Environmental Effects of On-Site Sewage Management in Glenorchy

Stage 2: Investigations

QLDC

September 2018

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Document Status

Version	Purpose of Document	Prepared By	Reviewer	Review Date
A	Draft for internal review	AB	GD	14/07/2018
B	Final Draft	AB	GD	16/07/2018
C	FINAL	AB	GD/UG	7/09/2018

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Executive Summary

e3Scientific Limited (e3s) was commissioned on behalf of QLDC to provide an assessment of the impacts of on-site sewage management systems on soil and water quality within the township of Glenorchy. e3s previously completed a desktop assessment of the available information and identified further investigations required to adequately assess the environmental effects of on-site sewage management in Glenorchy (e3Scientific Ltd, 2017). The investigations have been completed and are detailed in this report.

To investigate the impacts of on-site sewage management, e3s established a surface and groundwater monitoring network using existing monitoring locations and four new piezometers. These locations were surveyed and water levels monitored to determine the direction of flow paths and hence the receiving environment for septic tank effluent. Three rounds of water quality sampling were completed at 8 groundwater sites and 7 surface water sites in spring, summer and autumn. In addition, an ecological assessment of the lake margins and lagoon was completed in conjunction with the summer sampling. The ecological assessment has been reported in a stand-alone report (e3Scientific Ltd, 2018), and its findings incorporated into this assessment.

The hydrology of the Glenorchy township is complex. Contrary to previous groundwater and landfill investigations, water level monitoring and surveys have provided evidence that groundwater flows from the north, east and south beneath the township towards Lake Wakatipu. Groundwater is recharged from the Lagoon outflow/Rees River and flows south-west beneath the township towards Glenorchy Jetty and Harbour in Lake Wakatipu. Rainfall also flows off the Richardson Mountains and recharges groundwater flowing west beneath the township towards Lake Wakatipu. Finally, groundwater is also recharged from the Buckler Burn and flows north-west beneath the township towards Lake Wakatipu.

Consequently, on-site sewage management in Glenorchy affects firstly groundwater, and then Lake Wakatipu, which is the receiving environment for groundwater from below Glenorchy Township. Oxygen rich recharge waters from rainfall and surface water are depleted of oxygen as they flow beneath the township. Septic tanks provide additional inputs of organics and reduced forms of nitrogen, which promote further reduction of iron oxides and sulphates on the flowpath between the Rees River and Glenorchy Jetty, where the groundwater is shallowest and there is the greatest concentration of high risk septic tanks present in the township. This highly reduced, iron rich groundwater discharges into Lake Wakatipu near the Glenorchy Jetty, resulting in significant deposition of iron oxides. Groundwater flowing from the east and south towards Glenorchy Harbour is not as reducing, and therefore some nitrates and sulphates remain in the groundwater and there is less iron (no noticeable iron deposition). This may be due to less high-risk septic tanks present over the southern half of the town and consequently less organics leaching to groundwater.

e3s previously estimated that the nitrogen loading from septic tanks to Lake Wakatipu could be as high as 691 kg/year (e3Scientific Ltd, 2017). Based on the measured nitrogen concentrations in groundwater and surface water, and groundwater gradients across the township, a revised estimate of nitrogen flux has been calculated ranging from 1243 - 1264 kg N/year from groundwater into Lake Wakatipu. The reducing groundwater chemistry along the northern foreshore of Glenorchy decreases the nitrogen loading impact of septic tanks on the receiving environment of Lake Wakatipu, however the loading on the southern foreshore is likely to be much higher. The impacts of septic tanks on the main receiving environments in Lake Wakatipu are summarised below:

Location	Hydrology	Water Quality	Ecology (e3Scientific Ltd, 2018)
Glenorchy Harbour	Receives groundwater discharge. Sheltered harbour results in poorly mixed waters.	Total nitrogen exceeds ORC (2016) Schedule 15 good water quality targets for Lake Wakatipu for Total Nitrogen, NH_4-N and *E.coli*. Manganese and iron concentrations are also elevated.	There is evidence of current seasonal surface water quality degradation within the harbour that, based on the limited historical data available, may also be declining annually.
Glenorchy Jetty	Receives groundwater discharge and well mixed due to flows from the Rees River and large exposed areas subject to wind waves.	Septic tank inputs have induced or exacerbated a highly reducing groundwater environment which discharges into Lake Wakatipu between Glenorchy Harbour and the Rees River outlet, resulting in iron deposition.	Macroinvertebrates diversity and abundance is decreased in the area of iron deposition, and there are indications that the longevity of benthic dwelling fish may be limited in this area. Macrophyte communities located entirely within the iron deposition area suffered morphological iron toxicity symptoms

1 Introduction

Glenorchy Township is located on a river delta at the head of Lake Wakatipu (Figure 1). The township is bordered by the lake to the west and old river terraces at the foot of the Richardson Mountains to the east. The Glenorchy Lagoon and Rees River lie to the north and to the south the Buckler Burn River define the township's natural boundaries. Queenstown Lakes District Council (QLDC) commenced investigations into the provision of a reticulated sewerage scheme for Glenorchy in 2005. Both QLDC and Otago Regional Council (ORC) propose to implement the sewerage scheme in order to:

- "Improve levels of service to the community", and
- "Improve environmental conditions in terms of water quality and risks to water supplies (QLDC, 2015)"

As the adoption of a reticulated sewerage scheme for the community will impact the ratepayers of the Glenorchy township and surrounds, RCP commissioned e3Scientific Limited (e3s) on behalf of QLDC to provide further assessment of the impacts of on-site sewage management systems on soil and water quality within the township of Glenorchy. e3s completed a desktop assessment of the available information and identified further investigations required to adequately assess the environmental effects of on-site sewage management in Glenorchy.

NZ Property Titles, NZ Road Centre line (Electoral), NZ River Polygons (Topo, 1:50k), NZ Lake Polygons (Topo, 1:50k), NZ River Centrelines (Topo, 1:50k) sourced from the LINZ Data Service http://data.linz.govt.nz/ and licensed by LINZ for re-use under the Creative Commons Attribution 3.0 New Zealand licence.
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Figure 1: Glenorchy Township and Monitoring Network

1.1 Scope of Work

This scope of works is based on recommendations of e3s desktop assessment (e3Scientific, 2017):

1. Site visit to assess locations for monitoring piezometers, locations of existing piezometers and surface water/ecology sampling locations.
2. Installation of four groundwater monitoring piezometers- coordination of drilling works, logging and drilling supervision.
3. Water level survey of the Lake, Lagoon, Rees River, Buckler Burn and groundwater levels i.e. survey piezometer reference points in the new monitoring network and survey datum points for ongoing measurement of surface water levels at the jetty, Lagoon Bridge and in the Rees River.
4. Installation of three continuous water level loggers in the monitoring piezometers to capture water level fluctuations and any changes in flow paths due to flows and rainfall.
5. Coordinated surface water and groundwater quality sampling program using the newly established groundwater monitoring network and strategic surface water locations
6. An ecological assessment of the lake margins and lagoon during the summer months
7. Reporting – This report is one of two reports provided to document the investigations completed and analysis of all the data collected: 1) Ecological Assessment of the Lake Margins and Glenorchy Lagoon, and 2) Assessment of Environmental Effects of On-Site Sewage Management in the Glenorchy township.

1.2 Limitations

The findings of this report are based on the Scope of Work outlined above. e3Scientific Limited (e3s) performed the services in a manner consistent with the normal level of care and expertise exercised by members of the environmental science profession. No warranties, express or implied, are made. The confidence in the findings is limited by the Scope of Work.

The results of this assessment are based upon information provided in previous reports, site inspections conducted by e3s personnel and ecological, hydrological and laboratory analytical data collected during the study. All conclusions and recommendations are the professional opinions of e3s personnel involved with the project, subject to the qualifications made above. While normal assessments of data reliability have been made, e3s assumes no responsibility or liability for errors in any data obtained from regulatory agencies, statements from sources outside e3s, or developments resulting from situations outside the scope of this project.

1.3 Report Overview

This report details all of the investigations into the impacts of on-site sewage management on the Glenorchy environment. Section 2 provides the details of the surface and groundwater monitoring network. The methodology for all of the field investigations, including water level measurement, water quality sampling, the ecological assessment and iron deposition mapping is detailed in Section 3, followed by the results in Section 4. This includes the conceptual model devised from the investigation results. Finally, an assessment of the impacts of septic tanks in Glenorchy is completed in Section 5.

2 Water Monitoring Network

To determine the impact of on-site sewage management on the Glenorchy environment, a network of groundwater and surface water monitoring locations was established from which to take samples and measure water levels.

2.1 Overview

The groundwater monitoring network for Glenorchy includes the installation of four new monitoring piezometers, the use of the existing closed landfill monitoring bores and the town water supply bore, as shown in Figure 1.

The aim of the monitoring network is twofold:

1. Clarify the groundwater flow dynamics. Groundwater level data collected from the monitoring network will confirm the groundwater flow direction and thus the direction of contaminant transport. As there are significant surface water features surrounding the township of Glenorchy, it is important to understand where contaminants will move, and how this might change with lake level fluctuation.
2. Provide access points to sample groundwater quality, and thus determine the impacts of on-site sewage management on groundwater. It is important that both upgradient or baseline water quality is determined in addition to water quality both downstream and in the zone of potential contamination.

A brief summary of the rationale of including each of the bores in the monitoring network is provided in Table 1. All of the locations provide valuable information as to groundwater flow directions. Some of the bores were not included in the original proposal for the groundwater monitoring network, and this has been specified in the table.

Table 1: Monitoring Bore Network & Rationale

Piezometer/ Bore	Easting# (NZTM)	Northing# (NZTM)	I.D. (mm)	Final Depth (m.b.g.l.)	Screen Interval[1] (m.b.g.l)	Reference Point	Elevation of Reference Point#	Reason for inclusion
P1	1235134.41	5023214.41	25	10.1	2.1-10.1	Top of HDPE casing	311.15	Between township and Lake Wakatipu – measure contaminant transport between township and lake
P2	1235510.34	5023479.39	25	10.2	2.2 – 10.2	Top of HDPE casing	314.09	Between township and Lagoon – assessing flow directions.
P3	1235260.17	5023605.82	25	10.0	2.0-10.0	Top of HDPE casing	311.3	Between township and Rees River/Lagoon outlet. Important for understanding flow dynamics and potential contamination of Rees/Lagoon outlet
P4	1235380.41	5023305.97	25	10.0	2.0-10.0	Top of HDPE casing	314	Centre of township to assess contamination directly below source
MW1*	1235960.9	5023085.13	50	9.82	?	Metal well head	318.89	Landfill bore – included to account for any ongoing contaminant contribution from the closed landfill.
MW2*	1235829.74	5023245.55	50	7.74	?	Metal well head	316.55	Within township source, but assumed upgradient of centre of town
MW3*	1236200.17	5023105.38	50	15.4	?	Metal well head	324.27	Baseline water quality. Upgradient of township
Town water supply (E41/0100)	1235910.8	5022529.1	250	23.1	20.83 -?	Lid level	323.8	Baseline water quality, upgradient of township also important for supply of township. Community wishes to include.

#Surveyed by Aurum based on Dunedin Datum November 2017. Measurements were taken with GPS, estimated accuracy +/- 0.05m.

*Construction details could not be obtained for the landfill monitoring bores. The depth of the bores was measured 30 Nov 2017 from the top of the reference point.

[1] The large screen interval was installed to ensure the range of water levels could be captured, based on recorded water levels for the landfill monitoring bores. Further analysis has identified errors in the recordkeeping that indicate the range is not as large as previously thought. See Section 4.2.1.

Table 2: Surface Water Monitoring Locations

Location	Easting NZTM	Northing NZTM	Reference Point	Reference Elevation	Reason for inclusion
Glenorchy Jetty[1]	1235048	5023160	metal plate	311.44	Reference water level, location of heavy iron deposition
Glenorchy Harbour	1235178	5023092	-	-	Area of poorly mixed water with stormwater inputs adjacent to township
Rees River	1235124	5023562	Top of stake installed for project	310.64	Mixed water quality from lagoon and Rees River inlet, location close to township. Determine source or discharge for groundwater
Lagoon bridge	1235624	5023807.5	Metal side support base	311.99	Outlet from lagoon to determine potential for inputs from lagoon to groundwater
Buckler Burn (adjacent to town water supply)	1235872	5022472	Water Level	321.5	Potential source of groundwater. Represents control water quality away from township
Lagoon East Arm	1236046	5023854	-	-	Area of lagoon appears subject to less mixing after ecological assessment and potential source of groundwater
Upstream Lagoon Bridge	1235991	5024164	-	-	Water source upgradient of both Lagoon Bridge and Lagoon East Arm.

[1] Initially only included to measure lake water levels, however a sample was collected for Round 3.

2.2 Piezometer Installation

Piezometers P1-P4 were installed by Van Walt on 30-31st October 2017 using the lost cone method. All new piezometers were installed on council road reserve. Using this method, samples can only be obtained for the finer sediments. Once the alluvial gravels were intersected, no further sample could be obtained. The bore logs for each of the piezometers are included in Appendix A:. Each piezometer was constructed of 25 mm internal diameter (I.D.) HDPE covered with a filter sock, slotted from 2-10 m below ground level. At each site the screen depth was intended to intersect the gravel aquifer. It is noted that the screen is slightly below the water table depth at two of the sites (P1 & P3).

3 Field Investigations

3.1 Water Level Measurement

Water level measurement was completed to assess the flow paths around the Glenorchy township i.e. to understand the sources of recharge to groundwater and the receiving environment for groundwater discharge. Aurum were commissioned to survey piezometer reference points in the new monitoring network and survey datum points for ongoing measurement of surface water levels at the Glenorchy Jetty, Lagoon Bridge and in the Rees River. A water level measuring staff was temporarily installed for the duration of the project in the Rees River channel bank sediments which was surveyed by Aurum. Due to the high velocities and coarse grained sediments of the Bucker Burn, no staff was installed there and Aurum provided a single water surface elevation measurement. This survey was completed 14th November, 2017 based on the Dunedin Datum using a GPS, estimated accuracy +/- 0.05m.

Groundwater and surface water levels were measured four times during the assessment period using a dip meter, once during each sampling event and in mid-November during a site visit. Pressure transducers logging at 15 minute intervals were deployed in P1, P3 & P4 along with a barometric pressure logger from November - April 2018. Data was compensated for barometric pressure and converted to standing water levels using dip measurements.

3.2 Water Quality Sampling

3.2.1 Data Quality Objectives

The data quality objectives (DQOs) of the water sampling included the following:

- Characterise field parameters at each site, such as; pH, temperature, dissolved oxygen (DO), and electrical conductivity (EC);
- Assess levels of metals and major ions; and
- Investigate nutrient concentrations, such as; *Escherichia coli* (E. coli), nitrogen, ammoniacal nitrogen, nitrites, nitrates, phosphorus and dissolved organic carbon (DOC).

3.2.2 Water Quality Sampling Methodology

Three rounds of water quality sampling were completed:
Round 1: 30th November, 2017 (Spring)
Round 2: 22nd January 2018 (Summer)
Round 3: 18th April 2018 (Autumn)

Groundwater quality samples were collected using low flow sampling methodology with a peristaltic pump or a bladder pump. Prior to commencing pumping, standing water levels were measured in each piezometer, and were measured during pumping to ensure that pumping was not causing drawdown within the well. Drawdown did not exceed 0.01 m at any time. Tubing was lowered to below the top of the screen at each well (this had to be assumed at the landfill monitoring wells as there was no construction record, therefore the tubing was lowered to approximately the middle of the water bearing zone). New tubing was used for each sample.

Field parameters (pH, EC, T, DO, ORP) were measured using a calibrated YSI water quality meter at each site. Samples were collected after field parameters had stabilised to within 5% of the previous three measurements. Field filtering for metals analysis was completed for Rounds 2 & 3 of sampling, and was completed at the laboratory for Round 1.

Surface water quality samples were collected at each site using a sterile container to fill each of the sampling containers.

3.2.3 Analytical Parameters

All water quality samples were analysed for major ions (calcium, magnesium, potassium, sodium, alkalinity, chloride and sulphate), boron, bromide, redox sensitive species (iron, manganese) and nutrients (Nitrogen and phosphorous species), dissolved organic carbon and *E.coli*.

3.2.4 Water Quality Sampling Field and Laboratory QA/QC

The field QA/QC procedures performed during the water quality sampling are listed as follows:

- New tubing was used for pumping at each well to prevent contamination between sites;

- Field personnel wore a fresh pair of nitrile gloves between sampling events.
- Water samples were collected in bottles supplied by Hill Laboratories appropriate to the parameters to be analysed.
- Use of standardised field sampling forms and methods;
- Samples were transferred under chain of custody procedures;
- All samples were labelled to show point of collection, project number, and date;
- All samples were stored in a cooled chilly bin containing ice while in the field.
- A field duplicate was collected for quality assurance purposes during Round 1 & 3.

All water quality samples were couriered to Hill Laboratories within a day of collection. Hill Laboratories are accredited by IANZ. Hills conduct internal QA/QC in accordance with IANZ requirements.

3.2.5 Guideline Values

Currently there is no single set of aquatic life protection guidelines that evaluate the range of analytes and field parameters in this study. Therefore, it was deemed necessary to utilise five sets of guidelines (both National and International) to evaluate the surface water quality results. Aquatic species protection guidelines were primarily applied, when available. Guidelines cited are listed below:

1. The National Water Quality Management Strategy for Australia and New Zealand (ANZECC, 2000).
    a. Guidelines for Trigger Values for high value freshwater systems (99% species protection); and
    b. Guidelines for Recreational Values.
2. The Water Quality Guidelines for the Protection of Aquatic Life (Canadian Council of Ministers of the Environment, 2001).
3. The effects of Dissolved Oxygen on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage (Carter, 2005).
4. Aquatic ecosystems Total Dissolved Solids tolerance (Boyd, 1999).
5. Schedule 15 of the Regional Water Plan (ORC, 2016) specifies receiving water limits for nitrate-nitrite nitrogen, NH_4-N, *E.coli* and turbidity as targets for achieving good quality water and require 80% of samples collected when flows are at or below median flow over a rolling 5 year period to be

below the limits specified. Tributaries into Lake Wakatipu are to meet Receiving Water Group 3 limits and Lake Wakatipu is to meet Receiving Water Group 5 limits. Note that only the Glenorchy Harbour and Glenorchy Jetty are compared with the Receiving Group 5 limits. While not a tributary of Lake Wakatipu, groundwater has been compared with the Receiving Water Group 3 limits as it discharges into Lake Wakatipu.

3.2.6 Summary

Following the receipt of laboratory data, a detailed review of the data was performed to determine its accuracy and validity. All laboratory data were checked for analytical and typographical errors. Once the data quality was established the water quality data was checked against the Sampling Program DQOs.

3.3 Ecological Assessment

The ecological assessment of the Lake Wakatipu margins at Glenorchy and Glenorchy Lagoon was designed based on the findings of the Stage 1 desktop study completed in June 2017 (e3Scientific Ltd, 2017). The aim of the assessment was to provide a representation of the current state of the freshwater ecological habitats adjacent to the Glenorchy Township, i.e. both the Glenorchy lake margins and Glenorchy Lagoon. The assessment was completed in conjunction with the Round 2 summer sampling (20th – 22nd January) and included

- Fish and macroinvertebrate assessment
- Macrophyte assessments
- Interpretation of the three rounds of surface water sampling

The full methodology, results and discussion surrounding the ecological assessment has been documented in a separate report (e3Scientific Ltd, 2018) and has been used to inform the discussion regarding the impact of on-site sewage management on the Glenorchy environment.

3.4 Iron Deposition Mapping

Iron oxide precipitation was observed within the lake margins during the spring sampling event. Given the high concentrations of iron in groundwater in P1 and P3, the deposition provides evidence for the discharge of iron-rich groundwaters along the foreshore. The extent of the iron deposition was mapped using a handheld GPS during the summer sampling event (January 2018) by walking the length of the lake foreshore at Glenorchy and making visual observations.

4 Investigation Results

4.1 Climate Conditions During Monitoring Period

Rainfall data was downloaded from NIWA for Routeburn Station (ID 5154), situated 12 km west-north-west of Glenorchy township along the Dart River. Rainfall for each month is presented along with means for each month for the period 1999-2018. Rainfall between October 2017 to January 2018 was significantly below average (304 mm compared to the mean of 804 mm), followed by above average falls during February to April 2018.

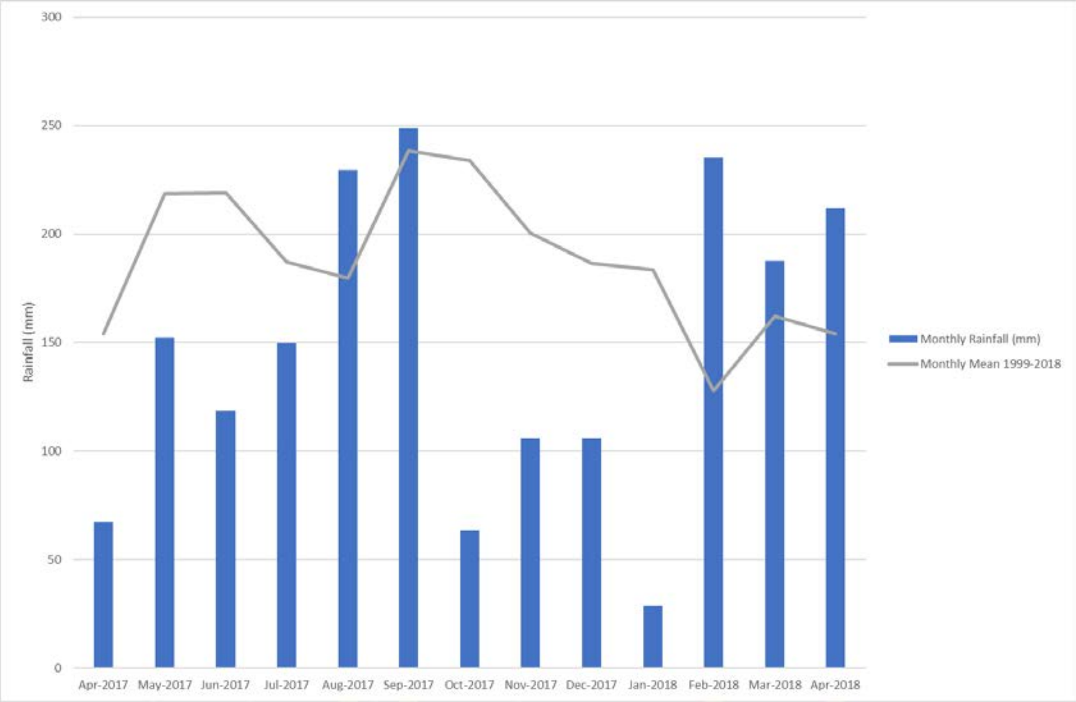

Figure 2: Rainfall at Routeburn Station (NIWA Station 5154)

4.2 Water Levels

4.2.1 Historic Water Level Monitoring

Standing water levels in the landfill monitoring bores 1999-2013 were obtained from QLDC and converted to elevations using the reference elevations obtained from the Aurum survey. The data indicates some erroneous record keeping, with data attributed to MW1 that is likely for MW2 and vice versa[i], and unlikely

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[i] The data indicated large unlikely flow reversals and fluctuations of up to 4 m over three months. When the data points were swapped, no flow gradients were consistent.

anomalies in the data based on relative water levels. This is most obvious in periods around 2003 and 2004. Record-keeping appears to have improved after 2010 with all of the data presenting a more expected trend. This later data has been plotted in Figure 3 along with the monthly rainfall for this period. This data demonstrates that the water level elevations at MW1 and MW2 are generally quite similar, with the gradient between the two sites reversing at times. Consequently, MW2 does not represent down gradient impacts of the landfill. During periods of lower rainfall (early-mid 2012), the gradient between MW3, MW1 and MW2 reduces, thus flow towards Lake Wakatipu is also likely to reduce.

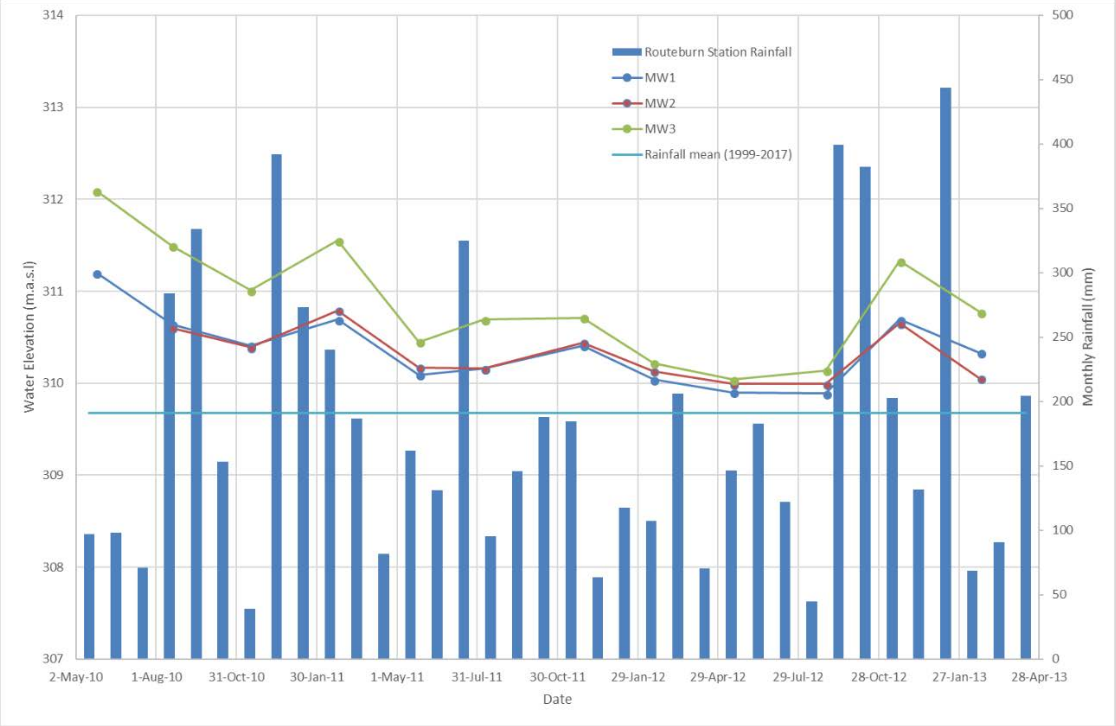

Figure 3: Water Levels at Landfill Monitoring Bores (Standing water levels obtained from QLDC)

4.2.2 Water Level Monitoring 2017-2018

Groundwater and surface water levels were measured four times during the assessment period using a dip meter, once during each sampling event and in mid-November during a site visit. This data is presented in Table 3, along with water elevations converted using the surveyed reference points (see Table 1). Water elevations from November 2017 are presented in Figure 4 with piezometric contours and groundwater flow directions.

Table 3: Water Level Measurements

Location	SWL (m.b.g)					Water Elevation (m.a.s.l.)			
	13/11/2017	30/11/2017	22/01/2018	18/04/2018	Range (m)	13/11/2017	30/11/2017	22/01/2018	18/04/2018
P1	1.29	1.33	1.43	1.35	0.38*	309.86	309.82	309.72	309.80
P2	3.78	3.87	3.97	3.80	0.19	310.31	310.22	310.12	310.29
P3	0.99	1.07	1.14	1.00	0.51*	310.31	310.23	310.16	310.30
P4	3.93	4.00	4.10	3.90	0.27*	310.07	310.00	309.90	310.10
MW1[#]		8.71	8.83	8.75	0.12		310.18	310.06	310.14
MW2	6.3	6.37	6.5	6.35	0.20	310.25	310.18	310.05	310.20
MW3	13.47	13.6	13.74	13.85	0.38	310.8	310.67	310.53	310.42
Rees stake	0.45	0.41	0.36	0.38	0.09	310.14	310.10	310.05	310.07
Lagoon bridge	0.9	1.06	1.1	0.88	0.22	311.09	310.93	310.89	311.11
Glenorchy Jetty	1.56	1.7	-	1.49	0.21	309.88	309.74	-	309.95

[#] Bore could not be accessed on 13/11/2017 *Range from logger measurements

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Figure 4: Water Level Elevations and Groundwater Flow Directions

The water level in the Buckler Burn adjacent to the location of the town water supply bores (Figure 4) was surveyed at the time of the Aurum survey in November 2017. At that time the water level was 321.5 m.a.s.l. The water level in the town water supply could not be measured due to the bore headworks. The standing water level measured at the time of installation was 10.38 m.b.g., which equates to a water level of 313.42 m.a.s.l if the reference point for the measurement was close to the top of the lid (the reference point surveyed by Aurum in November 2017). Based on this single measurement, it is likely that the Buckler Burn is disconnected from and losing to groundwater.

Pressure transducers logging at 15 minute intervals were deployed in P1, P3 & P4 along with a barometric pressure logger from November - April 2018. Data was compensated for barometric pressure and converted to standing water levels using dip measurements. This data is presented in conjunction with discrete measurements and recorded rainfall from Routeburn Station in Figure 5.

Groundwater is deepest to the west at MW3, and is shallow near the lake edge and Rees River (P1 and P3). Continuous water level measurements in P1 and P3 show rapid responses to rainfall. On 1st February, 2018, 85.5 mm of rainfall was recorded at Routeburn Station. Water levels rose 0.33 m in P1 over 29 hours and 0.47 m in P3 over 20 hours. As these water level rises cannot be purely from rainfall infiltration, there is likely both a pressure response to water level rises in the lake and Rees River, and recharge from both the Rees River and Lake Wakatipu. This is evidenced by a brief period (less than one day) of groundwater flow reversal with groundwater levels adjacent to Lake Wakatipu (P1) higher than groundwater levels in the centre of town at P4. For the rest of the monitoring period, groundwater gradients between P1, P3 and P4 remain reasonably constant.

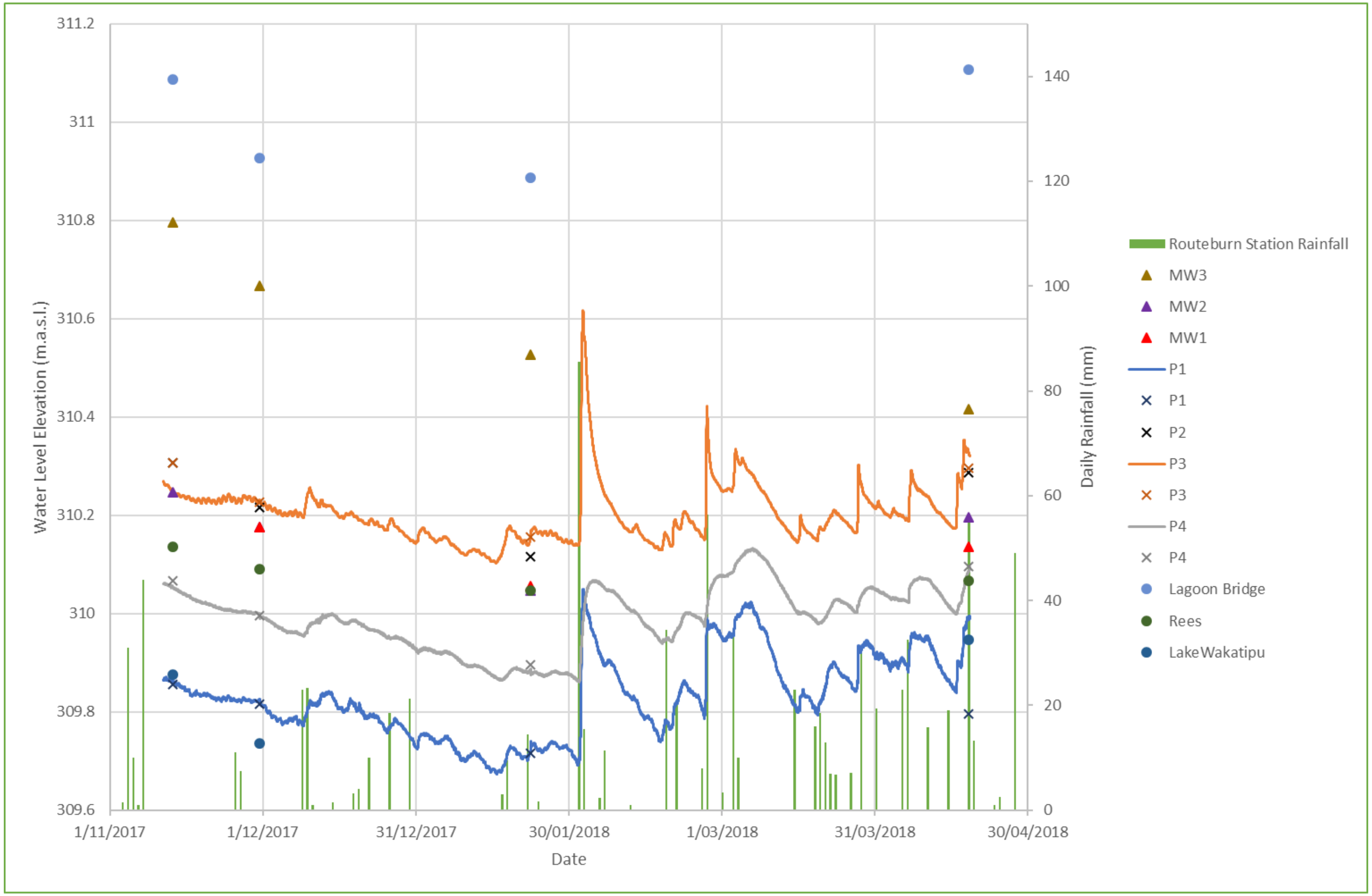


Figure 5: Standing water level measurements as Elevations

4.3 Water Quality Results

The results of water quality sampling are presented in Table 4 for surface water sites and

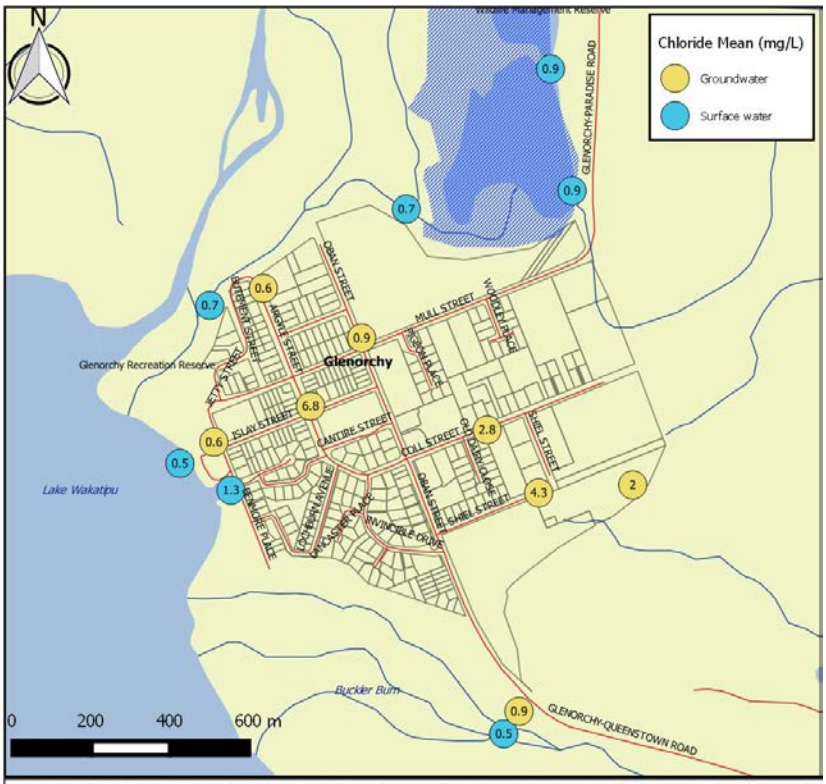
Table 5 for groundwater samples. Key observations regarding the water quality results are as follows:

Field parameters –

- pH was consistently more acidic in groundwaters upgradient of the township at MW3, MW2 and MW1. The Harbour site has the lowest pH of surface water sites. The Buckler Burn site consistently had the most basic levels, ranging between 7.6 and 7.9. All sites were within ANZECC (2000) recreational guidelines of 6.5 – 8.5.
- Dissolved Oxygen (DO) in groundwater is highest in MW3 upgradient of the township and depleted along its flowpath towards the discharge point into Lake Wakatipu. All surface water sites, except the Harbour site (in summer), were above the minimum DO level of 4 mg/L for salmonoid survival (adults and eggs) (Carter, 2005).

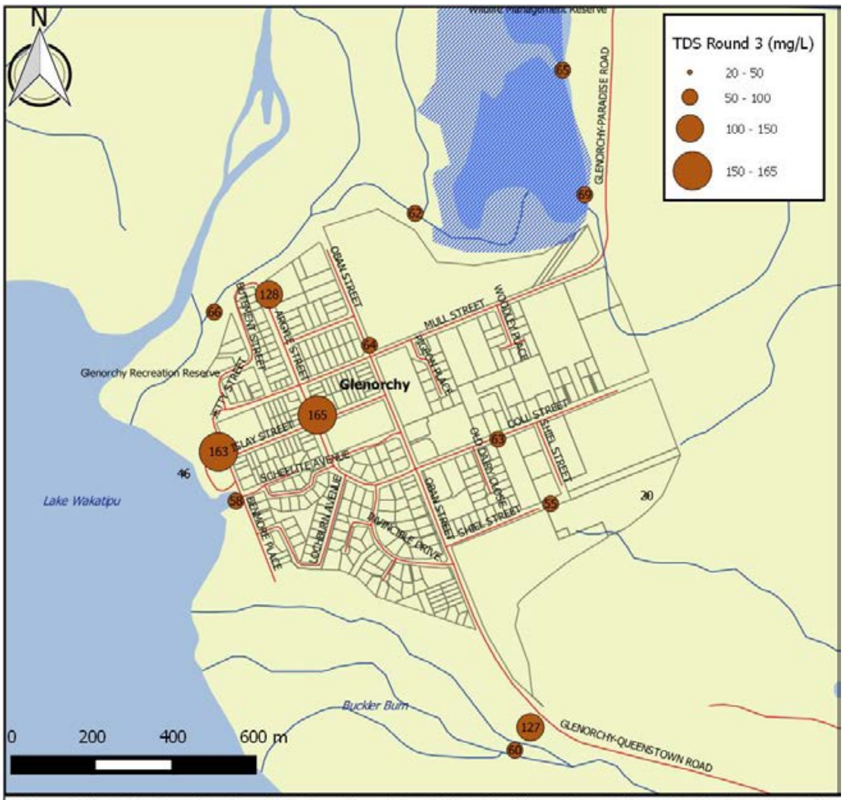
Major Ions –

- The major ion composition is further discussed in Section 4.3.1.
- Mean chloride ion concentration is mapped in Figure 6. Chloride is the most mobile of the major ions and can therefore be useful for tracing sources of water and mixing. The chloride concentration is highest in the centre of town at P4. Chloride concentrations in P3 and P1 are low, indicating that the site is strongly influenced by throughflow from the Rees River to Lake Wakatipu.
- The TDS from samples in Round 3 is mapped in Figure 7. The low TDS (20 mg/L) in MW3 indicates recently recharged waters. The TDS increases along the groundwater flow path towards Lake Wakatipu. While the TDS in most of the surface water sites did range by more than 20 mg/L, the range at the Glenorchy Harbour site was 49 mg/L. The range in the groundwater sites was highest at P4 (37 mg/L); the range at all other groundwater sites with more than one sample was less than 7 mg/L.



NZ Property Titles, NZ Road Centre line (Electoral), NZ River Polygons (Topo, 1:50k), NZ Lake Polygons (Topo, 1:50k), NZ River Centrelines (Topo, 1:50k) sourced from the LINZ Data Service http://data.linz.govt.nz/ and licensed by LINZ for re-use under the Creative Commons Attribution 3.0 New Zealand licence.

Figure 6: Mean chloride concentrations (mg/L)



NZ Property Titles, NZ Road Centre line (Electoral), NZ River Polygons (Topo, 1:50k), NZ Lake Polygons (Topo, 1:50k), NZ River Centrelines (Topo, 1:50k) sourced from the LINZ Data Service http://data.linz.govt.nz/ and licensed by LINZ for re-use under the Creative Commons Attribution 3.0 New Zealand licence.

Figure 7: Total Dissolved Solids of samples (Round 3)

Metals –

- Boron concentrations were below ANZECC (2000) aquatic species protection guideline value of 0.09 mg/L.
- Iron concentrations in surface waters ranged from a maximum of 0.79 mg/L at the Lagoon Bridge in spring, to below detection limits (< 0.02 mg/L) at the Buckler Burn in summer. Most sites exceeded the CCME (2001) aquatic life protection guidelines of 0.3 mg/L, except the Buckler Burn in each season, and the Harbour and Jetty sites in autumn. Iron concentrations in groundwater are highly elevated in P1 (28 – 31 mg/L) and P3 (13.1 – 15.7 mg/L). Iron concentrations do not exceed 0.1 mg/L in any other groundwater samples.
- Surface water manganese concentrations were highest in the summer sampled Harbour site at 0.75 mg/L and lowest in the Buckler Burn site which remained at 0.002 mg/L across the seasons. All sites were below the ANZECC (2000) aquatic species protection guidelines of 1.2 mg/L. In groundwater, manganese concentrations were highest in P1, adjacent to Lake Wakatipu with concentrations ranging from 1.38 – 1.43 mg/L, marginally higher than the ANZECC guidelines. The higher manganese concentrations within groundwater are causing elevated levels within Glenorchy Harbour.

Nutrients –

- In surface waters the Harbour site exceeded ORC (2016) Lake Wakatipu Receiving Water Group 5 limits for Total Nitrogen (TN), Nitrate-N, and Nitrate-N + Nitrite-N across all three sampling events. Total Ammoniacal-N (NH_4-N) exceeded the same limits for the spring and summer sampling events. All sites, except for Buckler Burn, exceeded ORC (2016) Schedule 15 limits for TN in the autumn sampling. In groundwaters, nitrate concentrations exceeded ORC (2016) Lake Wakatipu Receiving Water Group 3 limits for Nitrate-N at MW1, MW2, MW3, P2 and P4 across all three sampling events. However, nitrate was below detection levels at P1 indicating that groundwater discharge to Lake Wakatipu is unlikely to exceed nitrate-N limits, at least across the lakefront north of P1. Ammonium concentrations exceeded guidelines at P1, P3 and P4 during all sampling events and occasionally at MW1, MW2 and MW3.
- Dissolved Reactive Phosphorus (DRP) concentrations were all below laboratory detection limits, other than in P4, where DRP concentrations

exceeded ORC (2016) Schedule 15 limits for tributaries entering Lake Wakatipu.

- Total Phosphorus concentrations were highest during the autumn sampling, with the Buckler Burn and all three Lagoon sites having levels outside the Oligotrophic bracket (0.004 – 0.01 mg/L). The Buckler Burn had the highest level at 0.059 mg/L. There is no applicable limit for Total Phosphorous in groundwater, however Total Phosphorous was detected in all of the bores during the monitoring period, including MW3 (max 0.046 mg/L), which is upgradient of the township. Total Phosphorous was greater than 0.02 mg/L in P4 during all monitoring rounds.
- Dissolved Organic Carbon (DOC) levels in surface waters were highest in the Lagoon sites during autumn, with a range of 2.1 to 2.6 mg/L. All sites during summer sampling were below reporting limits. In groundwater, DOC was only above detection limit in MW1, MW2 and MW3. This indicates that the microbial population is efficient at processing the additional inputs of DOC to the groundwater system.
- *Escherichia coli* (*E. coli*) concentrations increased from spring to summer in all four surface water sites, with Rees and Lagoon Outflow continuing to increase through to autumn recording a maximum of 1,100 cfu/100mL, and 650 cfu/100mL, respectively. The Halfway Bridge site was found to be 900 cfu/100mL when tested in autumn, significantly higher than the other additional autumn Lagoon East Arm site, which was 130 cfu/100mL. ORC (2016) limits for both Lake Wakatipu (10 cfu/100mL) and Lake Wakatipu tributaries (50 cfu/100mL) were consistently exceeded over all three sampling events. The exception being Buckler Burn which did not exceed tributary limits in any sampling. The only other site to not exceed limits was the Harbour site during spring sampling. In groundwater, *E.coli* was only detected once at both MW2 and MW3.
- Concentrations of nutrients and *E.coli* in MW3 indicate that groundwaters are subject to some faecal impacts upgradient of the Glenorchy township. This may be due to the horses grazing in the paddock in which MW3 is located.

Table 4: Water Quality Results for Surface Water Sites

		Buckler Burn			Glenorchy Harbour			Glenorchy Jetty	Lagoon Halfway Bridge	Lagoon East Arm	Lagoon bridge			Rees			Guideline Values
	Parameters	30/11/2017	22/01/2018	18/04/2018	30/11/2017	22/01/2018	18/04/2018	18/04/2018	18/04/2018	18/04/2018	30/11/2017	22/01/2018	18/04/2018	30/11/2017	22/01/2018	18/04/2018	
Field Measurements	pH	7.26	7.94	7.45	6.45	6.21	7.02	7.54	6.85	7.12	7.27	7.35	6.93	7.27	7.33	7	**5.0 - 9.0[1]**
	EC	76.2	103	80	121	133.6	83.2	64.4	87.1	92.7	101	105.6	85.1	94.4	105.7	85.4	**n/a**
	Temp C	13.9	13.6	5.4	15.4	15.5	12	12.1	7.6	7.9	19.1	21.6	7.8	17.9	20.9	7.8	**n/a**
	Eh (mV)	104.1	136	136.1	27	32.2	17.3	2.6	57.8	46	-2.5	-10.4	29.1	-35	-16	44.4	**n/a**
	DO (mg/L)	11.23	9.88	12.67	6.22	3.99	9.65	10.41	8.88	8.49	8.24	8.48	8.77	9.18	8.56	9.33	**<4[2]**
Major ions (mg/L)	Calcium	13.6	17.8	13.7	17.9	19.4	11.4	9.4	13.4	14.3	17.5	17.7	12.7	16.2	17.2	12.8	**n/a**
	Magnesium	0.47	0.66	0.57	1.8	1.96	0.84	0.58	0.79	0.86	0.8	0.8	0.76	0.73	0.76	0.72	**n/a**
	Potassium	0.36	0.5	0.42	1.09	1.29	0.58	0.41	1.45	1.39	0.36	0.48	1.45	0.38	0.48	1.35	**n/a**
	Sodium	0.89	1.24	0.99	2.6	2.8	1.42	1.15	1.49	1.56	1.36	1.38	1.45	1.25	1.38	1.41	**n/a**
	Chloride	0.6	< 0.5	< 0.5	1.5	1.8	0.7	< 0.5	0.9	0.9	0.7	0.7	0.8	0.6	0.7	0.8	**120[3]**
	Bicarbonate (mg/L at 25°C)	41	55	40	69	76	38	29	42	45	55	55	40	51	58	43	**n/a**
	Sulphate	4.5	6.5	4.2	3.4	2.5	4.6	4.9	4.2	4.6	4.5	4.1	3.9	4.6	4.1	5	**n/a**
	Bromide	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	**n/a**
	TDS	61	82	60	99	107	58	46	65	69	81	81	62	75	83	66	**1000[4]**
Metals (mg/L)	Iron	0.03	< 0.02	0.04	0.56	0.43	0.15	0.13	0.32	0.56	0.79	0.34	0.57	0.64	0.52	0.55	**0.3[3]**
	Manganese	0.002	0.0021	0.0023	0.4	0.75	0.079	0.0155	0.034	0.04	0.126	0.142	0.049	0.084	0.123	0.052	**1.2[5]**
	Boron	< 0.0053	< 0.005	< 0.005	0.0073	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.0053	< 0.005	< 0.005	< 0.0053	< 0.005	< 0.005	**0.09[5]**
Nutrients & Organics (mg/L)	Total Nitrogen	< 0.11	< 0.11	0.13	0.38	0.5	0.14	< 0.11	0.19	0.19	0.12	< 0.11	0.18	< 0.11	< 0.11	0.14	**0.1[6b]**
	Total NH_4-N	0.012	< 0.010	< 0.010	0.036	0.036	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.014	< 0.010	< 0.010	< 0.010	< 0.010	**0.01[6a,b]**
	Nitrite-N	< 0.002	< 0.002	< 0.002	0.004	0.008	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	**0.075[6a*]**
	Nitrate-N	0.002	< 0.002	0.037	0.28	0.37	0.107	0.018	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	**0.075[6a*]**
	Total Kjeldahl Nitrogen (TKN)	< 0.10	< 0.10	< 0.10	< 0.10	0.13	< 0.10	< 0.10	0.19	0.19	0.12	< 0.10	0.18	< 0.10	< 0.10	0.14	**n/a**
	Dissolved Reactive Phosphorus	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	**0.005[6a]**
	Total Phosphorus	< 0.004	< 0.004	0.059	< 0.004	0.004	< 0.004	< 0.004	0.012	0.016	< 0.004	0.009	0.011	< 0.004	0.008	0.022	**Oligotrophic 0.004 – 0.01[3]/ 0.005[6b]**
	DOC	< 0.5	< 0.5	1	< 0.5	< 0.5	< 0.5	< 0.5	2.6	2.6	1.2	< 0.5	2.1	0.6	< 0.5	1.5	**n/a**
	E.coli (cfu/100mL)	< 1 [#]	46	7 [#]	4 [#]	25	14 [#]	170 [#]	900 [#]	130 [#]	150 [#]	380	1,100 [#]	110 [#]	200	650 [#]	**50[6a]/10[6b]**

Table 5: Water Quality Results for Groundwater Sites

		MW1			MW2			MW3			P1			P2			P3			P4			Town	Guideline Values
	Parameters	Nov-17	Jan-18	Apr-18	Nov-17	Jan-18	Apr-18	Nov-17	Jan-18	Apr-18	Nov-17	Jan-18	Apr-18	Nov-17	Jan-18	Apr-18	Nov-17	Jan-18	Apr-18	Nov-17	Jan-18	Apr-18	Apr-18	
Field Measurements	**pH**	5.5	5.3	5.3	5.4	4.9	5.2	5.3	4.9	5.5	7.1	6.8	7.1	6.1	5.4	6.0	6.8	6.4	6.7	6.1	5.8	6.0	7.7	**n/a**
	EC	86	94	96	101	97.8	113.7	28	29.7	28.3	230	230.8	233.9	80.4	83.3	83.8	183	176.7	172.1	172	180	242.7	162.7	**n/a**
	Temp C	15.2	11.3	11.2	10.9	11.4	11.6	11.3	11.6	11.1	10.5	12.6	11.1	10.8	12.2	12.2	9.5	11.4	11.2	10.4	12.7	12.6	9.3	**n/a**
	Eh (mV)	139	130	-120	181	233	150	169	120	-60	-151	123	-119	78	88	68	-59	-51	-62	96	84	101	690	**n/a**
	DO (mg/L)	3.8	4.3	2.66	6.7	4.13	2.4	11.1	10	9.54	0.32	0.26	0.29	7.51	3.34	3.34	0.19	0.3	0.27	1.67	1.19	6.5	8.93	**n/a**
Major ions (mg/L)	**Calcium**	8.4	8	9.5	8	7.8	8.7	1.96	2.1	1.96	25	25	25	12.1	12.1	12	24	23	22	22	23	27	30	**n/a**
	Magnesium	1.48	1.45	1.79	1.39	1.28	1.54	0.48	0.54	0.55	1.03	1.05	1.15	1.03	1.01	1.1	1.03	0.97	0.98	1.92	2.1	2.3	1.12	**n/a**
	Potassium	1.66	1.88	1.82	6	5.8	6.2	0.64	0.75	0.64	1.71	1.79	1.77	1.35	1.45	1.42	0.9	1.01	1.03	3.6	3.1	5.2	0.65	**n/a**
	Sodium	4.3	7.4	4.4	4.8	4	5	2.1	2.3	2.2	2	2.1	2.1	1.65	1.87	1.84	1.65	1.69	1.69	4.4	7	9.2	1.54	**n/a**
	Chloride	4.3	4.5	4.1	2.1	2.6	3.7	1.8	2.4	1.8	0.6	0.7	0.6	0.7	1	0.9	0.6	0.8	< 0.5	5	6	9.4	0.9	**120**[3]
	Bicarbonate (mg/L at 25°C)	25	29	27	25	23	26	12.6	11	12.1	94	97	103	46	47	45	90	87	88	84	94	102	88	**n/a**
	Sulphate	2.8	2.4	3.3	6.6	5.1	6.9	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	1	0.8	1.2	< 0.5	< 0.5	< 0.5	3.5	2.9	3.8	3.9	**n/a**
	Bromide	0.06	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	**n/a**
	TDS	51	57	55	58	53	63	20	20	20	157	157	163	64	66	64	135	129	128	128	141	165	127	**1000**[4]
Metals (mg/L)	**Iron**	0.073	< 0.02	< 0.02	< 0.021	< 0.02	< 0.02	0.029	< 0.02	< 0.02	31	28	28	< 0.021	< 0.02	< 0.02	15.7	13.8	13.1	0.037	< 0.02	< 0.02	< 0.02	**n/a**
	Manganese	0.0044	0.0035	0.0057	0.0042	0.0046	0.0053	0.0025	0.0066	0.004	1.43	1.38	1.41	0.004	0.0035	0.0007	0.68	0.65	0.64	0.56	0.51	0.55	< 0.0005	**1.2**[5]
	Boron	0.0058	< 0.005	0.008	0.022	0.009	0.016	< 0.0053	< 0.005	< 0.005	0.0058	< 0.005	< 0.005	< 0.0053	< 0.005	< 0.005	< 0.0053	< 0.005	< 0.005	0.0111	< 0.005	0.01	< 0.005	**0.09**[5]
Nutrients & Organics (mg/L)	**Total Nitrogen**	2.6	2.5	3.5	4.2	3.9	4.5	0.33	0.51	0.51	< 0.11	0.12	0.15	0.51	0.42	0.22	0.45	0.53	0.48	3.4	2.1	5.1	0.47	
	Total NH_4-N	0.017	< 0.010	0.01	0.013	< 0.010	< 0.010	0.011	< 0.010	0.011	0.1	0.101	0.117	< 0.010	< 0.010	< 0.010	0.46	0.46	0.45	1.93	1	2.6	< 0.010	**0.01**[6a]
	Nitrite-N	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.004	0.009	0.003	< 0.002	**0.075**[6a*]
	Nitrate-N	2.5	2.4	3.4	4.1	3.8	4.4	0.27	0.38	0.39	< 0.002	< 0.002	< 0.002	0.39	0.35	0.172	< 0.002	< 0.002	< 0.002	1.44	0.98	2.3	0.43	**0.075**[6a*]
	Total Kjeldahl Nitrogen (TKN)	0.12	< 0.10	0.14	0.12	0.1	0.14	< 0.10	0.13	0.12	< 0.10	0.12	0.14	0.12	< 0.10	< 0.10	0.45	0.53	0.48	1.98	1.1	2.8	< 0.10	**n/a**
	Dissolved Reactive Phosphorus	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	0.029	0.028	0.035	< 0.004	**0.005**[6a]
	Total Phosphorus	< 0.004	0.006	0.011	< 0.004	< 0.004	0.015	< 0.004	0.013	0.046	< 0.004	0.013	0.027	< 0.004	0.014	0.006	0.007	0.062	0.06	0.025 [#3]	0.04	0.047	0.004	
	DOC	< 0.5	< 0.5	0.8	0.8	< 0.5	0.8	1	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	**n/a**
	***E.coli* (cfu/100mL)**	< 1 [#]	< 1 [#]	< 1 [#]	< 1 [#]	< 1 [#]	20	< 1 [#]	38	< 1 [#]	< 10 [#]	< 10 [#]	< 1 [#]	< 1 [#]	< 1 [#]	< 1 [#]	< 1 [#]	< 1 [#]	< 1 [#]	< 1 [#]	< 1 [#]	< 1 [#]	< 1 [#]	**50**[6a]

Red text denotes exceedance of guideline value.
Statistically estimated count based on the theoretical countable range for the stated method.
1 Recreational guidelines (ANZECC, 2000).
2 The effects of Dissolved Oxygen on Steelhead Trout, Coho Salmon, and Chinook Salmon Biology and Function by Life Stage (Carter, 2005).
3 Long-term water quality guidelines for the protection of aquatic life (Canadian Council of Ministers of the Environment, 2001).
4 Aquatic ecosystems TDS tolerance (Boyd, 1999).
5 Trigger values for high value freshwater systems 99% species protection (ANZECC, 2000).
6 ORC (2016) Schedule 15 receiving water limits and targets for achieving good quality water for a) for Receiving Water Group 3 – tributaries of Lake Wakatipu b) Receiving Water Group 5 -Lake Wakatipu * Guideline value is for Nitrate-Nitrite-N
It has been noted in the Hills Lab report that the result for Total Ammoniacal-N was greater than that for Total Kjeldahl Nitrogen, but within the analytical variation of these methods.
It has been noted in the Hills Lab report that the result for Dissolved Reactive Phosphorus was greater than that for Total Phosphorus, but within the analytical variation of these methods.
Note that TDS is calculated as the sum of the major ions, metals and nutrients

4.3.1 Water Types

Analysis of water types can provide information regarding the source and flow paths of waters. The relative abundance of major ions in the samples is presented using Piper diagrams in Figure 8 and

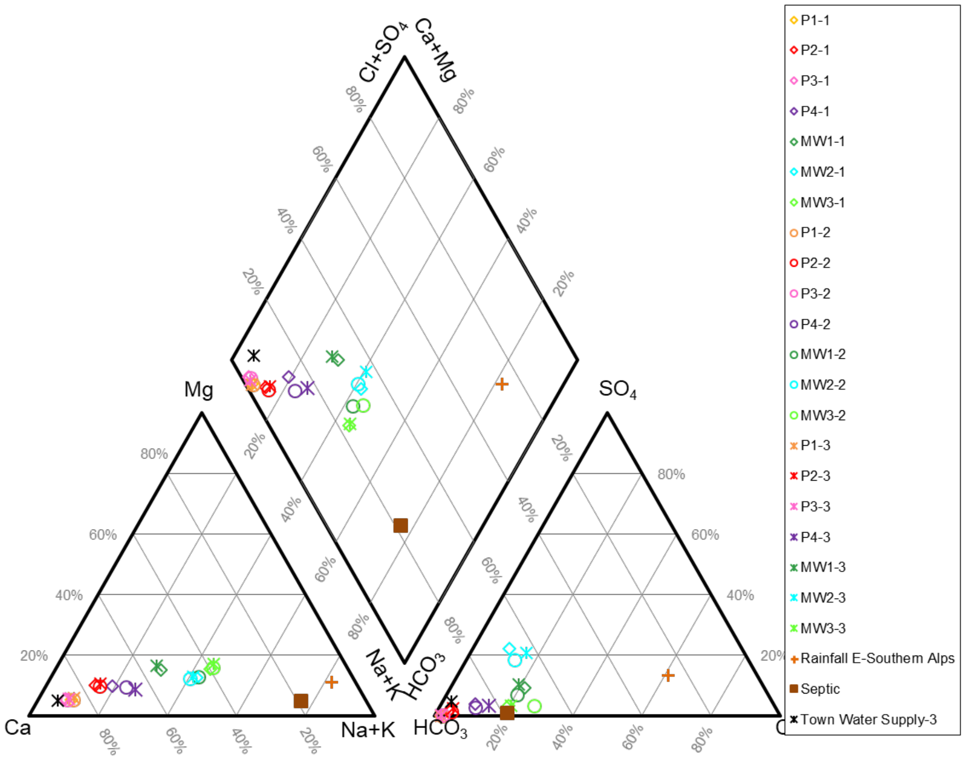


Figure 9. All of the surface waters from the lagoon, Rees River, Lake Wakatipu and Buckler Burn are similar in composition (calcium-bicarbonate). The groundwaters move from a calcium-sodium bicarbonate-chloride-sulphate water near the recharge areas to a calcium-bicarbonate water close to their discharge point in Lake Wakatipu. This may indicate mixing of groundwater and surface waters along the flow path, however, as the TDS of groundwater is much higher (see Figure 7), it is also possible that the similar water types are a reflection of the geological environment in which the water types have evolved. Water types from septic tanks and rainfall have been included on the plots for comparison. The data used for these points is summarised in Table 6. Septic tank effluent has similar bicarbonate concentrations, however is sodium rather than calcium dominated.

Table 6: Average water composition for Source waters

Sample Name	pH	Na	K	Ca	Mg	B	Cl	F	SO$_4$	HCO$_3$	NH$_4$	Fe	Mn
Rainfall Eastern Southern Alps[1]		0.33	0.13	0.03	0.03		0.46		0.14	0.34*			
Mean septic[2]	6.84	61	26	17	3*	0.02	51	0.63	6.21	356	55.0	0.198	0.078

[1] Rainwater composition sourced from University of Otago. Based on chloride concentrations in Greenstone, Dart and the Rees; the Easter Southern Alps site in the MacKenzie country was interpreted to best represent the processes of orographic rainfall over the main divide (S.Mager, pers comm. 6/03/2018).

[2] Mean values sourced from Richards, Paterson, Withers, & Stutter, (2016) and Richards, Withers, Paterson, McRoberts, & Stutter, (2016)

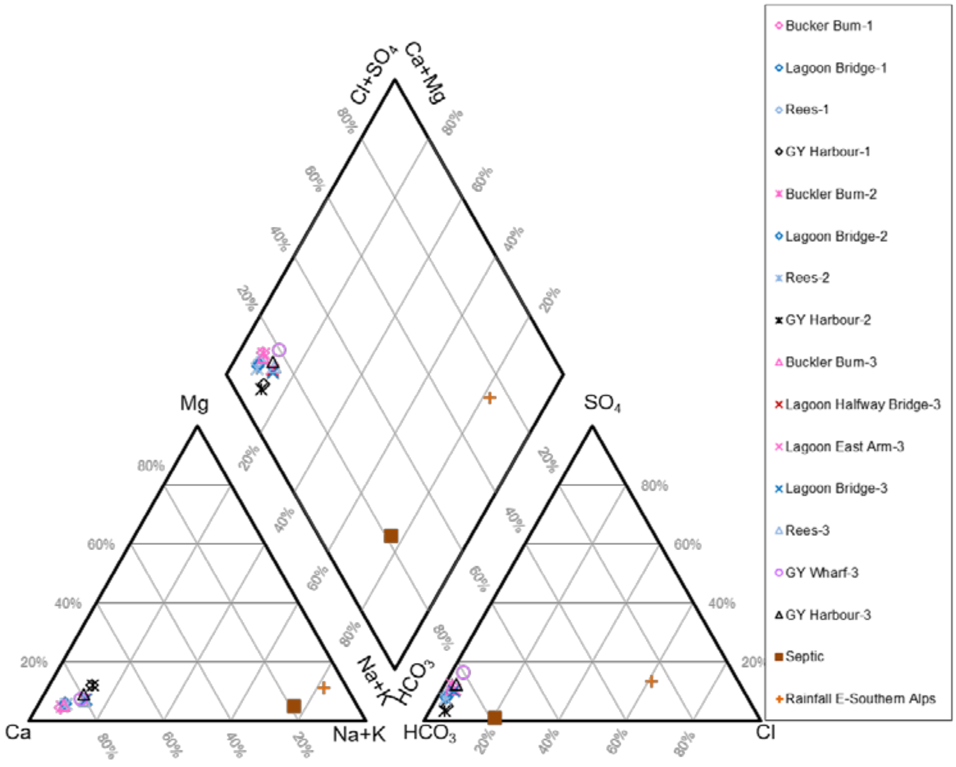


Figure 8: Piper Plot of Surface Waters

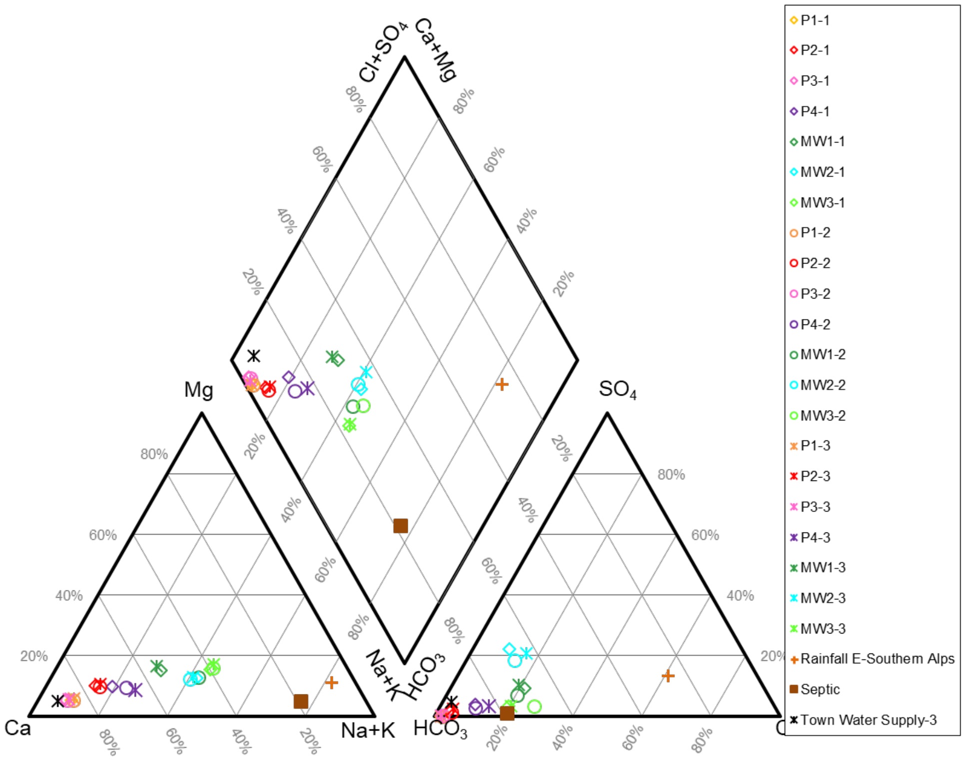


Figure 9: Piper plot of Groundwater Samples

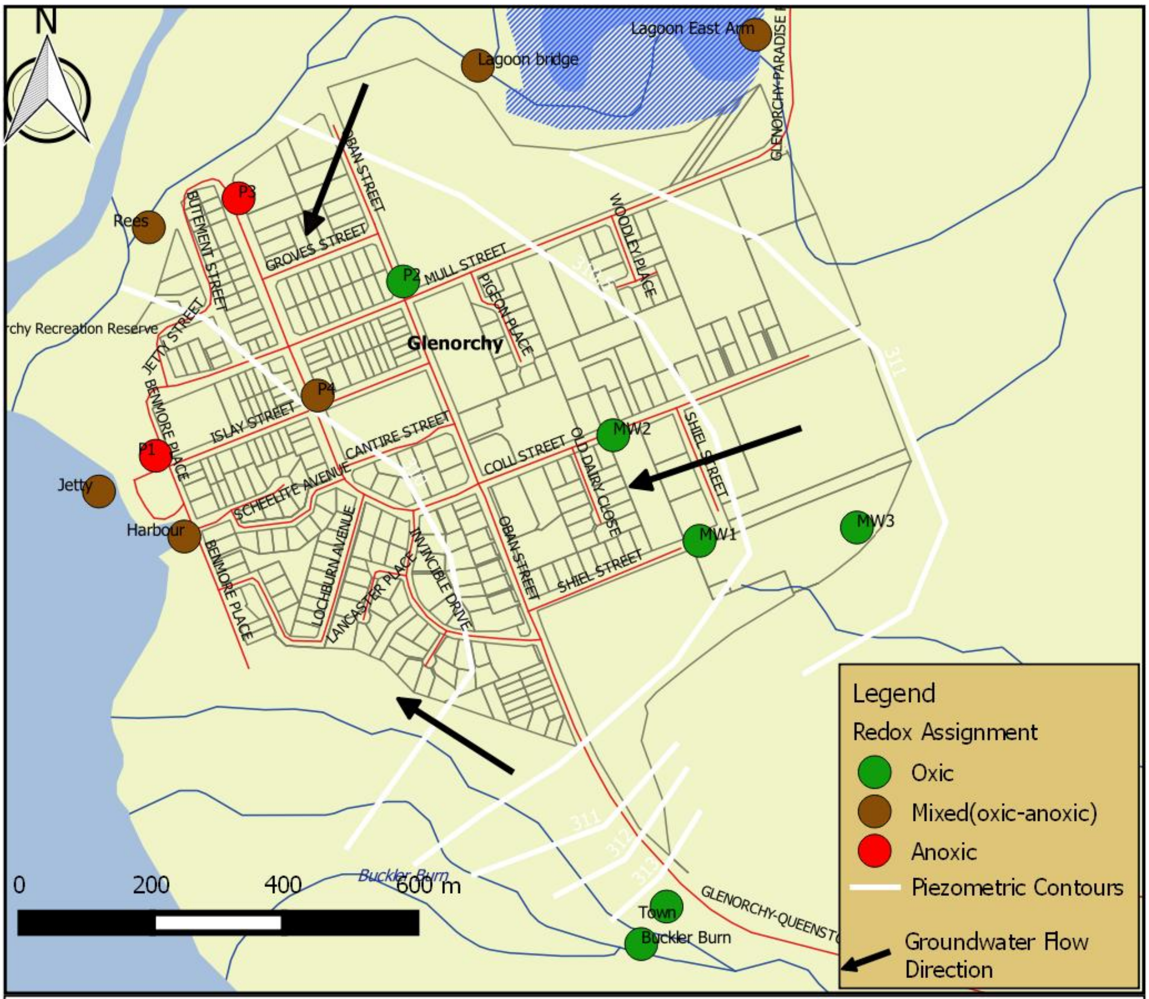
4.3.2 Redox Conditions

The redox state of groundwaters is most often driven by the microbially mediated oxidation of organic matter. In order of preference, microbes will used dissolved oxygen, nitrate, manganese oxides, iron oxides and sulphate as the electron acceptors for respiration due to the amount of energy released by the redox process. Therefore, as dissolved oxygen is removed from the system, nitrate will be used, and when nitrate is removed from the system, manganese oxides and so on. Transient redox conditions can be caused by seasonal infiltration events of oxygen rich rainwaters, which may also transport organic carbons from the vadose zone into the top of the aquifer. Where the source of iron is pyrite rather than iron oxides, the sulphide will be preferentially oxidised prior to the iron by oxygen or nitrate present in the system. While samples were not analysed for sulphides, none of the samples were odorous, indicating that the sulphide content was low.

The redox condition of the sampled waters was classified according to the framework devised by McMahon & Chapelle (2008) using the concentrations of dissolved oxygen, nitrate, manganese, iron, and sulphate and presented in Figure 10. Note that for each of the waters sampled more than once, the redox state did not change. The redox processes associated with each category are found in Table 7. This analysis indicates that groundwaters are oxic upgradient of the township and oxygen is depleted as the waters flow towards the lake. Of the surface waters, only water from the Buckler Burn has an oxic signal, all other surface waters have a mixed signal as multiple redox processes are occurring simultaneously.

Table 7: Redox Processes occurring at each site

Redox Category	Redox Processes	Locations
Oxic	O_2	MW1, MW2, MW3, P2, Town Water Supply, Buckler Burn
Anoxic	Fe(III)/SO_4	P1, P3
Mixed(oxic-anoxic)	O_2-Mn(IV)	P4
Mixed(oxic-anoxic)	O_2-Fe(III)/SO_4	Glenorchy Harbour, Glenorchy Jetty, Rees River, Upstream Lagoon Bridge, Lagoon East Arm, Lagoon Bridge



NZ Property Titles, NZ Road Centre line (Electoral), NZ River Polygons (Topo, 1:50k), NZ Lake Polygons (Topo, 1:50k), NZ River Centrelines (Topo, 1:50k) sourced from the LINZ Data Service http://data.linz.govt.nz/ and licensed by LINZ for re-use under the Creative Commons Attribution 4.0 New Zealand licence.
Aerial Imagery sourced from the the LINZ Data Service https://data.linz.govt.nz/layer/1910-otago-075m-rural-aerial-photos-2004-2011/ and licensed by Terralink International Limited and Otago Regional Council for re-use under the Creative Commons Attribution 4.0 New Zealand licence.

Figure 10: Redox state of sampled waters

4.3.3 QA/QC Results

Field Duplicates

A duplicate sample was taken from P1 in Round 1 and MW1 in Round 3. The percentage variation between duplicate samples was less than 5% for major ions and TDS, with the exception of sulphate in sample MW1 (14%). However, it should be noted that as the concentration is low (3 mg/L), the difference is not significant in terms of total concentration.

Laboratory Procedures

The charge balance of each sample was checked to ensure that each sample was within 5%. The charge balance was less than 5% for all surface water samples. Where the results demonstrated inadequate balance, the laboratory was asked to reanalyse the sample, however at sites P1 and P3 which consistently contained high concentrations of iron, the charge balance was higher than 5%. The laboratory has provided the following explanation: "It was noted that some of the anion / cation balances did not agree to within expected limits. This was largely attributed to the high levels of dissolved iron. We have included dissolved iron in the cation balance equations. However, the precipitation of large amounts of iron in the unpreserved containers (soon after sampling) will result in the loss of ions from solution and consumption of alkalinity. This may well result in the lower anions relative to the cations, being reported. The loss of soluble iron in the unpreserved container does not affect the cation balance, as the dissolved iron is sampled into an acid preserved container, stabilising the iron in solution."

4.4 Iron Deposition

The iron deposition area (Figure 11) was within the shallow (< 1.5 m) area between the wharf and harbour entrance. No iron deposition was evident in the harbour itself. The extent is mapped relative to on-site system risk in Figure 12. On-site system risk data was supplied by Hadleys and is based on the age and type of septic system installed.

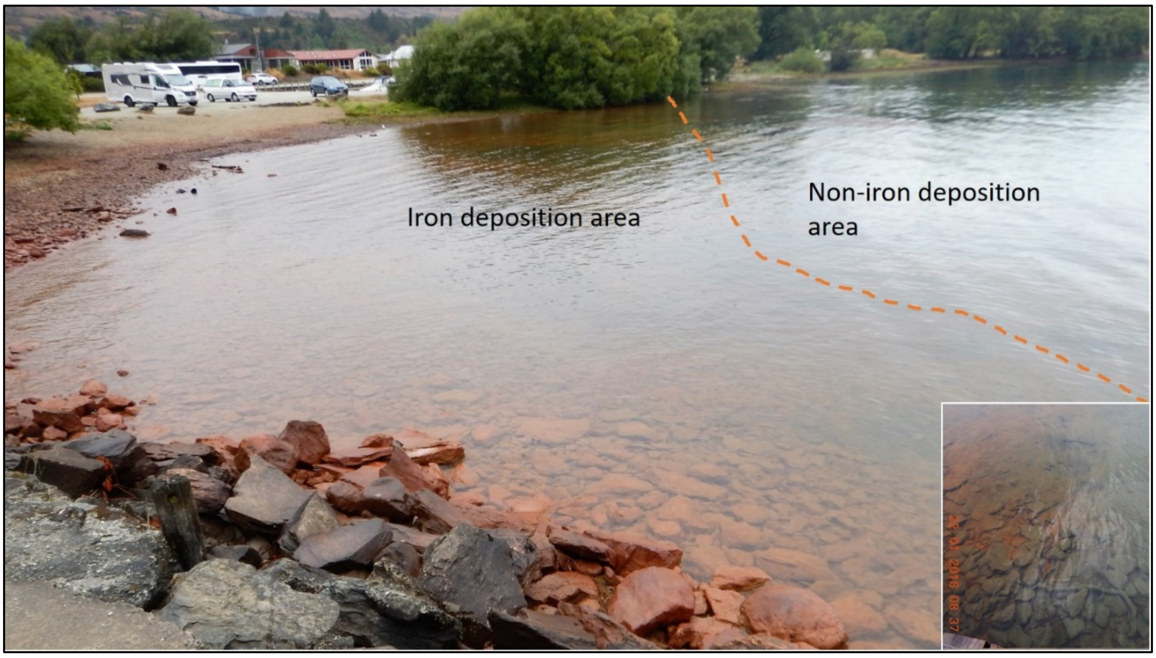
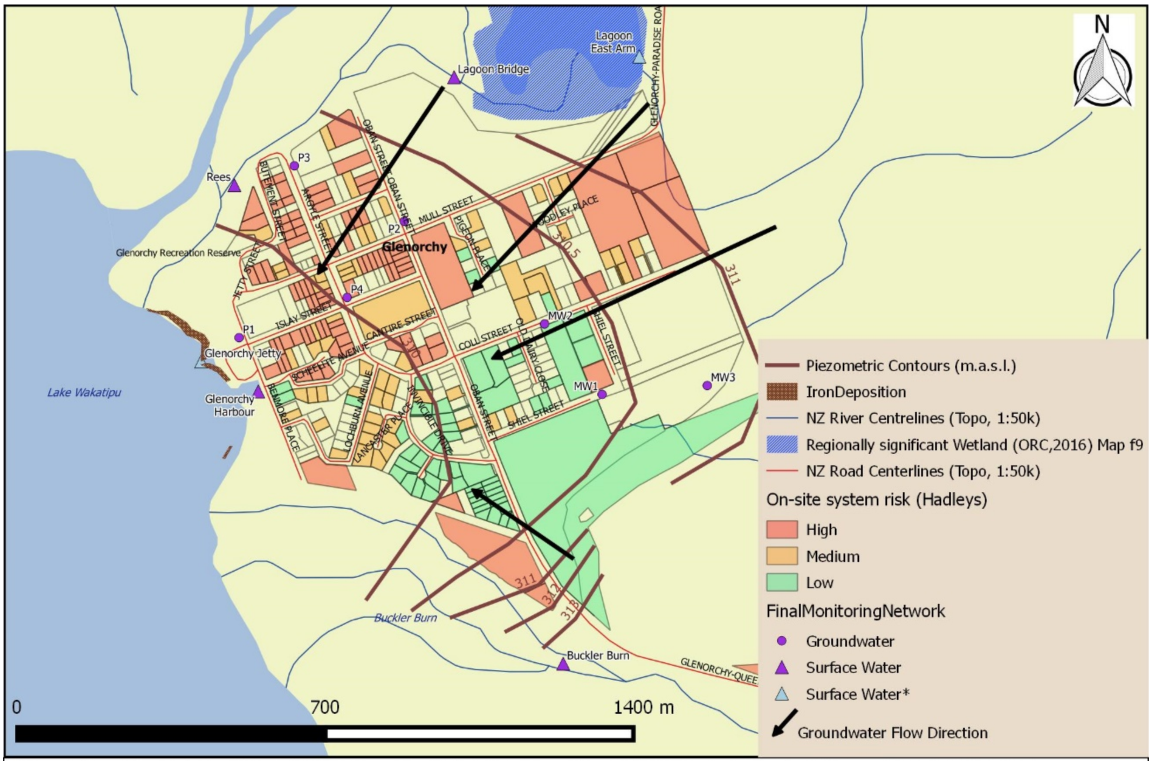


Figure 11: Lake Wakatipu looking south from Glenorchy wharf towards Glenorchy Harbour entrance. Insert: edge of the iron deposition from wharf pile two.



NZ Property Titles, NZ Road Centre line (Electoral), NZ River Polygons (Topo, 1:50k), NZ Lake Polygons (Topo, 1:50k), NZ River Centrelines (Topo, 1:50k) sourced from the LINZ Data Service http://data.linz.govt.nz/ and licensed by LINZ for re-use under the Creative Commons Attribution 3.0 New Zealand licence.
Aerial Imagery sourced from the the LINZ Data Service (insert URL) and licensed by (insert Licensee)l for re-use under the Creative Commons Attribution 3.0 New Zealand licence.

Figure 12: Iron Deposition extent and On-site System Risk

4.5 Ecological Assessment

The complete findings from the ecological state of the environment assessment for freshwater habitats adjacent to Glenorchy Township can be found in e3Scientific Ltd, (2018).

Based on the results of the lake margin assessment; the current ecological state of the environment adjacent to the Glenorchy Township appear to be slightly modified freshwater environments that support a number of common and threatened or at risk native species. There is evidence of current seasonal surface water quality degradation within the harbour that, based on the limited historical data available, may also be declining annually. The aquatic flora and fauna is representative of an oligotrophic, high country lake and it maintains the characteristic benthic cobble / gravel substrate that provides ecological character and habitat to this region. Future ecological issues within these environs may be further degradation to the water quality within the harbour and the spread of the invasive macrophyte, *Elodea canadensis*.

Results from the lake margin assessment also found that the area of iron deposition between the wharf and harbour entrance has observed ecological effects on the native flora and fauna. Visual assessment of rock substrates in sheltered areas near the wharf within the iron area found only the occasional snail (one species only) and no evidence of periphyton growth indicating a localized limitation on the aquatic ecosystem. Other snail species were collected within the adjacent harbour site but were not present within the iron area.

The impact of the iron deposition within the Glenorchy lake margin on fish populations is unclear, although there were some observed differences. It is unlikely to impact on the free ranging salmonids and the pelagic larval koaro, however, it was notable that the Gee minnow traps in the iron area accumulated a fine layer of iron precipitate overnight which may be having some impact on the localised populations of common bully. When iron precipitates in the water column, species are unable to process all the iron they take in from water or their food and it can build up in their internal organs. The abundance of juvenile common bully in macrophytes within the iron precipitate but noticeable lack of large adults (which were evident in the adjacent harbour environment) does indicate that longevity may be limited in this area, and it is possible that the juvenile bullies are migrating out from the boat harbour as the juvenile bullies seek to habitat less densely populated by adult bullies hence avoiding competition for space and food with the adult bullies.

The observed levels of iron deposition (i.e. the spectrum between a thick coating of precipitate to a light staining of the benthic substrate) correlated to macrophyte responses. Macrophyte communities that were located entirely within the iron deposition area suffered morphological iron toxicity symptoms, including stunted growth and disintegrating leaf and stems; whereas macrophyte communities near the edge of the iron deposition exhibited healthy growth and normal external morphology. At the control site (Site 2) where no iron was observed, biomass was higher, but less than the same species present at the edge of the iron deposition at Site 1. Although shelter from wind / wave action will also have an effect on the differing biomass between the two sites, these findings align with terrestrial and aquatic plant research (van Wijck, et al., 1992; (Xing, Huang, & Liu, 2010) which show that plant growth is promoted with high iron levels up to a point where the plant becomes iron saturated and photosynthesis is reduced due to deposition occurring on the leaves of the plant.

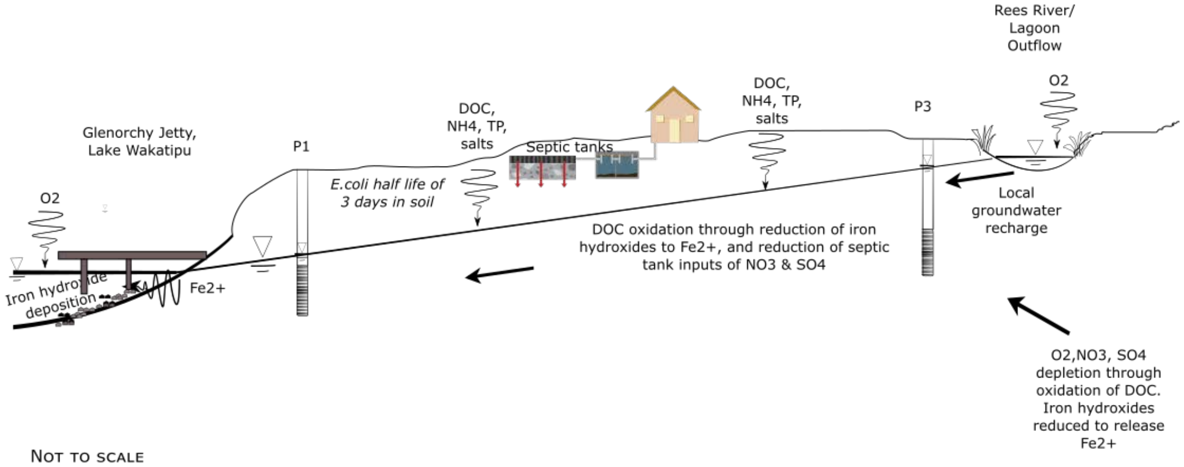
The findings from the assessment within the Glenorchy Lagoon indicate its current ecological state is a functioning wetland ecosystem, which provides habitat and food sources for native, threatened and at risk species. Despite the riparian vegetation surrounding the Glenorchy Lagoon not best representing its Ecological District, the exotic willows present, do not completely diminish the ecological significance of this site as they provide nesting materials and habitat for waterfowl and swamp birds. The aquatic flora and fauna represent a high country riverine wetland system and provide biodiversity, as well as providing filtration ecosystem processes to nearby land and water bodies. Future ecological issues would be nearby land use intensification and run-off “flipping” the wetland ecosystem from a nutrient sink to a source. This could be avoided by setting nutrient and organic limits and thresholds for the Rees catchment.

4.6 Conceptual Model

The investigations of water levels, water quality and iron deposition detailed in Sections 4.2 to Section 4.4 have been used to inform this conceptual model of the Glenorchy township. The hydrology of the Glenorchy township is complex; bordered by Lake Wakatipu to the west and old river terraces at the foot of the Richardson Mountains to the east, the Glenorchy Lagoon and Rees River to the north and to the south the Buckler Burn River. Contrary to previous groundwater and landfill investigations, water level monitoring and surveys have provided evidence that groundwater flows from the north, east and south of the township beneath the township towards Lake Wakatipu. Groundwater is recharged from the Lagoon outflow/Rees River and flows south-west beneath the township towards Glenorchy Jetty and Harbour in Lake Wakatipu. Rainfall recharge also flows off the Richardson Mountains and recharges groundwater flowing west beneath the township towards Lake Wakatipu. Finally, groundwater is also recharged from the Buckler Burn and flows north-west beneath the township towards Lake Wakatipu.

Consequently, on-site sewage management in Glenorchy will affect firstly groundwater, and then Lake Wakatipu, which is the receiving environment for groundwater from below Glenorchy Township. As the town water supply is sourced from groundwater which is hydraulically upgradient of the township, people are only exposed to the impacts of on-site sewage management via recreational use of Lake Wakatipu. The conceptual model for the flowpath of shallow groundwater from the Rees River to Lake Wakatipu is presented in Figure

13. Oxygen rich waters from the surface water recharge to the north (Lagoon and outflow from the Lagoon flowing into the Rees River) show mixed redox signals, as natural redox processes occur in the Lagoon as organic matter is processed. These waters are depleted of oxygen as they flow beneath the township. Septic tanks provide additional inputs of organics and reduced forms of nitrogen, which promote further reduction of iron oxides and sulphates. This highly reduced, iron rich groundwater discharges into Lake Wakatipu near the Glenorchy Jetty, resulting in significant deposition of iron oxides. The amount of deposition will be seasonally variable due to reduced groundwater flow gradients when rainfall is low.



Septic tank image source: Jane Thomas
(http://ian.umces.edu/imagelibrary/displayimage-6130.html)

Figure 13: Conceptual Model from Rees River to Lake Wakatipu

While this model presents a plausible interpretation of the data, there are some areas of uncertainty associated with this conceptual model:

1. The chloride concentrations in P1 and P3 are comparable to surface water concentrations and could be seen to indicate minor septic tank impacts in this area. However, when water composition in P3 is compared with Rees River water composition, P3 is consistently impacted by reduced forms of nitrogen NH_4-N, which is not present in the surface water, and higher Total Phosphorous. This area also corresponds with the shallowest groundwater and the area of highest density of high-risk on-site septic systems as mapped by Hadleys. It is likely that P2 is also receiving recharge from the lagoon system, however, it is upgradient from the township and waters

sampled from P2 are oxic. It should also be noted that Rees River/Lagoon outflow does contribute DOC to groundwater.

2. DOC concentrations below detection level under the township are likely to be due to the processing efficiency of the microbial population which would have developed during many years of septic tank operation in the township.
3. Water quality profiles with depth were not completed in groundwater wells. Variation of redox conditions with depth is possible.
4. Local mountain ranges are composed of schist containing gold-bearing quartz, scheelite and calcite veins. It is known that arsenopyrite (FeAsS) occurs in Mount Judah scheelite lodes and schist rock (Lindqvist, 1997). It is possible that some of the reducing environment is a consequence of the dissolution of arsenopyrite. However, there were no sulfide odours observed during sampling.

The conceptual model of the flowpath from the east and south flowing west and north-west towards Glenorchy Harbour is similar, however the groundwater is not as reducing, and therefore some nitrates and sulphate remain in the groundwater and there is less iron (no noticeable iron deposition). This may be due to increased depth to groundwater and lower-risk septic tanks present over the southern half of the town (Figure 12); consequently less organics leaching to groundwater.

5 Impacts of Septic Tanks in Glenorchy

5.1 Overview

Based on all of the investigations, and the conceptual model of the site, the impacts of septic tanks on the main receiving environments in Lake Wakatipu are summarised in Table 8.

Table 8: Septic tank impacts in Glenorchy

Location	Hydrology	Water Quality	Ecology (e3Scientific Ltd, 2018)
Glenorchy Harbour	Receives groundwater discharge. Sheltered harbour results in poorly mixed waters.	Total nitrogen exceeds ORC (2016) Schedule 15 good water quality targets for Lake Wakatipu for Total Nitrogen, NH_4-N and *E.coli*. Manganese and iron concentrations are also elevated.	There is evidence of current seasonal surface water quality degradation within the harbour that, based on the limited historical data available, may also be declining annually.
Glenorchy Jetty	Receives groundwater discharge and well mixed due to flows from the Rees River and large exposed areas subject to wind waves.	Septic tank inputs have induced a highly reducing groundwater environment which discharges into Lake Wakatipu between Glenorchy Harbour and the Rees River outlet, resulting in iron deposition.	Macroinvertebrates diversity and abundance is decreased in the area of iron deposition, and there are indications that the longevity of benthic dwelling fish may be limited in this area. Macrophyte communities located entirely within the iron deposition area suffered morphological iron toxicity symptoms .

5.2 Risks to Human Health

As the town water supply is sourced from groundwater which is hydraulically upgradient of the township, people are only exposed to the impacts of on-site sewage management via recreational use of Lake Wakatipu. *E.coli* concentrations were analysed in water quality samples throughout this study as *E.coli* is the most widely used faecal indicator in New Zealand. Concentrations in groundwaters were low throughout the monitoring period. Based on this assessment, it may be concluded that the risk to human health from septic tanks is low. However, it may be that sampling occurred during a low risk season, due to the dry conditions over summer and lower water tables. it is important to understand the relationship between faecal indicators and risks to human health, and the risks associated with the site conditions in Glenorchy.

5.2.1 Faecal indicators and human health risk

E.coli are bacteria that are normal flora in the human intestinal tract. As they are present in large numbers in human waste, they are useful indicators of faecal contamination. However, it should be noted that concentrations of *E.coli* may not correlate with the concentration of pathogens from septic tanks, as both viruses, protozoa and helminths are more resistant to environmental conditions than bacteria (Lusk, et al., 2017). The fate of pathogens from septic tanks will vary based on their physico-chemical properties, hence concentrations of *E.coli* may not reflect the risk to human health from septic tanks in Glenorchy. As viruses can survive longer in groundwater, they may also be transported further and can cause infection with fewer viable organisms remaining.

The difficulty with assessing the human health risk of on-site sewage management systems is choosing a suitable indicator organism that mimics the viability of viruses within groundwater, but is always present within wastewater. Pathogenic viruses will only be present when there has been infection, and may not be present during the sampling period. Phages (viruses that live in bacteria), such as F-RNA coliphages or *Bacteroides fragilis* bacteriophages have been proposed as a model organism, in that “their survival in natural water environments resembles that of enteric viruses” (Ashbolt, Grabow, & Snozzi, 2001), however there have been incidences of enteric viruses being present in the absence of coliphages. *Clostridium perfringens*, an anaerobic spore-forming bacterium, is always present in sewage, forms spores that are resistant in the environment and do not reproduce in the environment so can also be used as an index organism for enteric viruses and parasitic protozoa.

For additional assessment of risks to human health from on-site sewage management in Glenorchy, additional microbial indicators should be included in the suite of analysis.

5.2.2 Risks associated with environmental conditions

The soil conditions and shallow groundwater table in Glenorchy indicate that on-site sewage management may present an ongoing risk to human health for recreational use of the lake foreshore.

Environmental Science Research Limited (ESR) developed guidelines for separation distances between on-site sewage management and water wells in New Zealand based on virus transport, specifically for rotavirus and Hepatitis A (Moore, et al., 2010). They found that soils classified as 'Recent' under the New Zealand Soil Classification (NZSC) were likely to have Low microbial bypass flow, however GlenT_2a.1 (40% of the map unit) is listed as having High bypass flow, and the soils are shallow to very shallow (< 0.45 m). Based on this model, 10% of viruses from the wastewater may still be viable after passing through the soil zone.

For gravel aquifers, the ESR indicative guidelines suggest that a vadose zone greater than 10 m is required for the satisfactory removal of most infectious viruses within 300 m of the disposal field (Moore, et al., 2010). Note this is much larger than the AS/NZS1547:2012 *On-site domestic wastewater management* (Standards Australia Limited/Standards New Zealand, 2012) recommendation of groundwater setback distances of 1.5 m.b.g. for land application areas over gravel aquifers. In Glenorchy, the vadose zone is less than 4 m throughout most of the township (see Section 4.2.2). In the north-east of the Glenorchy township, where there is the highest density of high risk septic tanks (Figure 12), the vadose zone is closer to 1 m. This is the vertical distance from the base of the land application system to the highest seasonal water table level i.e. the zone of unsaturated aerobic soil conditions. It is also accepted within the literature that the efficacy of soil treatment of wastewater reduces "as septic tank density increases, as systems age, or if they are sited to close to groundwater or within saturated or otherwise unsuitable soils" (Lusk, et al., 2017).

5.3 Nutrient Loadings

Water Plan Change 6A (ORC, 2016) established nitrogen loading limits for diffuse discharges from agricultural discharges. It identified Lake Wakatipu as a nitrogen sensitive zone; nitrogen loading in the catchment should not exceed 15 kg N/ha/year (ORC, 2014). Otago Regional Council (ORC) investigated groundwater contamination risk using nitrogen loading and septic tank density across Otago. They recommended that areas where nitrogen loading exceeds 30 kg/ha/year due to septic tank inputs should be considered high priority for change. Glenorchy was identified as a septic tank contamination hotspot, with total nitrogen loading for the area calculated as 2200 kg/year, and 183 septic tanks situated in locations where nitrogen loading would exceed 183 kg/ha/year (ORC, 2015).

Based on the measured nitrogen concentrations in groundwater and surface water, and groundwater gradients across the township, a revised estimate of nitrogen flux has been calculated. Two key flow paths have been identified;

1. between MW3 and Glenorchy Harbour; and
2. the Rees River/Lagoon outlet to Glenorchy Jetty.

The groundwater levels were more seasonally variable in the upgradient bores (MW3) than in those closer to the lake. Consequently, the groundwater flow gradient, and hence flux, was also subject to higher variance. Nitrogen flux estimates ranged from 1243 - 1264 kg/year from groundwater into Lake Wakatipu. These calculations are included as Appendix E. These calculated fluxes are less than that estimated by ORC (2015), but more than those estimated by e3Scientific (2017).

Using the distance travelled by groundwater over the year, the area contributing to the yearly flux can be estimated, and hence the nitrogen loading/ha/year. These resulted in high nitrogen loading of 29 – 42 kg N/ha/year along the MW3 to Glenorchy Harbour flowpath. According to the criteria determined by ORC (2015), this should be considered a high priority for change. Along the Rees River/Lagoon outlet to Glenorchy Jetty flowpath the nitrogen loading is low (approximately 4 kg N/ha/year), due to reducing conditions. These conditions decrease the nitrogen loading impact of septic tanks on the receiving environment of Lake Wakatipu in this area.

5.4 Further Investigations

Should further evidence be required the confirm the conceptual model and the likely impacts of on-site sewage management in Glenorchy, the following works would be recommended:

- Installation of an additional monitoring piezometer near the lake at the southern end of the township to confirm the groundwater discharge quality in this area.
- For additional assessment of risks to human health from on-site sewage management in Glenorchy, additional microbial indicators should be included in the suite of analysis, such as *Clostridium perfringens* and phages.

- Stream gauging of the lagoon outlet/Rees River to confirm losses to groundwater
- Vertical profiling of water quality using low flow sampling in the monitoring piezometer P3 and P1.
- Hydrogeochemical modelling of the reactions between the Rees River/Lagoon outlet, P3 and P1.

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Appendices

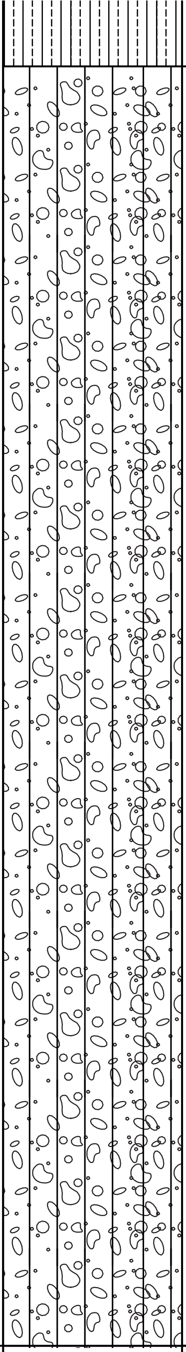
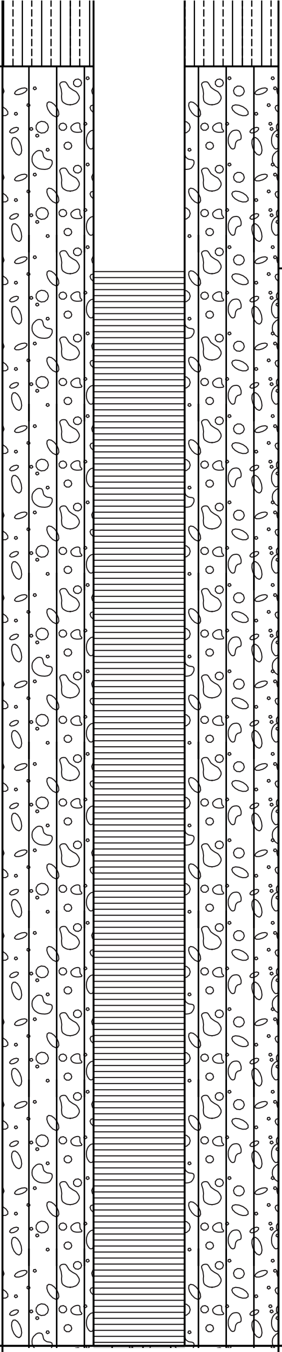
Appendix A: Bore Logs P1-P4

BORE LOG P1

PROJECT NUMBER 17053
PROJECT NAME Glenorchy Wastewater Scheme
LOGGED DK

DRILLING DATE 30th & 31 October 2017
TOTAL DEPTH 10m
DIAMETER 25mm
WATER LEVEL 1.29 BGL
COORDINATES 1235134.41 E 5023214.41 N

CASING Slotted High Density Polyethylene (2m)
SCREEN High Density Polyethylene (8m)
WRAP Polypropylene Filter Gauze
REFERENCE POINT Top Of Bore Casing
REFERENCE LEVEL 311.15

Depth (m)	**Graphic Log**	**Moisture**	**Material Description**	**Well Diagram**	**Bore Observations**
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10		Moist	Brown SILT with minor sand and clay, some organic material		Casing
		Wet	Poorly sorted GRAVEL with minor cobble, minor sand and silt		Screen
			Termination Depth at:10		

Disclaimer This bore log is intended for environmental not geotechnical purposes.

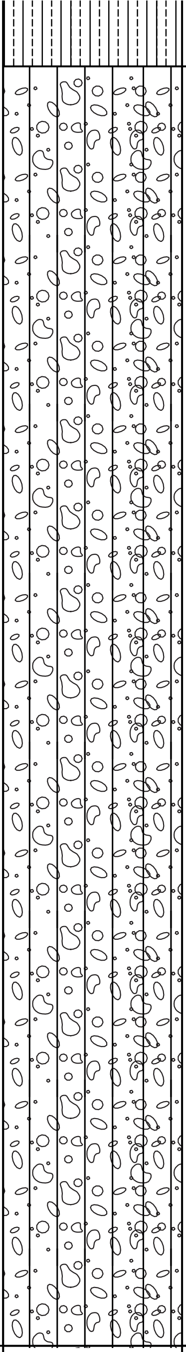
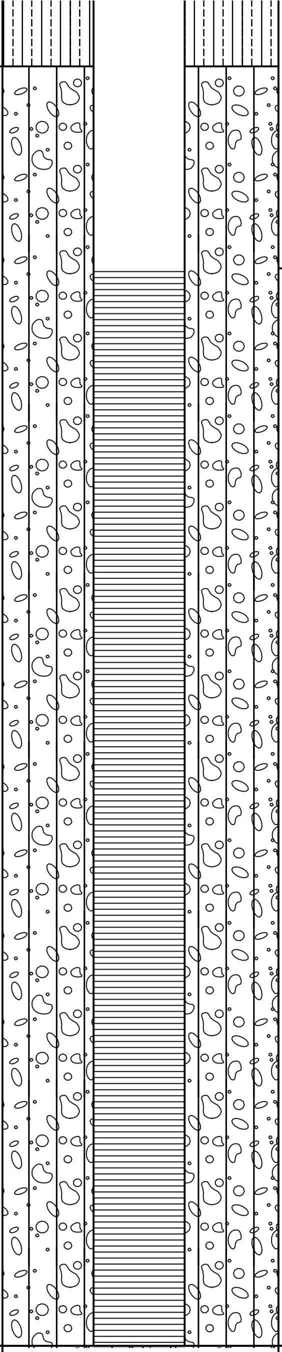
produced by ESlog.ESdat.net on 07 Dec 2017

BORE LOG P2

PROJECT NUMBER 17053
PROJECT NAME Glenorchy Wastewater Scheme
LOGGED DK

DRILLING DATE 30th & 31 October 2017
TOTAL DEPTH 10m
DIAMETER 25mm
WATER LEVEL 3.78 BGL
COORDINATES 1235510.34 E 5023479.39 N

CASING Slotted High Density Polyethylene (2m)
SCREEN High Density Polyethylene (8m)
WRAP Polypropylene Filter Gauze
REFERENCE POINT Top Of Bore Casing
REFERENCE LEVEL 314.09

Depth (m)	Graphic Log	Moisture	Material Description	Well Diagram	Bore Observations
0.5		Moist	Brown SILT with minor sand and clay, some organic material		Casing
1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5		Wet ▽	Poorly sorted GRAVEL with minor cobble, minor sand and silt		Screen
10			Termination Depth at:10		

Disclaimer This bore log is intended for environmental not geotechnical purposes.

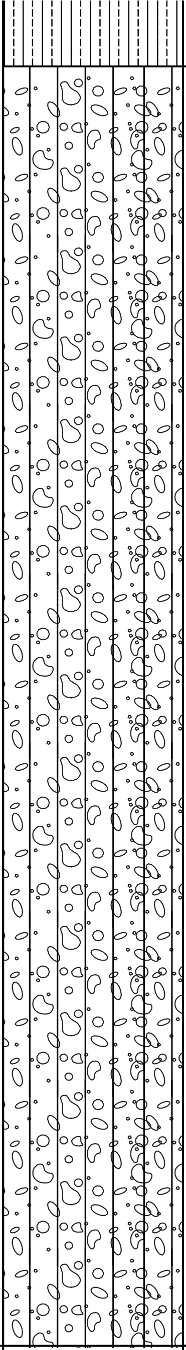
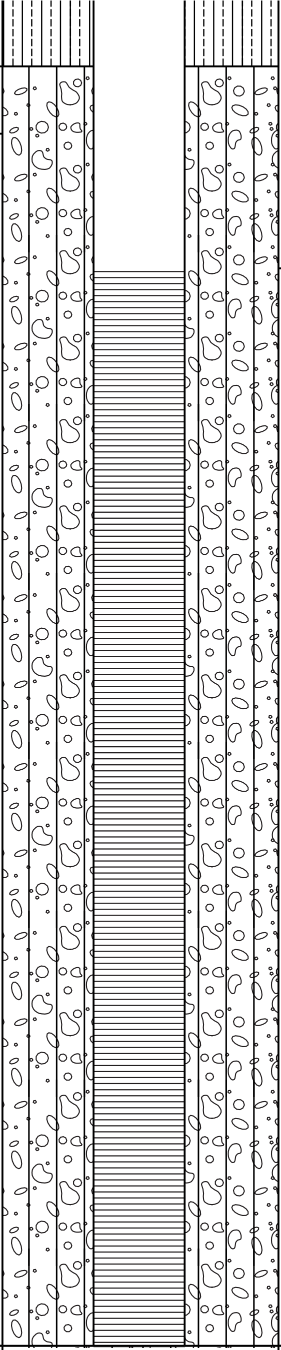
produced by ESlog.ESdat.net on 08 Dec 2017

BORE LOG P3

PROJECT NUMBER 17053
PROJECT NAME Glenorchy Wastewater Scheme
LOGGED DK

DRILLING DATE 30th & 31 October 2017
TOTAL DEPTH 10m
DIAMETER 25mm
WATER LEVEL 0.99
COORDINATES 1235260.17 E 5023605.82 N

CASING Slotted High Density Polyethylene (2m)
SCREEN High Density Polyethylene (8m)
WRAP Polypropylene Filter Gauze
REFERENCE POINT Top Of Bore Casing
REFERENCE LEVEL 311.3

Depth (m)	Graphic Log	Moisture	Material Description	Well Diagram	Bore Observations
		Moist	Brown SILT with minor sand and clay, some organic material		Casing
0.5		Wet	Grey SAND with minor silt and clay		
1 1.5		▽	Poorly sorted GRAVEL with minor cobble, minor sand and silt		
2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5					Screen
10			Termination Depth at:10		

Disclaimer This bore log is intended for environmental not geotechnical purposes.

produced by ESlog.ESdat.net on 08 Dec 2017

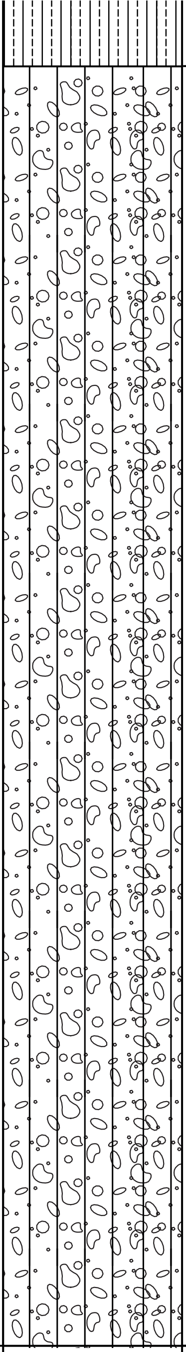
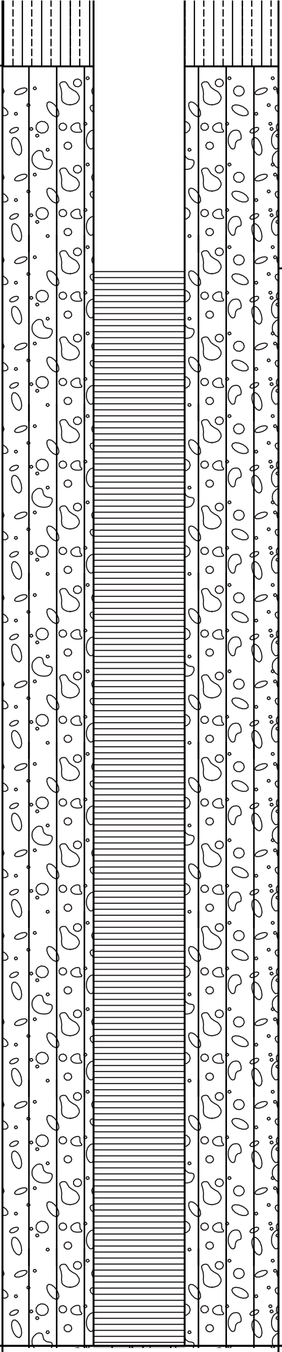
e3 Scientific

BORE LOG P4

PROJECT NUMBER 17053
PROJECT NAME Glenorchy Wastewater Scheme
LOGGED DK

DRILLING DATE 30th & 31 October 2017
TOTAL DEPTH 10m
DIAMETER 25mm
WATER LEVEL 3.93
COORDINATES 1235380.41 E 5023305.97 N

CASING Slotted High Density Polyethylene (2m)
SCREEN High Density Polyethylene (8m)
WRAP Polypropylene Filter Gauze
REFERENCE POINT Top Of Bore Casing
REFERENCE LEVEL 314

Depth (m)	Graphic Log	Moisture	Material Description	Well Diagram	Bore Observations
0.5		Moist	Brown SILT with minor sand and clay, some organic material		Casing
1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10		Wet	Poorly sorted GRAVEL with minor cobble, minor sand and silt		Screen
			Termination Depth at:10		

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Appendix B: Laboratory Analyses

Hill Laboratories
TRIED, TESTED **AND TRUSTED**

R J Hill Laboratories Limited
28 Duke Street Frankton 3204
Private Bag 3205
Hamilton 3240 New Zealand

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T +64 7 858 2000
E mail@hill-labs.co.nz
W www.hill-laboratories.com

ANALYSIS REPORT

Client:	E3 Scientific Limited	**Lab No:**	1887352 SPv2
Contact:	Alexandra Badenhop	**Date Received:**	01-Dec-2017
	C/- E3 Scientific Limited	**Date Reported:**	13-Dec-2017 **(Amended)**
	PO Box 2450	**Quote No:**	86953
	Wakatipu	**Order No:**	
	Queenstown 9349	**Client Reference:**	17053
		Submitted By:	Alexandra Badenhop

Sample Type: Aqueous

Sample Name:		P1 30-Nov-2017 8:20 am	P5 30-Nov-2017 8:35 am	P4 30-Nov-2017 9:33 am	P2 30-Nov-2017 11:11 am	P3 30-Nov-2017 9:50 am
Lab Number:		1887352.1	1887352.2	1887352.3	1887352.4	1887352.5
Sum of Anions	meq/L	1.56	1.57	1.70	0.82	1.50
Sum of Cations	meq/L	1.46	1.51	1.67	0.79	1.43
pH	pH Units	7.0	7.0	6.7	6.8	7.0
Total Alkalinity	g/m^3 as $CaCO_3$	77	77	69	38	74
Bicarbonate	g/m^3 at 25°C	94	94	84	46	90
Total Hardness	g/m^3 as $CaCO_3$	66	68	62	34	65
Electrical Conductivity (EC)	mS/m	14.9	15.1	17.5	7.9	14.5
Total Boron	g/m^3	0.0058	0.0055	0.0111	< 0.0053	< 0.0053
Dissolved Calcium	g/m^3	25	26	22	12.1	24
Total Iron	g/m^3	31	30	0.037	< 0.021	15.7
Dissolved Magnesium	g/m^3	1.03	1.05	1.92	1.03	1.03
Total Manganese	g/m^3	1.43	1.45	0.56	0.0040	0.68
Dissolved Potassium	g/m^3	1.71	1.79	3.6	1.35	0.90
Dissolved Sodium	g/m^3	2.0	2.2	4.4	1.65	1.65
Bromide	g/m^3	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Chloride	g/m^3	0.6	0.6	5.0	0.7	0.6
Total Nitrogen	g/m^3	< 0.11	0.16	3.4	0.51	0.45
Total Ammoniacal-N	g/m^3	0.100	0.116	1.93	< 0.010	0.46
Nitrite-N	g/m^3	< 0.002	< 0.002	0.004	< 0.002	< 0.002
Nitrate-N	g/m^3	< 0.002	< 0.002	1.44	0.39	< 0.002
Nitrate-N + Nitrite-N	g/m^3	< 0.002	< 0.002	1.45	0.39	< 0.002
Total Kjeldahl Nitrogen (TKN)	g/m^3	< 0.10 [#2]	0.15	1.98	0.12	0.45 [#2]
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	0.029	< 0.004	< 0.004
Total Phosphorus	g/m^3	< 0.004	< 0.004	0.025 [#3]	< 0.004	0.007
Sulphate	g/m^3	< 0.5	< 0.5	3.5	1.0	< 0.5
Dissolved Organic Carbon (DOC)	g/m^3	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Escherichia coli	cfu / 100mL	< 10 [#1]	< 10 [#1]	< 1 [#1]	< 1 [#1]	< 1 [#1]

Sample Name:		Rees 30-Nov-2017 10:10 am	Lagoon B 30-Nov-2017 10:30 am	BB 30-Nov-2017 2:02 pm	GY Harbour 30-Nov-2017 9:01 am	MW1 30-Nov-2017 11:45 am
Lab Number:		1887352.6	1887352.7	1887352.8	1887352.9	1887352.10
Sum of Anions	meq/L	0.95	1.02	0.79	1.26	0.77
Sum of Cations	meq/L	0.93	1.01	0.76	1.19	0.78
pH	pH Units	7.7	7.7	7.8	7.2	6.3
Total Alkalinity	g/m^3 as $CaCO_3$	42	45	34	56	20
Bicarbonate	g/m^3 at 25°C	51	55	41	69	25
Total Hardness	g/m^3 as $CaCO_3$	43	47	36	52	27
Electrical Conductivity (EC)	mS/m	9.3	9.9	7.5	12.0	8.5
Total Boron	g/m^3	< 0.0053	< 0.0053	< 0.0053	0.0073	0.0058

Sample Type: Aqueous

Sample Name:		Rees 30-Nov-2017 10:10 am	Lagoon B 30-Nov-2017 10:30 am	BB 30-Nov-2017 2:02 pm	GY Harbour 30-Nov-2017 9:01 am	MW1 30-Nov-2017 11:45 am
Lab Number:		1887352.6	1887352.7	1887352.8	1887352.9	1887352.10
Dissolved Calcium	g/m^3	16.2	17.5	13.6	17.9	8.4
Total Iron	g/m^3	0.64	0.79	0.030	0.56	0.073
Dissolved Magnesium	g/m^3	0.73	0.80	0.47	1.80	1.48
Total Manganese	g/m^3	0.084	0.126	0.0020	0.40	0.0044
Dissolved Potassium	g/m^3	0.38	0.36	0.36	1.09	1.66
Dissolved Sodium	g/m^3	1.25	1.36	0.89	2.6	4.3
Bromide	g/m^3	< 0.05	< 0.05	< 0.05	< 0.05	0.06
Chloride	g/m^3	0.6	0.7	0.6	1.5	4.3
Total Nitrogen	g/m^3	< 0.11	0.12	< 0.11	0.38	2.6
Total Ammoniacal-N	g/m^3	< 0.010	< 0.010	0.012	0.036	0.017
Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	0.004	< 0.002
Nitrate-N	g/m^3	< 0.002	< 0.002	0.002	0.28	2.5
Nitrate-N + Nitrite-N	g/m^3	< 0.002	< 0.002	0.002	0.28	2.5
Total Kjeldahl Nitrogen (TKN)	g/m^3	< 0.10	0.12	< 0.10	< 0.10	0.12
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Total Phosphorus	g/m^3	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Sulphate	g/m^3	4.6	4.5	4.5	3.4	2.8
Dissolved Organic Carbon (DOC)	g/m^3	0.6	1.2	< 0.5	< 0.5	< 0.5
Escherichia coli	cfu / 100mL	110 [#1]	150 [#1]	< 1 [#1]	4 [#1]	< 1 [#1]

Sample Name:		MW2 30-Nov-2017 1:50 pm	MW3 30-Nov-2017 1:20 pm			
Lab Number:		1887352.11	1887352.12			
Sum of Anions	meq/L	0.89	0.28	-	-	-
Sum of Cations	meq/L	0.88	0.25	-	-	-
pH	pH Units	6.2	6.4	-	-	-
Total Alkalinity	g/m^3 as $CaCO_3$	20	10.4	-	-	-
Bicarbonate	g/m^3 at 25°C	25	12.6	-	-	-
Total Hardness	g/m^3 as $CaCO_3$	26	6.9	-	-	-
Electrical Conductivity (EC)	mS/m	10.1	2.5	-	-	-
Total Boron	g/m^3	0.022	< 0.0053	-	-	-
Dissolved Calcium	g/m^3	8.0	1.96	-	-	-
Total Iron	g/m^3	< 0.021	0.029	-	-	-
Dissolved Magnesium	g/m^3	1.39	0.48	-	-	-
Total Manganese	g/m^3	0.0042	0.0025	-	-	-
Dissolved Potassium	g/m^3	6.0	0.64	-	-	-
Dissolved Sodium	g/m^3	4.8	2.1	-	-	-
Bromide	g/m^3	< 0.05	< 0.05	-	-	-
Chloride	g/m^3	2.1	1.8	-	-	-
Total Nitrogen	g/m^3	4.2	0.33	-	-	-
Total Ammoniacal-N	g/m^3	0.013	0.011	-	-	-
Nitrite-N	g/m^3	< 0.002	< 0.002	-	-	-
Nitrate-N	g/m^3	4.1	0.27	-	-	-
Nitrate-N + Nitrite-N	g/m^3	4.1	0.27	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m^3	0.12	< 0.10	-	-	-
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	-	-	-
Total Phosphorus	g/m^3	< 0.004	< 0.004	-	-	-
Sulphate	g/m^3	6.6	< 0.5	-	-	-
Dissolved Organic Carbon (DOC)	g/m^3	0.8	1.0	-	-	-
Escherichia coli	cfu / 100mL	< 1 [#1]	< 1 [#1]	-	-	-

Analyst's Comments

[#1] Statistically estimated count based on the theoretical countable range for the stated method.

[#2] It has been noted that the result for Total Ammoniacal-N was greater than that for Total Kjeldahl Nitrogen, but within the analytical variation of these methods.

[#3] It has been noted that the result for Dissolved Reactive Phosphorus was greater than that for Total Phosphorus, but within the analytical variation of these methods.

Amended Report: This report replaces an earlier report issued on 11 Dec 2017 at 4:22 pm
Reason for amendment: Following a query by the client, the alkalinity result for sample1887352.5 was reanalysed and found not to confirm that originally reported due to a possible instrument error [QOWQ 68749].

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter. Performed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch.	-	1-12
Total Digestion	Nitric acid digestion. APHA 3030 E 22nd ed. 2012 (modified).	-	1-12
Total Kjeldahl Digestion	Sulphuric acid digestion with copper sulphate catalyst.	-	1-12
Total Phosphorus Digestion	Acid persulphate digestion.	-	1-12
Total anions for anion/cation balance check	Calculation: sum of anions as mEquiv/L calculated from Alkalinity (bicarbonate), Chloride and Sulphate. Nitrate-N, Nitrite-N. Fluoride, Dissolved Reactive Phosphorus and Cyanide also included in calculation if available. APHA 1030 E 22nd ed. 2012.	0.07 meq/L	1-12
Total cations for anion/cation balance check	Sum of cations as mEquiv/L calculated from Sodium, Potassium, Calcium and Magnesium. Iron, Manganese, Aluminium, Zinc, Copper, Lithium, Total Ammoniacal-N and pH (H^+) also included in calculation if available. APHA 1030 E 22nd ed. 2012.	0.05 meq/L	1-12
pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 4500-H^+ B 22nd ed. 2012. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field.	0.1 pH Units	1-12
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (Modified for alk <20) 22nd ed. 2012.	1.0 g/m^3 as $CaCO_3$	3, 5
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2320 B (Modified for alk <20) 22nd ed. 2012.	1.0 g/m^3 as $CaCO_3$	1-2, 4, 6-12
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO_2 D 22nd ed. 2012.	1.0 g/m^3 at 25°C	1-12
Total Hardness	Calculation from Calcium and Magnesium. APHA 2340 B 22nd ed. 2012.	1.0 g/m^3 as $CaCO_3$	1-12
Electrical Conductivity (EC)	Conductivity meter, 25°C. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2510 B 22nd ed. 2012.	0.1 mS/m	1-12
Filtration for dissolved metals analysis	Sample filtration through 0.45µm membrane filter and preservation with nitric acid. APHA 3030 B 22nd ed. 2012.	-	1-12
Total Boron	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.0053 g/m^3	1-12
Dissolved Calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.05 g/m^3	1-12
Total Iron	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.021 g/m^3	1-12
Dissolved Magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.02 g/m^3	1-12
Total Manganese	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012 / US EPA 200.8.	0.00053 g/m^3	1-12
Dissolved Potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.05 g/m^3	1-12
Dissolved Sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.02 g/m^3	1-12
Bromide	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B 22nd ed. 2012.	0.05 g/m^3	1-12

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Chloride	Filtered sample from Christchurch. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500 Cl^- E (modified from continuous flow analysis) 22nd ed. 2012.	0.5 g/m^3	1-12
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3.	0.05 g/m^3	1-12
Total Ammoniacal-N	Filtered Sample from Christchurch. Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 22nd ed. 2012.	0.010 g/m^3	1-12
Nitrite-N	Filtered sample from Christchurch. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I 22nd ed. 2012 (modified).	0.002 g/m^3	1-12
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g/m^3	1-12
Nitrate-N + Nitrite-N	Filtered sample from Christchurch. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I 22nd ed. 2012 (modified).	0.002 g/m^3	1-12
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D. (modified) 4500 NH_3 F (modified) 22nd ed. 2012.	0.10 g/m^3	1-12
Dissolved Reactive Phosphorus	Filtered sample from Christchurch. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified). 22nd ed. 2012.	0.004 g/m^3	1-12
Total Phosphorus	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis) 22nd ed. 2012. Also modified to include the use of a reductant to eliminate interference from arsenic present in the sample. NAWASCO, Water & soil Miscellaneous Publication No. 38, 1982.	0.004 g/m^3	1-12
Sulphate	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B 22nd ed. 2012.	0.5 g/m^3	1-12
Dissolved Organic Carbon (DOC)	Filtered sample, Supercritical persulphate oxidation, IR detection, for Total C. Acidification, purging for Total Inorganic C. TOC = TC -TIC. APHA 5310 C (modified) 22nd ed. 2012.	0.5 g/m^3	1-12
Escherichia coli	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, Confirmation Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9222 G, 22nd ed. 2012.	1 cfu / 100mL	1-12

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

This report must not be reproduced, except in full, without the written consent of the signatory.

Martin Cowell - BSc
Client Services Manager - Environmental

Hill Laboratories
TRIED, TESTED **AND TRUSTED**

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Certificate of Analysis

Client:	E3 Scientific Limited	**Lab No:**	1912019	SPv2
Contact:	Bryony Miller	**Date Received:**	23-Jan-2018	
	C/- E3 Scientific Limited	**Date Reported:**	02-Mar-2018	**(Amended)**
	PO Box 2450	**Quote No:**	86953	
	Wakatipu	**Order No:**		
	Queenstown 9349	**Client Reference:**	17053	
		Submitted By:	Duncan Keenan	

Sample Type: Aqueous

Sample Name:		MW1 22-Jan-2018 8:00 am	MW2 22-Jan-2018 10:30 am	MW3 22-Jan-2018 9:30 am	GY Harbour 22-Jan-2018 11:45 am	Rees 22-Jan-2018 1:05 pm
Lab Number:		1912019.1	1912019.2	1912019.3	1912019.4	1912019.5
Sum of Anions	meq/L	0.83	0.83	0.28	1.38	1.06
Sum of Cations	meq/L	0.89	0.82	0.27	1.33	1.02
pH	pH Units	6.1	6.0	6.2	6.9	7.6
Total Alkalinity	g/m^3 as $CaCO_3$	24	19.1	9.0	63	48
Bicarbonate	g/m^3 at 25°C	29	23	11.0	76	58
Total Hardness	g/m^3 as $CaCO_3$	26	25	7.4	57	46
Electrical Conductivity (EC)	mS/m	9.2	9.5	2.6	13.3	10.3
Dissolved Boron	g/m^3	< 0.005	0.009	< 0.005	< 0.005	< 0.005
Dissolved Calcium	g/m^3	8.0	7.8	2.1	19.4	17.2
Dissolved Iron	g/m^3	< 0.02	< 0.02	< 0.02	0.43	0.52
Dissolved Magnesium	g/m^3	1.45	1.28	0.54	1.96	0.76
Dissolved Manganese	g/m^3	0.0035	0.0046	0.0066	0.75	0.123
Dissolved Potassium	g/m^3	1.88	5.8	0.75	1.29	0.48
Dissolved Sodium	g/m^3	7.4	4.0	2.3	2.8	1.38
Bromide	g/m^3	0.05	< 0.05	< 0.05	< 0.05	< 0.05
Chloride	g/m^3	4.5	2.6	2.4	1.8	0.7
Total Nitrogen	g/m^3	2.5	3.9	0.51	0.50	< 0.11
Total Ammoniacal-N	g/m^3	< 0.010	< 0.010	< 0.010	0.036	< 0.010
Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	0.008	< 0.002
Nitrate-N	g/m^3	2.4	3.8	0.38	0.37	< 0.002
Nitrate-N + Nitrite-N	g/m^3	2.4	3.8	0.38	0.37	0.002
Total Kjeldahl Nitrogen (TKN)	g/m^3	< 0.10	0.10	0.13	0.13	< 0.10
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Total Phosphorus	g/m^3	0.006	< 0.004	0.013	0.004	0.008
Sulphate	g/m^3	2.4	5.1	< 0.5	2.5	4.1
Dissolved Organic Carbon (DOC)	g/m^3	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Escherichia coli	cfu / 100mL	< 1 [#1]	< 1 [#1]	38	25	200

Sample Name:		LB 22-Jan-2018 1:20 pm	BB 22-Jan-2018 2:00 pm	P1 22-Jan-2018 11:29 am	P2 22-Jan-2018 1:45 pm	P3 22-Jan-2018 12:50 pm
Lab Number:		1912019.6	1912019.7	1912019.8	1912019.9	1912019.10
Sum of Anions	meq/L	1.01	1.05	1.61 [#2]	0.85	1.46 [#2]
Sum of Cations	meq/L	1.04	1.01	2.6 [#2]	0.81	1.89 [#2]
pH	pH Units	7.6	7.9	7.1	6.8	7.1
Total Alkalinity	g/m^3 as $CaCO_3$	45	45	80	39	72
Bicarbonate	g/m^3 at 25°C	55	55	97	47	87
Total Hardness	g/m^3 as $CaCO_3$	48	47	68	34	62
Electrical Conductivity (EC)	mS/m	10.3	10.1	15.6	8.3	14.2
Dissolved Boron	g/m^3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005

Sample Type: Aqueous

Sample Name:		LB 22-Jan-2018 1:20 pm	BB 22-Jan-2018 2:00 pm	P1 22-Jan-2018 11:29 am	P2 22-Jan-2018 1:45 pm	P3 22-Jan-2018 12:50 pm
Lab Number:		1912019.6	1912019.7	1912019.8	1912019.9	1912019.10
Dissolved Calcium	g/m^3	17.7	17.8	25	12.1	23
Dissolved Iron	g/m^3	0.34	< 0.02	28	< 0.02	13.8
Dissolved Magnesium	g/m^3	0.80	0.66	1.05	1.01	0.97
Dissolved Manganese	g/m^3	0.142	0.0021	1.38	0.0035	0.65
Dissolved Potassium	g/m^3	0.48	0.50	1.79	1.45	1.01
Dissolved Sodium	g/m^3	1.38	1.24	2.1	1.87	1.69
Bromide	g/m^3	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Chloride	g/m^3	0.7	< 0.5	0.7	1.0	0.8
Total Nitrogen	g/m^3	< 0.11	< 0.11	0.12	0.42	0.53
Total Ammoniacal-N	g/m^3	0.014	< 0.010	0.101	< 0.010	0.46
Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Nitrate-N	g/m^3	< 0.002	< 0.002	< 0.002	0.35	< 0.002
Nitrate-N + Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	0.35	< 0.002
Total Kjeldahl Nitrogen (TKN)	g/m^3	< 0.10	< 0.10	0.12	< 0.10	0.53
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Total Phosphorus	g/m^3	0.009	< 0.004	0.013	0.014	0.062
Sulphate	g/m^3	4.1	6.5	< 0.5	0.8	< 0.5
Dissolved Organic Carbon (DOC)	g/m^3	< 0.5	< 0.5	< 0.5	0.5	< 0.5
Escherichia coli	cfu / 100mL	380	46	< 10 [#1]	1 [#1]	< 1 [#1]

Sample Name:		P4 22-Jan-2018 12:15 pm				
Lab Number:		1912019.11				
Sum of Anions	meq/L	1.85	-	-	-	-
Sum of Cations	meq/L	1.79	-	-	-	-
pH	pH Units	6.8	-	-	-	-
Total Alkalinity	g/m^3 as CaCO$_3$	77	-	-	-	-
Bicarbonate	g/m^3 at 25°C	94	-	-	-	-
Total Hardness	g/m^3 as CaCO$_3$	66	-	-	-	-
Electrical Conductivity (EC)	mS/m	18.8	-	-	-	-
Dissolved Boron	g/m^3	< 0.005	-	-	-	-
Dissolved Calcium	g/m^3	23	-	-	-	-
Dissolved Iron	g/m^3	< 0.02	-	-	-	-
Dissolved Magnesium	g/m^3	2.1	-	-	-	-
Dissolved Manganese	g/m^3	0.51	-	-	-	-
Dissolved Potassium	g/m^3	3.1	-	-	-	-
Dissolved Sodium	g/m^3	7.0	-	-	-	-
Bromide	g/m^3	< 0.05	-	-	-	-
Chloride	g/m^3	6.0	-	-	-	-
Total Nitrogen	g/m^3	2.1	-	-	-	-
Total Ammoniacal-N	g/m^3	1.00	-	-	-	-
Nitrite-N	g/m^3	0.009	-	-	-	-
Nitrate-N	g/m^3	0.98	-	-	-	-
Nitrate-N + Nitrite-N	g/m^3	0.99	-	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m^3	1.10	-	-	-	-
Dissolved Reactive Phosphorus	g/m^3	0.028	-	-	-	-
Total Phosphorus	g/m^3	0.040	-	-	-	-
Sulphate	g/m^3	2.9	-	-	-	-
Dissolved Organic Carbon (DOC)	g/m^3	< 0.5	-	-	-	-
Escherichia coli	cfu / 100mL	< 1 [#1]	-	-	-	-

Analyst's Comments

#1 Statistically estimated count based on the theoretical countable range for the stated method.

#2 It was noted that some of the anion / cation balances did not agree to within expected limits. This was largely attributed to the high levels of dissolved iron. We have included dissolved iron in the cation balance equations. However, the precipitation of large amounts of iron in the unpreserved containers (soon after sampling) will result in the loss of ions from solution and consumption of alkalinity. This may well result in the lower anions relative to the cations, being reported. The loss of soluble iron in the unpreserved container does not affect the cation balance, as the dissolved iron is sampled into an acid preserved container, stabilising the iron in solution.

Amended Report: This report replaces an earlier report issued on 08 Feb 2018 at 10:55 am
Reason for amendment: AnCat balance comment added to report.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter. Performed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch.	-	1-11
Total Kjeldahl Digestion	Sulphuric acid digestion with copper sulphate catalyst.	-	1-11
Total Phosphorus Digestion	Acid persulphate digestion.	-	1-11
Total anions for anion/cation balance check	Calculation: sum of anions as mEquiv/L calculated from Alkalinity (bicarbonate), Chloride and Sulphate. Nitrate-N, Nitrite-N. Fluoride, Dissolved Reactive Phosphorus and Cyanide also included in calculation if available. APHA 1030 E 22nd ed. 2012.	0.07 meq/L	1-11
Total cations for anion/cation balance check	Sum of cations as mEquiv/L calculated from Sodium, Potassium, Calcium and Magnesium. Iron, Manganese, Aluminium, Zinc, Copper, Lithium, Total Ammoniacal-N and pH (H^+) also included in calculation if available. APHA 1030 E 22nd ed. 2012.	0.05 meq/L	1-11
pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 4500-H^+ B 22nd ed. 2012. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units	1-11
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2320 B (Modified for alk <20) 22nd ed. 2012.	1.0 g/m^3 as $CaCO_3$	1-11
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO_2 D 22nd ed. 2012.	1.0 g/m^3 at 25°C	1-11
Total Hardness	Calculation from Calcium and Magnesium. APHA 2340 B 22nd ed. 2012.	1.0 g/m^3 as $CaCO_3$	1-11
Electrical Conductivity (EC)	Conductivity meter, 25°C. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2510 B 22nd ed. 2012.	0.1 mS/m	1-11
Dissolved Boron	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.005 g/m^3	1-11
Dissolved Calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.05 g/m^3	1-11
Dissolved Iron	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.02 g/m^3	1-11
Dissolved Magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.02 g/m^3	1-11
Dissolved Manganese	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.0005 g/m^3	1-11
Dissolved Potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.05 g/m^3	1-11
Dissolved Sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.02 g/m^3	1-11
Bromide	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) 22nd ed. 2012.	0.05 g/m^3	1-11
Chloride	Filtered sample from Christchurch. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500 Cl^- E (modified from continuous flow analysis) 22nd ed. 2012.	0.5 g/m^3	1-11

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3.	0.05 g/m^3	1-11
Total Ammoniacal-N	Filtered Sample from Christchurch. Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 22nd ed. 2012.	0.010 g/m^3	1-11
Nitrite-N	Filtered sample from Christchurch. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I 22nd ed. 2012 (modified).	0.002 g/m^3	1-11
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g/m^3	1-11
Nitrate-N + Nitrite-N	Filtered sample from Christchurch. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I 22nd ed. 2012 (modified).	0.002 g/m^3	1-11
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D. (modified) 4500 NH_3 F (modified) 22nd ed. 2012.	0.10 g/m^3	1-11
Dissolved Reactive Phosphorus	Filtered sample from Christchurch. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified). 22nd ed. 2012.	0.004 g/m^3	1-11
Total Phosphorus	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis) 22nd ed. 2012. Also modified to include the use of a reductant to eliminate interference from arsenic present in the sample. NAWASCO, Water & soil Miscellaneous Publication No. 38, 1982.	0.004 g/m^3	1-11
Sulphate	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) 22nd ed. 2012.	0.5 g/m^3	1-11
Dissolved Organic Carbon (DOC)	Filtered sample, Supercritical persulphate oxidation, IR detection, for Total C. Acidification, purging for Total Inorganic C. TOC = TC -TIC. APHA 5310 C (modified) 22nd ed. 2012.	0.5 g/m^3	1-11
Escherichia coli	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, Confirmation Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9222 G, 22nd ed. 2012.	1 cfu / 100mL	1-11

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

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Martin Cowell - BSc
Client Services Manager - Environmental

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Certificate of Analysis

SPv1

Client:	E3 Scientific Limited	**Lab No:**	1965916
Contact:	Bryony Miller C/- E3 Scientific Limited PO Box 2450 Wakatipu Queenstown 9349	**Date Received:**	19-Apr-2018
		Date Reported:	04-May-2018
		Quote No:	86953
		Order No:	
		Client Reference:	17053
		Submitted By:	Duncan Keenan

Sample Type: Aqueous

	Sample Name:	MW1 18-Apr-2018 8:00 am	MW2 18-Apr-2018 11:09 am	MW3 18-Apr-2018 10:09 am	P1 18-Apr-2018 12:00 pm	P2 18-Apr-2018 1:30 pm
	Lab Number:	1965916.1	1965916.2	1965916.3	1965916.4	1965916.5
Sum of Anions	meq/L	0.87	0.99	0.28	1.71	0.79
Sum of Cations	meq/L	0.86	0.94	0.26	2.5	0.80
pH	pH Units	5.9	6.1	6.2	6.9	6.5
Total Alkalinity	g/m^3 as $CaCO_3$	22	21	9.9	85	37
Bicarbonate	g/m^3 at 25°C	27	26	12.1	103	45
Total Hardness	g/m^3 as $CaCO_3$	31	28	7.2	67	34
Electrical Conductivity (EC)	mS/m	9.8	10.9	2.7	16.6	8.2
Dissolved Boron	g/m^3	0.008	0.016	< 0.005	< 0.005	< 0.005
Dissolved Calcium	g/m^3	9.5	8.7	1.96	25	12.0
Dissolved Iron	g/m^3	< 0.02	< 0.02	< 0.02	28	< 0.02
Dissolved Magnesium	g/m^3	1.79	1.54	0.55	1.15	1.10
Dissolved Manganese	g/m^3	0.0057	0.0053	0.0040	1.41	0.0007
Dissolved Potassium	g/m^3	1.82	6.2	0.64	1.77	1.42
Dissolved Sodium	g/m^3	4.4	5.0	2.2	2.1	1.84
Bromide	g/m^3	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Chloride	g/m^3	4.1	3.7	1.8	0.6	0.9
Total Nitrogen	g/m^3	3.5	4.5	0.51	0.15	0.22
Total Ammoniacal-N	g/m^3	0.010	< 0.010	0.011	0.117	< 0.010
Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Nitrate-N	g/m^3	3.4	4.4	0.39	< 0.002	0.172
Nitrate-N + Nitrite-N	g/m^3	3.4	4.4	0.39	0.002	0.172
Total Kjeldahl Nitrogen (TKN)	g/m^3	0.14	0.14	0.12	0.14	< 0.10
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Total Phosphorus	g/m^3	0.011	0.015	0.046	0.027	0.006
Sulphate	g/m^3	3.3	6.9	< 0.5	< 0.5	1.2
Dissolved Organic Carbon (DOC)	g/m^3	0.8	0.8	< 0.5	< 0.5	< 0.5
Escherichia coli	cfu / 100mL	< 1 [#1]	20	3 [#1]	< 1 [#1]	< 1 [#1]

	Sample Name:	P3 18-Apr-2018 1:00 pm	P4 18-Apr-2018 1:45 pm	GY Harbour 18-Apr-2018 11:50 am	GY Wharf 18-Apr-2018 11:35 am	Rees 18-Apr-2018 11:05 am
	Lab Number:	1965916.6	1965916.7	1965916.8	1965916.9	1965916.10
Sum of Anions	meq/L	1.45	2.2	0.74	0.59	0.83
Sum of Cations	meq/L	1.82	2.3	0.72	0.58	0.81
pH	pH Units	6.9	6.5	7.1	7.4	7.3
Total Alkalinity	g/m^3 as $CaCO_3$	72	84	31	24	35
Bicarbonate	g/m^3 at 25°C	88	102	38	29	43
Total Hardness	g/m^3 as $CaCO_3$	60	76	32	26	35
Electrical Conductivity (EC)	mS/m	14.2	22.7	7.4	5.9	8.1

Sample Type: Aqueous

Sample Name:		P3 18-Apr-2018 1:00 pm	P4 18-Apr-2018 1:45 pm	GY Harbour 18-Apr-2018 11:50 am	GY Wharf 18-Apr-2018 11:35 am	Rees 18-Apr-2018 11:05 am
Lab Number:		1965916.6	1965916.7	1965916.8	1965916.9	1965916.10
Dissolved Boron	g/m^3	< 0.005	0.010	< 0.005	< 0.005	< 0.005
Dissolved Calcium	g/m^3	22	27	11.4	9.4	12.8
Dissolved Iron	g/m^3	13.1	< 0.02	0.15	0.13	0.55
Dissolved Magnesium	g/m^3	0.98	2.3	0.84	0.58	0.72
Dissolved Manganese	g/m^3	0.64	0.55	0.079	0.0155	0.052
Dissolved Potassium	g/m^3	1.03	5.2	0.58	0.41	1.35
Dissolved Sodium	g/m^3	1.69	9.2	1.42	1.15	1.41
Bromide	g/m^3	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Chloride	g/m^3	< 0.5	9.4	0.7	< 0.5	0.8
Total Nitrogen	g/m^3	0.48	5.1	0.14	< 0.11	0.14
Total Ammoniacal-N	g/m^3	0.45	2.6	< 0.010	< 0.010	< 0.010
Nitrite-N	g/m^3	< 0.002	0.003	< 0.002	< 0.002	< 0.002
Nitrate-N	g/m^3	< 0.002	2.3	0.107	0.018	< 0.002
Nitrate-N + Nitrite-N	g/m^3	< 0.002	2.3	0.108	0.019	0.002
Total Kjeldahl Nitrogen (TKN)	g/m^3	0.48	2.8	< 0.10	< 0.10	0.14
Dissolved Reactive Phosphorus	g/m^3	< 0.004	0.035	< 0.004	< 0.004	< 0.004
Total Phosphorus	g/m^3	0.060	0.047	< 0.004	< 0.004	0.022
Sulphate	g/m^3	< 0.5	3.8	4.6	4.9	5.0
Total Biochemical Oxygen Demand (TBOD$_5$)	$g\ O_2/m^3$	-	-	< 2	< 2	< 2
Dissolved Organic Carbon (DOC)	g/m^3	< 0.5	< 0.5	< 0.5	< 0.5	1.5
Escherichia coli	cfu / 100mL	< 1 [#1]	< 1 [#1]	14 [#1]	170 [#1]	650 [#1]

Sample Name:		Lagoon Bridge 18-Apr-2018 10:30 am	Lagoon East Arm 18-Apr-2018 9:55 am	Lagoon Halfway Bridge 18-Apr-2018 9:05 am	Buckler Burn 18-Apr-2018 11:40 am	TS 18-Apr-2018 12:00 pm
Lab Number:		1965916.11	1965916.12	1965916.13	1965916.14	1965916.15
Sum of Anions	meq/L	0.77	0.86	0.80	0.76	1.60
Sum of Cations	meq/L	0.82	0.91	0.85	0.79	1.66
pH	pH Units	7.2	7.2	7.2	7.6	7.8
Total Alkalinity	g/m^3 as $CaCO_3$	33	37	35	33	73
Bicarbonate	g/m^3 at 25°C	40	45	42	40	88
Total Hardness	g/m^3 as $CaCO_3$	35	39	37	37	79
Electrical Conductivity (EC)	mS/m	8.1	8.8	8.3	7.9	16.1
Dissolved Boron	g/m^3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Dissolved Calcium	g/m^3	12.7	14.3	13.4	13.7	30
Dissolved Iron	g/m^3	0.57	0.56	0.32	0.04	< 0.02
Dissolved Magnesium	g/m^3	0.76	0.86	0.79	0.57	1.12
Dissolved Manganese	g/m^3	0.049	0.040	0.034	0.0023	< 0.0005
Dissolved Potassium	g/m^3	1.45	1.39	1.45	0.42	0.65
Dissolved Sodium	g/m^3	1.45	1.56	1.49	0.99	1.54
Bromide	g/m^3	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Chloride	g/m^3	0.8	0.9	0.9	< 0.5	0.9
Total Nitrogen	g/m^3	0.18	0.19	0.19	0.13	0.47
Total Ammoniacal-N	g/m^3	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Nitrate-N	g/m^3	< 0.002	< 0.002	< 0.002	0.037	0.43
Nitrate-N + Nitrite-N	g/m^3	< 0.002	< 0.002	< 0.002	0.037	0.43
Total Kjeldahl Nitrogen (TKN)	g/m^3	0.18	0.19	0.19	< 0.10	< 0.10
Dissolved Reactive Phosphorus	g/m^3	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Total Phosphorus	g/m^3	0.011	0.016	0.012	0.059	0.004
Sulphate	g/m^3	3.9	4.6	4.2	4.2	3.9
Total Biochemical Oxygen Demand (TBOD$_5$)	$g\ O_2/m^3$	< 2	< 2	< 2	< 2	-
Dissolved Organic Carbon (DOC)	g/m^3	2.1	2.6	2.6	1.0	< 0.5
Escherichia coli	cfu / 100mL	1,100 [#1]	130 [#1]	900 [#1]	7 [#1]	< 1 [#1]

Sample Type: Aqueous

Sample Name:		Dup 1 18-Apr-2018 7:00 pm				
Lab Number:		1965916.16				
Sum of Anions	meq/L	0.88	-	-	-	-
Sum of Cations	meq/L	0.88	-	-	-	-
pH	pH Units	6.1	-	-	-	-
Total Alkalinity	g/m³ as $CaCO_3$	23	-	-	-	-
Bicarbonate	g/m³ at 25°C	28	-	-	-	-
Total Hardness	g/m³ as $CaCO_3$	32	-	-	-	-
Electrical Conductivity (EC)	mS/m	9.8	-	-	-	-
Dissolved Boron	g/m³	0.009	-	-	-	-
Dissolved Calcium	g/m³	9.7	-	-	-	-
Dissolved Iron	g/m³	< 0.02	-	-	-	-
Dissolved Magnesium	g/m³	1.88	-	-	-	-
Dissolved Manganese	g/m³	0.0068	-	-	-	-
Dissolved Potassium	g/m³	1.83	-	-	-	-
Dissolved Sodium	g/m³	4.4	-	-	-	-
Bromide	g/m³	< 0.05	-	-	-	-
Chloride	g/m³	3.8	-	-	-	-
Total Nitrogen	g/m³	3.7	-	-	-	-
Total Ammoniacal-N	g/m³	< 0.010	-	-	-	-
Nitrite-N	g/m³	< 0.002	-	-	-	-
Nitrate-N	g/m³	3.6	-	-	-	-
Nitrate-N + Nitrite-N	g/m³	3.6	-	-	-	-
Total Kjeldahl Nitrogen (TKN)	g/m³	< 0.10	-	-	-	-
Dissolved Reactive Phosphorus	g/m³	0.005	-	-	-	-
Total Phosphorus	g/m³	0.008	-	-	-	-
Sulphate	g/m³	2.5	-	-	-	-
Dissolved Organic Carbon (DOC)	g/m³	0.7	-	-	-	-
Escherichia coli	cfu / 100mL	1 [#1]	-	-	-	-

Analyst's Comments

[#1] Statistically estimated count based on the theoretical countable range for the stated method.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter. Performed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch.	-	1-16
Total anions for anion/cation balance check	Calculation: sum of anions as mEquiv/L calculated from Alkalinity (bicarbonate), Chloride and Sulphate. Nitrate-N, Nitrite-N. Fluoride, Dissolved Reactive Phosphorus and Cyanide also included in calculation if available. APHA 1030 E 22nd ed. 2012.	0.07 meq/L	1-16
Total cations for anion/cation balance check	Sum of cations as mEquiv/L calculated from Sodium, Potassium, Calcium and Magnesium. Iron, Manganese, Aluminium, Zinc, Copper, Lithium, Total Ammoniacal-N and pH (H^+) also included in calculation if available. APHA 1030 E 22nd ed. 2012.	0.05 meq/L	1-16
pH	pH meter. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 4500-H^+ B 22nd ed. 2012. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units	1-16
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2320 B (Modified for alk <20) 22nd ed. 2012.	1.0 g/m³ as $CaCO_3$	1-16

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO_2 D 22nd ed. 2012.	1.0 g/m^3 at 25°C	1-16
Total Hardness	Calculation from Calcium and Magnesium. APHA 2340 B 22nd ed. 2012.	1.0 g/m^3 as $CaCO_3$	1-16
Electrical Conductivity (EC)	Conductivity meter, 25°C. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2510 B 22nd ed. 2012.	0.1 mS/m	1-16
Dissolved Boron	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.005 g/m^3	1-16
Dissolved Calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.05 g/m^3	1-16
Dissolved Iron	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.02 g/m^3	1-16
Dissolved Magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.02 g/m^3	1-16
Dissolved Manganese	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.0005 g/m^3	1-16
Dissolved Potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.05 g/m^3	1-16
Dissolved Sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B 22nd ed. 2012.	0.02 g/m^3	1-16
Bromide	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) 22nd ed. 2012.	0.05 g/m^3	1-16
Chloride	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) 22nd ed. 2012.	0.5 g/m^3	1-16
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3.	0.05 g/m^3	1-16
Total Ammoniacal-N	Filtered Sample from Christchurch. Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 22nd ed. 2012.	0.010 g/m^3	1-16
Nitrite-N	Filtered sample from Christchurch. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I 22nd ed. 2012 (modified).	0.002 g/m^3	1-16
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g/m^3	1-16
Nitrate-N + Nitrite-N	Filtered sample from Christchurch. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I 22nd ed. 2012 (modified).	0.002 g/m^3	1-16
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-Norg D. (modified) 4500 NH_3 F (modified) 22nd ed. 2012.	0.10 g/m^3	1-16
Dissolved Reactive Phosphorus	Filtered sample from Christchurch. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified). 22nd ed. 2012.	0.004 g/m^3	1-16
Total Phosphorus	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis) 22nd ed. 2012. Also modified to include the use of a reductant to eliminate interference from arsenic present in the sample. NAWASCO, Water & soil Miscellaneous Publication No. 38, 1982.	0.004 g/m^3	1-16
Sulphate	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) 22nd ed. 2012.	0.5 g/m^3	1-16
Total Biochemical Oxygen Demand ($TBOD_5$)	Incubation 5 days, DO meter, no nitrification inhibitor added, seeded. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 5210 B (modified) 22nd ed. 2012.	2 g O_2/m^3	8-14
Dissolved Organic Carbon (DOC)	Filtered sample, Supercritical persulphate oxidation, IR detection, for Total C. Acidification, purging for Total Inorganic C. TOC = TC -TIC. APHA 5310 C (modified) 22nd ed. 2012.	0.5 g/m^3	1-16
Escherichia coli	Membrane filtration, Count on mFC agar, Incubated at 44.5°C for 22 hours, Confirmation Analysed at Hill Laboratories - Microbiology; 101c Waterloo Road, Hornby, Christchurch. APHA 9222 G, 22nd ed. 2012.	1 cfu / 100mL	1-16

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

Martin Cowell - BSc
Client Services Manager - Environmental

Appendix C: Criteria for identifying redox processes

Table 1. Criteria and threshold concentrations for identifying redox processes in ground water. Source: (Jurgens, McMahon, Chapelle, & Eberts, 2018)

[Table was modified from McMahon and Chapelle, 2008. Redox process: O2, oxygen reduction; NO3, nitrate reduction; Mn(IV), manganese reduction; Fe(III), iron reduction; SO4, sulfate reduction; CH4gen, methanogenesis. Chemical species: O2, dissolved oxygen; NO3-, dissolved nitrate; MnO2(s), manganese oxide with managanese in 4+ oxidation state; Fe(OH)3(s), iron hydroxide with iron in 3+ oxidation state; FeOOH(s), iron oxyhydroxide with iron in 3+ oxidation state; SO42–, dissolved sulfate; CO2(g), carbon dioxide gas; CH4(g), methane gas. Abbreviations: mg/L, milligram per liter; —, criteria do not apply because the species concentration is not affected by the redox process; ≤, less than or equal to; ≥, greater than or equal to; <, less than; >, greater than]

Criteria for inferring process from water-quality data

Redox category	**Redox process**	**Electron acceptor (reduction) half-reaction**	**Dissolved oxygen (mg/L)**	**Nitrate, as Nitrogen (mg/L)**	**Mn (mg/L)**	**Iron (mg/L)**	**Sulfate (mg/L)**	**Iron/ sulfide (mass ratio)**
Oxic	O2	$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	≥0.5	—	<0.05	<0.1	—	
Suboxic	Suboxic	Low O2; additional data needed to define redox process	<0.5	<0.5	<0.05	<0.1	—	
Anoxic	NO3	$2NO_3^- + 12H^+ + 10e^- \rightarrow N_{2(g)} + 6\ H_2O$; $NO_3^- + 10H^+ + 8e^- \rightarrow NH_4^+ + 3H_2O$	<0.5	≥0.5	<0.05	<0.1	—	
Anoxic	Mn(IV)	$MnO_{2(s)} + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$	<0.5	<0.5	≥0.05	<0.1	—	
Anoxic	Fe(III)/SO4	Fe(III) and (or) SO4^{2-} reactions as described in individual element half reactions	<0.5	<0.5	—	≥0.1	≥0.5	no data
Anoxic	Fe(III)	$Fe(OH)_{3(s)} + H^+ + e^- \rightarrow Fe^{2+} + H_2O$; $FeOOH_{(s)} + 3H^+ + e^- \rightarrow Fe^{2+} + 2H_2O$	<0.5	<0.5	—	≥0.1	≥0.5	>10
Mixed (anoxic)	Fe(III)-SO4	Fe(III) and SO4^{2-} reactions as described in individual element half reactions	<0.5	<0.5	—	≥0.1	≥0.5	≥0.3, ≤10
Anoxic	SO4	$SO_4^{2-} + 9H^+ + 8e^- \rightarrow HS^- + 4H_2O$	<0.5	<0.5	—	≥0.1	≥0.5	<0.3
Anoxic	CH4gen	$CO_{2(g)} + 8H^+ + 8e^- \rightarrow CH_{4(g)} + 2H_2O$	<0.5	<0.5	—	≥0.1	<0.5	

Appendix D: Septic Tank Effluent Characteristics

To assess the likely variation in septic tank effluent quality, a brief literature review was completed of international studies in Scotland and U.S.A (Richards, Paterson, Withers, & Stutter, 2016) (Richards, Withers, Paterson, McRoberts, & Stutter, 2016), (Lowe, et al., 2009). Richards, Paterson, Withers, & Stutter (2016) completed sampling of thirty-two (32) residential septic tanks in permanenly occupied houses in four rural river catchments in north-east Scotland. They analysed the impact of tank management on effluent composition including receiving roof runoff, having a dishwasher and desludging frequency. Receiving roof runoff (n=6) resulted in lower pH., alkalinity, EC, turbidity, COD, BOD and DOC, total coliforms and nutrients (with the exception of nitrate which increased due to the additional oxidation potential of the rainwater). Receiving dishwasher effluent (n=26) impacted on TN and nutrient particulates, and reduced desludging frequency resulted in higher nutrient loads. The results of this analysis are presented in the following table:

Parameter	Unit	Range	Mean ± 1 s.e.	Mean
pH		6.37–7.68	7.01	7.01
EC	µS/cm	160–1730	866 ± 69	866
COD	mg/L	48–5514	655 ± 164	655
BOD	mg/L	16–565	234 ± 26	234
Alkalinity	mg/L	15–698	303 ± 27	303
DOC	mg/L	5–179	48 ± 7	48
TP	mg/L	1.13–32.49	14.55 ± 1.46	14.55
TDP	mg/L	0.22–26.43	9.46 ± 1.18	9.46
SRP	mg/L	0.15–25.68	8.37 ± 1.06	8.37
TN	mg/L	11–146	68 ± 6	68
NH_4–N	mg/L	2–144	55 ± 6	55
NO_3–N	mg/L	0.01–3.85	0.44 ± 0.15	0.44
SO_4	mg/L	0.53–20.78	6.21 ± 0.89	6.21
Br	mg/L	0.018–0.062	0.02 ± 0.00	0.02
Cl	mg/L	18–94	51 ± 4	51
E. coli	MPN/100 mLa	10^3–10^7	1.3 × 10^6	1.3 × 10^6
Fe	mg/L	<0.001 - 1.486	0.198 ± 0.047	0.198

a Most probable number in 100 mL.
b Colony formed unit in 1 mL.
c Fluorescence intensity unit.
d Enrichment factor = $\sum([STE_{n = 10}] / [upstream_{n = 10}]) / n$.
e Skewness: (−1 to +1) is N, (1 to 3) is Sk+, (N3) is Sk++, (−3 to −1) is Sk−.
f Only detectable in downstream waters.
g n = 10 as only possible where receiving watercourse present.

Appendix E: Nitrogen Flux Calculations

Groundwater flux (Q) was estimated according to Darcy's Law

$$Q = k.\frac{\delta h}{\delta x}.A$$

Where;

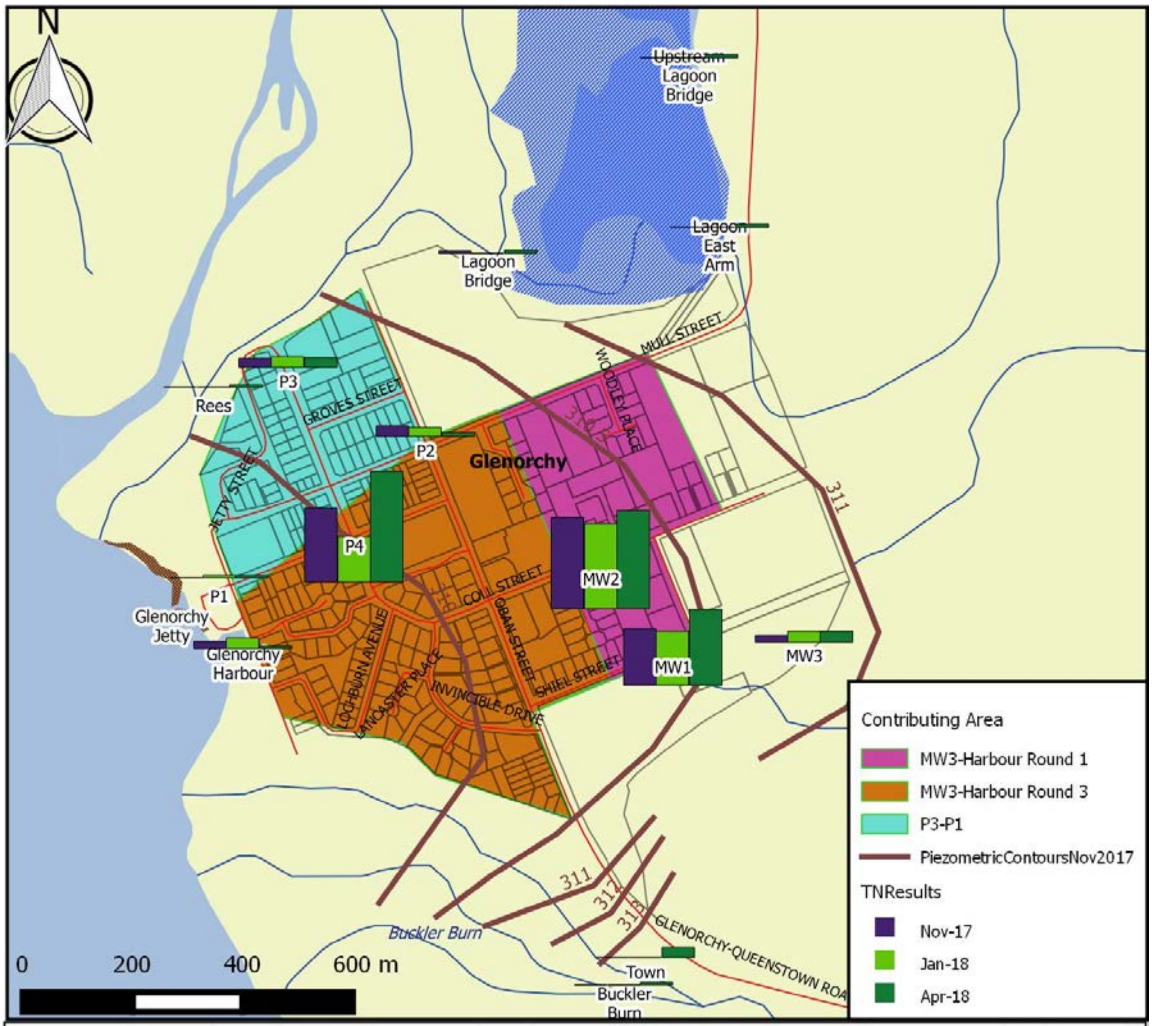
k = hydraulic conductivity
dh/dx = hydraulic gradient
A = Area of the flux window (Height x width)

A representative hydraulic conductivity was used of 3×10^{-2} m/s for coarse gravels (Aqtesolv http://www.aqtesolv.com/aquifer-tests/aquifer_properties.htm, accessed 13/07/2018). This is considered a conservative estimate as it is at the higher end of likely hydraulic conductivity.

Table: Nitrogen Flux Calculations

Flowpath	Round 1		Round 3	
	P3-P1	MW3- Glenorchy Harbour	P3-P1	MW3- Glenorchy Harbour
K (m/day)	2592	2592	2592	2592
dh	0.45	0.94	0.50	0.62
dx	410	1019	410	1019
dh/dx	0.0011	0.0009	0.0012	0.0006
Distance travelled per year (m)	1038	873	1154	576
Contributing Area (ha)	13	41	13	28
Height of flux window (m)	1.5	1.5	1.5	1.5
Width of flux window (m)	300	300	300	300
A (m2)	450	450	450	450
Groundwater Flux (m3/day)	1280	1076	1422	710
Site representing water quality at discharge site	P1	P4	P1	P4
TN (g/m3)*	0.1	3.1	0.1	4.6
Nitrogen inflow (kg/year)	47	1217	52	1192
Total (kg/year)	**1264**		**1243**	
Nitrogen inflow (kg/ha/year)	3.7	29.4	4.1	42.3

* The concentration of TN in the upgradient bore MW3 was subtracted from the concentration at P4 to isolate the TN contribution from the Glenorchy township i.e. additional TN is likely to be impacting Lake Wakatipu, however it is sourced upgradient of the township.



NZ Property Titles, NZ Road Centre line (Electoral), NZ River Polygons (Topo, 1:50k), NZ Lake Polygons (Topo, 1:50k), NZ River Centrelines (Topo, 1:50k) sourced from the LINZ Data Service http://data.linz.govt.nz/ and licensed by LINZ for re-use under the Creative Commons Attribution 3.0 New Zealand licence.
DEM supplied by QLDC.

Figure: Total Nitrogen Concentrations and Contributing Areas to Nitrogen Loading Calculations