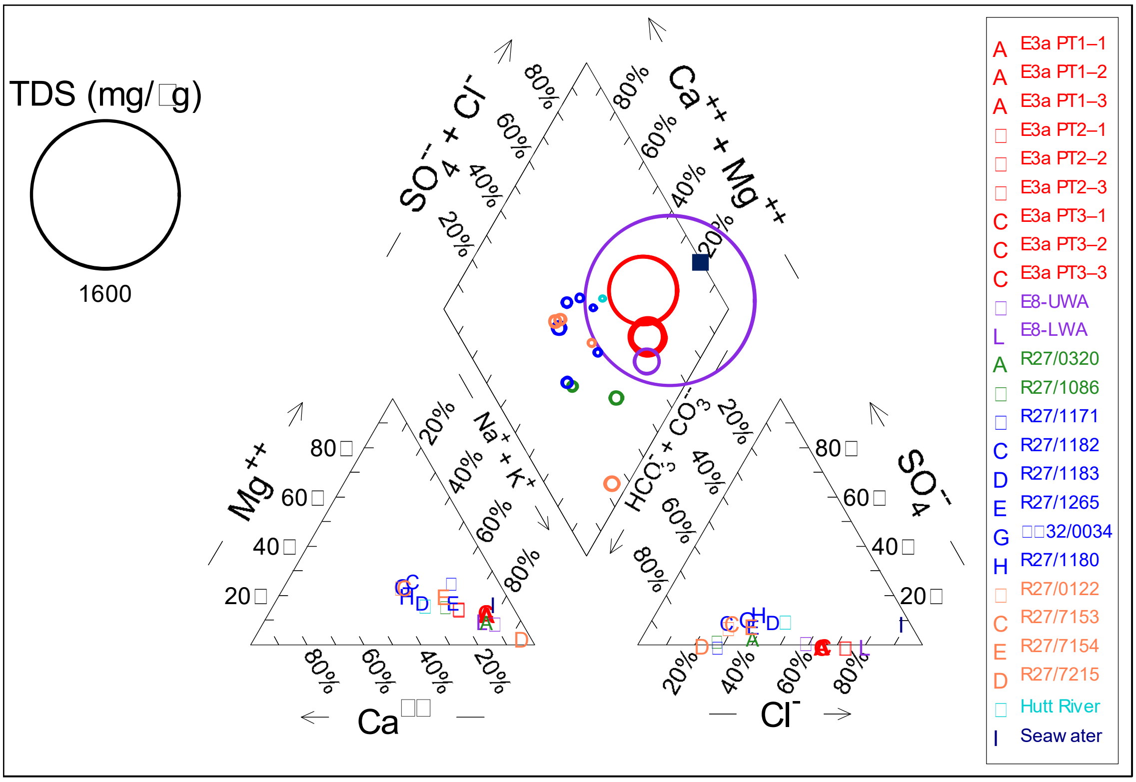

Figure 2 Piper diagram showing the median major ion chemistry in the Lower Hutt aquifer system and chemistry of the exploratory bores E3a and E8. The left and right triangles show the major cation and anion ratios on an equivalence basis respectively, and the centre diamond plots projections based on the two triangular plots. Symbols in the centre diamond are sized relative to total dissolved solids (TDS) concentration. Seawater is shown for reference, as represented by the dark blue square, and is not scaled to TDS.

Concentrations of major ions increase along the groundwater flow-path (Figure 3). Increases in major ions are generally related to mineral dissolution and redox processes. Comparison of Na to chloride (Cl) shows most Na in the groundwater from wells depicted in Figure 2 and Figure 3 is not derived from sea water. Na increases with distance away from the recharge zone due to dissolution of sodium aluminium silicate minerals (Downes, 1□85). In the deeper Moera aquifer, higher Na concentrations accompanied by low Ca concentrations may be caused by groundwater interaction with a different mineral assemblage, or (more likely) ion exchange processes whereby Na ions replace Ca and magnesium (Mg) ions in solution in the presence of clay minerals (Rosen 2001).

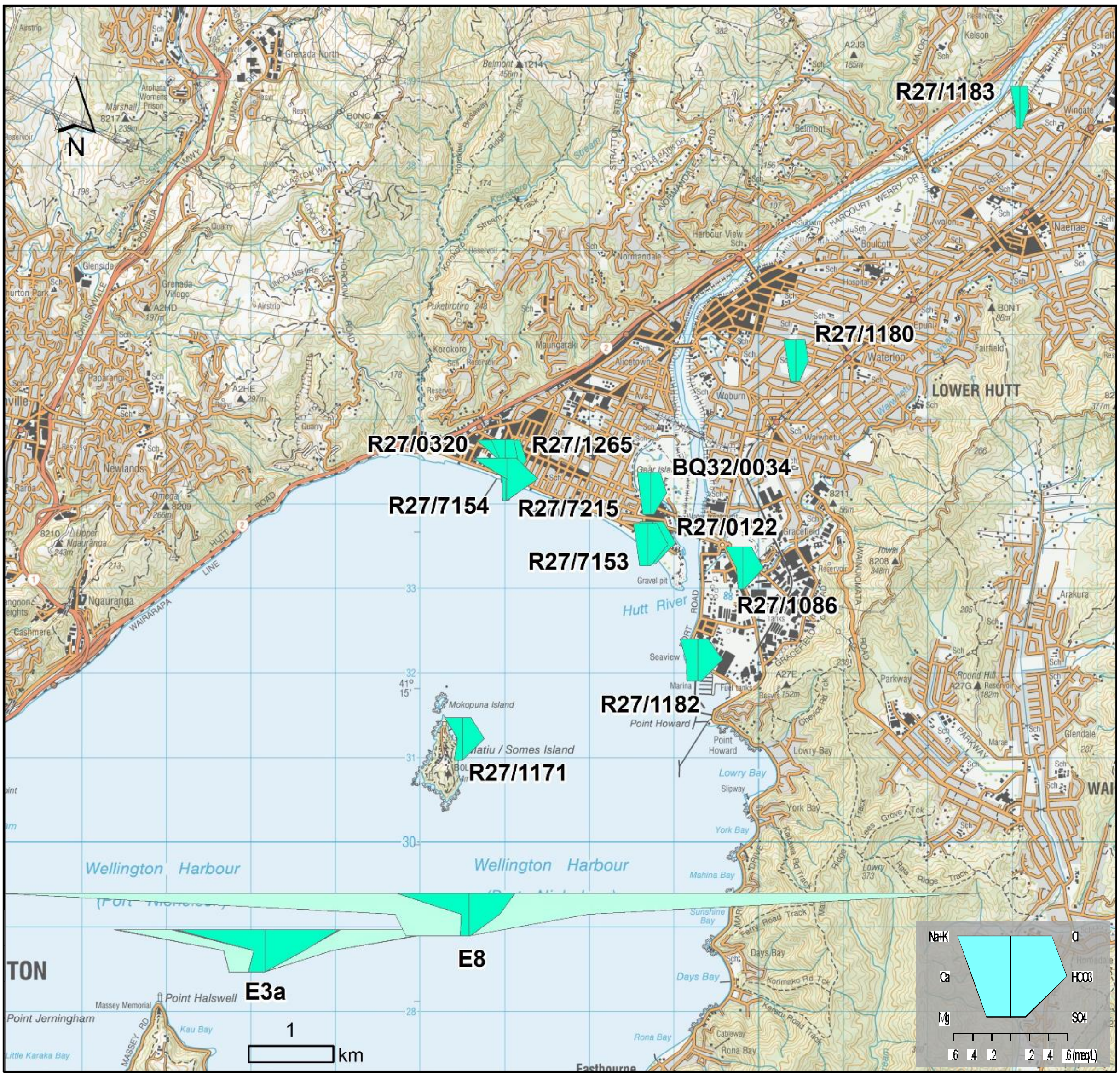

Figure 3	Map of groundwater chemistry in the Lower Hutt aquifer system. Symbols are Stiff diagrams which show the proportions of the major ion median concentrations present in groundwater from each well. The lighter colour diagrams for E3a and E8 are for the deeper screened intervals. The inset key is the Stiff diagram for R27/1180 and is not to the same scale as the main figure.

As well as mineral dissolution, the chemical evolution of groundwater in the Lower Hutt aquifer system is strongly influenced by redox processes which occur after recharge (Downes 1985). After entering the aquifer, dissolved oxygen in recharge waters is rapidly depleted by the oxidation of organic matter. Once oxygen is depleted other redox processes can occur. A series of reactions dictated by the most favourable terminal electron-accepting process (TEAP) takes place. The order of these processes is O_2 > NO_3^- > Mn(IV) > Fe(III) > SO_4^{2-} > methanogenesis.

High dissolved oxygen concentrations only occur in the river and wells situated near the recharge zone. In the confined zone the groundwater evolves towards an anoxic state. Once oxygen is depleted nitrate begins to be reduced and concentrations decrease, followed by increases in dissolved manganese (Mn) and dissolved iron (Fe). Sulphate concentrations remain relatively high throughout the aquifer until highly reducing conditions are reached, which can be observed in the groundwater from well R27/1171 at Somes Island. Dissolved methane is zero for most of the Waiwhetu Aquifer, with the exception of Somes Island, and at trace levels near the detection limit in some wells located near the Petone foreshore (van der Raaij 2013). Deeper wells in the Moera Aquifer, for example R27/1086, also contain dissolved methane.

3. CHEMISTRY OF THE EXPLORATORY BORES

Cl is much higher in water from the exploratory bores E3a and E8 than in other Hutt aquifer wells. The concentrations are much higher than expected through groundwater evolution, as there is expected to be a lack of Cl-containing minerals in the aquifer matrix (Rosen 2001). Geochemical modelling indicates that groundwater in nearby upgradient wells (i.e., Somes island and Petone) cannot evolve to the chemistry composition observed at the exploratory bores without the addition of seawater, accompanied by expected geochemical processes such as mineral dissolution, clay formation and ion exchange. For E3a PT1 and PT3 the proportion of seawater necessary to achieve the observed composition is 0.55 % of the total volume of water. For E3a PT2, the proportion of seawater necessary to achieve the observed composition is 1.5 % of the total volume of water. For E8 UWA and E8 LWA the proportions of seawater necessary to achieve the observed compositions are 0.3% and 4.2% respectively.

Assuming no seawater contamination occurred during the sampling process, the source of the seawater could be through seawater intrusion (either recent or historic) caused by hydrostatic pressure differentials within the aquifers, or through the presence of 'paleo' seawater trapped in marine derived sediments at the time of deposition. While the groundwater chemistry itself does not indicate which of these are more likely, groundwater from the Somes Island SoE monitoring well R27/1171 does not show the influence of seawater. Additionally, at both exploratory bores, the proportion of seawater present is greater in the deeper aquifer, suggesting that recent seawater intrusion is less likely. Bore E3a PT2, screened in the Moera Aquifer, is less saline than the shallower screened E8 LWA, which is screened in the lower Waiwhetu Aquifer.

For E3a PT1, E3a PT3, E8 UWA and E8 LWA, Na concentrations increase as expected due to the addition of seawater accompanied by mineral dissolution (Figure 4a). For E3a PT2, Na is seemingly depleted from what would be expected. This implies that Na has been removed from the groundwater through reverse ion exchange. Reverse ion exchange can occur when saline waters encounter Ca rich clays (Rosen 2001). Accordingly, there is a proportionate increase in the Ca concentration observed in the water from E3a PT2.

The increase of fluoride (F) from less evolved aquifer water to that of E3a PT1, E3a PT3 and E8 UWA is not related to the influx of seawater, but is due to mineral dissolution (Figure 4b). For E3a PT2 and E8 LWA, F appears to be have been removed by adsorption onto clays through ion exchange processes. Bromide (Br) is primarily from atmospheric sources (i.e., sea spray) via recharge, not from mineral dissolution, and the subsequent increases observed at E3a and E8 are primarily due to the influx of seawater (Figure 4c). Initial increases of boron (B) in the Hutt aquifer system appear to be related to mineral dissolution, while the large increases observed at E3a and E8 are consistent with the influx of seawater (Figure 4d).

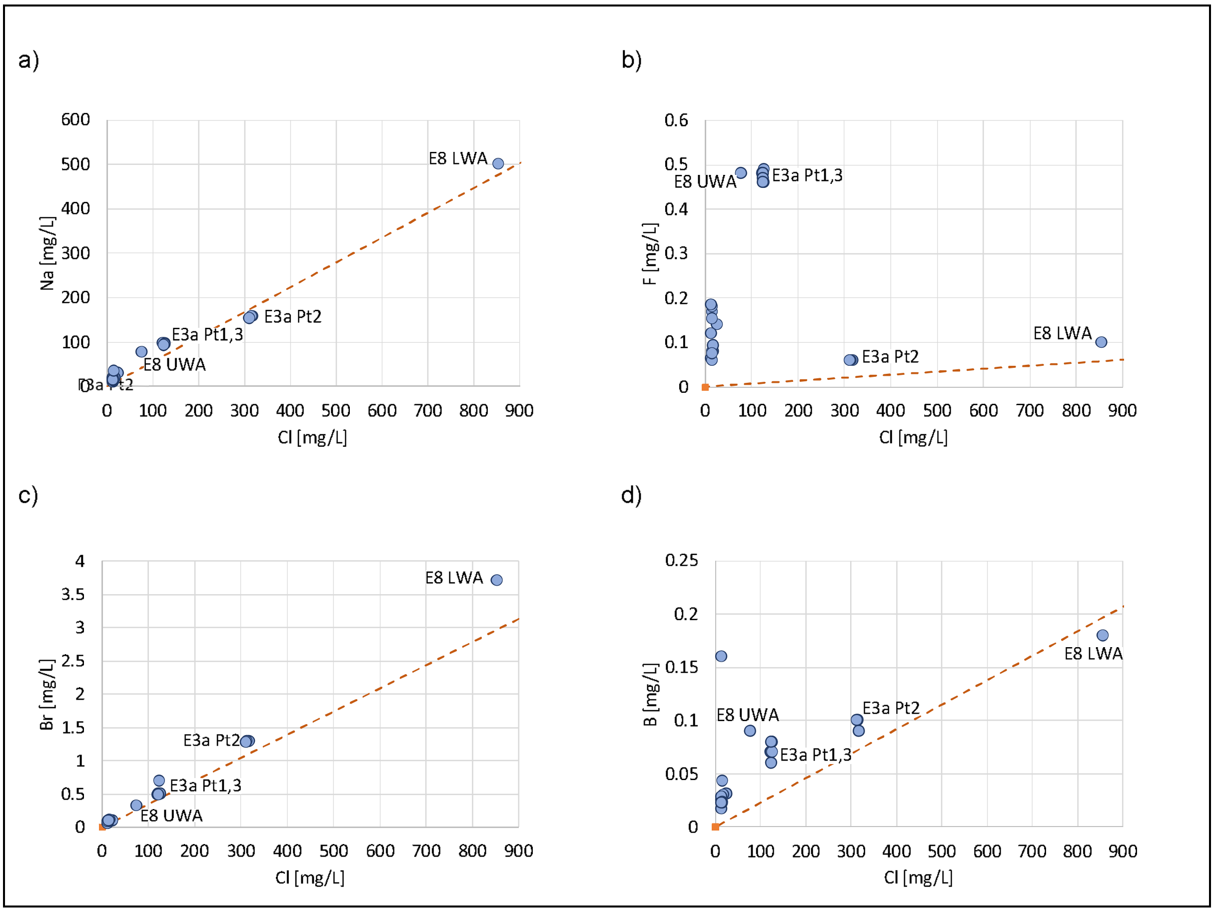

Figure 4 a) Na against Cl concentrations. b) F against Cl concentrations. c) Br against Cl concentrations. d) B against Cl concentrations. The dashed lines are sea water concentration dilution lines.

There are small but statistically significant differences (α=0.05) of 2 to 3% between acid soluble and dissolved concentrations of Ca, magnesium (Mg) and potassium (K). The differences could indicate the presence of particulates or, as the differences are relatively small, could reflect differences in analytical or sampling methodology. There is also a 1% difference between acid soluble and dissolved concentrations of Na and B respectively, but these are not statistically significant. There are statistically significant differences between acid soluble and dissolved concentrations of trace metals, most notably with iron (Fe) but also observed for aluminium (Al), copper, manganese and zinc. Other measured trace metals were close to or at the detection limit, so no differences could be discerned.

On average, there is a 55% difference between acid soluble and dissolved Fe concentrations observed at bore E3a. However, this appears to be dependent on the time of sampling. For instance, for E3a PT1, the acid soluble concentration remains reasonably constant over the duration of the pump test, dropping only from 3 mg/L to 2.8 mg/L. However, the corresponding dissolved Fe concentrations increase from 0.6 mg/L to 2.1 mg/L. This suggests that most of the acid soluble Fe in the early sample from E3a PT1 is present as Fe in particulate form, possibly derived from dissolved Fe that precipitated due to changes (such as introduction of air or oxygenated water) induced from the drilling process. As the pump test progresses, this affected water is flushed from the system, resulting in the change of ratio between particulate and dissolved forms of Fe. Particulate matter may also be the result of disturbances caused by the drilling process, or introduced during this process. Measured suspended solids, along with turbidity, decrease dramatically over the course of the PT1 test. This may be partly related to precipitation of Fe, but these parameters are also correlated with the concentration of acid soluble Al, suggesting that at least some of the particulate matter may be derived from aquifer matrix or drilling muds.

The changes in the ratio of particulate to dissolved Fe are not as apparent in the test for the deeper well (E3a PT2), but do seem to repeat for the later test of the shallower well (E3a PT3). These later tests are not accompanied by the same dramatic changes in suspended solids and turbidity, supporting the hypothesis that at least some of the particulate matter was caused by the drilling process, and subsequently removed during the first pump test. Differences between acid soluble and dissolved Fe are also observed in the samples from bore E8. As only one sample from each screened depth was taken, it is less clear if this is related to the time of sampling as for bore E3a. For E8 LWA, all the Fe appears to be present in particulate form, as dissolved Fe was below the detection limit for this sample.

Differences in acid soluble and dissolved Fe concentrations may also be due to processes that occurred after sampling. Samples were not filtered in the field, so there is potential that some of the dissolved Fe precipitated out of solution prior to the sample being filtered and analysed at the laboratory.

Regardless of whether Fe precipitation occurred within the aquifer, or after sampling, over the long term most Fe would be present in the groundwater as the reduced, dissolved form; which is not unexpected given the anoxic conditions of the groundwater. Categorisation of the groundwater redox state, based on concentrations of redox species (dissolved oxygen, NO_3, Fe, Mn and SO_4), shows that the water at the E3a and E8 bores is highly anoxic and has reached the stage of methanogenesis (McMahon and Chapelle 2008). This is confirmed by measurements of dissolved methane performed on the CFCs samples collected for groundwater dating. The measured methane concentrations were [illegible]41 µmol/kg for E3a PT1 1254 µmol/kg for E3a PT2, 54 µmol/kg for E8 UWA and 1883.854 µmol/kg for E8 LWA. Concentrations observed at E3a and E8 LWA are high for groundwater and are in the top 5 % of methane concentrations observed in New Zealand groundwaters (van der Raaij 2013).

A similar difference is seen between acid soluble and dissolved Mn. However, the difference between acid soluble and dissolved Mn concentrations is not as great as for Fe, with an average difference of 6%. The reduced, soluble form of Mn is more stable than that of Fe across a range of pH and redox conditions (Daughney 2003). Therefore, the amount of Mn precipitation caused by drilling influences would be expected to be lower. Most Mn is present in soluble form, which is again not unexpected given the anoxic conditions of the groundwater.

Significant concentrations of ammonia in groundwater are only observed under anoxic conditions (Rosen 2001). The concentrations of ammonia observed at both E3a and E8 are too high to be derived completely from the reduction of nitrate, and are likely derived from the ammonification of organic matter trapped in the sediments.

Sample E8 UWA has an elevated dissolved Arsenic (As) concentration of 0.022 mg/L. This is above the maximum acceptable value of 0.01 mg/L specified by the Drinking-water Standards for New Zealand 2005 (Ministry of Health 2008). The majority of wells in the Hutt aquifer system have As concentrations below the detection limit (<0.001 mg/L), while exploratory bore E3a PT 1 and PT3 had slightly elevated As concentrations of around 0.005 mg/L, which are below the Drinking-water Standards limit. While elevated As concentrations are commonly linked with reduced groundwaters, it is unclear why this is only seen in E8 LWA and not in the other exploratory bore samples.

□. SUMMARY AND RECOMMENDATIONS

Groundwater at exploratory bores E3a and E8 differ from that of upgradient wells in the Hutt aquifer system. Geochemical modelling indicates that groundwater in nearby upgradient wells (i.e., Somes island and Petone) cannot evolve to the chemistry composition observed at the exploratory bore without the addition of seawater, accompanied by expected geochemical processes such as mineral dissolution, clay formation and ion exchange. For E3a PT1 and PT3 the proportion of seawater necessary to achieve the observed composition is 0.55 % of the total volume of water, while for E3a PT2, this proportion is 1.5 % of the total volume of water. For E8 UWA and E8 LWA the proportions of seawater necessary to achieve the observed compositions are 0.3% and 4.2% respectively. The source of the seawater is unknown and could either be through seawater intrusion (either recent or historic), or through the presence of trapped ‘paleo’ seawater, assuming no seawater contamination during the collection of the samples. Additional tracer (stable isotopes, radiocarbon) or chemical analyses are unlikely to elucidate the source of the seawater.

Groundwater at the exploratory bores E3a and E8 is highly anoxic and methanogenic. High concentrations of dissolved Fe, Mn and ammonia are observed and not unexpected. Differences between acid soluble and dissolved concentrations of many analytes, especially for Fe, indicate disturbances caused by the drilling process may have mobilised particulate matter and/or caused precipitation of dissolved Fe.

Sample E8 UWA has an elevated dissolved Arsenic (As) concentration of 0.022 mg/L which is above the maximum acceptable value of 0.01 mg/L specified by the Drinking-water Standards for New Zealand 2005 (Ministry of Health 2008). Samples from E3a PT 1 and PT3 had slightly lower As concentrations of around 0.005 mg/L

□. REFERENCES

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Yours sincerely

Rob van der Raaij	Heather Martindale
Scientist, Isotope Hydrology	(Reviewer)

APPENDIX 8: Age dating results (GNS)

Letter Report No: CR 2018/24 LR
Project No: 630W0906

9 March 2018

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Attention: Hayden Pipe

Dear Hayden

Results of groundwater age-tracer analyses and interpretation of groundwater age for Wellington Harbour exploratory bore E3a

This report provides the results of age-tracer, radon and stable isotope analyses of two groundwater samples from the E3a exploratory bore located in Wellington Harbour. Bore details are provided in Table 1. Interpreted groundwater mean residence times (MRTs) are presented in Table 2. The analytical results are presented in Tables 3 – 6.

Table 1 Summary of bore details.

Site ID	Sampling Date	Total bore depth [m] [1]	Screen depth [m] [1]	Aquifer Type [2]	Aquifer name [2]
E3a PT1 7hr	25/07/2017	25.5	24 – 25.5	confined	Waiwhetu
E3a PT2 7.5hr	09/08/2017	77	74 – 77	confined	Moera

[1] Bore and screen depths are in metres below the sea bed.

[2] Bore details provided by Stantec (Stantec 2017)

Groundwater mean residence times (MRT) have been calculated using an exponential piston flow model (EPM) matched to the tracer concentrations presented in Tables 3 and 4. The methodology is described in Appendix 1. MRTs have been modelled using an estimated 70% exponential mixed flow. The use of 70% exponential mixed flow is a conservative estimate, and takes into account that it is not possible to accurately estimate the input age distribution parameters of the model when tracer concentrations are as low as they are at these wells.

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Tritium concentrations in groundwater from both samples are at the detection limit, indicating overall that the groundwaters are likely more than several decades old (Figure 1). Minimum MRTs modelled for the samples from the shallow and deep screen depths are 205 years and 175 years, respectively. However, as the tritium concentrations are at the detection limit the actual age of the water may be much greater. Gas tracer concentrations, (CFCs and SF_6) are not consistent with such low tritium concentrations. This suggests these samples have most likely been affected by contact with air that could have occurred either during the drilling or sampling process. The possibility of air contact during the drilling process is somewhat supported by chemistry data for these samples (van der Raaij 2017).

Table 2 Groundwater mean residence time calculated using the EPM with stated mixing parameters.

Site ID	Exponential mixed flow %	MRT [years]
E3a PT1 7hr	70	>205
E3a PT2 7.5hr	70	>175

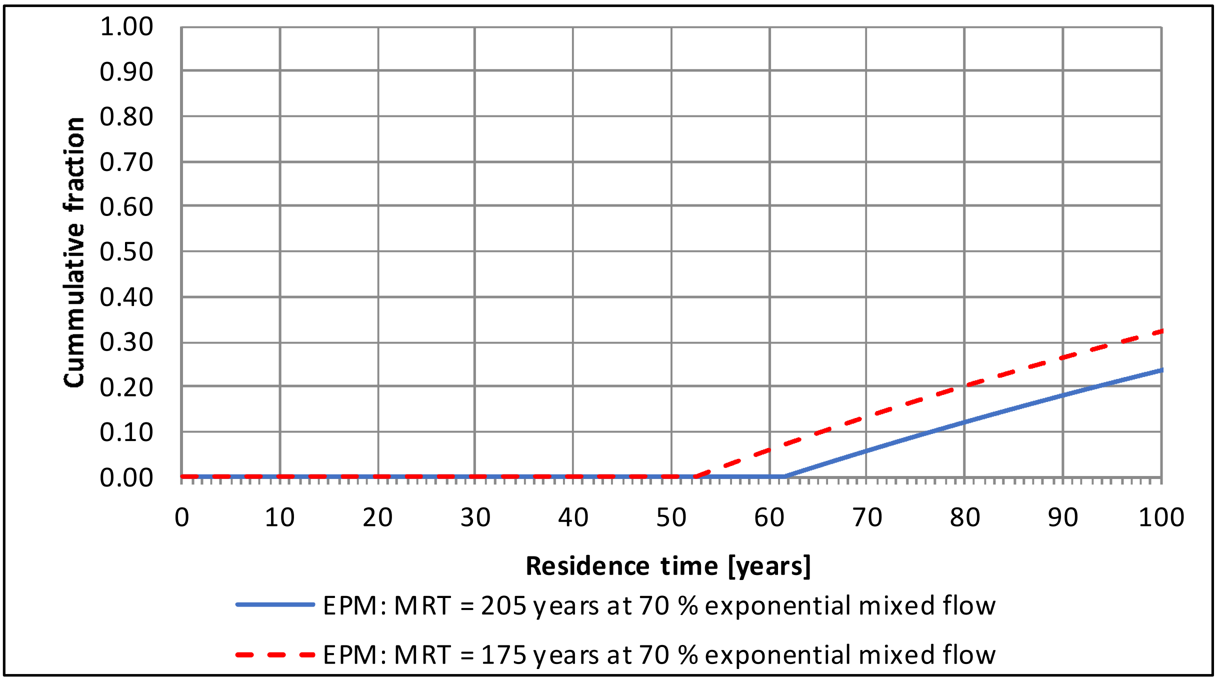

Figure 1 Cumulative residence time distribution for the minimum modelled MRTs for the Wellington harbour samples using an EPM with 70% exponential mixed flow.

Stable isotope measurements (^{2}H, ^{18}O) are consistent with recharge originating from the Hutt River and/or local rainfall, while the measured radon concentrations (Table 3) are within the typical range expected for greywacke alluvial aquifers.

Yours sincerely

Rob van der Raaij
Scientist, Isotope Hydrology

Heather Martindale
(Reviewer)

Table 3 Summary of Tritium (^{3}H), radon and stable isotope concentrations in groundwater samples collected in □uly and August 2017 from the Wellington Harbour exploratory bore.

Site ID	Tritium Lab no□	^{3}H [TR] [1]	□^{3}H [TR] [2]	$\delta^{2}H$ [□]	$\delta^{1□}$□ [□]	Rn □□q□L□	□ Rn
E3a PT1 7hr	TW1790	-0.025	0.016	-35.5	-6.05	33.2	1.9
E3a PT2 7.5hr	TW1792	0.016	0.015	-36.0	-6.09	25.2	1.4

[1] Tritium concentrations are expressed as ^{3}H:^{1}H ratios with a Tritium Ratio (TR) of one equal to a ratio of 1:1×10^{18}.

[2] The quoted measurement error is the combined statistical standard uncertainty from all processes contributing to the measurement uncertainty, expressed as one-sigma standard deviation (Ellison et al. 2000).

Table 4 Calculated atmospheric partial pressures of C□Cs and S□$_6$ for groundwater samples collected in □uly and August 2017 from the Wellington Harbour exploratory bore E3a. Partial pressures are calculated from the measured concentrations via Henry□s Law using recharge temperatures after correction for excess air, as given in Table 6.

Site ID	CFC-11 [ppt] 1	± CFC-11 [ppt] 2	CFC-12 [ppt] 1	± CFC-12 [ppt] 2	CFC-113 [ppt] 1	± CFC-113 [ppt] 2	SF_6 [ppt] 1	± SF_6 [ppt] 2	H-1301 [ppt]	± H-1301 [ppt]
E3a PT1 7hr	15.3	3.9	43.4	8.6	6.8	5.7	1.38	0.21	0.09	0.03
E3a PT2 7.5hr	1	1.5	1.8	5.8	0	5.6	3.28	1.04	0.09	0.09

[1] CFC, SF_6 and partial pressures are expressed in parts per trillion (ppt) where 1ppt signifies a volumetric ratio of 1×10^{-12}.

[2] The quoted measurement error is the combined statistical standard uncertainty from all processes contributing to the measurement uncertainty, expressed as one standard deviation (Ellison et al. 2000).

Table 5 Summary of measured CFC and SF_6 concentrations in groundwater samples collected in July and August 2017 from the Wellington Harbour exploratory bore E3a.

Site ID	CFC no.	CFC-11 [pmol/kg] 1	± CFC-11 [pmol/kg] 3	CFC-12 [pmol/kg] 1	± CFC-12 [pmol/kg] 3	CFC-113 [pmol/kg] 1	± CFC-113 [pmol/kg] 3	SF_6 no.	SF_6 [fmol/kg] 2	± SF_6 [fmol/kg] 3	H1301 [fmol/kg] 3	H1301 [fmol/kg] 3
E3a PT1 7hr	FWEL20	0.28	0.07	0.21	0.04	0.04	0.03	SWEL20	0.58	0.06	0.28	0.11
E3a PT2 7.5hr	FWEL21	0.02	0.03	0.01	0.03	0.00	0.03	SWEL21	0.90	0.08	0.28	0.27

1. Dissolved CFC concentrations are expressed in pmol/kg where 1 pmol = 1×10^{-12} mol.
2. Dissolved SF_6 and H1301 concentrations are expressed in fmol/kg where 1 fmol = 1×10^{-15} mol.
3. The quoted measurement error is the combined statistical standard uncertainty from all processes contributing to the measurement uncertainty, expressed as one standard deviation (Ellison et al. 2000).

Table 6 Dissolved argon, nitrogen and methane concentrations and the derived variables recharge temperature and excess air for groundwater samples in July and August 2017 from the Wellington Harbour exploratory bore E3a.

Site ID	Ar [mL(STP)/kg] 1	± Ar 2	N_2 [mL(STP)/kg] 1	± N_2 2	CH_4 [µmol/kg]	± CH_4 [µmol/kg]	Temp. [°C]	± Temp. [°C] 2	Excess Air [mL(STP)/kg] 1	± Excess Air [mL(STP)/kg] 2
E3a PT1 7hr	0.380	0.008	15.06	0.34	941	53	12.5	2.0	1.6	1.0
E3a PT2 7.5hr	0.340	0.013	12.06	0.65	1254	69	13.0	3.7	-2.0	1.8

1. Ar, N_2 and excess air concentrations are expressed in mL of gas at standard temperature and pressure per kg of water. Negative values indicate degassing has occurred.
2. The quoted measurement error is the combined statistical standard uncertainty from all processes contributing to the measurement uncertainty, expressed as one standard deviation (Ellison et al. 2000).

APPENDIX 1: DETERMINATION OF GROUNDWATER RESIDENCE TIME USING TRITIUM, CFCS AND SF$_6$

Chlorofluorocarbons (CFCs) are entirely synthetic compounds. Significant production of CFCs began in the 1930s. Sulphur hexafluoride (SF$_6$) is predominantly anthropogenic with industrial production beginning in the 1950s. However, a small amount of SF$_6$ is also produced in certain volcanic minerals and fluids. Groundwater age-dating using CFCs and SF$_6$ is possible due to the steady increase in atmospheric concentrations of these gases since production began (Figure A 1.1). These gases are dissolved in recharge waters and are isolated from the atmosphere when this recharge enters the groundwater zone. Thus, the gases hold a record in the groundwater of past atmospheric concentrations. CFCs have been measured continuously in the atmosphere at various sites worldwide since the late 1970s but their concentrations have begun to decline since use of them was phased out following the Montreal Protocol in 1987 thus losing effectiveness for age-dating over this period (IAEA, 2006).

After measured CFC and SF$_6$ concentrations in groundwater are corrected for excess air, they are used to calculate relative atmospheric concentrations using Henry's Law and an estimated recharge temperature. Excess air is air in excess of the equilibrium soluble amount at the given recharge temperature and is thought to originate by processes such as bubble entrapment occurring during recharge. The excess air correction and recharge temperature are calculated from the ratio of dissolved nitrogen and argon concentrations (Heaton and Vogel, 1981). These nitrogen and argon concentrations are measured simultaneously with the CFC concentrations. The calculated atmospheric concentrations are then used to calculate the CFC and SF$_6$ model residence times of the groundwater (Plummer and Busenberg 2000).

Under certain circumstances, CFCs and SF$_6$ can undergo diffusive exchange processes in the unsaturated zone, increasing their concentrations in groundwater. In these cases, the model ages derived from the CFC and SF$_6$ concentrations should be regarded as minimum ages for groundwater. CFCs are also susceptible to degradation processes underground, particularly in anoxic environments, and to contamination. SF$_6$ is less susceptible to these but is affected more by excess air and diffusion.

Tritium (^3H) is a component of the water molecule and thus forms an ideal tracer for groundwater studies. Age-dating using tritium is based on radioactive decay of tritium after rainwater penetrates the ground during recharge. The half-life of tritium is 12.32 years. Tritium is produced naturally by cosmic radiation in the upper atmosphere but was also released into the atmosphere by nuclear weapons testing. Figure A 1.1 shows the history of the tritium concentration in rainfall—the peak in tritium concentration in the 1960s and early 1970s is a result of this testing (Stewart and Morgenstern 2001). Tritium data may give ambiguous residence times, because of this irregularly shaped peak. Often this will be resolved by measuring the change in tritium concentration in groundwater over a time interval of a few years or by comparison to CFC and SF$_6$ data.

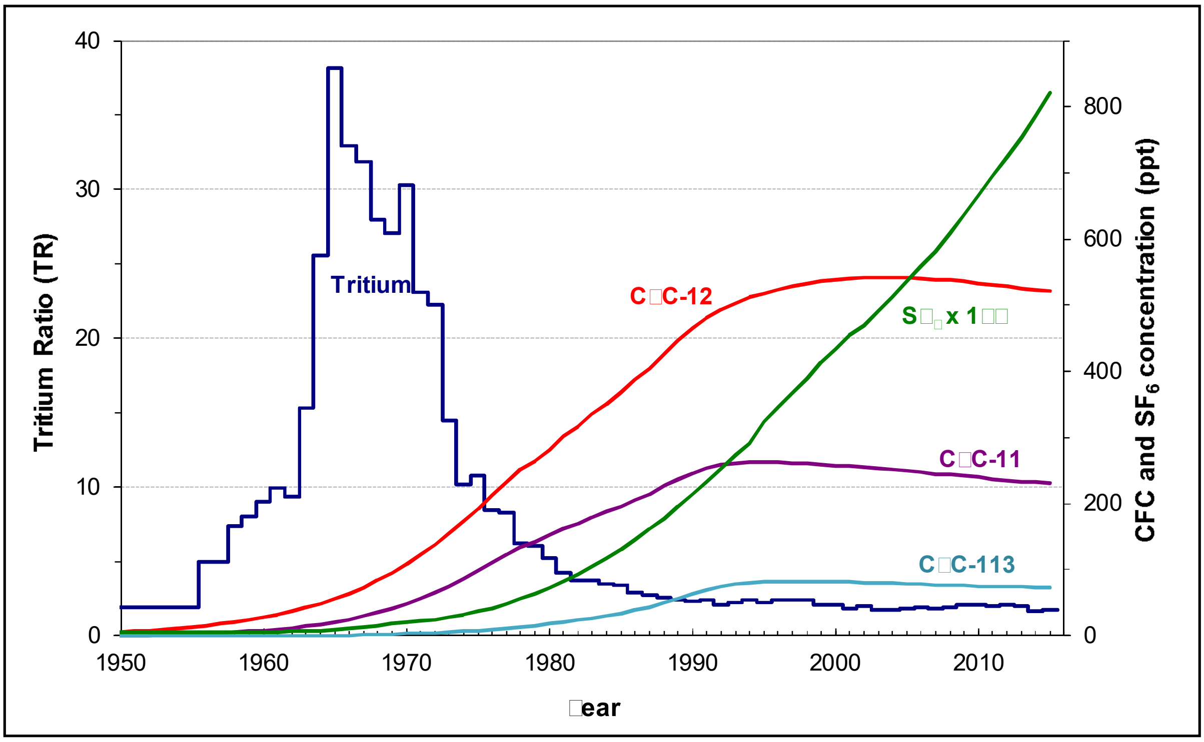

Figure A 1.1 Tracer input curves. The tritium concentrations are from rainfall at Kaitoke, New Zealand, and have been measured monthly since the 1960s. CFC and SF_6 concentrations are for southern hemispheric air (IAEA, 2006).

Groundwater extracted from a bore or other discharge point is a mixture of water with different ages due to the convergence of different flow lines within the aquifer at the discharge point (Figure A 1.2). Groundwater age-dating therefore yields an average age of the water. To calculate the average age (i.e., mean residence time) the distribution of groundwater age must also be determined. This distribution can be described using lumped-parameter mixing models. Lumped parameter models are a commonly used method of interpreting groundwater ages in scientific studies (Turnadge and Smerdon 2014) and are well-suited for characterisation of data-poor groundwater systems. Piston flow is a simplified approximation of no mixing of flow lines and is suitable for aquifers in which the recharge zone is narrow with respect to the overall distance from recharge zone to sampling point, while the exponential model describes complete mixing of the flow lines within a system. The mixing of different flow lines occurs at the sampling point. For more realistic scenarios, which are intermediate between piston flow and exponential mixing, the exponential piston flow model (EPM) may be applied (Maloszewski and Zuber 1982). The EPM has been applied successfully to groundwaters from many areas of New Zealand (Daughney et al. 2010; Morgenstern and Daughney 2012).

The EPM is described by two parameters - the MRT and the fraction of exponential mixed flow. The fraction of exponential mixed flow is a measure of the degree of mixing and reflects the distribution of travel-times of different components of groundwater around the MRT (Figure A1.3). The fraction of exponential mixed flow observed at the bore depends on the characteristics of the sampling point as well as the hydrogeologic attributes of the aquifer concerned (which affect the variety of possible flow paths that may be intersected by the bore). This fraction is best estimated by matching to the tritium data using a series of measurements separated in time by several years. If such a time series is not available, comparison of the tritium data to CFC and SF_6 data can sometimes be used for less precise estimates of the mixing fraction, but should be confirmed by future sampling.

There are certain limitations with this modelling approach that must be borne in mind. First, as with any model, the robustness of predictions is a function of the number, type and accuracy of the measurements that are used for its calibration. In this study, there are a limited number of tracer measurements at each site. The robustness of the age distribution modelling at any site can be increased by collecting additional tracer measurements in the future. Second, the lumped parameter models used here, although previously applied to many New Zealand groundwater systems, are nonetheless a simplification of reality. For example, fitting a single lumped parameter model to tracer measurements made in different years will only provide an indication of the long-term (steady-state) age distribution at the well; such a model cannot predict seasonal or event-specific changes to the age distribution (for example after heavy rain). In addition, the shape of the age distribution may be more complex than the lumped parameter model can represent. If there is a need to evaluate seasonal or event-specific age distributions and/or age distributions of complex shape, a numerical groundwater flow and transport model should be developed (e.g., Toews et al. 2016).

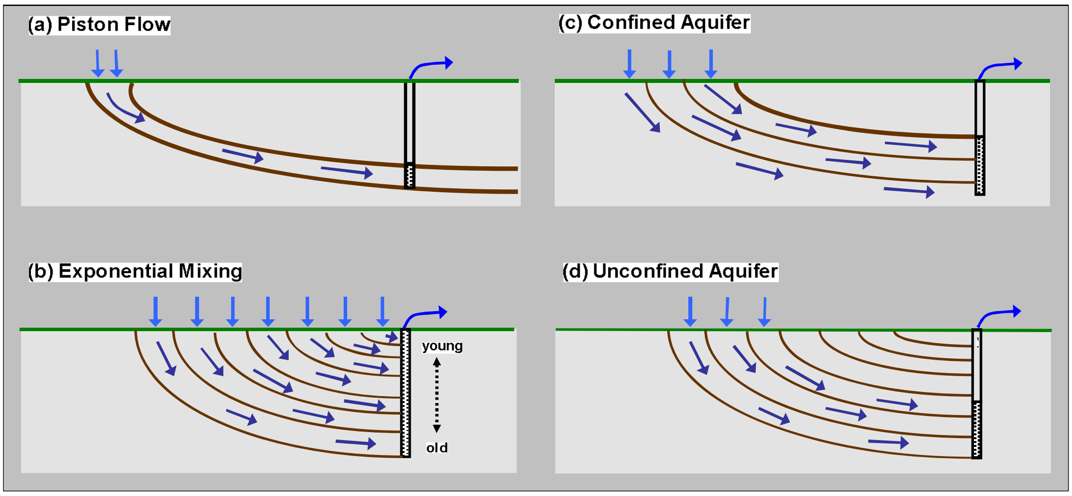

Figure A 1.2 Conceptual groundwater flow situations which can be described by lumped parameter mixing models.

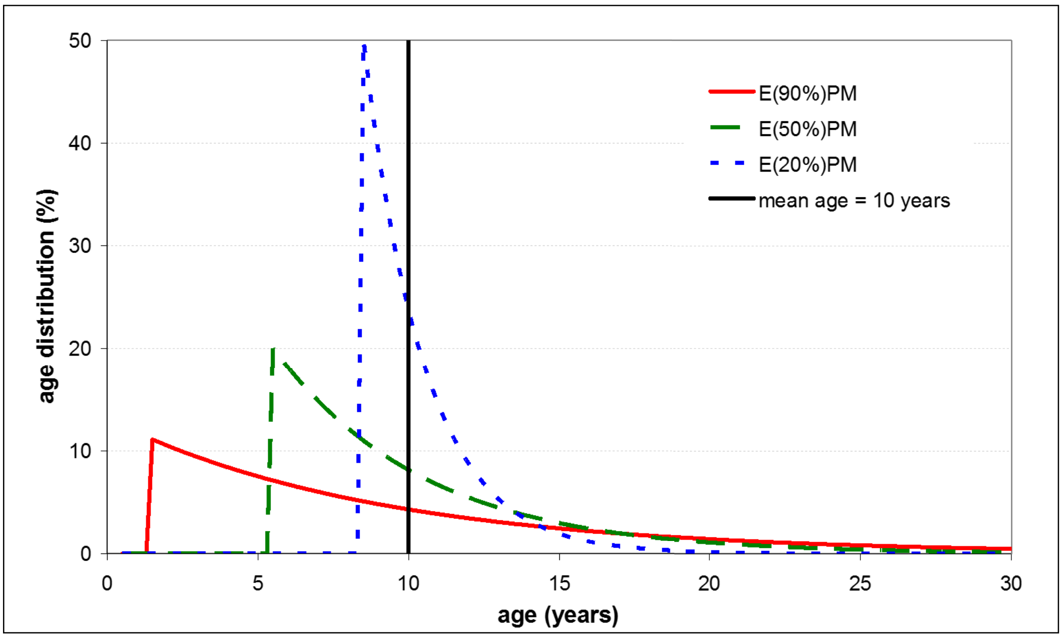

Figure A 1.3 Age frequency distributions for the exponential piston flow model for MRT = 10 years, with typical parameter values (20%, 50% and 90% of the flow is exponential mixed flow).

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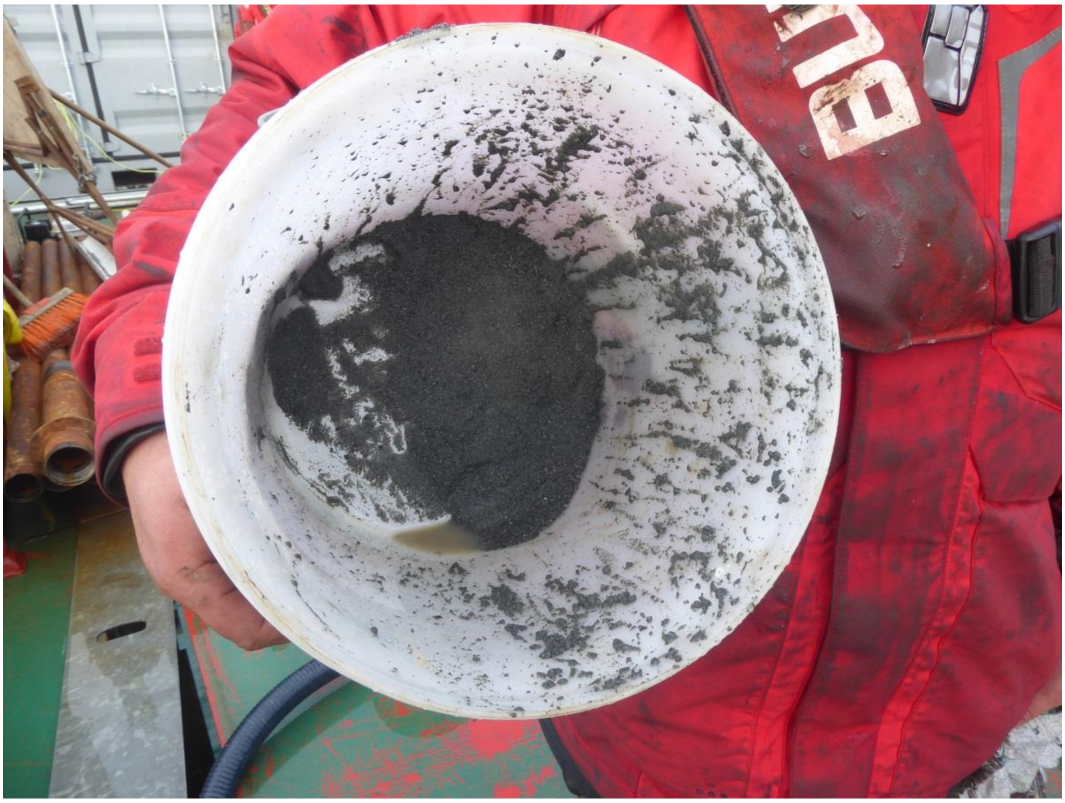
APPENDIX 9: Site photographs

Jack-up barge which acted as the drilling platform for the project

Tidal gauge comprising a pressure transducer installed within a steel tube bolted to the platform

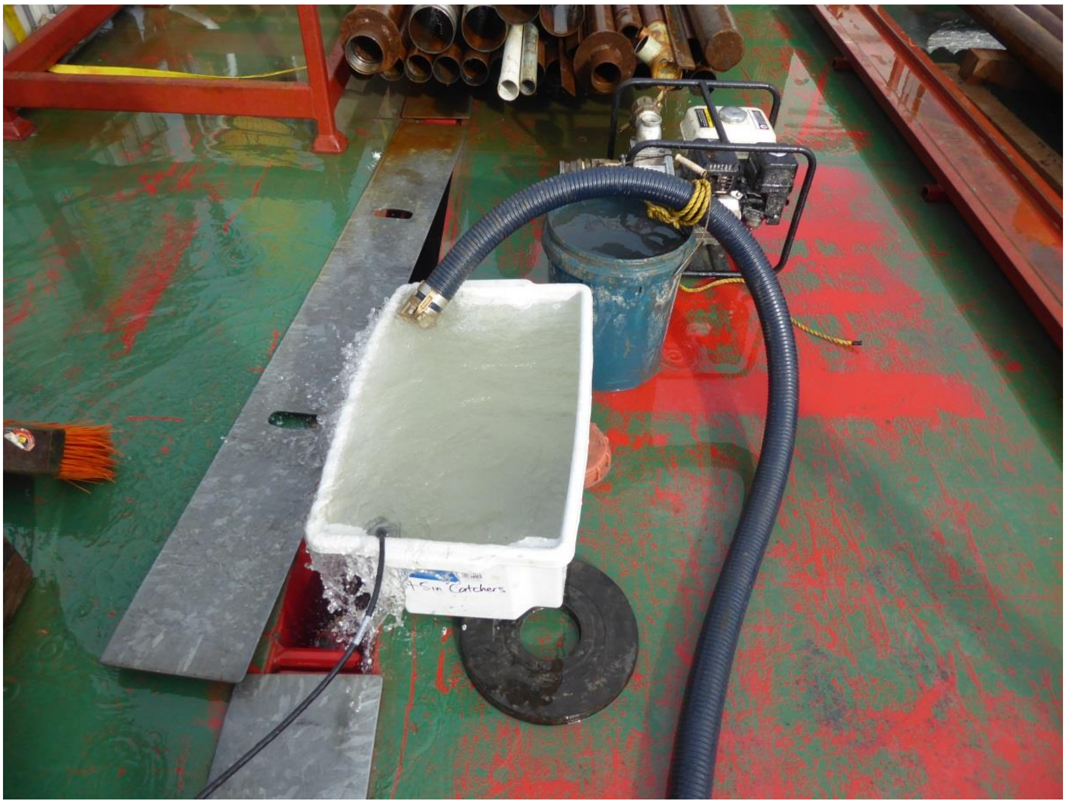
Airlift development of the bore using a compressor

Sediment from groundwater in the middle of the bore development process

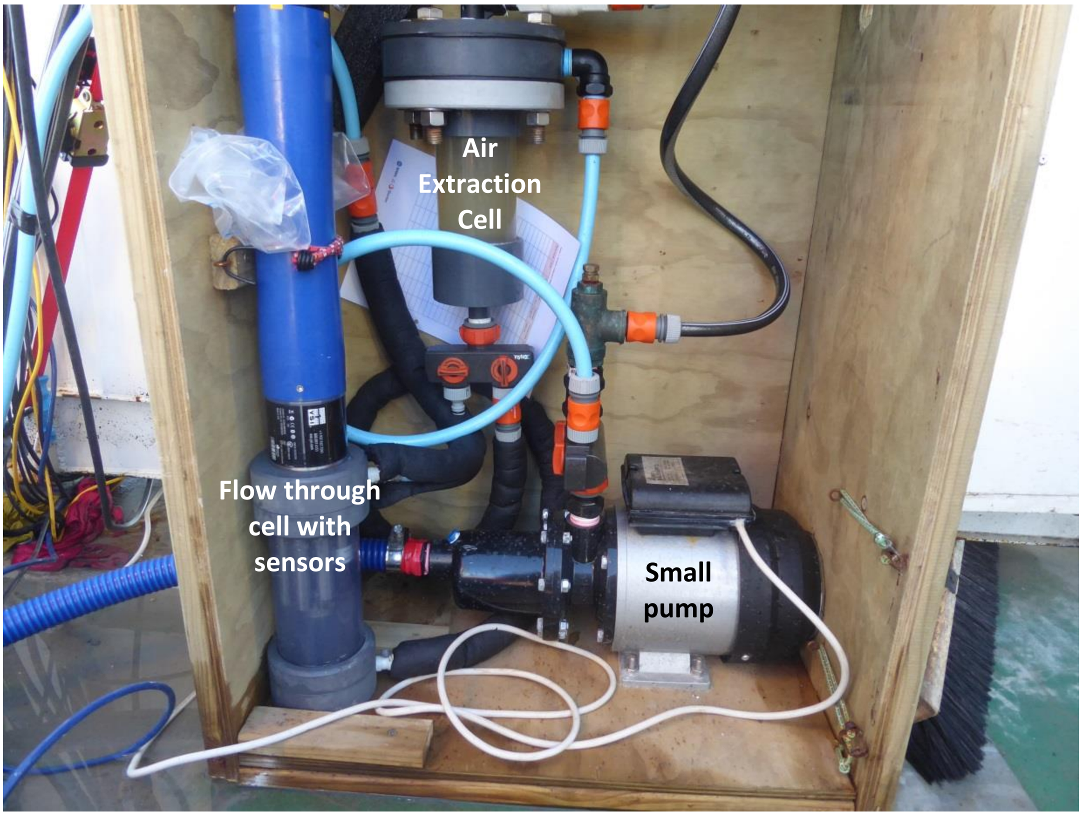


Sediment present towards end of bore development

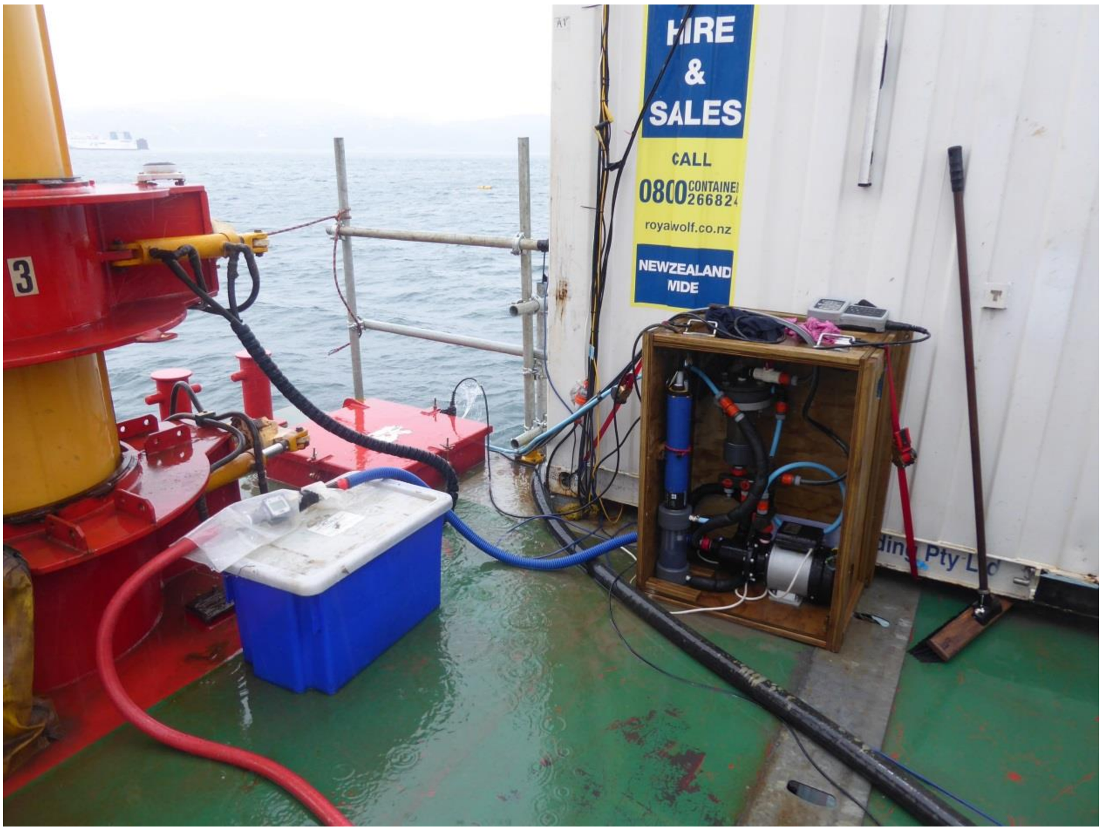
Manual Water Quality Monitoring during development



PUFTS



PUFTS and manual WQ meter with flow through cell (standard set-up)



Sediment trap, PUFTS and manual WQ meter and flow through cell

Well head set up with original mechanical flow meter and submersible pump

Well head set up with surface pump and electronic flow meter

Manual measurements of water level during pumping tests

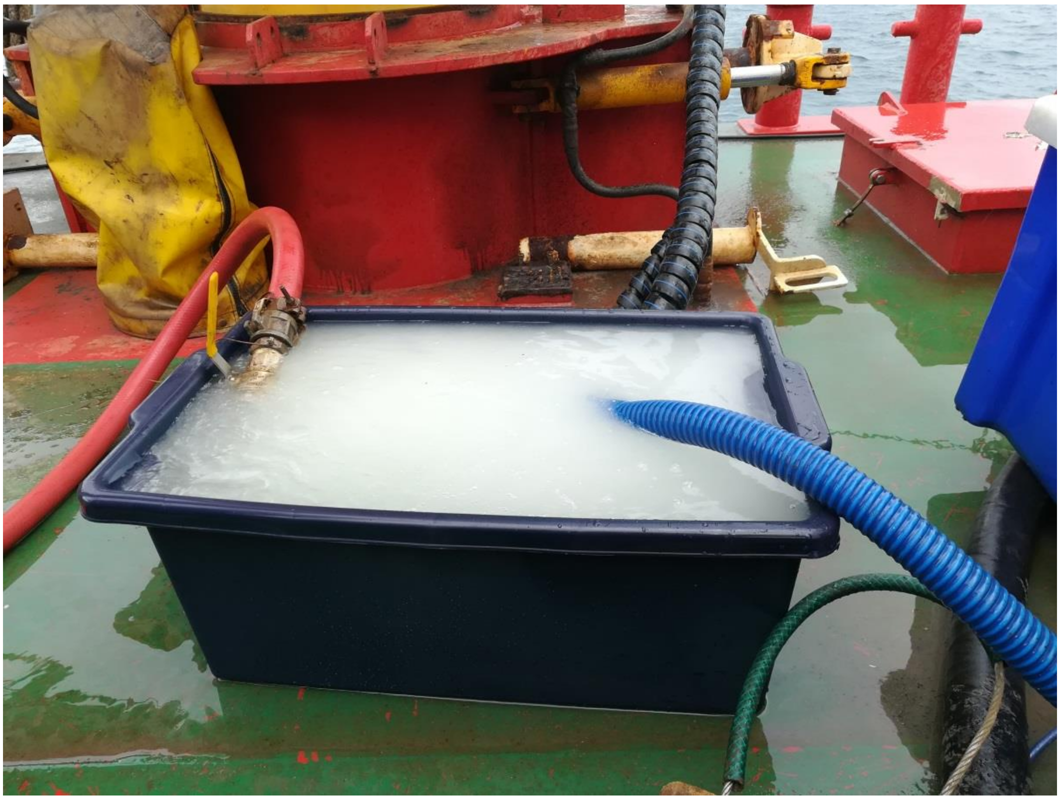
Manual check of flow rate using bucket test method

Water overtopping bore when pump turned off

Gas bubbles in flow through cell

Groundwater degassing following bucket test

Gas bubble trap before PUFTS (E8 LWA)



Some improvement during pumping at high rates, but still contains many bubbles

APPENDIX 10: Further modelling: Calibration/uncertainty analysis and using the HAM4 model to test selected hypotheses

Matt Knowling (GNS Science Ltd)

Further modelling: Calibration/uncertainty analysis and using the HAM4 model to test selected hypotheses

Matt Knowling (GNS Science Ltd)

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This section summarises modelling undertaken over a three-week period to further explore local salinisation risk associated with pumping from the upper Waiwhetu aquifer at or around well E8. This further modelling work utilised the existing HAM4 model described in previous chapters and comprised an analysis of the uncertainty associated with model outputs, which underpin recommendations made in the previous chapters.

The following analysis exercises two assumptions:

1. That the vertical migration of brackish water from the lower Waiwhetu aquifer to the upper Waiwhetu aquifer, in response to the reversal of the natural (downward) hydraulic gradient following abstraction, constitutes the critical salinisation risk to the upper Waiwhetu aquifer at E8; and
2. That the source of brackish water observed in the lower Waiwhetu aquifer at E8 is the “active” ocean (i.e., saline water originates from the lateral ocean/aquifer boundary located in the harbour heads, or from the overlying ocean/aquifer boundary), rather than connate water originating from the harbour sediments. This is because the source of brackish water is presently unknown, and initial modelling showed that the brackish water observed at E8 can be simulated as originating from a lateral or overlying ocean/aquifer boundary when taking into account the uncertainty in aquifer and boundary properties alone.

Proposed modelling approach

A “hypothesis testing” modelling approach (Dausman et al. 2010) was proposed to test whether the salinisation risk was credible. The proposed analysis for the HAM4 model involves the following steps:

i. Significantly increasing the parameterisation detail of the HAM4 model to allow for the uncertainty associated with model parameters (and therefore predictions made by the model) to be expressed more completely. The need to represent and express the uncertainty of prediction-salient spatially and temporally variable parameters is well established (Hunt et al., 2007). Without this enhancement in parameter detail, the predictive uncertainty of the HAM4 model would be significantly underestimated, thereby precluding robust descriptions of risk.
ii. Undertake model calibration (or “history matching”) using available field observations (herein referred to as the “Base Calibration”). The available field observations included head, salinity and river leakage flux data.

iii. Undertake a subsequently model calibration (in addition to the Base Calibration) using the above-mentioned field observations, as well as an additional "observation" corresponding to a hypothesised prediction of interest (herein referred to as the "Hypothesis Calibration"). The additional "hypothesis observation" in this case is a salinity observation exceeding an acceptability threshold at E8, following abstraction at a given rate for a given number of months. More specifically, the hypothesis under investigation was: The salinity in the upper Waiwhetu aquifer at E8 will exceed the acceptability threshold of 0.45 (1% seawater derived from 250 mg/L Cl) following abstraction at a rate of 15 ML/d for period of 6 months.
iv. Evaluate the degree of parameter reasonableness (or lack thereof) resulting from the Hypothesis Calibration as to determine whether or not the salinisation hypothesis can be rejected or not with a certain degree of confidence. The hypothesis cannot be rejected if both the parameter values remain credible and the model can reproduce both the existing field data and the "bad" prediction.
v. Repeat steps (ii) to (iv), using the method outlined in Moore et al. (2010) and/or Moore et al. (2014), for a range of parameter realisations, so that the likelihood of the tested hypotheses can be explored by assessing the tension between parameter credibility and fitting observations.

However, this formal analysis described above, was not possible using the current model, for the reasons explained below. Instead, the analyses undertaken allowed the current model's capabilities and limitations in the context of quantification of a local risk of salinisation to be clarified. We provide recommendations to overcome these limitations, so that a formal analysis is possible are described below.

Model calibration and uncertainty analyses were conducted through application of state-of-the-art software package PESTPP-IES (White, accepted for publication; https://github.com/dwelter/pestpp/). PESTPP-IES combines the industry-standard PEST (Doherty, 2016; http://www.pesthomepage.org/) and PESTPP (Welter et al. 2015; https://github.com/dwelter/pestpp/) suites with a new iterative ensemble smoother form of the industry standard Gauss-Marquardt-Levenberg algorithm. PESTPP-IES conducts parameter estimation (calibration) on the basis of an ensemble of random parameter realisations. As a result, it simultaneously performs calibration and uncertainty analysis.

The entire workflow was performed using the Python scripting language together with the following specialised packages: flopy (which supports all MODFLOW-based models, including SEAWAT; Bakker et al., 2016; https://github.com/modflowpy/flopy), pyemu (White et al., 2016; https://github.com/jtwhite79/pyemu). This allows for the experimentation undertaken to be entirely reproducible.

Results and findings

The major findings and results of the work undertaken are summarised below.

1. *Step (i): Increased parameterisation detail*
   Spatially distributed pilot-point parameters were assigned for aquifer hydraulic conductivity (horizontal and vertical) and effective porosity at a 3-cell-spacing (300 m) in model layers (5-10; top of upper Waiwhetu-bottom of lower Waiwhetu) where heterogeneity is most salient to the risk under investigation. A total of 10,674 adjustable (i.e., "uncertain") parameters were included in the analysis, including general-head boundary stages and conductances,

constant-head boundary stages, storativity distributions, dispersivity, in addition to those mentioned above.

2. *Step (ii): Base Calibration*.
   The modelling approach outlined above was unable to be progressed beyond step (ii). Instead, analyses based on the outcomes of this step were used to clarify the current model's capabilities and limitations in the context of quantification of a local risk of salinisation. Suggestions to overcome these limitations are described in the Recommendations section below.

   Model instability. The first challenge encountered (during the early stages of running the parameter ensembles) was the high degree of numerical instability. The vast majority of runs failed to converge, particularly during the course of parameter updating. While convergence failures are not unexpected when sampling wide portions of large-scale groundwater model parameter space, the proportion of such failures for this model was significant and prohibitively high for the proposed calibration/uncertainty quantification work.

   Model run times. Another challenge encountered was excessive model run times. On average, model run times were approximately 24 hours, with some exceeding 30 hours. The need to perform many (thousands of) runs for calibration/uncertainty analysis purposes poses a significant limitation to utility of the model in this context. Such run times leaves much less time for necessary model testing and improvements to be made during the course of the modelling process.

   These two factors – numerical instability and excessive model run times – significantly compromise the model's ability to provide a robust basis for quantifying uncertainty (which inherently involves many model evaluations with different parameter sets), and therefore restrict its ability to be used in a formal risk assessment and uncertainty quantification context such as that of the current modelling approach. This is primarily because the HAM4 model simulates far more than is required to explore this risk. It is important to note that these factors do not pose a constraint to the main body of HAM4 modelling above.

   Model structure challenges indicated by stochastic calibration*.* Figure 1 shows model-to-measurement misfit for head and salinity observations. Grey vertical lines depict the prior (i.e., pre-calibration) parameter ensemble (made up of 44 realisations; the remaining 66 realisations did not converge). Blue lines depict the posterior (i.e., post-calibration) parameter ensemble (made up of 22 realisations; the remaining 22 realisations failed during parameter upgrading). Despite the relatively low observation weights that were assigned to head observations, a clear improvement in the fit to head data is evident.

   Lack of fit to the salinity observations. For the salinity observations, the prior ensemble spans the measured values. That is, pre-calibration parameter realisations collectively capture observed salinity values (illustrated by the grey line crossing the dashed 1:1 line). During the calibration process, the fit to lower (<0.5) salinity observations is improved (including in the upper Waiwhetu at E8). However, at the same time, the fit to the salinity observation in the lower Waiwhetu at E8 is significantly diminished. This indicates that there exists a tension between the model's ability to match the observed salinity in the upper Waiwhetu and the observed salinity in the lower Waiwhetu aquifer at E8. That is, the model cannot simultaneously fit the upper and lower aquifer salinities at E8. This result was also validated by a number of forward model runs under different scenarios, which showed that nearly identical simulated salinities exist in the upper and lower Waiwhetu aquifer at E8 for all cases. The significance of this finding is discussed later.

It should be noted that the model is also unable to simultaneously fit salinity observations in the upper Waiwhetu and Moera aquifers at E3. The model therefore demonstrates a general inability to replicate observed vertical salinity differences across model layers representing aquitard units (potentially over a scale of only several metres). This occurs despite the significant levels of variability in aquifer property fields present across the model realisations, some of which would be expected to promulgate an increased vertical salinity difference, and hence a better fit to both the upper- and lower-aquifer salinities overall.

The model's inability to simultaneously match the vertical variations in salinity observations, is considered to relate to two main factors. The first is numerical dispersion, caused by coarse grid cells within the aquitard separating the upper and lower Waiwhetu aquifer and within each of these aquifers; specifically, additional model layers within the aquitard are required if the vertical concentration gradient is to be represented. This effectively precludes the simulation of sharp vertical concentration gradients. Such numerical dispersion will result in a general overestimation of salinisation risks, and overwhelm the simulated salinity changes in response to abstraction. Numerical dispersion is a widely recognised mass transport modelling issue arising from coarse grid cell sizes. While coarse grids are often necessary from a computational point-of-view when modelling large systems, this often compromises finer-scale predictive capabilities, such as in the present case of vertical salinity gradients.

The second reason for the failure of the model to reproduce vertical salinity differences may also indicate that the model contains some structural defects (i.e., "conceptualisation errors"). These errors may relate to the conceptualisation of the hydrological and geological conditions that underpin the lateral aquifer/ocean model boundary condition (which are complex and unknown; hence, they can only be represented in the model in an abstract manner). The identification of such conceptual-model errors, and an improved system conceptualisation is likely to depend on further targeted data collection strategies.

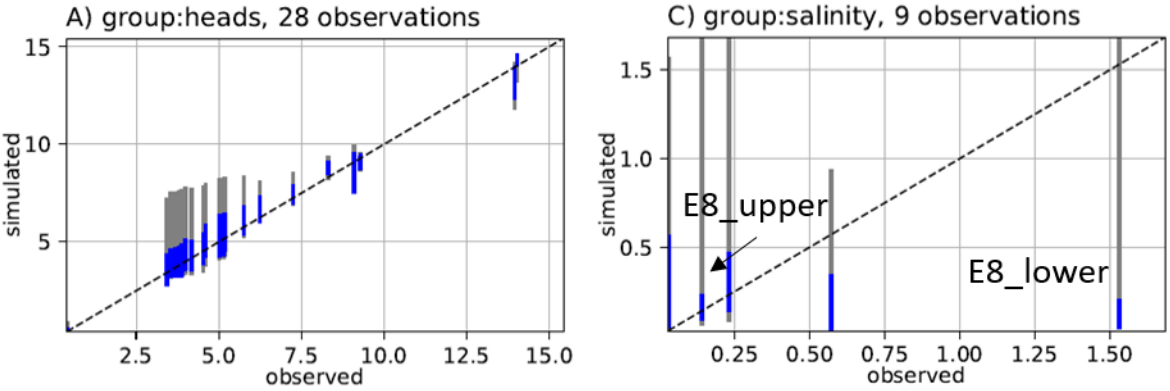

Figure 1. Model-to-measurement scatterplots and residual plots for (a) head and (c) salinity data. Grey vertical lines depict the prior (i.e., pre-calibration) parameter ensemble; blue lines depict the posterior (i.e., post-calibration) parameter ensemble. The dashed line depicts zero misfit.

Following these results, a number of additional Base Calibrations were undertaken with higher observation weights placed on E8 salinity observations (upper and lower Waiwhetu), and with varying parameterisation details. This was targeted at testing whether or not it was possible to simultaneously match salinity observations in the upper and lower Waiwhetu aquifer at E8.

All attempts to improve the fit in both the upper and lower Waiwhetu ultimately failed. This is despite the fact the observation weights ensured that the calibration objective function is initially dominated by salinities at E8. In fact, zero parameter upgrades were successful in reducing the mean ensemble objective function among the trials with higher weights on E8 observations. The prior ensemble results from the series of tests conducted are similar to those shown in Figure 1.

3. *Summary of results and findings*

In summary, it appears that it is not possible to reproduce the observed vertical salinity differences at E8 (i.e., high quality water in the upper Waiwhetu and brackish water in the lower Waiwhetu) with the existing form of the HAM4 model. Unfortunately, this is a critical finding in the context of the salinisation risk being investigated. The observed salinity data in the upper and lower Waiwhetu aquifer at E8 constitute the most valuable and risk-salient information available. The fact that the model is unable to match these observed salinities ultimately means that it cannot be used as a basis for quantifying risk, nor to test the hypothesis of salinisation of the upper Waiwhetu aquifer at E8 in response to abstraction. Furthermore, the hypothesis that the upper Waiwhetu aquifer at E8 will become salinised in response to abstraction cannot be rejected on the basis of the current modelling.

Some comments on the HAM4 model. Despite its attempts to simulate many complex aspects of groundwater flow in both source and discharge areas, the HAM4 model has been shown to be unable to reproduce some important phenomena, including some that are highly relevant to the primary salinisation threat, namely the existence of brackish water in the lower Waiwhetu aquifer and its absence in the upper Waiwhetu aquifer. However, this should not be construed as criticism of the HAM4 model and the abstraction scenarios presented in the main report (see below a recap of the objectives of the HAM4 model, and its contribution to an improved understanding of potential salinisation mechanisms and regional-scale abstraction impacts). It simply recognises the problems that the model faces in simulating complex flow and transport conditions over a large model domain in general, and in complex outflow areas, in particular. It also constitutes recognition of the fact that a single model simply cannot do all things, and that purpose-driven, prediction-specific models are required for exploration and understanding of local processes that a regional model can represent only in an approximate fashion (see Recommendation section for more on this). The key processes and parameters governing the upward advection of salt from the lower Waiwhetu to the upper Waiwhetu are expected to operate over significantly smaller scales than can possibly be resolved with a regional-scale model such as HAM4.

The HAM4 model was designed to explore the veracity of the offshore aquifer/geological conceptualisations and evaluate a range of potential salinisations risks and regional-scale responses to abstraction in terms of drawdown and salinity distributions. It was also designed to be a “whole-system” model recognising that onshore and offshore systems are intimately associated and that onshore stresses (i.e., recharge and abstraction) need to be considered in a risk assessment. The HAM4 model has also been successful in exposing potential salinisation risk mechanisms (i.e., from the lateral ocean/aquifer boundary and from connate water in the western side of the harbour). However, HAM4 was not designed solely for the purposes of a detailed and localised assessment of the risk of salinisation from upward salt migration in response to abstraction.

Recommendations

Considering the limitations of the HAM4 model discussed above, and considering the outstanding need for a robust risk assessment of potential water supply resource salinisation (following upward advection from the brackish lower Waiwhetu aquifer), the following outline for future work is recommended.

It is recommended that a “streamlined”, prediction- and decision-targeted modelling approach is adopted. This approach would be designed specifically from the outset to be able to quantify risk and test (and potentially reject with some level of confidence) the hypothesis that the upper Waiwhetu aquifer will become salinised from upward flow of the brackish water in response to abstraction. The ability of a model to quantify risk is a prerequisite to satisfy its role in providing decision-making support (Freeze et al., 1990; Doherty and Moore, 2017). A simpler, smaller-scale, fast-running model such as the one being proposed here (described below) would allow rapid exploration of the risk associated with abstraction from E8. Unfortunately, the undertaking of such a modelling approach was not possible given the time constraints present during the course of the project.

The recommended modelling approach would focus on simulating aspects of the system that are central to the specific risk under investigation in sufficient detail. This would include reliable simulation of the rate at which salt travels from the lower Waiwhetu to the upper Waiwhetu in response to abstraction, which will depend on the extent of local drawdown and the vertical hydraulic conductivity of the intervening aquitard. This would also include reliable simulation of the mixing of the brackish water transported from below with the large amount of freshwater being drawn horizontally to the abstraction well through the upper Waiwhetu aquifer.

The model would also provide a basis for exploring the following factors (among others):

- local hydraulic property variability both of the aquifer and underlying aquitard;
- extent of lateral continuity of the aquitard, and/or of holes in the aquitard;
- impact of different rates of extraction from the upper Waiwhetu aquifer;
- relative risks of pumping impacts at 1 month, 6 months, 12 months, etc.

It would also possess a greater flexibility to assess alternative abstraction scenarios such as whether pumping takes place from one of a number of wells (the latter scenario presumably reducing local drawdown and hence upward salt movement).

Some additional points related to the proposed modelling strategy are as follows:

- Such a model would need to have relatively simple boundary conditions as its task would be to simulate possible salt movement in close proximity to the extraction well, which is located a reasonable distance from the model’s boundaries. However, prediction-salient aspects of the model would need to be as representative of local conditions as possible (and where available gleaned from the HAM4 model). This includes the amount of water that flows through (horizontally) the upper aquifer. (The ratio of through-flow to extraction is likely to have a profound effect on the spread of the cone of depression towards outflow areas, and on dilution of brackish water flowing upwards in response to pumping.) Regional-scale (i.e., beyond the scale of the model domain) system details and responses to abstraction would be informed by the HAM4 model through updating boundary condition (e.g., Sreekanth and Moore, 2018).

- The model need only include the representation of two (or possibly three) geological units, namely the upper Waiwhetu aquifer, the aquitard below it and (possibly) the lower Waiwhetu aquifer. Each of these should be represented by numerous model layers to mitigate numerical dispersion issues. The lower Waiwhetu aquifer layer could potentially be represented adequately as a boundary condition (head and concentration) rather than as an explicitly simulated layer (thereby enhancing execution speeds).
- The model may not necessarily need to account for the effects of density differences on flow. Use of MT3DMS instead of SEAWAT in this way would allow for significant improvements in run times. However, this would need to be tested.

The proposed model would be detailed enough to simulate at fine spatial and temporal resolutions the ~12-hour pumping test that has already taken place (or a potential longer-term pumping test), and, through calibration against any information that is available from that test, draw some inferences on local hydraulic properties. It therefore provides an enhanced potential for the uncertainty of model predictions to be reduced based on the utility of such information.

A final remark: an example and potentially critical caveat to any numerical modelling

It is important to appreciate that, regardless of the groundwater modelling approach adopted to explore salinisation risk in Wellington Harbour, a significant assumption needs to be made: that there are no structural changes to the subsurface during or following an earthquake (i.e., no change in the aquifer permeability field as a result of earthquake is assumed). Violation of this assumption alone may be enough to nullify the outcomes and recommendations made based on any numerical groundwater modelling.

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