# Water quality and ecosystem health in the Lake Tuakitoto catchment

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# Overview

## *Background*

The Otago Regional Council (ORC) is responsible for managing Otago's groundwater and surface-water resources. ORC has carried out regular water quality monitoring at Lake Tuakitoto as part of its State of the Environment (SOE) water quality monitoring programme for 20 years, but this is the first targeted, short-term monitoring investigation undertaken in the Lake Tuakitoto catchment.

## *Why was this targeted investigation deemed necessary?*

This investigation was undertaken to:

- provide a baseline of water quality in the Lake Tuakitoto catchment
- compare water quality in the Lake Tuakitoto catchment to water quality limits set out in Plan change 6A (PC6A).
- provide a baseline of ecological health in the Tuakitoto catchment
- investigate the density of freshwater mussels (kakahi) in the lake

## *What has this study found?*

- Water quality in Frasers Stream was of consistently better quality than Lovells Creek and Stony Creek.
- Lovells Creek and Stony Creek had poorer water quality in the upper catchment when compared to the lower catchment. Catchment investigations revealed no obvious 'source' of pollution, other than stock access to tributaries in a more extensive farming landscape.
- All sites in the catchment are likely to comply with PC6A Schedule 15 limits for ammoniacal nitrogen ($NH_4$-N) and dissolved reactive phosphorus (DRP), however most sites are unlikely to comply with Schedule 15 limits for nitrate-nitrite nitrogen (NNN) and *Escherichia coli* (*E. coli*). Total phosphorus (TP) and total nitrogen (TN) limits (Schedule 15, Group 5) were exceeded at the Lake Tuakitoto outlet.
- The Lake Tuakitoto catchment supports a diverse fish community, including several species of conservation concern. The macroinvertebrate community indicates water quality is 'fair' to 'good' and prolific periphyton growth is limited by suitable habitat and the availability of phosphorus.
- The mussel survey undertaken in 2013 indicates that there has been a decline in the mussel population, when compared to the 1991 study (Ogilvie 1995).
- In recent years (since 2006) the lake has spent longer below the minimum lake level of 100.77m (30 September to 16 May). As the lake is so shallow a sustained low lake level will adversely affect ecosystem values.

## *What should be done next?*

The results of this study will be used to guide future policy decisions and to promote good practice among the community and other stakeholders to maintain and enhance water quality in the Lake Tuakitoto catchment, in particular to protect the regionally significant wetland.

# Technical summary

Lake Tuakitoto is a large freshwater wetland situated in the lower Clutha River catchment in South Otago. Much of the catchment consists of intensively grazed pasture with some scrub, and plantation forestry. There has been intensification of land use in the catchment which has the potential to affect water quality in the lower part of Lovells Creek and Frasers Stream.

The objectives of this report are to:

- provide a baseline of water quality in the Lake Tuakitoto catchment
- compare water quality in the Lake Tuakitoto catchment to water quality limits set out in plan change 6A.
- provide a baseline of ecological health in the Tuakitoto catchment
- Investigate the density of freshwater mussels (kakahi) in the lake

ORC has undertaken bi-monthly SOE monitoring at Lake Tuakitoto outlet since July 1995. Water quality analysis shows that the significant changes in water quality over this period are a reduction in ammoniacal nitrogen ($NH_4$-N) and an increase in dissolved reactive phosphorus (DRP).

During this study (25 September 2012 to 10 September 2013), thirteen sites were sampled fortnightly. Water quality in the catchment was compared to the water quality limits for receiving waters in Plan Change 6A. Of the 23 sampling occasions, ten occurred when flows were less than median flow and these data were compared to the Schedule 15 limits. The results showed that:

- all sites in the catchment complied with the receiving water quality limits for $NH_4$-N (0.1 mg/l) and DRP (0.026 mg/l).
- the receiving water quality limit for NNN (0.444 mg/l) was exceeded at all sites in Stony Creek and at the upper sites in Lovells Creek.
- the only sites to meet the receiving water quality limit for *E. coli* was the upper Frasers Stream site, Lovells Creek east branch and Lake Tuakitoto at the outlet. Stock access may be a cause of high *E.coli* concentrations in the smaller tributaries.
- Lake Tuakitoto exceeded the receiving water quality limit for turbidity, TN and TP based on samples taken at the outlet.

**Comparison of 80th percentiles of water quality parameters with receiving water quality limits in plan change 6A. Values that exceeded the limit are in bold type. The Schedule 15 limit for Lake Tuakitoto at the Outlet applies at all flows, the other values calculated using samples collected when flows were at or below median flow (0.143 $m^3/s$), as this is when Schedule 15 limits apply.**

| Site Name | TN | NNN | $NH_4$-N | DRP | TP | E-Coli |
|---|---|---|---|---|---|---|
| **Schedule 15 limit (Group 1)** | | **0.444** | **0.1** | **0.026** | | **260** |
| **Lovells Creek** | | | | | | |
| West Branch (Hillend Rd) | 3.380 | **1.956** | 0.030 | 0.005 | 0.262 | **670** |
| East Branch (Fallaburn Rd) | 1.078 | **0.700** | 0.005 | 0.020 | 0.056 | 84 |
| Northwest Branch (Fallaburn Rd) | 1.020 | **0.468** | 0.005 | 0.016 | 0.105 | **3260** |
| Bloxham Rd | 0.746 | 0.384 | 0.005 | 0.011 | 0.040 | **568** |
| Station Rd | 0.792 | 0.366 | 0.006 | 0.015 | 0.045 | **1300** |
| **Frasers Stream** | | | | | | |
| Elliotvale Rd | 0.334 | 0.041 | 0.005 | 0.013 | 0.031 | 200 |
| Station Rd | 0.592 | 0.201 | 0.009 | 0.011 | 0.047 | **372** |
| **Stony Creek** | | | | | | |
| Hillend Rd | 2.018 | **1.074** | 0.039 | 0.023 | 0.156 | **754** |
| Stony Ck (Hillend Rd u/s Farm) | 3.620 | **1.214** | 0.027 | 0.013 | 0.516 | **1880** |
| Stony Ck (Hillend Rd d/s Farm) | 1.384 | **1.032** | 0.005 | 0.020 | 0.055 | **406** |
| Stony Ck at SH1 | 0.924 | **0.480** | 0.005 | 0.020 | 0.083 | **1420** |
| **Schedule 16 discharge threshold** | | 3.6 | 0.2 | 0.045 | | 550 |
| Stony Ck (Farm Tile Drain) | 3.700 | 3.500 | 0.005 | 0.002 | 0.008 | 420 |
| **Schedule 15 limit (Group 4)** | 0.55 | | | | 0.033 | 126 |
| Lake Tuakitoto at Outlet | **1.340** | 0.488 | 0.071 | 0.057 | **0.118** | **198** |

The macroinvertebrate community at the Lovells Creek site indicated that water quality was generally ‘good’, while Frasers Stream indicated ‘fair’ water quality. The two streams had little sedimentation and good riparian cover, the small substrate size is likely to be easily disturbed, limiting available habitat.

Algal community composition shows that in Frasers Stream diatoms (*Encyonema*) were dominant, *Phormidium* was present, but its abundance was ‘occasional’, and is unlikely to bloom due to habitat restrictions. Little periphyton was found in Lovells Creek.

Lovells Creek and Frasers Stream support a diverse fish community, with six species collected, including longfin eel, and lamprey which have been classified as ‘at risk’ and ‘declining’ under the New Zealand Freshwater Fish Threat Classification.

The mussel survey undertaken in 2013 indicates that there has been a decline in the mussel population, when compared to the 1991 study (Ogilvie 1995). The filtration of a volume of water equal to that of the lake equated to once every 32 hours, in 2013 this had increased to once every 102 hours.

This may be due to low lake levels. In recent years (since 2006) the lake has spent longer well below the minimum lake level of 100.77m (30 September to 16 May). The intent of the minimum lake level was to protect the regionally significant recreational and wildlife features of the lake, sustained low lake levels will adversely affect ecosystem values as the lake is so shallow.

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# 1. Introduction

Lake Tuakitoto is a large regionally significant freshwater wetland situated in the Lower Clutha River catchment. It has three main tributaries: Lovells Creek, Stony Creek and Frasers Stream.

**Figure 1 Lake Tuakitoto catchment.**

Land use in the Lake Tuakitoto catchment is dominated by a mixture sheep farming (45%) and mixed sheep and beef farming (30%) and increasingly, dairy farming (10%). There is no consented stream abstraction for irrigation purposes and stock water is supplied through a scheme maintained by Clutha District Council.

Lovells Creek is the principal tributary of Lake Tuakitoto and has a minimum flow of 5 litres/sec (ORC, 2013). The quantity and level of water in the Lake is largely dependent on incoming water flow from Lovells Creek.

Routine State of the Environment (SOE) monitoring has been conducted at the outlet of Lake Tuakitoto since 1995. During this period the statistically significant changes in water quality (1995 to 2013) were a reduction in ammoniacal nitrogen and an increase in dissolved reactive phosphorus. The SOE report card (ORC, 2013) classified Lake Tuakitoto as having ‘poor’ water quality, the Lake is nutrient rich and prone to high turbidity due to it’s shallowness.

This report documents the results of a 12-month investigation of water quality in the Lake Tuakitito catchment. The investigation was undertaken between September 2012 and September 2013 and involved fortnightly testing of surface water. A one-off assessment of aquatic ecological health and substrate condition was undertaken in April 2013. In 1991, a survey of freshwater mussels was undertaken in Lake Tuakitoto to investigate the potential for using mussels to control phytoplankton in eutrophic lakes, this survey was replicated in April 2013.

The main aim of the investigation was to

- provide a baseline of water quality in the Lake Tuakitoto catchment and compare water quality to limits set out in PC6A.
- provide a baseline of ecological health in the Tuakitoto catchment including macroinvertebrates, periphyton, fish and mussels.

# 2. Background

This section outlines the main features of the Tuakitoto catchment, including:

- catchment description
- geology and soil type
- landuse
- water use and hydrology
- climate
- natural values of the Tuakitoto catchment
- drainage management

## 2.1. Catchment description

Lake Tuakitoto is a large freshwater wetland situated in the Lower Clutha River Catchment in South Otago, it's location to the south of the catchment is shown in **Error! Reference source not found.Error! Reference source not found.**.

The Lake is 0.3 m above mean sea level and at normal lake levels of about one metre, the available habitat totals 500 hectares. It is the only major wetland remaining in the Lower Clutha catchment, the area having been extensively drained for agricultural purposes.

Lovells Creek (and its main tributary Frasers stream) is the main inflow to the Lake, but there are many other small streams in the catchment including Saddle and Two Stone Hill Streams, Stony Creek, and other minor unnamed tributaries. They are all single-channel lowland type streams.

In it's upper reaches, Lovells Creek, is stable and deeply incised in gullies with a steep gradient and rocky bed, and numerous small ephemeral inflows. As it reaches the lowland plain, it's character changes, as the bed has been extensively modified through channelisation works. Frasers Stream, the tributary entering Lovells Stream, is smaller, and is a man made channel in its lower reaches. Stony Creek which enters the lake from the west is similar in nature to the upper reaches of Lovells Creek. Other tributaries entering the lake from the east are small ephemeral streams on the lowlands, but they form permanent water courses where they flow across the low lying swampland of the lake.

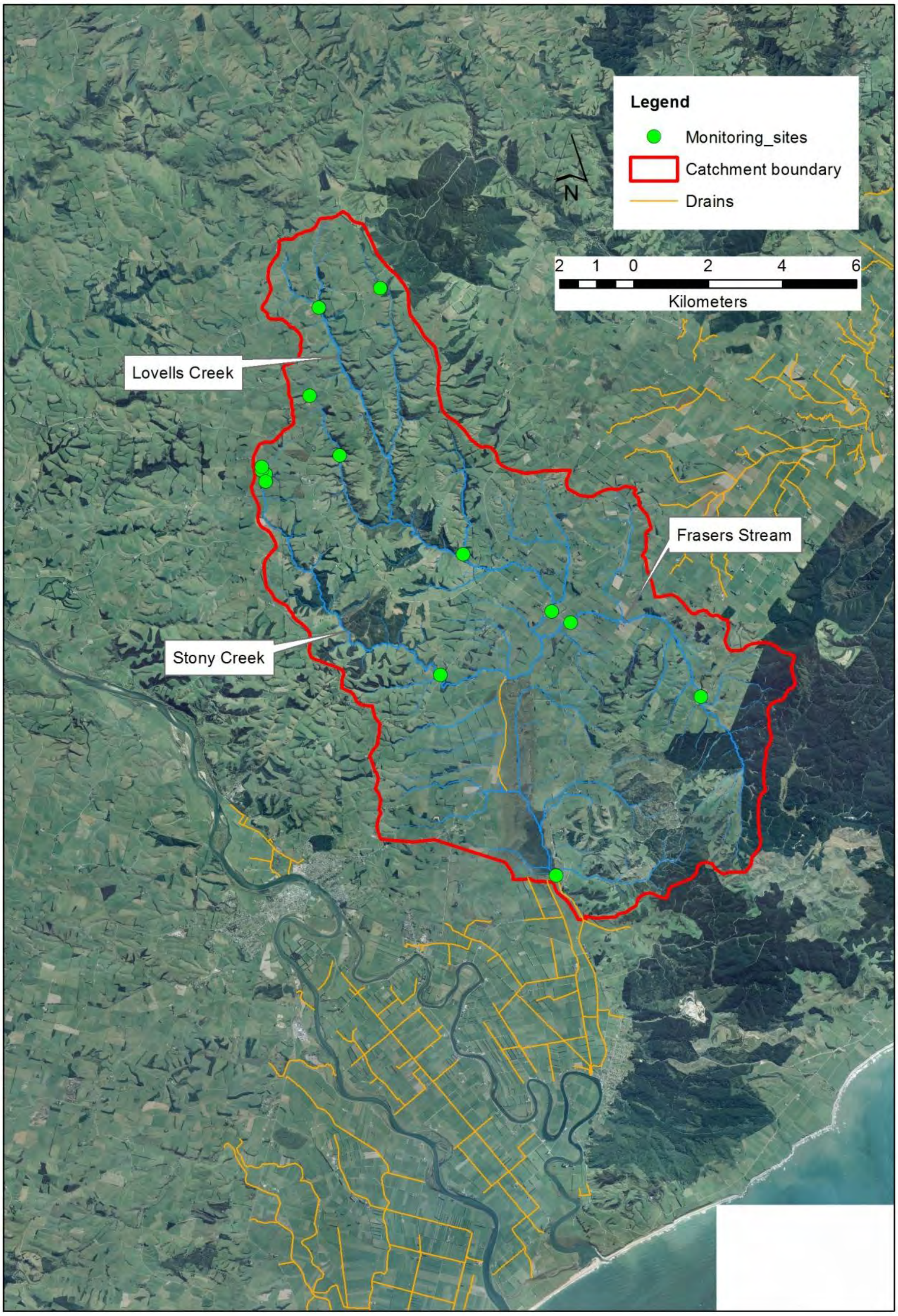


**Figure 2** Lake Tuakitoto catchment showing water quality monitoring sites

## 2.2. Geology and soil type

Figure 3 shows the geology of the Lake Tuakitoto catchment.

Geologically, the Lake Tuakitoto basin and Lower Clutha area are formed of glacial till, alluvial gravels, and glacial outwash gravels, with areas of peat in swampy locations. Schist outcrops are found in the headwaters of Lovells Stream, where as greywacke and argillite form the rest of the catchment on the western side of the basin. The coastal hills to the east are composed of conglomerates of quartz, and schist, with sandstone, siltstone and mudstone containing seams of lignite.

The soils of the basin are gley, gley-recent, and organic soils. Yellow grey earths mantle the downlands to the north and west, and yellow brown earths cover the coastal hills. The Benhar Lignite deposit site includes areas within Lake Tuakitoto itself and the extensive wetland and marshy areas on the fringe of the water body, particularly on the northern and western edges. In the catchment, the deposits occur on the undulating pasture west of the Lake up to State Highway 1 and about Lovells flat.

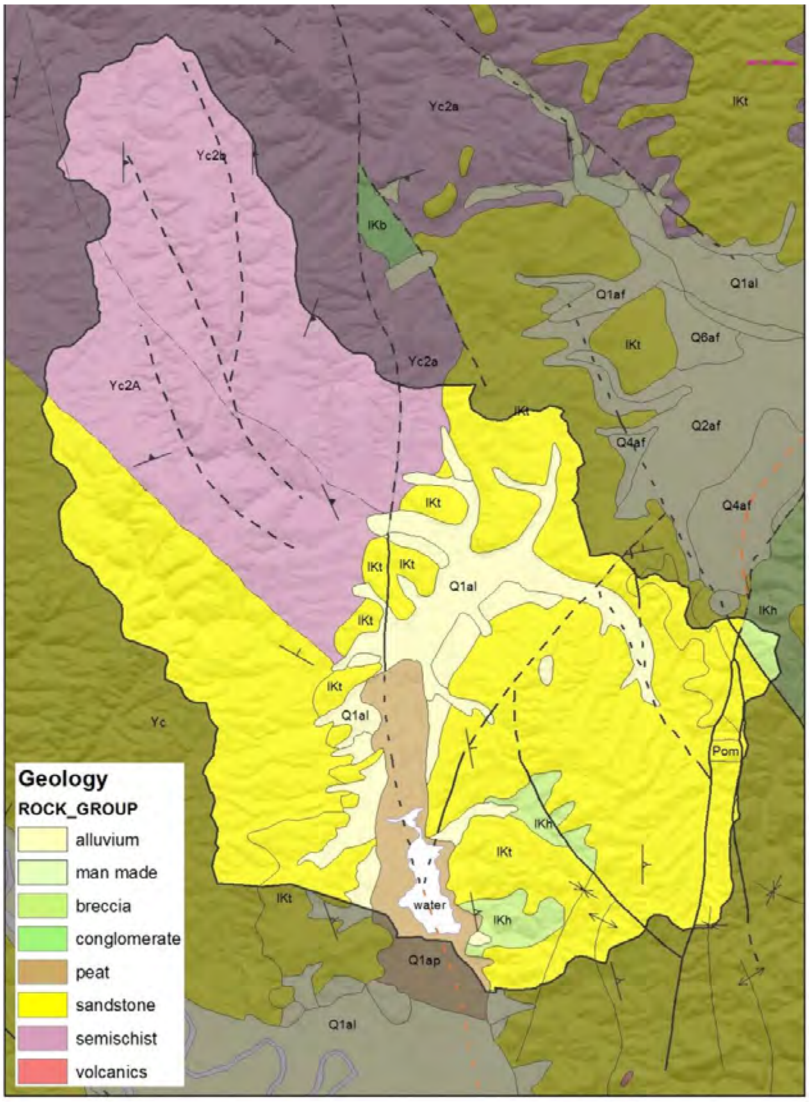


**Figure 3 Geology of the Lake Tuakitoto catchment**

## 2.3. Landuse

Land use in the Lake Tuakitoto catchment is dominated by a mixture of dry-stock and, increasingly, dairy farming. The farm type is shown in Figure 4 and Table 1.

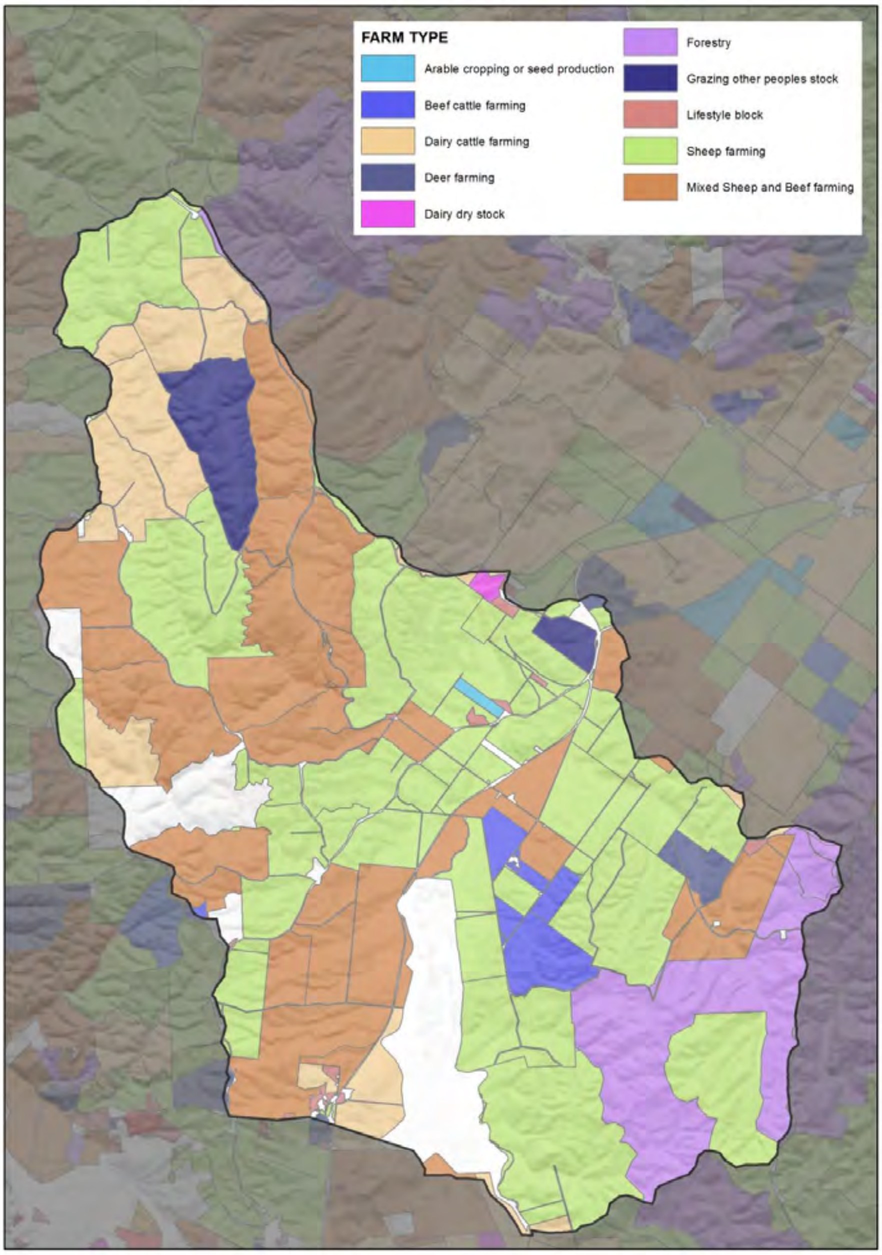


**Figure 4 Land-use of the Lake Tuakitoto catchment**

The high producing exotic grassland supports intensive sheep farming (40%) mixed sheep and beef (27%) and dairy farming (8%). In 2013 there were five dairy farms with over 2680 cows in the catchment. Four of the farms were in the Lovells Creek catchment and one in the Lake Tuakitoto catchment. Forestry is supported in the steeper country of the Frasers Stream catchment.

**Table 1 Lake Tuakitoto catchment farm types in hectares (Agribase, 2012).**

| Farm Description | Hectares (ha) | Percentage (%) |
|---|---|---|
| Sheep farming | 5738 | 40 |
| Mixed sheep and beef farming | 3863 | 27 |
| Dairy cattle farming | 1217 | 8 |
| Forestry | 1192 | 8 |
| Grazing other peoples stock | 431 | 3 |
| Beef cattle farming | 313 | 2 |
| Deer farming | 108 | 0.7 |
| Lifestyle block | 60 | 0.4 |
| Dairy dry stock | 22 | 0.1 |
| Arable cropping or seed production | 20 | 0.1 |
| Unrecorded | 1387 | 10.7 |
| TOTAL | 14351 | 100 |

## 2.4. Lake Tuakitoto hydrology

The water resource of the Tuakitoto catchment is not used for irrigation purposes. Clutha District Council maintain a scheme to supply stock-water to the catchment's farms.

Lovells Creek at SH1 has a minimum flow of 5 litres/sec. Lovells Creek is the principal tributary of Lake Tuakitoto. As such the quantity of water in the Lake is partially dependent on the water flows in Lovells Creek. Although Lovells Creek may fall below its minimum flow due to natural conditions, the minimum flow will avoid human induced low flows through regulation on takes, diversions, floodgates and dams, to ensure water is available to the Lake ecosystem. Table 2 shows historical and current flow statistics in Lake Tuakitoto and Lovells Creek.

**Table 2 Flow statistics for 2012-2013 and historical data for Lake Tuakitoto outlet and Lovells Creek.**

| | Lake Tuakitoto outlet | Lovells Creek |
|---|---|---|
| Catchment area ($km^2$) | 143.4 | 38.78 |
| 7-day low flow (l/s) 2012/13 | 42.6 | 12 |
| 7-day MALF (l/s) (historical) | 53.2 | 15 |
| Catchment yield 7-day MALF ($l/s/km^2$) | 0.37 | 0.39 |
| Mean flow (l/s) 2012/13 | 1593 | 449 |
| Mean flow (l/s) (historical) | 1287 | 363 |
| Median flow (l/s) 2012/13 | 695 | 196 |
| Median flow (l/s) (historical) | 546 | 154 |
| Historical data record length | Jun 1969 - Sep 2013 (large gap Jun 1980 - Mar 1999) | |

## 2.5. Climate

Annual sunshine hours (Balclutha) are in excess of 2000 hours, with common summer temperatures (30 year normal 1981-2010) of 14.6°C.

Table 3 shows that rainfall in the lower Clutha catchment varies seasonally, with the lowest rainfall occurring in the winter and highest in summer.

**Table 3 Mean monthly precipitation in mm.**

| Month | Balclutha (E1349473, N4874447) | Lovells Creek (E1355360, N4882061) |
|---|---|---|
| January | 71 | 79.9 |
| February | 68 | 68 |
| March | 48.7 | 68.4 |
| April | 46.5 | 65.7 |
| May | 65.5 | 84.3 |
| June | 56.3 | 72.3 |
| July | 44.5 | 64.2 |
| August | 42.7 | 55.1 |
| September | 47.1 | 63.9 |
| October | 57.3 | 72.9 |
| November | 54.3 | 61.4 |
| December | 70.9 | 82 |
| Total | 673 | 838 |

## 2.6. Natural values

The NIWA freshwater fish database contains records of numerous species of fish and one species of freshwater crayfish in the Lake Tuakitoto catchment (Table 4). European perch (*Perca fluviatilis*) is an introduced species and is the most common fish in the area.

**Table 4 Fish species present in the Lake Tuakitoto catchment (NIWA Freshwater Fish Database July 2012).**

| Common name | Species name | Lake Tuakitoto | Lovells Creek | Frasers Stream | Saddle Stream | Two Stone Hill |
|---|---|---|---|---|---|---|
| Shortfin eel | *Anguilla australis* | yes | yes | | | yes |
| Longfin eel | *Anguilla dieffenbachii* | yes | yes | yes | yes | |
| Giant kokopu | *Galaxias argenteus* | yes | | | yes | |
| Inanga | *Galaxias maculatus* | yes | yes | | | |
| Common bully | *Gobiomorphus* | yes | | | yes | |
| Koura | *Paranephrops sp.* | | yes | | | |
| FW shrimp | *Paratya curvirostris* | yes | | | | |
| European perch | *Perca fluviatilis* | yes | yes | yes | yes | yes |
| Common smelt | *Retropinna retropinna* | | yes | | | |
| Brown trout | *Salmo trutta* | yes | yes | yes | yes | |

Lake Tuakitoto is the only large humic lake on the East Coast of the South Island and the only major wetland remaining in the Lower Clutha catchment. It contains the regionally significant wetland values shown in Table 5. These values are listed in Policy 10.4.1 of the Water Plan.

**Table 5 Lake Tuakitoto wetland values**

| Value | Description |
|---|---|
| A1 | Habitat for nationally or internationally rare or threatened species or communities.<br>Provides roosting, feeding and breeding habitat for the threatened Australasian Bittern (*Botaurus poiciloptilus*) and Banded Dotterel (*Charadrius bicinctus bicinctus*). Also breeding area for the uncommon Marsh Crake (*Porzana pusilla affinis*), Spotless Crake (*Porzana tabuensis plumbea*) and South Island Fernbird (*Bowdleria* punctata punctata). Habitat for threatened giant kokopu (*Galaxias argenteus*). The threatened plant species swamp nettle (*Urtica linearifolia*) and Isolepis basilaris present on swamp margin. |
| A3 | High diversity of wetland habitat types<br>A diverse mosaic of vegetation types and wildlife habitats. Regionally and nationally important habitat for waterfowl, waders and swamp birds. Supports a significant proportion of the national population of Mallard (*Anas platyrhynchos*) and New Zealand Shoveller/Kuruwhengi (*Anas rhynchotis variegata*), Grey Teal (*Anas gracilis*) and Black Swan (*Cygnus atratus*). All these species breed here. Considered nationally important as a fresh water fishery habitat, supporting longfin eel (*Anguilla dieffenbachii*), shortfin eel (*Anguilla australis*), whitebait/inaka (*Galaxias spp.*) and common bully/pako (*Gobiomorphus cotidianus*) populations as well as the giant kokopu (*Galaxias argenteus*) (Davis 1987 97). |
| A5 | Wetland scarce in Otago in terms of its ecological or physical character<br>Less than 15% of swamps remain in Otago. |
| A6 | Highly valued by Kai Tahu for cultural and spiritual beliefs, values and uses, including mahika kai and waahi taoka.<br>Wetland highly valued by Kai Tahu for its historical associations, and as a traditional food gathering area. |
| A7 | High diversity of indigenous flora and fauna.<br>An exceptionally high diversity of bird life present, a reflection of the high habitat diversity (above). Some 50 species of bird recorded. |
| A9 | Significant hydrological values including maintaining water quality and low flows, or reducing flood flows.<br>Lake Tuakitoto and surrounding wetlands perform a valuable hydrological function. Serves as a flood ponding area and is an integral part of the Lower Clutha Flood Control and Drainage Scheme. |

## 2.7. Lake Tuakitoto Drainage Management

Lake Tuakitoto is a remnant of a very much larger wetland system which included Lake Kaitangata. Drainage work carried out in the past has allowed farming to establish around Lake Tuakitoto, on what was once part of the wetland complex. Originally it was planned to continue drainage and development so that Lake Tuakitoto could be reclaimed. These plans were averted and the natural values of this now rare, lowland, wetland habitat are nationally recognised.

Lake Tuakitoto is part of the Lower Clutha Flood Control and Drainage System. To mitigate the effects of high rainfall in the catchment, and to protect the farmland, Lake Tuakitoto has a significant amount of drainage infrastructure, shown in Figure 5.

The operation of drainage structures needs to find a balance to provide for the natural values of the wetland complex and the objectives of the drainage Scheme.

Two levels have been set

- The Local Water Conservation (Lake Tuakitoto) Notice 1991 set boundary of the lake area at 101.42 metres above datum. This level was set to ensure land outside of the Lake Tuakitoto area was not significantly adversely affected by manipulation of lake water levels. The intent of this was to protect grazing land, which requires good land drainage and flood mitigation.
- A minimum lake level of 100.77 metres above datum (0.77 metres above sea level) was set for the lake for the period beginning 30 September in any year and ending 16 May in any following year, by The intent of this was to protect the regionally significant recreational and wildlife features of the lake. This level was adopted by the Regional Plan Water (ORC, 2013).

The main factors that influence lake level are:

- Stream flow and evaporation from the lake.
- The operating regime of drainage infrastructure (to include the diversion control gate, outlet weir, Kaitangata flood gate and culvert maintenance).

### 2.7.1. Drainage infrastructure

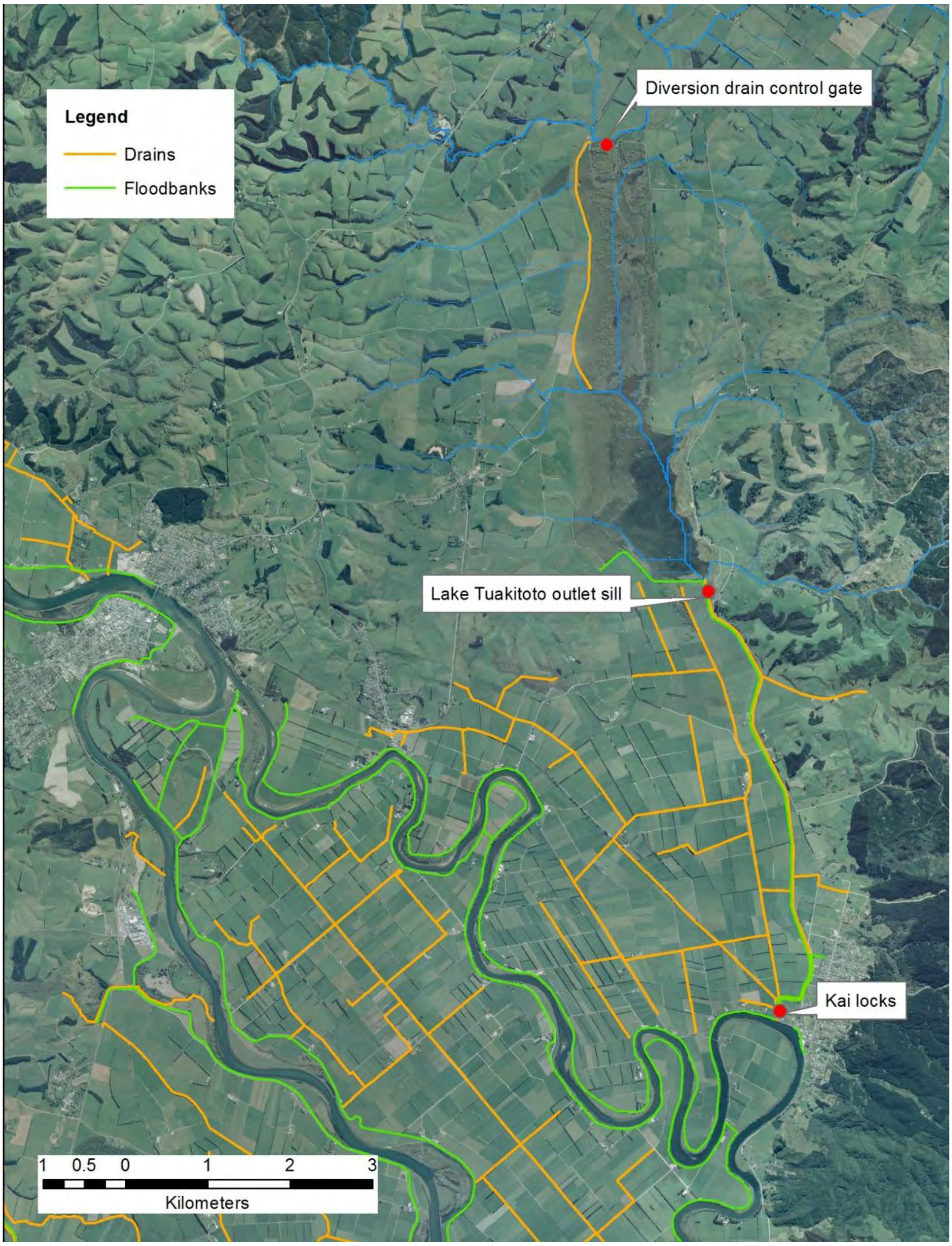


**Figure 5** **Lake Tuakitoto showing drains (yellow lines), floodbanks (green lines) and locations of drainage scheme structures that may influence lake level (red circles).**

Water levels are controlled by a complex series of pumps and floodgates. In consultation with affected parties, decisions have been made on the summer and winter lake levels for Lake Tuakitoto. Summer levels are kept as high as possible whereas some lowering of winter levels may occur, to protect adjacent farmland from the risk of flooding. The design water level (100.77m summer minimum) remains below spring tide level (approx 100.960).

The diversion channel takes Stony Creek out of Robsons Lagoon and diverts it to Lake Tuakitoto, this diversion channel can be seen as the blue line in Figure 6. The diversion channel can also take water from Lovells Creek via a diversion drain control gate. This is shown in more detail in Figure 6.

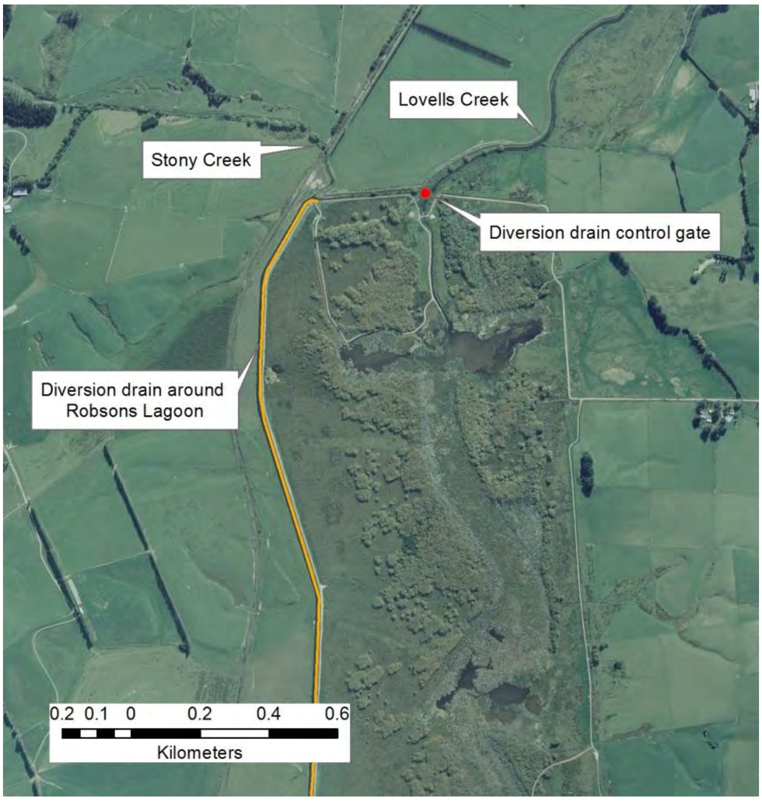


**Figure 6** **Robsons lagoon showing Lovells Creek, the diversion drain (in orange) and Stony Creek.**

The diversion channel control gate shown in (Figure 7) is an adjustable gate structure at the head of the lake/ wetland complex that allows flow from Lovells Creek to be diverted around part of the wetland via the diversion channel. This structure is to be replaced in the near future.


**Figure 7** **The diversion drain control gate (shut and open).**

Stony Creek enters the diversion channel approximately 300m downstream of the diversion control gate (Figure 8).

In 1974, an adjustable weir was installed at the lake outlet (Figure 8) which ensured an average minimum summer water depth of 15 to 30 cm. The objective of the adjustable weir was to maximise outflow during the winter while providing for higher summer water levels (to maintain the wildlife values).

**Figure 8** **The left hand photo shows Stony Creek converging with the diversion channel and the right hand photo shows the Lake Tuakitoto outlet sill.**

In the 1950's stop banks (flood banks) were constructed around low lying land at the bottom western end of the lake (Figure 5) to increase wetland drainage and pasture production.

The Matau Branch of the Clutha River directly affects the hydrological functioning of the Lake as it varies in height with tides and the functioning of the Roxburgh dam. The Kaitangata flood gates (Kai locks) (Figure 9) prevent Clutha flood flows from entering Lake Tuakitoto, but allow for normal inflows at high tide.

**Figure 9** **Kai locks.**

# 3. Lake Tuakitoto: Assessment of surface-water quality

This section outlines the temporal and spatial pattern of surface-water quality in the Lake Tuakitoto catchment. In particular, it discusses:

- water quality guidelines – Water Plan Change 6A
- trophic status of Lake Tuakitoto
- historical trends in water quality
- water quality in the Lake Tuakitoto catchment (September 2012 to September 2013).

## 3.1. Water quality guidelines – Water Plan Change 6A

Water Plan Change 6A was adopted on 1 May 2013 and sets out numerical water quality limits for all catchments in the Otago region (Schedule 15) and establishes thresholds for all discharges to lakes, rivers, wetlands and drains in two discharge threshold areas (Schedule 16).

The Tuakitoto catchment streams and tributaries are in Group 1 and the numerical water quality limits for this group are outlined in Table 6. They are applied as 5-year, 80$^{th}$ percentiles when flows are at or below median flow at a reference flow site (0.143 $m^3/s$ at Lovells Creek).

**Table 6 PC6A limits and thresholds**

| | Schedule 15 limits | Schedule 15 limits | Schedule 16 thresholds |
|---|---|---|---|
| | Group 1 (rivers) | Group 5 (lakes) | Area 1 |
| Total nitrogen (TN) mg/l | - | 0.55 | - |
| Total phosphorus (TP) mg/l | - | 0.033 | - |
| Turbidity NTU | 5 | 5 | - |
| Ammoniacal nitrogen ($NH_4$-N)mg/l | 0.1 | 0.1 | 0.2 |
| Escherichia coli (*E.coli*) cfu/100ml | 260 | 126 | 550 |
| Nitrate-nitrite nitrogen (NNN)mg/l | 0.444 | - | 3.6 |
| Dissolved reactive phosphorus (DRP)mg/l | 0.026 | - | 0.045 |

Lake Tuakitoto is in Group 5, (Table 6), the receiving water limits outlined are applied as 5-year, 80$^{th}$ percentiles at all times.

The thresholds for discharges (Schedule 16) in the Lake Tuakitoto catchment are in Area 1 (Table 6).

## 3.2. Trophic status of Lake Tuakitoto

The Trophic Level Index (TLI) is widely used to measure changes in the nutrient (trophic) status of lakes. The TLI classifies the actual state of a lake at a specific time

The commonly accepted variables that define lake trophic condition are; algal growth (chlorophyll *a*), clarity (secchi depth) and nutrient concentrations (TN and TP).

The higher the TLI, the lower the water quality. Trophic level bands are grouped into trophic states for quantitative description, microtrophic to hypertrophic as shown in Table 7.

**Table 7 Values of variables defining the boundaries of different trophic levels (Burns *et al.*, 2000).**

| Lake Type | Trophic Level | Chla ($mg/m^3$) | Secchi Depth (m) | TP ($mg/m^3$) | TN ($mg/m^3$) |
|---|---|---|---|---|---|
| Ultra-microtrophic | 0.0-1.0 | 0.13-0.33 | 33-25 | 0.8-1.8 | 16-34 |
| Microtrophic | 1.0-2.0 | 0.33-0.82 | 25-15 | 1.8-4.1 | 34-73 |
| Oligotrophic | 2.0-3.0 | 0.82-2.0 | 15-7 | 4.1-9.0 | 73-157 |
| Mesotrophic | 3.0-4.0 | 2.0-5.0 | 7-2.8 | 9.0-20 | 157-337 |
| Eutrophic | 4.0-5.0 | 5.0-12 | 2.8-1.1 | 20-43 | 337-725 |
| Supertrophic | 5.0-6.0 | 12-31 | 1.1-0.4 | 43-96 | 725-1558 |
| Hypertrophic | 6.0-7.0 | >31 | <0.4 | >96 | >1558 |

The shaded cells in Table 7 show the status of Lake Tuakitoto (SOE data July 1995 to June 2013), with the resulting classification of supertrophic. Supertrophic lakes are fertile and saturated in phosphorus and nitrogen, have very high algae growth and can bloom during calm sunny periods.

## 3.3. Historical trends in water quality

State of the Environment monitoring has been undertaken at the Lake Tuakitoto outlet since July 1995.

To see whether there had been significant changes in water quality, Seasonal Kendall analysis was undertaken using data available between July 1995-June 2013 (over six seasons, as ORC samples bi-monthly). The trend test calculates the probability of finding a trend slope at least as big as that measured, or whether a trend existed at all. The result is the p-value. If the p-value is small enough, a statistically significant trend exists. P-values of 0.05 or less are regarded as indicating that a trend is statistically significant at the 95.0% confidence level (i.e. unlikely to be due to chance).

**Table 8 Trends in water quality parameters at the SOE monitoring site (Lake Tuakitoto at the outlet) between July 1995 and June 2013[1].**

| . | *Z* | *P* | Trend |
|---|---|---|---|
| TP | 0.151 | 0.87 | None |
| DRP | 4.126 | 0.00 | Yes (increasing) |
| TN | 1.247 | 0.26 | None |
| NNN | -0.303 | 0.762 | No |
| $NH_4$-N | -2.99 | 0.003 | Yes (decreasing) |
| Chlorophyll *a* | -0.293 | 0.770 | No |
| *E. coli* | 2.143 | 0.109 | None |
| Suspended solids (SS) | -1.010 | 0.312 | None |

[1] The *Z*-statistic indicates the direction of any trend detected, while the *P*-value indicates the probability of that trend being occurring by chance. Trends with a *P*-value of less than 0.05 are considered to be statistically significant

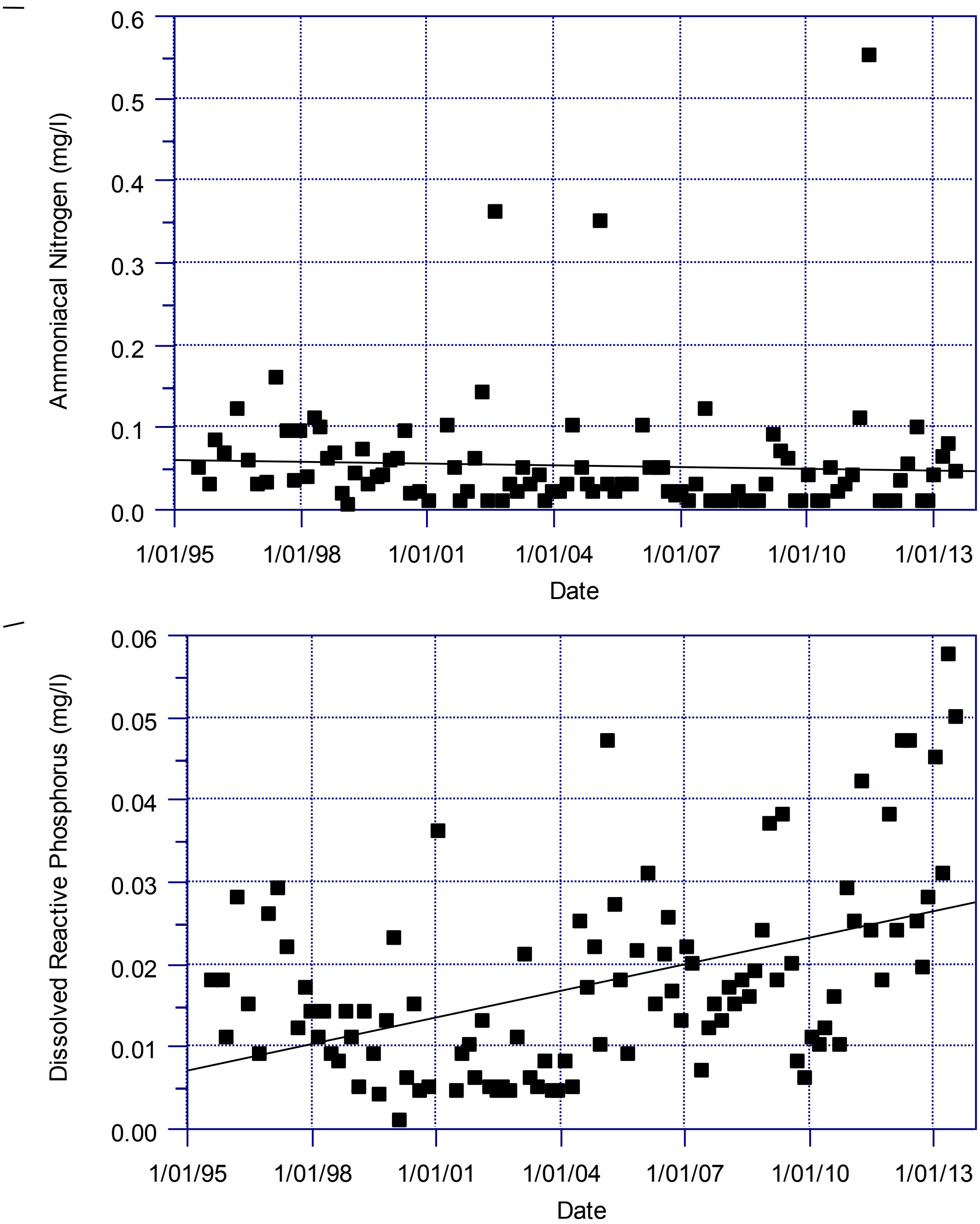


**Figure 10 $NH_4$-N and DRP trends in Lake Tuakitoto at the outlet (1995 to 2013)**

The significant changes in water quality over this period are a reduction in $NH_4$-N and an increase in DRP (Table 8 and Figure 10). Concentrations of $NH_4$-N are quite low, with 16% of readings being below the detection limit (0.01 mg/l) and only 7% being above 0.1 mg/l. The highest recorded concentration of $NH_4$-N was 0.55 mg/l (June 2011). To assess compliance with the Schedule 15 limits, SOE monitoring data collected from Lake Tuakitoto at the Outlet (below median flow) were used to calculate 80$^{th}$ percentiles, which were compared to the appropriate limit.

Of the water quality variables considered, TN, TP, turbidity and *E.coli* generally exceeded relevant Schedule 15 (Group 1) limits and $NH_4$-N generally met the Schedule 15 (Group 1) limit. This is shown in Figure 11.

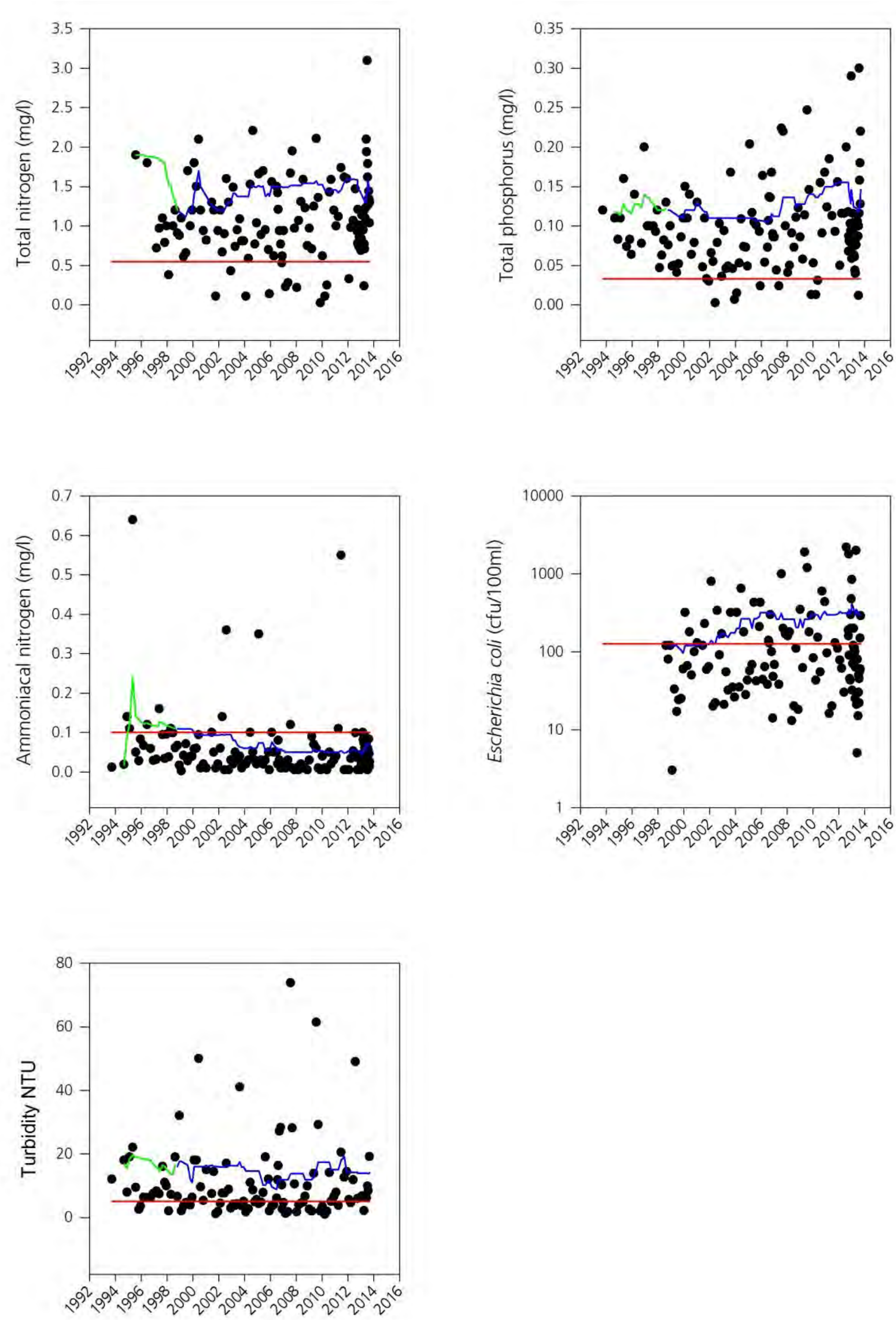


**Figure 11** **Lake Tuakitoto (outlet). TN, TP, $NH_4$-N, turbidity and *E. coli* (note that this is on a logarithmic scale). Schedule 15 limits are shown as red lines, the rolling 80th percentile is shown as the green line, the rolling 5 year 80th percentile is shown as the blue line.**

## 3.4. Water quality (September 2012 to September 2013)

Fourteen sites (Figure 12 and

Table 9) were sampled fortnightly, on the same day, between 25 September 2012 and 10 September 2013. The sites included six sites on Lovells Creek, two sites on Frasers Stream, two sites on Stony Creek and the outlet at Lake Tuakitoto. Three further sites were monitored, the upstream and downstream boundaries of a farm on Stony Creek and a tile drain discharging to Stony Creek from that farm.

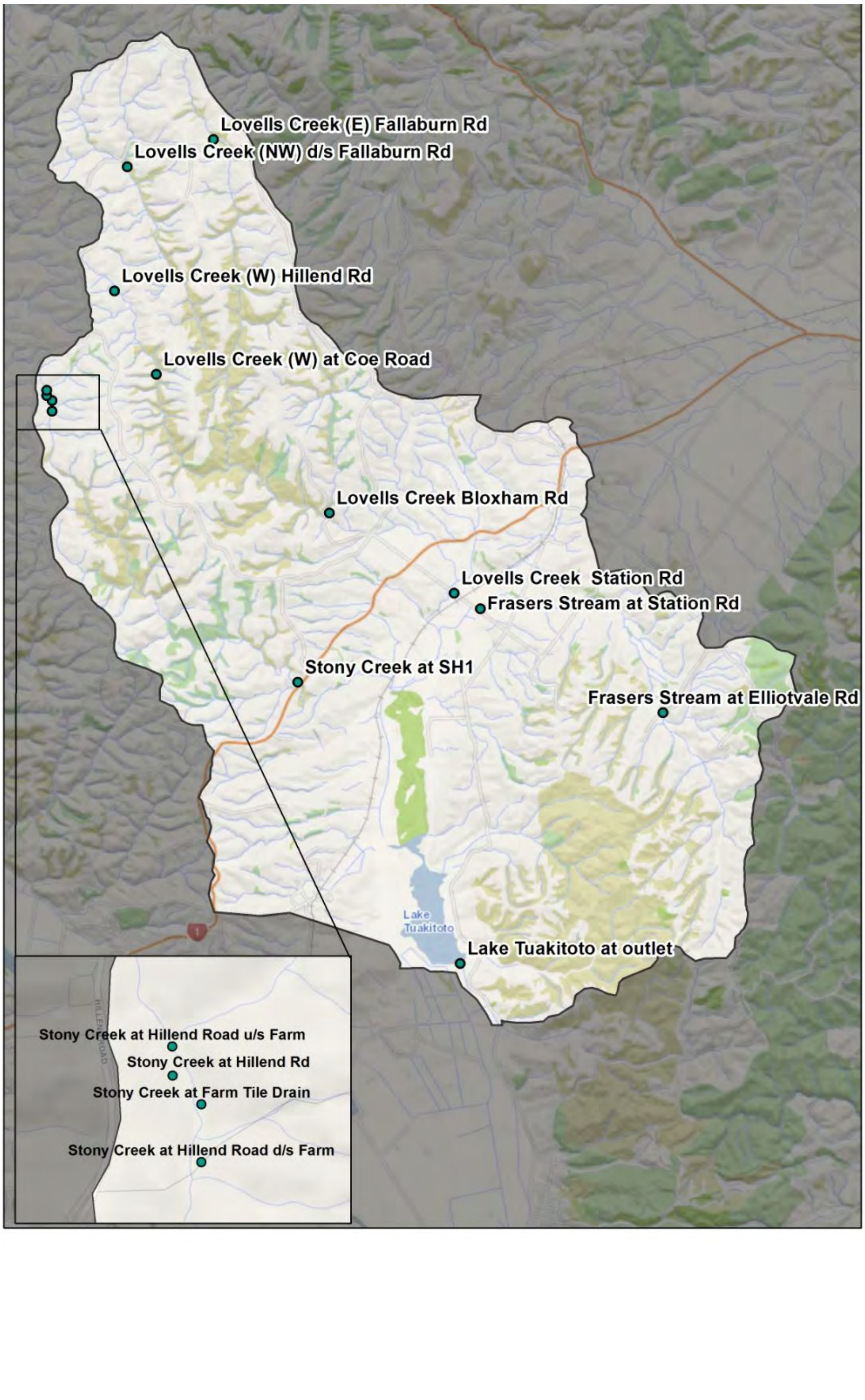

**Figure 12 ORC water quality monitoring sites in the Lake Tuakitoto catchment**

**Table 9 Water quality monitoring sites**

| Site | Easting | Northing |
|---|---|---|
| Frasers Creek at Elliotvale Rd | 1359567 | 4879668 |
| Frasers Creek at Station Rd | 1356062 | 4881662 |
| Lake Tuakitoto at outlet | 1355675 | 4874860 |
| Lovells Creek Station Rd | 1355561 | 4881962 |
| Lovells Creek (NW) d/s Fallaburn Rd | 1349294 | 4890133 |
| Lovells Creek (W) Hillend Rd | 1349048 | 4887752 |
| Lovells Creek Bloxham Rd | 1353168 | 4883498 |
| Lovells Creek (E) Fallaburn Rd | 1350944 | 4890656 |
| Lovells Creek (W) at Coe Road | 1349851 | 4886152 |
| Stony Creek at SH1 | 1352563 | 4880255 |
| Stony Creek at Farm Tile Drain | 1347851 | 4885648 |
| Stony Creek at Hillend Rd | 1347752 | 4885748 |
| Stony Creek at Hillend Road d/s Farm | 1347852 | 4885448 |
| Stony Creek at Hillend Road u/s Farm | 1347751 | 4885848 |

At each river site, water samples were collected for analysis. Analytes included TP, TN, NNN, $NH_4$-N, DRP, *E. coli* and SS.

Water quality data is presented as box plots, as they provide information on distribution (Figure 13). The lower and upper boundaries of the box represent the lower (25%) and upper (75%) quartiles of the data, respectively. The horizontal line inside the box represents the median value, the tips of the 'whiskers' extending below and above the box represent the $5^{th}$ and $95^{th}$ percentile values, respectively and the black dots represent outliers.

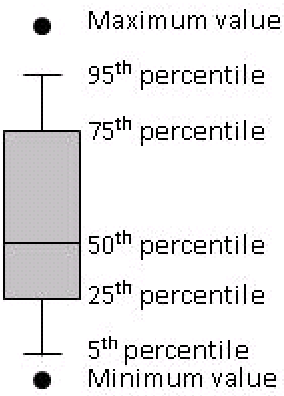


**Figure 13 The interpretation of the various components of a box plot, as presented in this report**

Table 10 gives the $80^{th}$ percentile values (for results when flow was below median) for monitoring undertaken in the Lake Tuakitoto catchment between 25 September 2012 and 10 September 2013.

**Table 10 80th percentile values (25 September 2012 to 10 September 2013) for each parameter when flows were below 0.143 $m^3/s$ at Lovells Creek. The Schedule 15 limit for Lake Tuakitoto at the Outlet applies at all flows.**

| Site Name | TN | NNN | $NH_4$-N | DRP | TP | E-Coli |
|---|---|---|---|---|---|---|
| **Schedule 15 limit (Group 1)** | | **0.444** | **0.1** | **0.026** | | **260** |
| **Lovells Creek** | | | | | | |
| West Branch (Hillend Rd) | 3.380 | **1.956** | 0.030 | 0.005 | 0.262 | **670** |
| East Branch (Fallaburn Rd) | 1.078 | **0.700** | 0.005 | 0.020 | 0.056 | 84 |
| Northwest Branch (Fallaburn Rd) | 1.020 | **0.468** | 0.005 | 0.016 | 0.105 | **3260** |
| Bloxham Rd | 0.746 | 0.384 | 0.005 | 0.011 | 0.040 | **568** |
| Station Rd | 0.792 | 0.366 | 0.006 | 0.015 | 0.045 | **1300** |
| **Frasers Stream** | | | | | | |
| Elliotvale Rd | 0.334 | 0.041 | 0.005 | 0.013 | 0.031 | 200 |
| Station Rd | 0.592 | 0.201 | 0.009 | 0.011 | 0.047 | **372** |
| **Stony Creek** | | | | | | |
| Hillend Rd | 2.018 | **1.074** | 0.039 | 0.023 | 0.156 | **754** |
| Stony Ck (Hillend Rd u/s Farm) | 3.620 | **1.214** | 0.027 | 0.013 | 0.516 | **1880** |
| Stony Ck (Hillend Rd d/s Farm) | 1.384 | **1.032** | 0.005 | 0.020 | 0.055 | **406** |
| Stony Ck at SH1 | 0.924 | **0.480** | 0.005 | 0.020 | 0.083 | **1420** |
| **Schedule 16 discharge threshold** | | 3.6 | 0.2 | 0.045 | | 550 |
| Stony Ck (Farm Tile Drain) | 3.700 | 3.500 | 0.005 | 0.002 | 0.008 | 420 |
| **Schedule 15 limit (Group 4)** | 0.55 | | | | 0.033 | 126 |
| Lake Tuakitoto at Outlet | **1.340** | 0.488 | 0.071 | 0.057 | **0.118** | **198** |

### 3.4.1. Nutrients

Nitrogen and phosphorus are essential nutrients for the growth of aquatic plants and algae, which are an important part of any healthy stream ecosystem. However, excessive concentrations of these nutrients can lead to proliferations of algae and macrophtyes, which may compromise a range of instream values, such as amenity, native fish conservation and recreation (Biggs, 2000).

The concentrations at which nitrogen or phosphorus start to have an adverse effect on ecosystem health or amenity values vary from site to site and catchment to catchment. For example, a stream with primarily muddy substrate may be more resistant to nuisance blooms than a rock or cobble-bottomed stream, given similar concentrations of nutrients (MfE, 2009).

The extent and opportunity for plant growth depends largely on the time of year. Below median flow is used to represent the growing season because flows below median flow usually occur during the summer months and coincide with the best growing conditions for periphyton. The two main nutrients available for plant growth are NNN and DRP.

### 3.4.2. Total nitrogen (TN)

All organisms need nitrogen for the basic processes of life: to make proteins, grow and reproduce. Nitrogen is very common and found in many forms. Inorganic forms include nitrate ($NO_3$), nitrite ($NO_2$), ammonia ($NH_4$-N and $NH_3$-N) and nitrogen gas ($N_2$). Organic nitrogen is found in the cells of all living things and is a component of proteins, peptides and amino acids. In rural landscapes TN is affected by wastewater effluent, agricultural runoff and animal waste (MfE, 2009).

The results of water sampling at all flows, and below median flow are shown in Figure 14. TN concentrations were relatively high at the upper catchment sites in Lovells Creek (west branch) and Stony Creek (Hillend Road), Frasers Stream had lower concentrations with a median of 0.6 mg/l at Station Road.

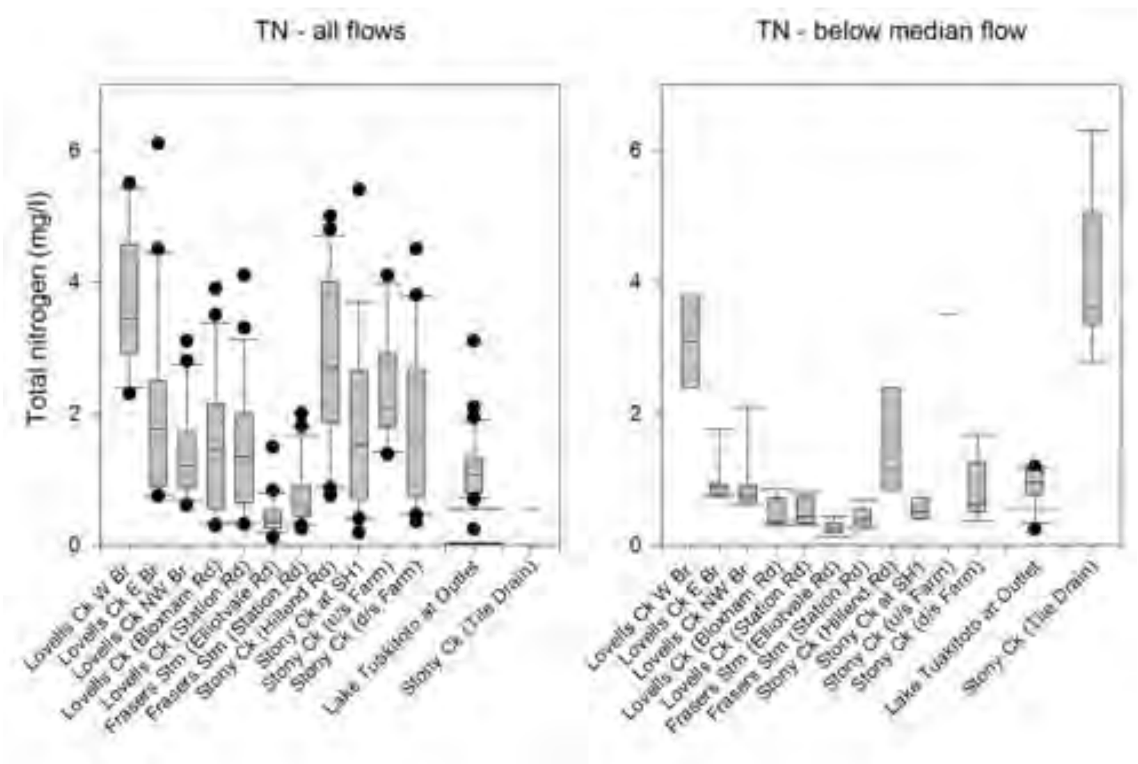


**Figure 14** **Total nitrogen concentrations in the Lake Tuakitoto catchment. Plan Change 6A Schedule 15 limits for the outlet at Lake Tuakitoto are represented by the red line (Group 4)**

### 3.4.3. Total phosphorus (TP)

TP is a measure of all the forms of phosphorus, dissolved or particulate, found in a sample. Phosphorus is a natural element found in rocks, soils and organic material as it clings tightly to soil particles. In rural landscapes, TP concentrations are affected by waste-water effluent, fertilisers and animal waste, (MfE, 2009).

The results of water sampling at all flows, and below median flow are shown in Figure 15. TP concentrations were high, particularly in the upper catchment sites of Lovells Creek and Stony Creek.

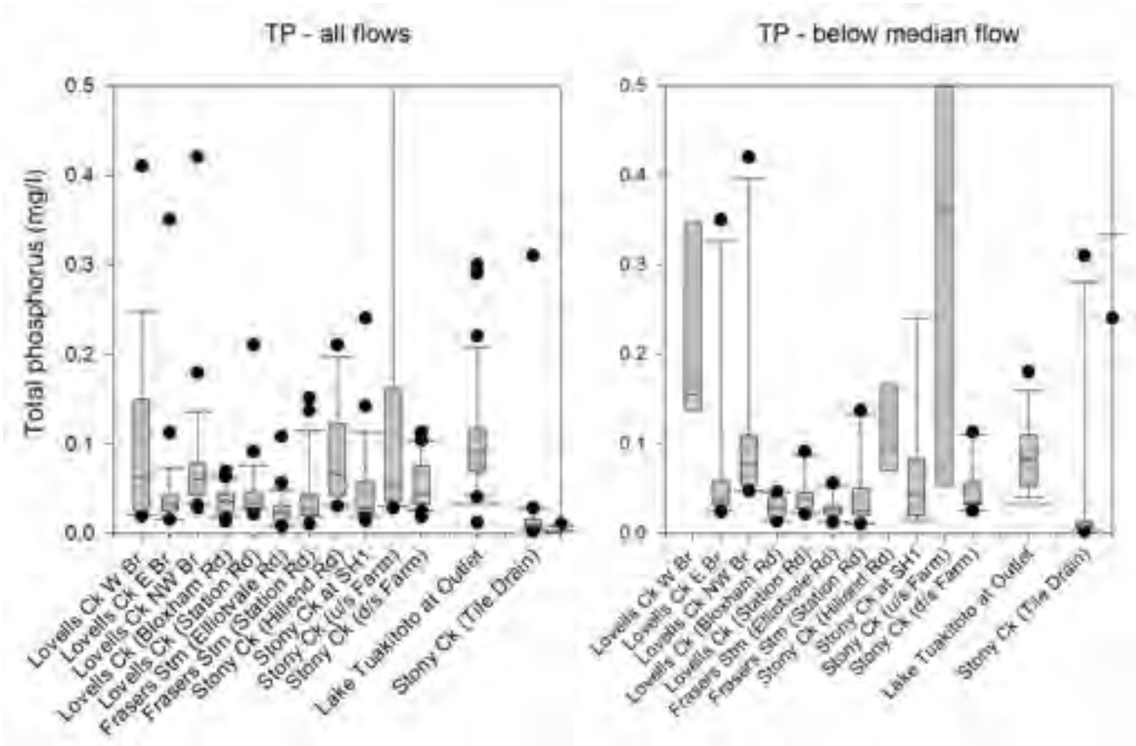


**Figure 15** **Total phosphorus concentrations in the Lake Tuakitoto catchment. Plan Change 6A Schedule 15 limits for the outlet at Lake Tuakitoto are represented by the red line (Group 4)**

### 3.4.4. Nitrite-nitrate-nitrogen (NNN)

NNN is the nitrogen available for plant growth and is beneficial up to a point, but may easily become a nuisance. NNN is by far the most common bioavailable form of N in surface waters and better reflects bioavailability than TN. NNN is affected by waste-water effluent, agricultural runoff and animal waste.

NNN water quality results (all flows, and below median flow) are shown in Figure 16. Results at all sites were quite similar to TN, lower concentrations were found in Frasers Stream when compared to Lovells Creek and Stony Creek. Concentrations of NNN decreased with distance downstream in both Lovells Creek and Stony Creek.

The 80th percentiles of NNN concentrations at the upper three sites in Lovells Creek (west, east and northwest branches) exceeded the PC6A limit, as did all the Stony Creek sites. Only Frasers Stream and the lower sites in Lovells Creek (Bloxham Road and Station Road) were within the receiving water quality limit.

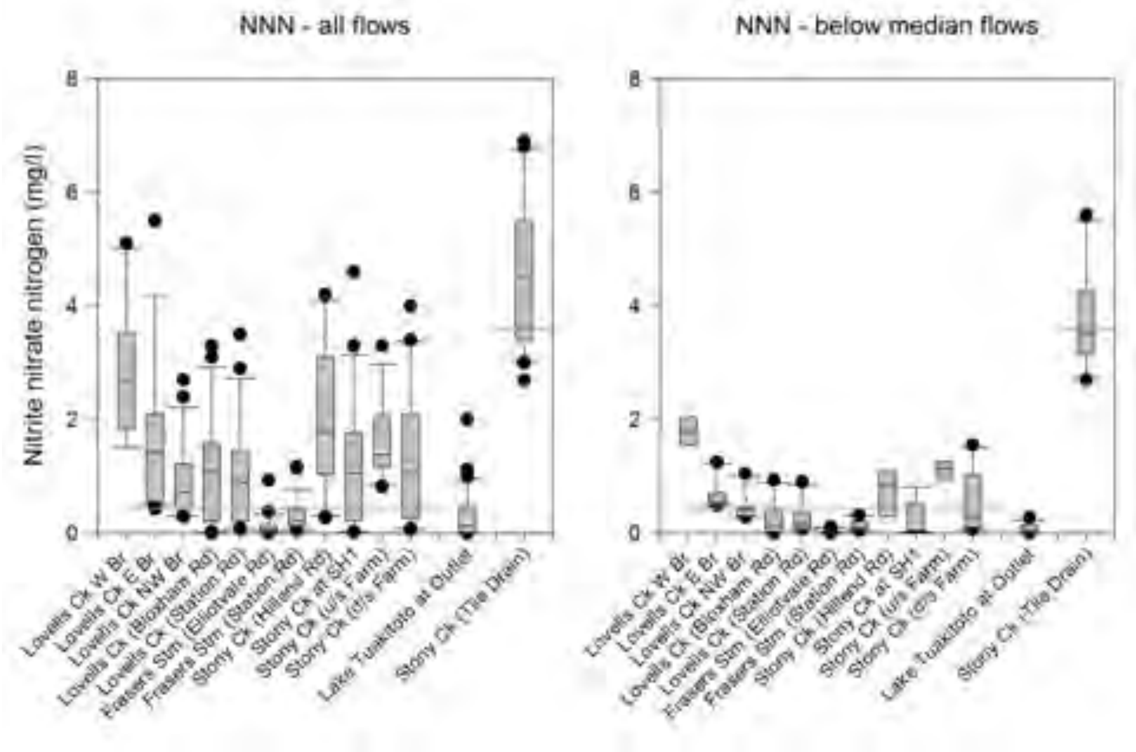


**Figure 16** **Nitrate-nitrite nitrogen concentrations in the Lake Tuakitoto catchment. Plan Change 6A Schedule 15 limits are represented by the blue line (Group 1) and the red line (Group 4)**

### 3.4.5. Dissolved reactive phosphorus (DRP)

DRP is a measure of orthophosphate, the filterable (soluble, inorganic) fraction of phosphorus, which is directly taken up by plant cells. Phosphorus is often found to be the growth-limiting nutrient, because it occurs in the least amount relative to the needs of plants. In rural landscapes DRP concentrations are affected by waste-water effluent, fertilisers and, animal waste (MfE, 2009).

DRP water quality results (all flows, and below median flow) are shown in Figure 17. Data collected when flows were below median flow were compared to the Schedule 15 limits. show that the 80th percentile of the DRP concentration was below the Schedule 15 limit at all sites.

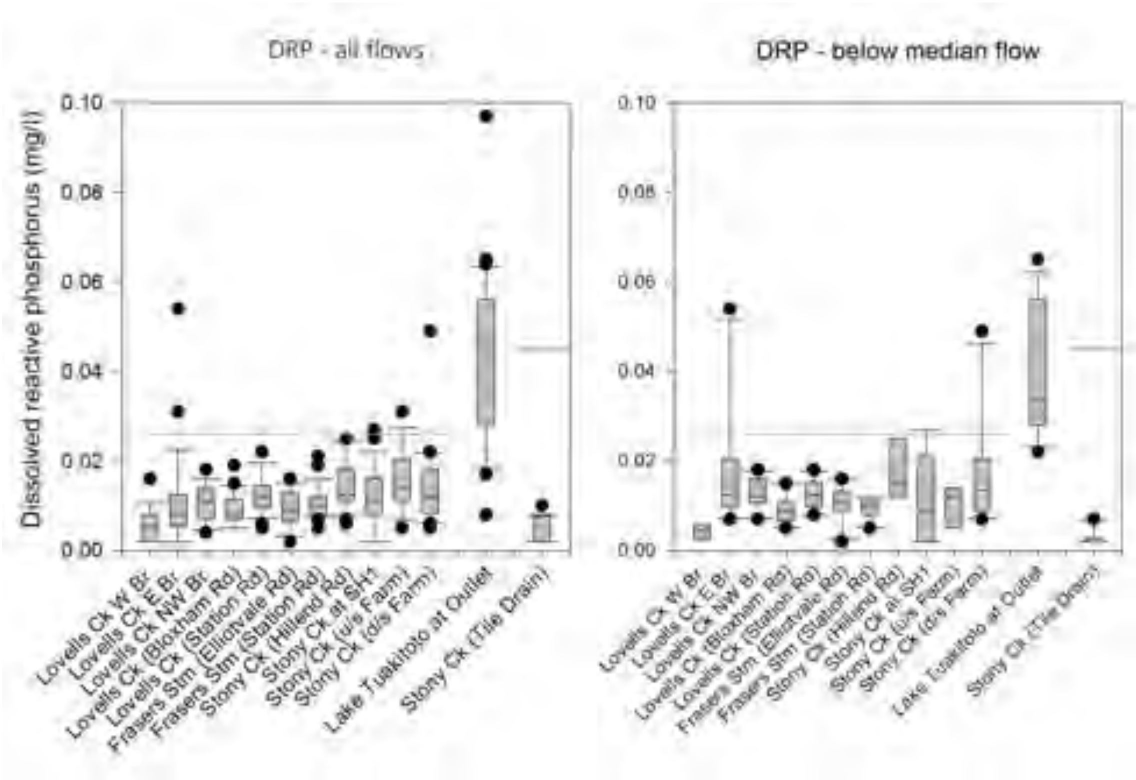


**Figure 17** **Dissolved reactive phosphorus concentrations in the Lake Tuakitoto catchment. Plan Change 6A Schedule 15 limits are represented by the blue line (Group 1) and the red line (Group 4)**

### 3.4.6. Ammoniacal nitrogen ($NH_4$-N)

Ammoniacal nitrogen can, at sufficiently high concentrations, be toxic to fish and other aquatic life. In farmed catchments, elevated concentrations are generally due to direct discharges of effluent, paddock runoff or stock access to streams. High concentrations are most likely to occur when stream flows are low, and when cattle use streams for drinking water.

Ammonia is found in water in two forms: ammonium ion ($NH_4$-N) and dissolved, unionised (no electrical charge) ammonia gas ($NH_3$-N). Total ammonia is the sum of ammonium and unionised ammonia. The dominant form depends on the pH and temperature of the water. The form of ammonia changes easily when pH changes. As pH increases, the $H^+$ concentration decreases, and $OH^-$ concentrations increase, which increases the amount of aqueous $NH_3$-N. When the pH is below 8.75, $NH_4$-N predominates. At pH 9.24, about half of aqueous $NH_3$-N is transformed to $NH_4$-N. Above pH 9.75, $NH_3$-N predominates. Unionised ammonia ($NH_3$-N) is much more toxic to aquatic organisms than the ammonium ion ($NH_4$-N).

Ammoniacal nitrogen concentrations at all sites were well within the Schedule 15 limit (Figure 18). Median concentrations were highest at Lovells Creek (west branch), Stony Creek (Hillend Road) and Lake Tuakitoto at the outlet

Data collected when flows were below median flow (10 of 23 sampling occasions) were compared to the Schedule 15 limits. The 80th percentile of the $NH_4$-N concentration was below the Schedule 15 limit at all sites.

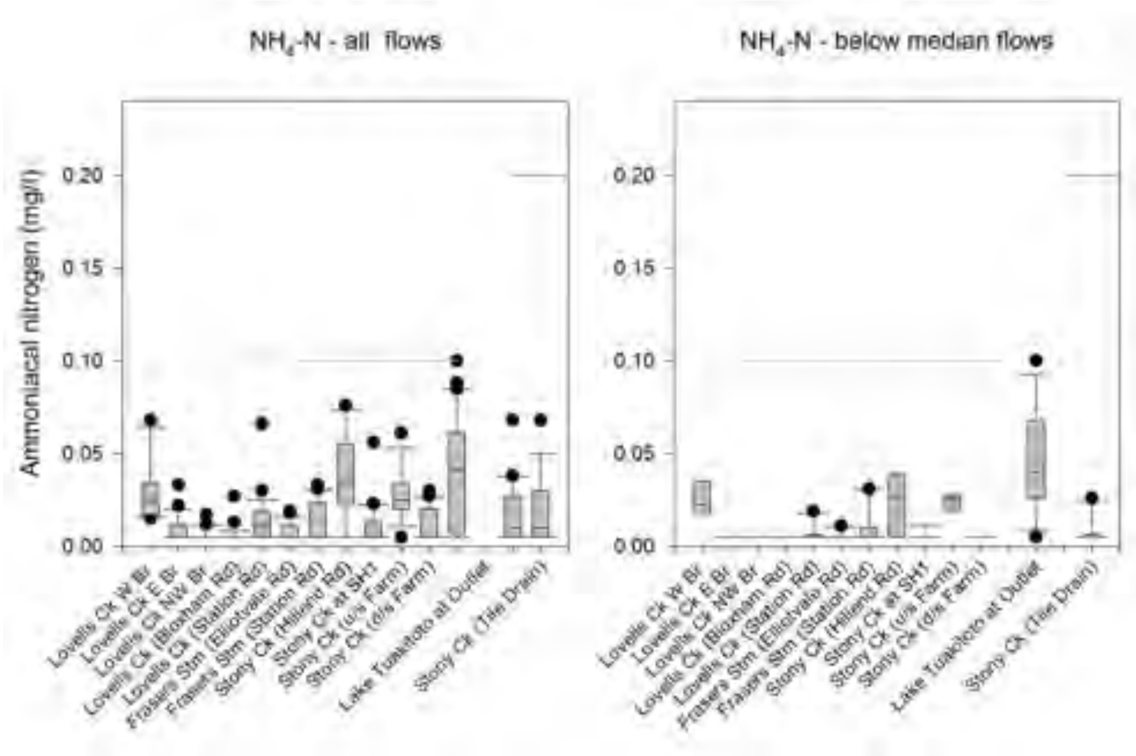


**Figure 18** **Ammonical nitrogen concentrations in the Lake Tuakitoto catchment. Plan Change 6A Schedule 15 limits are represented by the blue line (Group 1) and the red line (Group 4)**

### 3.4.7. Nitrogen: phosphorus ratio

The excessive growth of algae or macrophytes is only possible if nutrients, particularly NNN and DRP (which are biologically available for plant uptake) are available. If one of these nutrients is in low supply (limiting nutrient), then plant growth is restricted. Adding a limiting nutrient will stimulate plant growth more than adding any other element.

Redfield *et al.* (1963) published data that indicated a molar ratio of N, and P of 16:1 was reasonably constant during phytoplankton growth. On a mass basis (mg/l), the Redfield N:P ratio is 7:1. In this study, an N:P ratio of <7:1 for N-limitation and >15:1 for P-limitation (mass basis) was applied (McDowell, 2009).

The lowest nitrogen to phosphorus (N:P) ratio was 30:1 (Fraser Stream at Station Road), this suggests that periphyton in the Lake Tuakitoto catchment is phosphorus-limited, as well as being limited by temperature and habitat availability.

### 3.4.8. Sediments and turbidity

SS and turbidity can affect human values such as fishing, swimming and amenity and is known to cause ecological effects via two main pathways. SS can cause abrasion, clogging of feeding and gill structures and reduced water clarity and light penetration. This can lead to a loss of sensitive species, reduced resilience and lower primary productivity. Deposited sediment can cause benthic habitats to be smothered and can affect the quality of food resources for invertebrates (MfE, 2009).

High SS concentrations are commonly associated with high flows and are also naturally elevated in catchments with soft (erosion-prone) geology or sandy-bottomed streams. However, high SS and turbidity (which generally result in low visual clarity (ANZECC, 2000)) may also indicate stream bank and paddock erosion associated with poor land management (MfE, 2009).

SS concentrations were elevated in the smaller tributaries with low flows; Lovells Creek (west and north west branches) and Stony Creek (Hillend Road and upstream of the farm). The other sites had median concentrations of suspended solids below 10 mg/l.
Turbidity was not monitored between 25 September 2012 and 10 September 2013, however, it was measured as part of SOE monitoring at the outlet from Lake Tuakitoto. During this period the median turbidity recorded was 9.8 NTU, and the 80$^{th}$ percentile was 6.7 NTU (N=6). These values do not meet the Schedule 15 value for Lake Tuakitoto (5 NTU).

### 3.4.9. Faecal contaminants

Faecal contamination of waterways poses a public health risk. Illness may be contracted as a result of ingesting water (including eating fish and shellfish) containing bacterial, viral and protozoal pathogens that occur in faecal material. Faecal material reaches streams in numerous ways, including runoff from the land, effluent-pond discharges, stock and water fowl defecating directly into the water (e.g. Davies-Colley *et al*., 2004), overland runoff after rain and septic-tank discharges.

The indicator commonly used to assess this risk is *E. coli*, a faecal coliform bacterium that originates in the gut of warm-blooded animals and indicates the presence of other potentially harmful microbes. Pathogens are typically present in such small amounts that it is impractical to monitor them directly (MfE, 2009).

Figure 19 shows that *E. coli* counts (below median flow) were above the Schedule 15 limit at all sites other than Lovells Creek East branch (84 cfu/100ml) and Frasers Stream at Elliotvale Road (200 cfu/100ml). The highest counts were found at Lovells Creek NW branch, Lovells Creek at Station Road, Stony Creek upstream of the farm and Stony Creek at SH1.

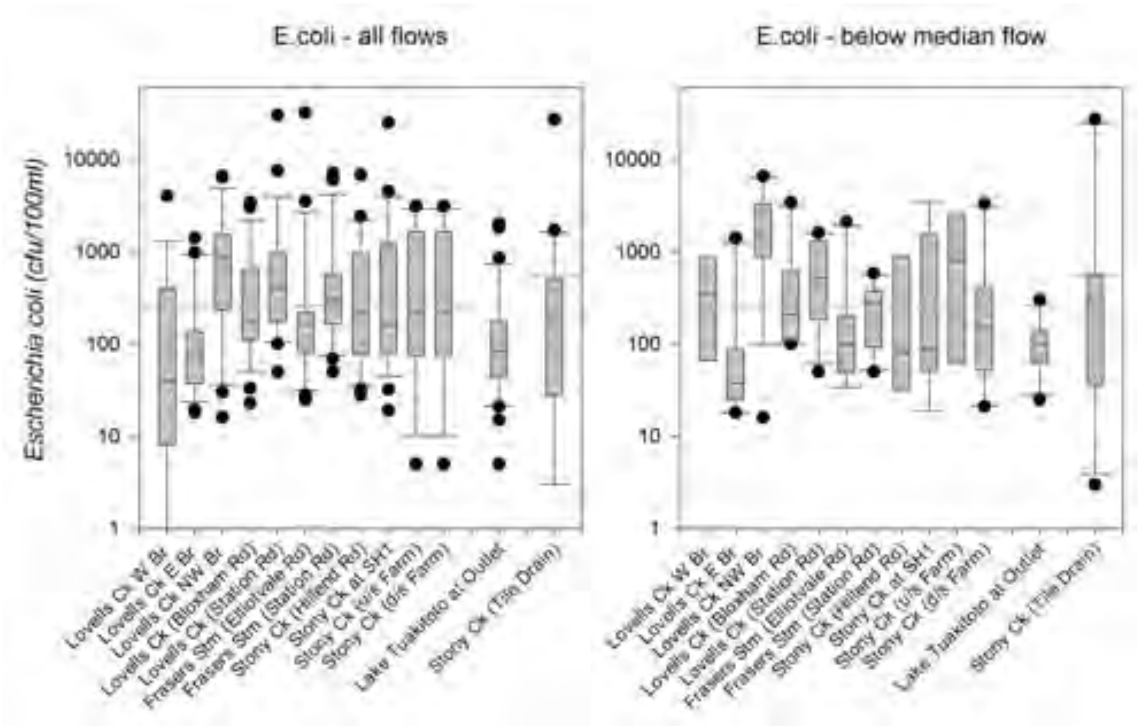


**Figure 19** ***Escherichia coli*** **concentrations in the Lake Tuakitoto catchment. Plan Change 6A Schedule 15 limits are represented by the blue line (Group 1) and the red line (Group 4)**

# 4. Stream habitat and instream biology

This section provides an assessment of stream habitat at Lovells Creek (Station Road) and Frasers Stream (Station Road), including:

- analysis of bed substrate (size, embeddedness and compactness).
- organic matter, bank cover and riparian cover

## 4.1. Substrate

The influence of bed substrate on stream communities is compounded by the range of substrate size and its embeddedness and compactness. A stream bed with highly variable substrate size classes may provide abundant potential refugia for macroinvertebrates and fish, while a bed with a fine uniform substrate size provides little refuge. Embeddedness is an indication of how much of the dominant substrate is buried by finer sediment. Compactness is a measure of how tightly packed substrate is. Under certain conditions (e.g. frequent flash flows or sedimentation), substrate can become highly compacted. When this happens, bed substrate can become very stable, adversely affecting steam biological health by reducing or eliminating interstitial spaces, the habitat for macroinvertebrates and fish.

Substrate was assessed at the two sites during baseline flows in November 2013. The sites were assessed for substrate size in run and riffle reaches. For each site, two riffles and two runs were chosen for a cross-sectional survey. The substrate size of ten randomly selected particles was measured while wading across the stream's cross section. The second widest axis of each particle was measured. These measurements were assessed against the Wentworth scale (Table 11).

**Table 11 Wentworth scale.**

| Score | Substrate type | Size |
|---|---|---|
| 7 | Bedrock | >4000 mm |
| 6 | Boulder | >256-4000 mm |
| 5 | Cobble | >64 to 256 mm |
| 4 | Pebble | >16 to 64 mm |
| 3 | Gravel | >2 to 16 mm |
| 2 | Sand | >0.063 to 2 mm |
| 1 | Silt | <0.063 mm |

From the substrate measurements, the Substrate Index (SI) was calculated. This index, proposed by Harding *et al.* (2009), was based on the Wentworth scale, originally a modified form of the SI used by Jowett and Richardson (1990). The following formula was used to calculate SI.

*Substrate index (SI)* = 0.08*%bedrock + 0.07*%boulder + 0.06*%cobble + 0.05*%pebble + 0.04*%gravel + 0.03*%sand and silt

A stream bed consisting entirely of bedrock will have an SI = 0.08*100% bedrock (i.e. 8), while a sandy bottom stream will have an SI = 0.03*100% sand (i.e. 3).

For each of the ten randomly selected particles, the degree of substrate embeddedness and compactness was noted. The definitions of embeddedness and compactness are given in Table 12

**Table 12 Scores for the degree of embeddedness and compactness.**

| Score | Substrate embeddedness | Substrate compactness |
|---|---|---|
| 1 | Not embedded, the substrate on top of the bed | Loose, easily moved substrate |
| 2 | Slightly embedded, >25% of the particle is buried or | Mostly loose, little compaction |
| 3 | Firmly embedded, about 50% of the substrate is | Moderately packed |
| 4 | Heavily embedded, >66% of the substrate is buried | Tightly packed substrate |

The substrate at both Lovells Creek and Frasers Stream was on top of the bed at each site (score 1) and compactness was low, with loose easily moved substrate at both sites (score 1). Table 13 shows that both streams had gravel as their dominant substrate. The SI scores were also very similar.

**Table 13 Summary results of physical habitat assessment**

| | Lovells Creek | Frasers Stream |
|---|---|---|
| Median particle size based on the Wentworth | >2 to 16mm | >2 to 16mm |
| Substrate Index | 4.4 | 4.5 |
| Estimated gravel and fine sediment cover (%) | 55 | 45 |
| Compactness score | 1 | 1 |
| Embeddedness score | 1 | 1 |

## 4.2. Instream organic matter, bank cover and riparian cover

Organic matter and overhanging vegetation can provide important habitat for stream invertebrates and fish.

Macrophytes were not present at either site, the presence of algae was also limited to thin films, other than a small amount of filamentous algae present in Fraser's Stream. The sites had less than 50% bank cover, the composition of which was mainly overhanging rank exotic weedy shrubs, with very little organic matter present. The extent of woody debris and leaf packs was also minimal.

Riparian cover and vegetation was assessed at the two sites November 2013. Riparian cover was assessed according to protocol 'P2d', as described in the Stream Habitat Assessment Protocols for wadeable rivers and streams of New Zealand (Harding *et al.,* 2009).

The protocol assesses the attributes that determine riparian zone influence on stream habitat and aims to allow inter-site comparisons. The P2d protocol allows scores to be derived for 12 key riparian attributes (Table 14). Each of the 12 key riparian attributes could be scored from one to five (five being good).The total score for each site is out of 125. All attributes (other than shading) are scored out of ten (five for the left bank and five for the right bank, then summed).

The scores were quite similar, within 3 points of each other. There was no open livestock access at either site, and the buffer intactness was good.

**Table 14 Riparian cover assessment.**

| | Lovells Creek | FrasersStream |
|---|---|---|
| Shading of water | 3 | 2 |
| Buffer width | 5 | 7 |
| Buffer intactness | 7 | 5 |
| Vegetation composition of buffer | 3 | 3 |
| Vegetation composition of land adjacent to buffer | 2 | 2 |
| Bank stability | 5 | 6 |
| Livestock access | 10 | 10 |
| Riparian soil denitrification potential | 4 | 4 |
| Land slope 0-30 m from stream bank | 6 | 6 |
| Groundcover of buffer | 8 | 6 |
| Ground cover of land adjacent to buffer | 7 | 6 |
| Soil drainage | 6 | 6 |
| Rills/channels | 7 | 7 |
| TOTAL | 73 | 70 |

# 5. Macroinvertebrates

This section provides results from an assessment of macroinvertebrates. The assessment includes analysis of the species richness, EPT taxa, MCI scores and SQMCI scores found at Lovells Creek (at Station Road) and Frasers Stream (at Station Road)

Aquatic macroinvertebrates are organisms that live on or within the bottom substrate (e.g. rocks, gravels, sands, silts and organic matter, such as macrophytes, or organic debris, such as logs and leaves), in rivers and streams. Examples include insect larvae (e.g. mayflies, stoneflies, caddisflies and beetles), aquatic oligochaetes (worms), snails and crustaceans (e.g. amphipods and crayfish). These macroinvertebrates are a useful means of assessing the biological health of a river because they are found everywhere and have different tolerances to temperature, dissolved oxygen, sediment and chemical pollution. They also have life-cycles ranging from a few months to a year or two; thus, the presence or absence and abundance of taxa can provide insight into long-term changes in water quality.

Macroinvertebrates are used in biomonitoring around the world. In New Zealand, the MCI (Stark, 1985), and its derivatives (SQMCI, QMCI: Stark, 1998), are used as a measure of organic enrichment and sedimentation in gravel-bed streams.

Macroinvertebrate communities were sampled at both sites in October 2013. At each site, one extensive kick-net sample was collected, following Protocol C2, 'hard-bottomed, semi-quantitative sampling of stream macroinvertebrate communities' (Stark *et al.*, 2001), which requires sampling a range of habitats, including riffles, mosses, wooden debris and leaf packs. Samples were chilled and returned to a laboratory for processing. Following Protocol P1, 'semi-quantitative coded abundance', macroinvertebrate samples were coded into one of five abundance categories (Table 15): In the laboratory, the samples were passed through a 500 µm sieve to remove fine material. The sieve contents were then placed onto a white tray, and the macroinvertebrates were identified under a dissecting microscope (10-40X), using the identification key of Winterbourn *et al.* (2000).

The indices commonly used to measure stream health are summarised below:

- Species richness: The total number of species (or taxa) collected at a sampling site. In general terms, high species richness may be considered 'good'; however, mildly impacted or polluted rivers, with slight nutrient enrichment, can have higher species richness than unimpacted, pristine streams.

- Ephemeroptera plecoptera and trichoptera (EPT) richness: The sum of the total number of Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) species collected. These insects are often the most sensitive to organic pollution; therefore, low numbers might indicate a polluted environment. Comparing the percentage of EPT species to the total number of species found at a site can give an indication of the importance of these species in the overall community.

- Macroinvertebrate community index (MCI): Assesses the occurrence of specific macroinvertebrate taxa to determine the level of organic enrichment in a stream. Taxa are assigned scores of between 1 and 10, depending on their tolerance. A score of 1 represents taxa that are highly tolerant of organic pollution, while 10 represents taxa that are sensitive to organic pollution. The MCI score is obtained by adding the scores of individual taxa and dividing the total by the number of taxa present at the site and multiplying this figure by 20 (a scaling factor). MCI scores can be interpreted based on the water quality classes proposed by Stark *et al.* (2001) (Table 16).

- Semi-quantitative macroinvertebrate community index (SQMCI): Is a variation of the MCI that accounts for the abundance of pollution sensitive and tolerant species. The SQMCI is calculated from coded-abundance data. As with the MCI, SQMCI scores can be interpreted based on the water quality classes proposed by Stark *et al.* (2001) (Table 16).

**Table 15 Coded abundance scores used to summarise macroinvertebrate data (after Stark,1998).**

| Abundance | Coded abundance | Weighting factor |
|---|---|---|
| 1 to 4 | Rare (R) | 1 |
| 5 to 19 | Common (C) | 5 |
| 20 to 99 | Abundant (A) | 20 |
| 100 to 499 | Very abundant (VA) | 100 |
| >500 | Very very abundant (VVA) | 500 |

**Table 16 Interpretation of MCI values from Boothroyd and Stark (2000) (quality class A) and Stark and Maxted (2007) (quality class B).**

| Quality class A | Quality class B | MCI | SQMCI |
|---|---|---|---|
| Clean water | Excellent | >120 | >6 |
| Doubtful quality | Good | 100 to 119 | 5 to 5.99 |
| Probable moderate pollution | Fair | 80 to 99 | 4 to 4.99 |
| Probable severe pollution | Poor | <80 | <4 |

Macroinvertebrate health indices (Table 17) show that a ‘good’ MCI value was found in Lovells Creek and a ‘fair’ MCI value in Frasers Stream. The most common macroinvertebrates found in both streams were crustacea (*Paracalliope fluviatilis* ‘very abundant’) and mollusca (the snail *Potamopyrgus antipodarum* was ‘very abundant’ in Lovells Creek and ‘very very abundant in Frasers Stream). In Frasers Stream Plecoptera (*Zelandobius* species) was ‘very abundant’ and in Lovells Creek the caddis Trichoptera (*Pycnocentria* species and *Pycnocentrodes* species) were ‘very abundant’.

**Table 17 Macroinvertebrate health indice results for Lovells Creek and Frasers Stream**

| Taxon | Lovells Creek | Frasers Stream |
|---|---|---|
| Number of taxa | 24 | 17 |
| Number of EPT taxa | 12 | 5 |
| EPT% | 50 | 29 |
| MCI score | 100 | 86 |
| SQMCI score | 5.2 | 4.3 |

The SQMCI scores shown in Table 17 reflect the MCI scores. Lovells Creek obtained the highest score of 5.2 to place it in the ‘good’ category and Frasers Stream was categorised as ‘fair’ with a SQMCI score of 4.3.

When the EPT data were expressed as a percentage of the total number of species Lovells Creek had 50% EPT taxa and Frasers Stream had more than 29% EPT taxa. The main difference being the large number (11) of Trichoptera species found in Lovells Creek, compared to Frasers Stream (2).

# 6. Periphyton

This section provides an assessment of algae and includes:

- algal community composition (all sites)
- accrual periods to determine the frequency and duration of algal proliferations
- algal biomass and nutrient concentrations.

The periphyton community forms the slimy coating on the surface of stones and other substrates in freshwaters. This community can include green (Chlorophyta), yellow-green (Xanthophyta), golden brown (Chrysophyta) and red (Rhodophyta) algae, blue-greens (Cyanobacteria), diatoms (Bacillariophyta), bacteria and fungi. Periphyton is an integral part of stream food webs. It captures energy from the sun and converts it, via photosynthesis, to energy sources available to macroinvertebrates, which feed on it. These, in turn, are fed on by other invertebrates and fish. However, periphyton can form nuisance blooms that can detrimentally affect other instream values, such as aesthetics, biodiversity, recreation (swimming and angling), water takes (irrigation, stock/drinking water and industrial) and water quality.

Periphyton community composition was monitored at Lovells Creek at Station Road and Frasers Stream at Station Road in October 2013. Algal samples were collected by selecting three stones at each site, taken from one-quarter, one-half and three-quarters of the stream width. At each collection point, a stone was randomly selected and removed to the river bank. A 5 cm x 5 cm (0.0025 $m^2$) area of each stone surface was scrubbed with a small brush into a tray and rinsed with river water. The scrubbings from the three stones were pooled and transferred to a sample container using river water. The sample was transported to the laboratory and preserved in formaldehyde.

Each sample was thoroughly mixed, and three aliquots were removed to an inverted microscope settling chamber. They were then allowed to settle for 10 minutes. Samples were analysed according to the 'relative abundance using an inverted microscope' method outlined in Biggs and Kilroy (2000). Samples were inspected under 200-400x magnification to identify algal species present using the keys of Biggs and Kilroy (2000), Entwisle *et al*. (1988) and Moore (2000).

The relative abundance of taxa was determined on subsamples. Algae were given an abundance score ranging from 1 (rare), 2 (rare-occasional), 3 (occasional), 4 (occasional, common), 5 (common), 6 (common abundant), 7 (abundant) to 8 (dominant), based on the protocol of Biggs and Kilroy (2000). Internal quality assurance procedures were followed. Results are shown in Table 18.

Algal community composition shows diatoms were dominant in Frasers Stream (*Encyonema*), in Lovells Creek little periphyton was found .

**Table 18 Periphyton abundance results for Lovells Creek and Frasers Stream**

| | Lovells Creek | Frasers Stream |
|---|---|---|
| **Filamentous green algae** | | |
| *Stigeoclonium* | | 2 |
| **Filamentous red algae** | | |
| *Audouinella* | 2 | 2 |
| **Cyanobacteria** | | |
| *Oscillatoria/Phormidium* | | 3 |
| **Diatoms** | | |
| *Encyonema* | | 7 |
| *Frustulia* | 1 | 1 |
| Naviculoid diatoms | 2 | 2 |
| *Nitzschia* | | 1 |
| *Synedra* | | 2 |

## 6.1. Accrual periods

The frequency and duration of algal proliferations in streams rely, in part, on the hydrologic regime of the stream. The shorter the accrual period (the average time between flood events >3x the median flow), the less likely the build up of periphyton and therefore the higher the nutrient concentration guideline. The accrual period for Lovells Creek is relatively short at 23 days (Table 19). The filter period has been applied variously as a 5-day interval (Snelder et al., 2004) and a 10-day interval (Snelder et al., 2005) (i.e. removing events <5 and <10 days from the accrual period). In this instance a filter of <5 days was used.

**Table 19 Accrual days in the period (all record 10/4/81 to 11/6/12) with a 5-day filter.**

| Catchment | Time period | Mean | Median | Upper | Events/yea |
|---|---|---|---|---|---|
| Lovells Creek | 01/01/00 to | 23 | 17 | 33.0 | 1.71 |

## 6.2. Algal biomass and nutrients

Linking periphyton biomass to stream nutrient concentrations is very difficult. The accrual period affects which nutrient guideline to use (Biggs, 2000). The longer the accrual period, the more likely the build up of periphyton and therefore the lower the nutrient concentration guideline The same principle has been used in placing the Lake Tuakitoto catchment in Schedule 15, Group 1 (PC6A), which has higher nutrient limits compared to other Groups with longer accrual periods.

Nutrients are important in influencing the accrual of algal biomass. Biomass levels >150-200 mg/m$^2$ chlorophyll *a* are very conspicuous in streams and can compromise the use of rivers (Biggs, 2000). To prevent excessive algal growth in streams with accrual periods of <30 d, Biggs (2000) recommended that mean monthly dissolved nutrient concentrations must be quite low (NNN<0.295 and DRP<0.026). The prime algae growth season is between September and March.

The concentrations of NNN and DRP in Lovells Creek (Station Road) and Frasers Stream (Station Road) were calculated as means over this period and shown in Table 20. The mean concentration of NNN in Lovells is more than that recommended by Biggs (2000) to prevent biomass from exceeding 200 $mg/m^2$ chlorophyll *a* and also exceeded the PC6A limit. The DRP concentrations at this site is low.

**Table 20 Mean concentration of NNN and DRP at Lovells Creek and Frasers Stream over the period September 2012 to March 2013.**

| | Nitrite/nitrate nitrogen (mg/l) | Dissolved reactive phosphorus (mg/l) |
|---|---|---|
| PC6A guideline | 0.444 | 0.026 |
| Lovells Creek at Station Road | 0.518 | 0.013 |
| Frasers Stream at Station Road | 0.255 | 0.011 |

The nutrient concentration in the tributaries has a bearing on Lake Tuakitoto health as it directly affects lake chlorophyll *a* concentrations.

Chlorophyll *a* is the pigment that allows algae to use sunlight to convert simple molecules into organic compounds via the process of photosynthesis. Chlorophyll *a* is a measurement of the amount of food available to fuel the lakes food web and is an integral component of the trophic level index.

Table 7 shows that the chlorophyll *a* concentration in Lake Tuakitoto is high and in the ‘eutrophic’ category, and Table 8 shows that chlorophyll *a* concentrations have not significantly changed since 1995.

# 7. Fish communities

In May 2013 Lovells Creek at Station Road and Frasers Stream at Station Road were electric-fished, using a pulsed DC Kainga EFM300 backpack electro-shocker. Fishing was undertaken by stop-netting off an area of about 100 $m^2$, and electric-fishing this area in an downstream direction in three passes. Fish from each pass were measured, counted and then released downstream of the downstream stop-net. At each site, all trout were also weighed (in grams) and then measured from the tip of the snout to the caudal fork (total length, mm).

The NIWA New Zealand Freshwater fish database for the Lake Tuakitoto catchment (October 2013) shows 10 fish species listed (Table 4). This survey found three native species in Lovells Creek (Table 21) and one native species in Frasers Stream. Brown trout were also found at both sites. As a known area was sampled, fish density could be calculated. Lovells Creek had 0.31 fish per 100$m^2$ and Frasers Stream had 0.37 fish per 100$m^2$

**Table 21 Fish species (and numbers) found in the Lovells Creek and Frasers Stream (May 2013).**

| | **Lovells Creek** | **Frasers Stream** |
|---|---|---|
| Method | Electric-fished | Electric-fished |
| Area fished ($m^2$) | 100 | 100 |
| Longfin eel | 3 | 6 |
| Perch | 2 | 17 |
| Lamprey | 5 | |
| Common bully | 4 | |
| Brown trout | 16 | 11 |
| Crayfish | 1 | 3 |
| Fish density | 0.31 fish per 100$m^2$ | 0.37 fish per 100$m^2$ |

# 8. Freshwater mussel survey

This section outlines mussel sampling undertaken in Lake Tuakitoto, including:

- Comparing 1991 results to 2013 results
- Mussel density and biomass

In 1991, a survey of freshwater mussels was undertaken in Lake Tuakitoto to investigate the potential for using mussels to control phytoplankton in eutrophic lakes. The survey was undertaken as part of a University of Otago postgraduate degree (Ogilvie 1993), and was presented in an international science journal (Ogilvie and Mitchell 1995). In 2013 ORC engaged Ryder Consulting to replicate the original survey. The same methodology as described in Ogilvie (1993) and Ogilvie and Mitchell (1995) was used.

Field collection of the mussels was undertaken on the 22nd and 23rd of April 2013. Twenty five stations were sampled from the same locations as the 1991 survey (Figure 20). At each station, water depths were recorded (between 0.19 m and 0.56 m at the sampling stations) and mussels were taken from three quadrats (area 1 $m^2$) by ‘finger sifting’ the substratum to a depth of approximately 10 cm while snorkelling.

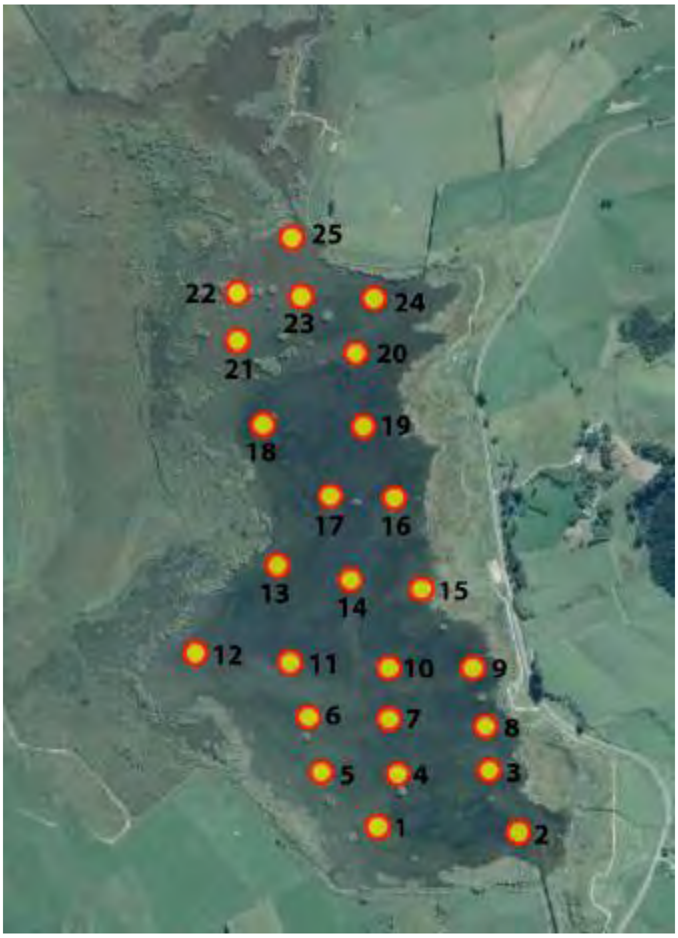


**Figure 20 Mussel sampling locations in Lake Tuakitoto**

The mussels were counted and their anterior-posterior (A-P) lengths were measured. One hundred mussels were collected and brought back to the laboratory (Figure 21) to determine the relationship between length and ash-free dry weight (AFDW) (Figure 22)

**Figure 21 Mussels collected from Lake Tuakitoto**

In the laboratory the flesh from 99[2] mussels was removed, dried at 70°C for 72 hours, then weighed to determine the dry weight. The dried flesh was then incinerated in a muffle furnace at 550°C for 1 hour to determine the ash weight. The AFDW was calculated as dry weight minus ash weight. The relationship between AFDW and A-P length appeared to be linear (Figure 22) and is described by the regression equation: $Y = 0.1096x - 6.0093$ ($R^2 = 0.7042$, n=99). Where Y = AFDW (g) and x is A-P length (mm).

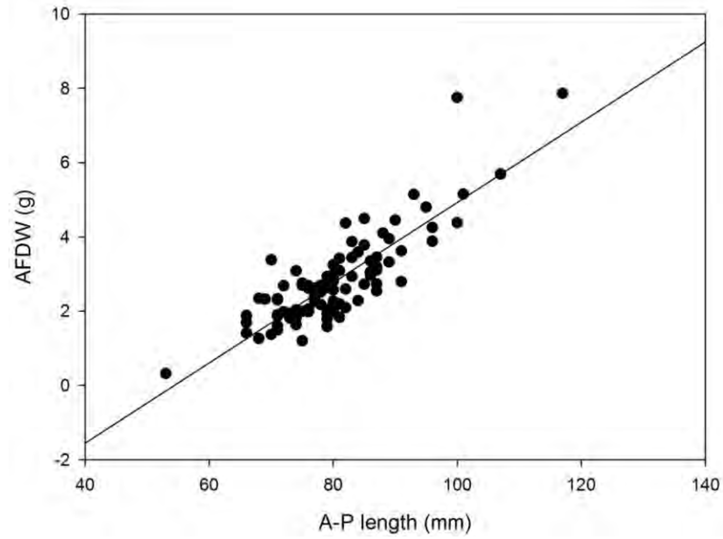


**Figure 22 Relationship between flesh biomass (ADFW) and anterior-posterior (A-P) length for 100 mussels**

[2] While 100 mussels were collected from Lake Tuakitoto for laboratory processing only 99 mussels were suitable for processing.

In 1991 no mussels were found at the four stations which were less than 0.5m deep (Figure 26). During this survey 18 stations had a water depth of less than 0.5m, and of these two stations (15 and 19) had no mussels.

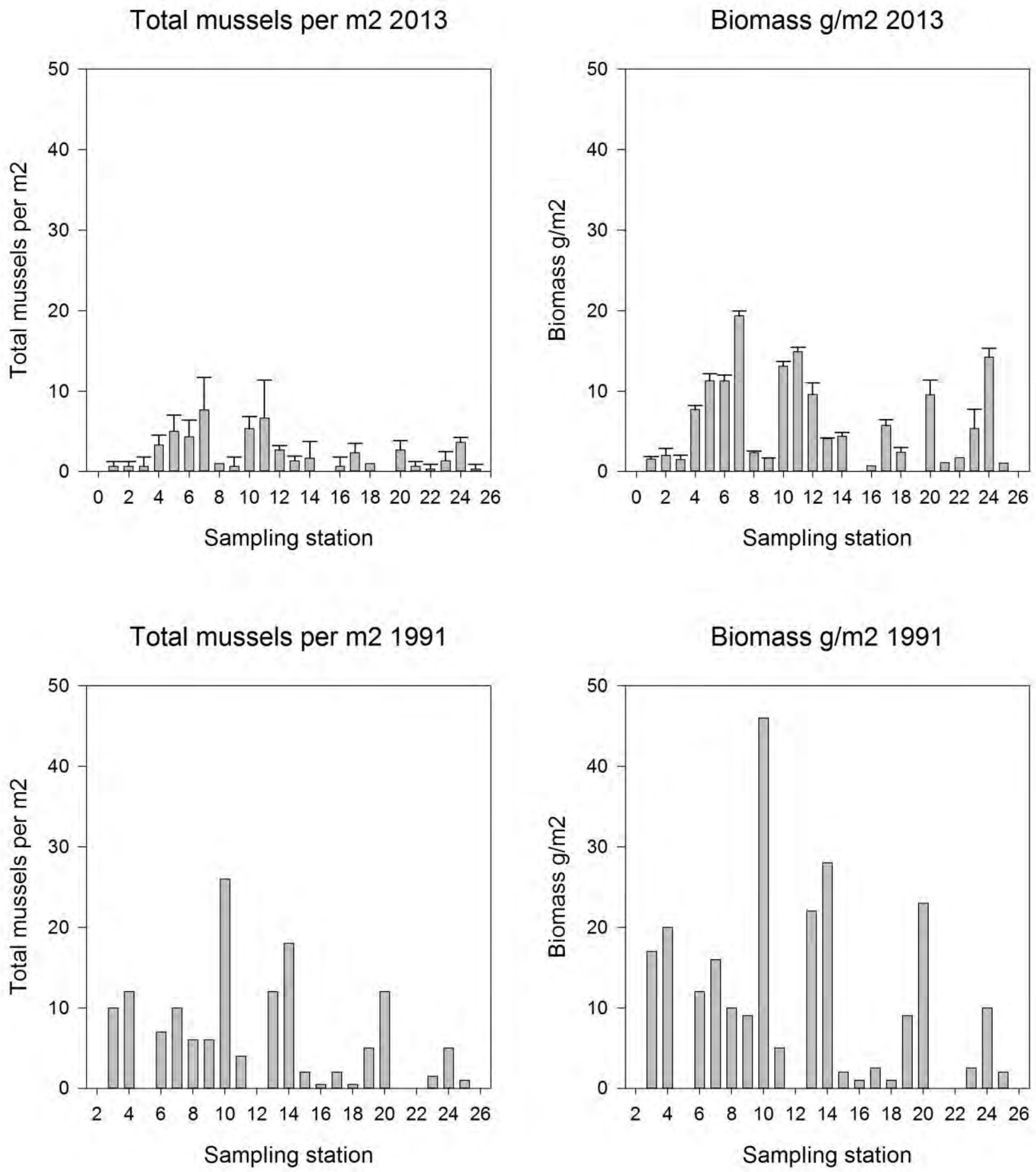


**Figure 23 Comparison of 1991 (Ogilvie, 1995) and 2013 (ORC) data for the density (no/m2) and biomass (g/m2 AFDW) of mussels at 25 sampling stations in Lake Tuakitoto.**

Assuming that the area, depth and volume of Lake Tuakitoto have not changed since 1991, and that the percentage of active filtering by mussels has remained at 93%. Table 22 shows that in 2013 there were significantly fewer mussels/m$^2$ and the biomass was significantly less than in 1991. This is supported by Unsworth (2007), whose research noted Lake Tuakitoto mussels were over 20 years of age (estimated by counting the annual rings and measuring the width of the shell) and that replenishment was not occurring.

**Table 22 Comparison of 2013 and 1991 mussel statistics**

| | ORC 2013 | 1991 (Ogilvie, 1995) |
|---|---|---|
| Area (km) | 1.18 | 1.18 |
| Depth (m) | 0.7 | 0.7 |
| Volume (l) | 826,000,000 | 826,000,000 |
| Stations with no mussels | 4 | 2 |
| Stations less than 0.5 m depth | 18 | 4 |
| Range of AFDW (g/m$^2$) | 0.32 to 7.86 | 0 to 46 |
| Mean mussel density (m$^2$) | 2.20 | 5.50 |
| Mean biomass (g/m$^2$) | 5.86 | 12.30 |
| Mean filtration rate (l hr$^{-1}$ g$^{-1}$) | 1.26 | 1.91 |
| Active filtering (%) | 0.93 | 0.93 |
| Volume water filtered by mussels m$^2$ h$^{-1}$ | 6.87 | 21.85 |
| Volume water filtered by musels l/hr | 8,102,762 | 25,781,218 |
| Hours it takes to filter lake | 102 | 32 |

It has been assumed that the lake has a mean depth of 70 cm (typical summer depth). The filtration of a volume of water equal to that of the lake equated to once every 32 hours in 1991, but by 2013 this had increased to once every 102 hours.

# 9. Assessment of Lake Levels

A minimum lake level of 100.77 metres above datum (0.77 metres above sea level) was set for the lake for the period beginning 30 September in any year and ending 16 May in any following year, by a Local Water Conservation (Lake Tuakitoto) Notice 1991. The intent of this was to protect the regionally significant recreational and wildlife features of the lake whilst not impacting on land drainage.

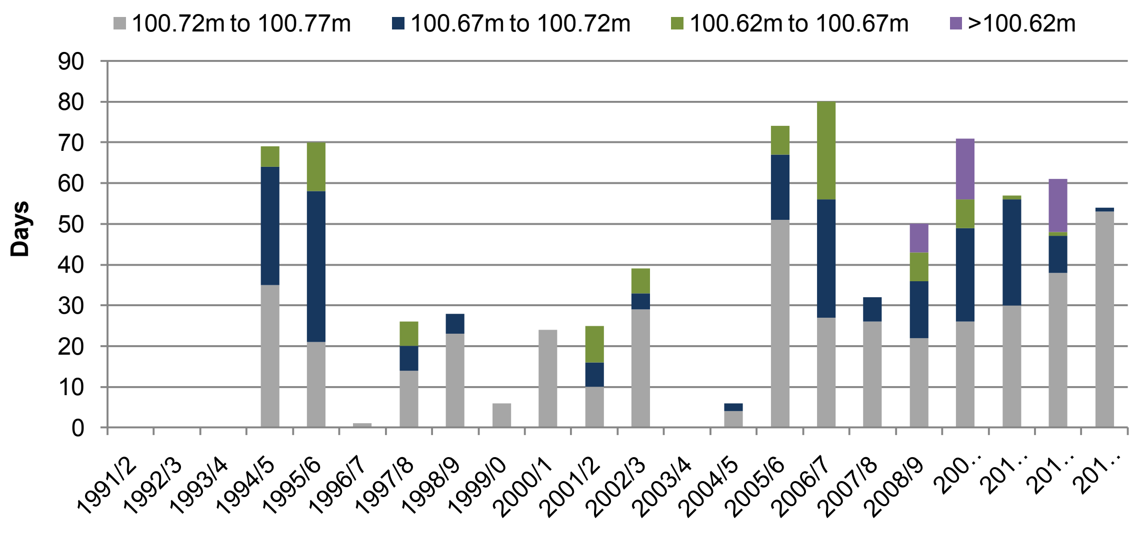


**Figure 24 Lake Tuakitoto. Number of days spent below 100.77m.**

The lake level at the outlet has been monitored by ORC since 1961. Figure 24 shows data from 1991 onwards, specifically the number of days in each year (30 September to 16 May) that the level at the outlet has fallen below 100.77m above datum.

Until the year 1994/5 the lake did not drop below 100.77m. In recent years (since 2006) the lake has spent longer below the minimum lake level of 100.77m (30 September to 16 May) when compared to previous years (Figure 24).

# 10. Discussion

## 10.1. Historical water quality

Since 1995 Lake Tuakitoto at the outlet has been monitored bimonthly as part of ORC's SOE water quality monitoring programme. Between July 1995 and June 2013 the significant changes in water quality were a reduction in $NH_4$-N and an increase in DRP..

Of the water quality variables considered, TN, TP, $NH_4$-N and *E.coli* generally exceed relevant PC6A Schedule 15 limits. $NH_4$-N generally meets the PC6A Schedule 15 limit.

## 10.2. Compliance with plan change 6A limits

Plan change 6A outlines the water quality limits for receiving waters (Schedule 15, Table 6) and discharge thresholds (Schedule 16). Receiving water limits are applied as 5-year, 80$^{th}$ percentiles, when flows are at or below median flow (0.143 $m^3$/s). The reference flow for the Lake Tuakitoto catchment has been set at Lovell's Creek.

The sites in the Lake Tuakitoto catchment were sampled between 25 September 2012 and 10 September 2013. During this time, ten samples were collected when flows were below median flow. Consequently, 80$^{th}$ percentiles were calculated on the basis of limited data and should be treated with caution. This is not a concern for the SOE monitoring site at the outlet of Lake Tuakitoto.

Between 2012 and 2013, NNN concentrations at seven of the sites monitored, exceeded the Schedule 15 limit (Table 6), in contrast the 80$^{th}$ percentiles of $NH_4$-N and DRP did not exceed the Schedule 15 limits at any of the sites (Table 6). The only site not to exceed the Schedule 15 limit for *E. coli* was the upper site in Frasers Stream at Elliotvale Road.

The tile drain was assessed against Schedule 16, all parameters other than DRP met the Schedule 16 threshold. Lake Tuakitoto at the outlet was assessed against Schedule 15 (Group 5 for lakes), 80$^{th}$ percentiles of all parameters other than *E.coli*, TN and TP met the limit.

## 10.3. Nutrients and algae

Nuisance algae growths can be common in rivers affected by excessive nutrient contamination. If prolific algae growth is present, instream values, such as swimming and angling, can be adversely affected .

In both Frasers Stream and Lovells Creek periphyton was sparse, with only a thin assemblage covering the larger substrate. The main benthic cyanobacterium in New Zealand rivers is *Phormidium* (Order: Oscillatoriales), which has been associated with dog deaths throughout New Zealand, this was 'present' in Frasers Stream. It usually grows attached to the bed (referred to as 'benthic') and under the right conditions (high levels of light, warm temperatures and stable flows), it can form thick mats, which can affect water quality, this was not seen, and has never been observed, in Frasers Stream or Lovells Creek.

Algal biomass is driven by the availability of nutrients, light and water temperature, while biomass loss is driven by disturbance (substrate instability, water velocity and SS) and grazing (mainly by invertebrates). The nutrients available for plant growth are NNN and DRP, the tributaries in the Lake Tuakitoto catchment all had N:P ratios of >15:1 indicating that algae growth is inhibited by P limitation (mass basis).

NNN concentrations were lowest in Frasers Stream and elevated in both the upper Stony Creek catchment and Lovells Creek. Higher NNN levels in the catchment are likely to be due to a combination of farming practice in the agricultural landscape, as well as naturally high N concentrations found in the shallow groundwater. A concentration of more than 4.0 mg/l TN from the spring fed tile drain seems to support this theory.

There is little algae growth in the tributaries of Lake Tuakitoto, this is likely to be due to low DRP concentrations coupled with frequent disturbance to substrate and low temperatures.

Concentrations of TP were high, particularly in the upper catchment sites of Lovells Creek and Stony Creek, this is more than likely to be due to the low flows in the small tributaries and disturbance of suspended sediment in the stream bed by stock.

There is enough nutrient in Lake Tuakitoto for high chlorophyll *a* concentrations to persist, at a concentration that Burns et al (2000) considered ‘eutrophic’. This situation is unlikely to change, but water quality problems (i.e. algal blooms) will be exacerbated if water volumes and depths decrease.

## 10.4. Toxicants

Ammonia is a common agricultural pollutant from animal-waste products. It exists in two forms in water: non-toxic ionised ammonium ($NH_4$-N) and unionised ammonia ($NH_3$-N), which is very toxic to many aquatic species, even at low concentrations. The ratio of $NH_3$-N to $NH_4$-N increases with pH, such that both are approximately equal at 20°C and pH 9.4. When concentrations of $NH_4$-N reach about 1–2 mg/l (Wilcock *et al*., 2007), concentrations of unionised $NH_3$-N can become toxic to stream life, especially to invertebrates (Hickey and Vickers, 1994).

Although such concentrations can occur in streams of pasture catchment (MfE, 2009), the highest concentration found was 0.37 mg/l in Stony Creek at Hillend Road. Historical temperature and pH results mean that toxic concentrations of $NH_3$-N are unlikely to be present.

## 10.5. Faecal contaminants

The presence of *E.coli* bacteria in the water indicates the presence of faecal material and, with it, the possibility that other disease-causing organisms may also be present. These organisms are able to enter water through a number of routes. In the Tuakitoto catchment, this is most likely to occur through direct runoff from pastoral farm land, directly through tile drains and through wildlife living in and around water bodies.

Water contaminated with faecal matter poses a range of possible health risks to recreational users, including serious gastrointestinal and respiratory illnesses. Counts of the bacterium *E. coli* are commonly used as an indicator of faecal contamination and a measure of the probability of the presence of other disease-causing agents, such as the protozoa *Giardia* and *Cryptosporidium*, the bacterium *Campylobacter* and various other bacteria and viruses.

One of the major contributors to bacterial contamination is probably effluent irrigation when soils are at or near saturation. As a rule of thumb, irrigation should not exceed the water-storage capacity of the soil. To prevent nutrient and bacteria loss to waterways in wet weather, adequate storage is needed to allow for deferred irrigation (Houlbrooke *et al*., 2004). The Lake Tuakitoto catchment, has five dairy farms, two had more than a months dairy effluent storage, the other farms had between 0-21 days' storage. On these farms, deferred irrigation is probably not possible all the time.

In the Lake Tuakitoto catchment, sub-surface artificial drains commonly underlie pasture. Only one drain was sampled, which came from a sheep and beef property with no effluent irrigation. Over the sampling period, the drain had *E. coli* concentrations of between 1 and 27000 cfu/100 ml. The $80^{th}$ percentile when flows were below median was just over 550 cfu/100ml.

Faecal contamination of streams can be very high during floods due to the disturbance and mobilisation of sediments and the introduction of agricultural runoff. Bacteria concentrations at base flow are more important when considering the health risk to downstream water users (such as swimmers) and stock drinking water. (MfE, 2009). When looking at flows below median, Lovells Creek (East Branch) and Frasers Stream (Elliotvale Rd).were the most compliant with the MfE 'alert' level of 260 *E. coli*/100 ml, they met this guideline on every occasion bar one. These two sites were also compliant with PC6A Schedule 15 limits.

Counts of *E. coli* in the Lake Tuakitoto catchment were therefore generally high, with the highest median count (3260 cfu/100 ml) found at Lovells Creek (NW Branch). An investigation into the consistently high *E.coli* counts at this site was undertaken in April 2013. The cause of the high counts could not be identified, other than widespread stock access through lack of fencing (Figure 25) to the Creek combined with very low flows (which have the effect of concentrating contaminant concentrations).

**Figure 25 Widespread stock access in the upper Lovells Creek catchment**

## 10.6. Substrate and riparian cover

As well as water quality, the quantity and quality of habitat are important factors that can affect many instream values, among which composition of the stream bed is particularly important because it provides the attachment substrate for periphyton and is an important factor determining the habitat quality for macroinvertebrates and fish. The substrate at Station Road (Lovells Creek and Frasers Stream) were dominated by gravels and cobbles, with no sign of significant fine sediment deposition. Similarly, there was no significant sediment compaction or embeddedness at the sites.

The sites in the lower catchment had stable banks and were shaded by the surrounding landscape and riparian vegetation. In contrast, further up the catchment in the smaller channels of the streams, sediment was evident. There are many sources for instream sediment. The most common source is erosion, exacerbated by stock access to water, which causes banks to be destabilised and slump into rivers.

Stock access, particularly to the upper catchment tributaries, has caused damage to riparian zones (where they exist). Addressing the need for appropriate riparian management, would help to improve water and habitat quality and the ecological values of the streams. Healthy riparian zones act as buffers by reducing erosion (as they slow down the speed of overland water flow before it reaches the river) and by filtering inputs of sediment, nutrients and bacteria in overland flow. Riparian zones also protect banks from erosion and lessen the impact of floods.

## 10.7. Macroinvertebrates and fish

Lovells Creek (Station Road) and Frasers Stream (Station Road) were not affected by sedimentation (which reduces habitat availability and can cause degraded macroinvertebrate and fishery values) and there was little loss of riparian vegetation. The ecological values in the streams may be affected by other factors, such as the shallowness of the river in the reach monitored and the velocity of the water during periods of high flow.

MCI values were ‘fair’ at Frasers Stream which, according to Stark et al. (2001), suggests probable moderate pollution. Lovells Creek was classified as ‘good’, suggesting doubtful water quality. Both streams were dominated by caddisflies, *Pycnocentrodes* and *Pycocentria*, which are the most common stony-cased caddis, and also the mollusc *Potamopyrgus antipodarum*, which is a widespread snail that can tolerate a wide range of water quality.

Small rivers and streams, particularly those close to the coast, are prime habitat for many native fish species, due to easy access and also as a direct response to many fish species being diadromous (i.e. migrating up from the sea). The strongest swimmers and climbers are able to migrate the furthest from the coast and for this reason, the best predictor of the number of fish species is distance from the coast. Fish passage into Lake Tuakitoto relies, in part, on the Kai locks being left open during normal river levels, with them only being closed in anticipation of the Clutha being in flood.

**Figure 26 Brown Trout, Common Bully and Lamprey**

Usually, fish tend to be most abundant where the habitat quality is best (water velocity, depth, substrate, cover), and fewer in number where the habitat is poor or absent. Frasers Stream and Lovells Creek support a fairly diverse fish community (Figure 26), with six species collected, including two species (longfin eel and lamprey) that have been classified as ‘at risk’ and ‘declining’ under the New Zealand Freshwater Fish Threat Classification. Native NZ fish species are benthic dwelling and use the stream bed for shelter, foraging and nesting, therefore the coarse substrate and intersistial space (the spaces between stones) are particularly important. In this study three species of native fish were found in Lovells Creek and one species in Frasers Stream. Longfin eels were found in both streams. Their main habitat requirement is suitable cover (substrate or vegetation) and adequate food.

## 10.8. Mussel beds and lake level

The study undertaken in 2013 indicates that there has been a decline in the mussel population, especially along the lake perimeter when compared to the 1991 study (Ogilvie 1995).

A number of factors can influence the density of mussels, in Lake Tuakitoto the water level variability since 1995, has resulted in areas that periodically dry out. This is likely to be important, as mussels will only be supported in the deeper regions, which as the lake level decreases become limited. Reduced water levels may also mean wave action becomes more detrimental to the mussel population (as the lake becomes shallower), with juveniles and even adults being adversely affected (James, 1985).

Unsworth (2007) noted that most mussels were over 20 years old, with no recruitment occurring. The life cycle of mussels involves the larval stage (glocidia) developing while attached to fish gills. *Galaxias* (whitebait) brush over the adult mussels and the glochidia (parasitic stage of the mussel larvae) hook onto the gill region. The decline in mussels may be due to a decline in the number of Galaxias.

Ogilvie (1995) estimated that mussels filtered the entire volume of the lake every 32 hours, by 2013 this had increased to 102 hours. With decreasing mussel populations and an associated decrease in filtration, there is a risk that phytoplankton biomass may increase, increasing the risk of algae blooms.

Maintaining the minimum lake level of 100.77 metres above datum, will help to maintain the mussel population as it will avoid dewatering of shallow beds.

# 11. Conclusions

- Lake Tuakitoto is classified as supertrophic, with high concentrations of nutrients and chlorophyll *a*. As it is so shallow, wind causes disturbance of bed sediment, reducing clarity and releasing sediment bound phosphorus.
- Historical water quality data shows a statistically decreasing trend in $NH_4$-N and an increasing trend in DRP.
- PC6A limits and thresholds are set out in Table 6 and were applied to the data collected fortnightly, (25 September 2012 to 10 September 2013.) when flows were below median The results showed that:
  - Lake Tuakitoto at the outlet exceeded the receiving water quality limit for turbidity, TN and TP.
  - the receiving water quality limit for NNN (0.444 mg/l) was breached at all sites in Stony Creek and at the upper sites in Lovells Creek.
  - all sites met the receiving water quality limit for DRP (0.026 mg/l) and $NH_4$-N (0.1 mg/l).
  - Nitrogen to phosphorus (N:P) ratios suggest that periphyton in streams of the Lake Tuakitoto catchment is phosphorus-limited.
  - *E. coli* counts were above the Schedule 15 limit at all sites other than Lovells Creek East branch (84 cfu/100ml) and Frasers Stream at Elliotvale Road (200 cfu./100ml).
- Algal community composition shows diatoms were dominant in Frasers Stream (*Encyonema*), in Lovells Creek little periphyton was found. *Phormidium* was found in Frasers Stream, but at such low levels it had not been observed by the sampler.
- The macroinvertebrate community at the Lovells Creek site indicated that water quality was generally ‘good’, while Frasers Stream indicated ‘fair’ water quality. The two streams had little sedimentation and good riparian cover, the small substrate size is likely to be easily disturbed, limiting habitat available.
- The Lake Tuakitoto catchment supports a diverse fish community, with six species collected (including Koura), including the longfin eel, and lamprey which have been classified as ‘at risk’ and ‘declining’ under the New Zealand Freshwater Fish Threat Classification.
- The mussel survey undertaken in 2013 indicates that there has been a decline in the mussel population, when compared to the 1991 study (Ogilvie 1995). The filtration of a volume of water equal to that of the lake equated to once every 32 hours (Ogilvie, 1995), in 2013 this had increased to once every 102 hours.
- In recent years (since 2006) the lake has spent longer below the minimum lake level of 100.77m (30 September to 16 May). As the lake is so shallow sustained low lake levels will adversely affect ecosystem values.

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# 13. Appendices

## Appendix 1. Lake Tuakitoto sampling sites (showing median flow during monitoring period)

| | | |
|---|---|---|
|  |  |  |
| Stony Creek at Hillend Road (0.012 $m^3$) | Stony Creek at SH1 (0.0425 $m^3$) | Stony Creek upstream of farm |
|  |  |  |
| Stony Creek downstream of farm | Stony Creek tile drain | Lovells Creek NW at Fallaburn Road (0.004 $m^3$) |
|  |  |  |
| Lovells Creek E at Fallaburn Road (0.009 $m^3$) | Lovells Creek W at Hillend Road | Lovells Creek at Bloxham Road |
|  |  |  |
| Lovells Creek at Station Road (0.166 $m^3$) | Frasers Stream at Elliotvale Road (0.03 $m^3$) | Frasers Stream at Station Road (0.054 $m^3$) |

# Appendix 2. Water quality results

| | Lake Tuakitoto at Outlet | | | | | |
|---|---|---|---|---|---|---|
| | TN | NNN | $NH_4$-N | TP | DRP | *E. coli* |
| | mg/l | mg/l | mg/l | mg/l | mg/l | cfu/100ml |
| 25-Sep-2012 | 0.930 | 0.016 | 0.005 | 0.118 | 0.017 | 190 |
| 01-Oct-2012 | 0.780 | 0.023 | 0.036 | 0.068 | 0.022 | 160 |
| 09-Oct-2012 | 1.210 | 0.117 | 0.005 | 0.087 | 0.022 | 1800 |
| 23-Oct-2012 | 1.010 | 0.112 | 0.005 | 0.081 | 0.008 | 90 |
| 06-Nov-2012 | 0.740 | 0.003 | 0.005 | 0.080 | 0.028 | 45 |
| 20-Nov-2012 | 0.860 | 0.004 | 0.005 | 0.103 | 0.049 | 43 |
| 04-Dec-2012 | 0.760 | 0.017 | 0.005 | 0.102 | 0.028 | 300 |
| 18-Dec-2012 | 0.720 | 0.031 | 0.005 | 0.290 | 0.036 | 480 |
| 04-Jan-2013 | 0.690 | 0.300 | 0.044 | 0.059 | 0.035 | 850 |
| 15-Jan-2013 | 0.840 | 0.001 | 0.019 | 0.072 | 0.022 | 32 |
| 29-Jan-2013 | 1.140 | 0.008 | 0.040 | 0.116 | 0.065 | 70 |
| 07-Feb-2013 | 1.010 | 0.022 | 0.033 | 0.104 | 0.058 | 87 |
| 12-Feb-2013 | 0.980 | 0.062 | 0.039 | 0.082 | 0.043 | 120 |
| 25-Feb-2013 | 1.160 | 0.020 | 0.100 | 0.096 | 0.047 | 200 |
| 12-Mar-2013 | 0.950 | 0.165 | 0.082 | 0.063 | 0.031 | 110 |
| 26-Mar-2013 | 1.190 | 0.117 | 0.074 | 0.061 | 0.034 | 110 |
| 03-Apr-2013 | 0.240 | 0.051 | 0.048 | 0.044 | 0.032 | 100 |
| 09-Apr-2013 | 0.770 | 0.087 | 0.040 | 0.040 | 0.028 | 25 |
| 23-Apr-2013 | 0.710 | 0.128 | 0.062 | 0.040 | 0.025 | 63 |
| 07-May-2013 | 1.100 | 0.480 | 0.052 | 0.076 | 0.043 | 2000 |
| 20-May-2013 | 1.230 | 0.400 | 0.088 | 0.085 | 0.053 | 21 |
| 06-Jun-2013 | 2.100 | 1.120 | 0.073 | 0.115 | 0.064 | 5 |
| 11-Jun-2013 | 1.940 | 0.900 | 0.085 | 0.106 | 0.062 | 80 |
| 2-Jul-2013 | 3.100 | 2.000 | 0.042 | 0.087 | 0.044 | 15 |
| 11-Jul-2013 | 1.620 | 0.770 | 0.005 | 0.012 | 0.008 | 30 |
| 16-Jul-2013 | 1.790 | 0.990 | 0.060 | 0.100 | 0.056 | 50 |
| 30-Jul-2013 | 1.340 | 0.590 | 0.046 | 0.300 | 0.060 | 22 |
| 1-Aug-2013 | 1.270 | 0.490 | 0.054 | 0.116 | 0.057 | 45 |
| 13-Aug-2013 | 1.440 | 0.340 | 0.083 | 0.158 | 0.097 | 55 |
| 27-Aug-2013 | 1.340 | 0.280 | 0.046 | 0.180 | 0.056 | 150 |
| 2-Sep-2013 | 1.040 | 0.159 | 0.014 | 0.128 | 0.056 | 60 |
| 10-Sep-2013 | 1.300 | 0.144 | 0.026 | 0.220 | 0.042 | 290 |
| 80%ile | 1.340 | 0.488 | 0.071 | 0.118 | 0.057 | |
| median | 1.070 | 0.123 | 0.041 | 0.092 | 0.043 | |

**Water quality results continued**

| | Frasers Stream at Elliotvale Road | | | | | | |
|---|---|---|---|---|---|---|---|
| | TN | NNN | $NH_4$-N | TP | DRP | *E. coli* | Flow |
| | mg/l | mg/l | mg/l | mg/l | mg/l | cfu/100ml | l/s |
| 25-Sep-2012 | 0.310 | 0.101 | 0.005 | 0.008 | 0.004 | 25.00 | 0.03 |
| 09-Oct-2012 | 0.330 | 0.095 | 0.018 | 0.019 | 0.010 | 150.00 | 0.04 |
| 23-Oct-2012 | 0.770 | 0.142 | 0.005 | 0.108 | 0.013 | 32000.00 | 0.05 |
| 06-Nov-2012 | 0.340 | 0.069 | 0.005 | 0.016 | 0.008 | 190.00 | 0.03 |
| 20-Nov-2012 | 0.360 | 0.048 | 0.005 | 0.022 | 0.009 | 180.00 | 0.03 |
| 04-Dec-2012 | 0.440 | 0.041 | 0.005 | 0.024 | 0.011 | 54.00 | 0.03 |
| 18-Dec-2012 | 0.320 | 0.066 | 0.005 | 0.038 | 0.013 | 1500.00 | 0.02 |
| 04-Jan-2013 | 0.670 | 0.290 | 0.005 | 0.043 | 0.016 | 920.00 | 0.14 |
| 15-Jan-2013 | 0.330 | 0.020 | 0.005 | 0.029 | 0.010 | 190.00 | 0.02 |
| 29-Jan-2013 | 0.320 | 0.007 | 0.005 | 0.030 | 0.013 | 90.00 | 0.02 |
| 12-Feb-2013 | 0.250 | 0.014 | 0.005 | 0.028 | 0.011 | 160.00 | 0.02 |
| 25-Feb-2013 | 0.190 | 0.015 | 0.005 | 0.056 | 0.014 | 34.00 | 0.01 |
| 12-Mar-2013 | 0.190 | 0.010 | 0.011 | 0.022 | 0.016 | 110.00 | 0.01 |
| 26-Mar-2013 | 0.210 | 0.006 | 0.005 | 0.025 | 0.011 | 34.00 | 0.01 |
| 09-Apr-2013 | 0.120 | 0.007 | 0.005 | 0.012 | 0.009 | 90.00 | 0.01 |
| 23-Apr-2013 | 0.260 | 0.043 | 0.005 | 0.033 | 0.009 | 2100.00 | 0.02 |
| 07-May-2013 | 1.490 | 0.930 | 0.014 | 0.042 | 0.014 | 3500.00 | 0.31 |
| 20-May-2013 | 0.260 | 0.068 | 0.005 | 0.016 | 0.008 | 180.00 | 0.03 |
| 06-Jun-2013 | 0.690 | 0.220 | 0.010 | 0.023 | 0.006 | 70.00 | 0.09 |
| 2-Jul-2013 | 0.570 | 0.260 | 0.019 | 0.008 | 0.007 | 90 | 0.06 |
| 16-Jul-2013 | 0.830 | 0.380 | 0.011 | 0.022 | 0.006 | 200 | 0.15 |
| 30-Jul-2013 | 0.340 | 0.148 | 0.012 | 0.014 | 0.002 | 160 | 0.03 |
| 13-Aug-2013 | 0.350 | 0.130 | 0.012 | 0.009 | 0.007 | 90 | 0.03 |
| 27-Aug-2013 | 0.350 | 0.112 | 0.005 | 0.014 | 0.002 | 240 | 0.03 |
| 10-Sep-2013 | 0.500 | 0.083 | 0.013 | 0.028 | 0.005 | 28 | 0.04 |
| 80%ile | 0.590 | 0.162 | 0.012 | 0.034 | 0.013 | 376.00 | |
| median | 0.340 | 0.069 | 0.005 | 0.023 | 0.009 | 160.00 | |

**Water quality results continued**

| | Frasers Stream at Station Road | | | | | |
|---|---|---|---|---|---|---|
| | **TN** | **NNN** | **$NH_4$-N** | **TP** | **DRP** | ***E. coli*** |
| | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **cfu/100ml** |
| 25-Sep-2012 | 1.750 | 1.200 | 0.005 | 0.042 | 0.005 | 23 |
| 09-Oct-2012 | 1.670 | 1.300 | 0.005 | 0.033 | 0.008 | 170 |
| 23-Oct-2012 | 1.850 | 1.420 | 0.005 | 0.063 | 0.005 | 1600 |
| 06-Nov-2012 | 1.450 | 1.080 | 0.005 | 0.022 | 0.007 | 110 |
| 20-Nov-2012 | 1.280 | 0.760 | 0.005 | 0.043 | 0.010 | 390 |
| 04-Dec-2012 | 0.720 | 0.380 | 0.005 | 0.040 | 0.006 | 220 |
| 18-Dec-2012 | 0.840 | 0.330 | 0.005 | 0.069 | 0.008 | 3000 |
| 04-Jan-2013 | 2.300 | 1.730 | 0.005 | 0.060 | 0.019 | 1000 |
| 15-Jan-2013 | 0.850 | 0.400 | 0.005 | 0.046 | 0.010 | 1400 |
| 29-Jan-2013 | 0.710 | 0.280 | 0.005 | 0.040 | 0.015 | 360 |
| 12-Feb-2013 | 0.360 | 0.101 | 0.005 | 0.026 | 0.009 | 140 |
| 25-Feb-2013 | 0.290 | 0.026 | 0.005 | 0.017 | 0.005 | 110 |
| 12-Mar-2013 | 0.300 | 0.031 | 0.005 | 0.019 | 0.009 | 110 |
| 26-Mar-2013 | 0.360 | 0.065 | 0.005 | 0.023 | 0.008 | 360 |
| 09-Apr-2013 | 0.390 | 0.127 | 0.005 | 0.013 | 0.007 | 200 |
| 23-Apr-2013 | 0.360 | 0.001 | 0.005 | 0.041 | 0.013 | 3400 |
| 07-May-2013 | 3.900 | 3.300 | 0.027 | 0.060 | 0.014 | 900 |
| 20-May-2013 | 1.620 | 1.150 | 0.005 | 0.036 | 0.014 | 180 |
| 06-Jun-2013 | 3.300 | 2.800 | 0.005 | 0.034 | 0.008 | 140 |
| 2-Jul-2013 | 3.500 | 3.100 | 0.005 | 0.020 | 0.009 | 60 |
| 16-Jul-2013 | 3.000 | 2.700 | 0.013 | 0.024 | 0.008 | 100 |
| 30-Jul-2013 | 2.000 | 1.750 | 0.005 | 0.028 | 0.009 | 140 |
| 13-Aug-2013 | 1.570 | 1.230 | 0.005 | 0.040 | 0.014 | 33 |
| 27-Aug-2013 | 1.250 | 0.940 | 0.005 | 0.030 | 0.008 | 100 |
| 10-Sep-2013 | 2.400 | 1.400 | 0.005 | 0.051 | 0.005 | 250 |
| 80%ile | 2.320 | 1.734 | 0.005 | 0.047 | 0.013 | |
| median | 1.450 | 1.080 | 0.005 | 0.036 | 0.008 | |

**Water quality results continued**

| | Lovells Creek at Station Road | | | | | | |
|---|---|---|---|---|---|---|---|
| | TN | NNN | $NH_4$-N | TP | DRP | *E. coli* | Flow |
| | mg/l | mg/l | mg/l | mg/l | mg/l | cfu/100ml | l/s |
| 25-Sep-2012 | 1.550 | 1.160 | 0.015 | 0.029 | 0.005 | 120 | 0.202 |
| 09-Oct-2012 | 0.630 | 0.195 | 0.005 | 0.032 | 0.012 | 350 | 0.39 |
| 23-Oct-2012 | 2.100 | 0.940 | 0.066 | 0.210 | 0.022 | 30000 | 0.671 |
| 06-Nov-2012 | 1.350 | 1.010 | 0.005 | 0.030 | 0.006 | 400 | 0.23 |
| 20-Nov-2012 | 1.210 | 0.700 | 0.022 | 0.043 | 0.011 | 490 | 0.195 |
| 04-Dec-2012 | 0.800 | 0.390 | 0.019 | 0.048 | 0.011 | 1600 | 0.109 |
| 18-Dec-2012 | 0.780 | 0.320 | 0.005 | 0.063 | 0.013 | 7500 | 0.158 |
| 04-Jan-2013 | 2.200 | 1.630 | 0.013 | 0.065 | 0.022 | 930 | 0.449 |
| 15-Jan-2013 | 0.790 | 0.360 | 0.010 | 0.043 | 0.015 | 550 | 0.104 |
| 29-Jan-2013 | 0.690 | 0.220 | 0.005 | 0.044 | 0.010 | 50 | 0.049 |
| 12-Feb-2013 | 0.430 | 0.074 | 0.005 | 0.028 | 0.008 | 390 | 0.044 |
| 25-Feb-2013 | 0.350 | 0.076 | 0.005 | 0.091 | 0.009 | 190 | 0.021 |
| 12-Mar-2013 | 0.310 | 0.084 | 0.005 | 0.028 | 0.018 | 550 | 0.017 |
| 26-Mar-2013 | 0.410 | 0.090 | 0.005 | 0.033 | 0.014 | 1300 | 0.013 |
| 09-Apr-2013 | 0.320 | 0.089 | 0.005 | 0.021 | 0.014 | 160 | 0.015 |
| 23-Apr-2013 | 0.650 | 0.270 | 0.005 | 0.043 | 0.016 | 1300 | 0.062 |
| 07-May-2013 | 4.100 | 3.500 | 0.030 | 0.056 | 0.018 | 1000 | 0.939 |
| 20-May-2013 | 1.420 | 1.050 | 0.011 | 0.033 | 0.014 | 450 | 0.137 |
| 06-Jun-2013 | 3.000 | 2.600 | 0.013 | 0.027 | 0.010 | 110 | 0.974 |
| 2-Jul-2013 | 3.300 | 2.900 | 0.012 | 0.036 | 0.009 | 120 | 0.607 |
| 16-Jul-2013 | 2.900 | 2.500 | 0.021 | 0.029 | 0.009 | 230 | 1.085 |
| 30-Jul-2013 | 1.900 | 1.640 | 0.018 | 0.028 | 0.010 | 100 | 0.211 |
| 13-Aug-2013 | 1.600 | 1.210 | 0.019 | 0.027 | 0.014 | 400 | 0.169 |
| 27-Aug-2013 | 1.360 | 0.900 | 0.005 | 0.027 | 0.011 | 500 | 0.117 |
| 10-Sep-2013 | 1.870 | 1.280 | 0.021 | 0.034 | 0.013 | 250 | 0.454 |
| 80%ile | 2.120 | 1.632 | 0.019 | 0.050 | 0.015 | 1060 | |
| median | 1.350 | 0.900 | 0.011 | 0.033 | 0.012 | 400 | |

**Water quality results continued**

| | Lovells Creek East Branch at Fallaburn Road | | | | | | |
|---|---|---|---|---|---|---|---|
| | TN | NNN | $NH_4$-N | TP | DRP | *E. coli* | Flow |
| | mg/l | mg/l | mg/l | mg/l | mg/l | cfu/100ml | l/s |
| 25-Sep-2012 | 1.920 | 1.590 | 0.005 | 0.028 | 0.002 | 55.00 | 0.014 |
| 09-Oct-2012 | 1.930 | 1.730 | 0.005 | 0.015 | 0.007 | 130.00 | 0.036 |
| 23-Oct-2012 | 2.600 | 2.300 | 0.005 | 0.031 | 0.002 | 190.00 | 0.044 |
| 06-Nov-2012 | 1.680 | 1.420 | 0.005 | 0.016 | 0.002 | 110.00 | 0.013 |
| 20-Nov-2012 | 1.250 | 0.890 | 0.005 | 0.025 | 0.006 | 140.00 | 0.010 |
| 04-Dec-2012 | 0.960 | 0.640 | 0.005 | 0.034 | 0.031 | 120.00 | 0.007 |
| 18-Dec-2012 | 0.750 | 0.430 | 0.005 | 0.042 | 0.008 | 520.00 | 0.010 |
| 04-Jan-2013 | 2.600 | 2.100 | 0.013 | 0.046 | 0.014 | 980.00 | 0.021 |
| 15-Jan-2013 | 0.900 | 0.510 | 0.005 | 0.042 | 0.009 | 75.00 | 0.000 |
| 29-Jan-2013 | 0.870 | 0.510 | 0.005 | 0.042 | 0.010 | 27.00 | 0.000 |
| 12-Feb-2013 | 0.780 | 0.530 | 0.005 | 0.033 | 0.010 | 39.00 | 0.003 |
| 25-Feb-2013 | 0.740 | 0.490 | 0.005 | 0.039 | 0.016 | 28.00 | 0.002 |
| 12-Mar-2013 | 0.770 | 0.520 | 0.005 | 0.112 | 0.017 | 36.00 | 0.002 |
| 26-Mar-2013 | 0.900 | 0.590 | 0.005 | 0.034 | 0.014 | 19.00 | 0.002 |
| 09-Apr-2013 | 0.840 | 0.620 | 0.005 | 0.024 | 0.011 | 18.00 | 0.002 |
| 23-Apr-2013 | 1.770 | 0.940 | 0.005 | 0.350 | 0.054 | 1400.00 | 0.007 |
| 07-May-2013 | 6.100 | 5.500 | 0.033 | 0.044 | 0.011 | 900.00 | 0.084 |
| 20-May-2013 | 2.200 | 1.750 | 0.011 | 0.026 | 0.008 | 30.00 | 0.012 |
| 06-Jun-2013 | 4.500 | 4.200 | 0.015 | 0.031 | 0.005 | 40.00 | 0.058 |
| 2-Jul-2013 | 4.400 | 4.100 | 0.010 | 0.018 | 0.006 | 80 | 0.032 |
| 16-Jul-2013 | 4.400 | 4.200 | 0.014 | 0.015 | 0.005 | 42 | 0.054 |
| 30-Jul-2013 | 2.400 | 2.100 | 0.022 | 0.026 | 0.006 | 43 | 0.007 |
| 13-Aug-2013 | 1.880 | 1.580 | 0.018 | 0.030 | 0.011 | 80 | 0.009 |
| 27-Aug-2013 | 1.550 | 1.250 | 0.005 | 0.029 | 0.007 | 70 | 0.004 |
| 10-Sep-2013 | 2.200 | 1.930 | 0.005 | 0.018 | 0.005 | 90 | 0.011 |
| 80%ile | 2.600 | 2.140 | 0.013 | 0.042 | 0.014 | 150.00 | |
| median | 1.770 | 1.420 | 0.005 | 0.031 | 0.008 | 75.00 | |

**Water quality results continued**

| | Lovells Creek NW branch 1 at Fallaburn Road | | | | | |
|---|---|---|---|---|---|---|
| | TN | NNN | $NH_4$-N | TP | DRP | *E. coli* |
| | mg/l | mg/l | mg/l | mg/l | mg/l | cfu/100ml |
| 25-Sep-2012 | 1.310 | 0.940 | 0.005 | 0.066 | 0.004 | 30.00 |
| 09-Oct-2012 | 1.180 | 0.840 | 0.005 | 0.034 | 0.008 | 1500.00 |
| 23-Oct-2012 | 1.650 | 1.230 | 0.005 | 0.060 | 0.004 | 1300.00 |
| 06-Nov-2012 | 1.410 | 1.120 | 0.005 | 0.028 | 0.005 | 460.00 |
| 20-Nov-2012 | 1.060 | 0.660 | 0.005 | 0.048 | 0.007 | 500.00 |
| 04-Dec-2012 | 0.850 | 0.540 | 0.005 | 0.058 | 0.009 | 1000.00 |
| 18-Dec-2012 | 1.030 | 0.450 | 0.005 | 0.107 | 0.016 | 6400.00 |
| 04-Jan-2013 | 1.100 | 0.700 | 0.010 | 0.067 | 0.014 | 600.00 |
| 15-Jan-2013 | 0.890 | 0.440 | 0.005 | 0.072 | 0.016 | 1400.00 |
| 29-Jan-2013 | 0.920 | 0.450 | 0.005 | 0.086 | 0.016 | 1500.00 |
| 12-Feb-2013 | 0.740 | 0.400 | 0.005 | 0.055 | 0.012 | 900.00 |
| 25-Feb-2013 | 0.610 | 0.300 | 0.005 | 0.179 | 0.012 | 850.00 |
| 12-Mar-2013 | 0.730 | 0.290 | 0.005 | 0.081 | 0.018 | 3900.00 |
| 26-Mar-2013 | 0.720 | 0.310 | 0.005 | 0.084 | 0.014 | 3100.00 |
| 09-Apr-2013 | 0.610 | 0.320 | 0.005 | 0.050 | 0.011 | 1600.00 |
| 23-Apr-2013 | 2.100 | 0.430 | 0.005 | 0.420 | 0.011 | 6600.00 |
| 07-May-2013 | 1.650 | 1.220 | 0.017 | 0.032 | 0.014 | 1600.00 |
| 20-May-2013 | 1.210 | 0.710 | 0.005 | 0.063 | 0.011 | 450.00 |
| 06-Jun-2013 | 2.800 | 2.100 | 0.012 | 0.065 | 0.009 | 350.00 |
| 2-Jul-2013 | 3.100 | 2.700 | 0.005 | 0.031 | 0.008 | 60 |
| 16-Jul-2013 | 2.700 | 2.400 | 0.011 | 0.041 | 0.006 | 120 |
| 30-Jul-2013 | 2.000 | 1.720 | 0.005 | 0.042 | 0.007 | 50 |
| 13-Aug-2013 | 1.770 | 1.440 | 0.011 | 0.043 | 0.012 | 40 |
| 27-Aug-2013 | 1.420 | 1.050 | 0.005 | 0.047 | 0.007 | 16 |
| 10-Sep-2013 | 1.510 | 1.060 | 0.005 | 0.075 | 0.006 | 590 |
| 80%ile | 1.816 | 1.272 | 0.006 | 0.082 | 0.014 | |
| median | 1.210 | 0.710 | 0.005 | 0.060 | 0.011 | |

## Water quality results continued

| | Lovells Creek West Branch at Hillend Road | | | | | |
|---|---|---|---|---|---|---|
| | TN | NNN | $NH_4$-N | TP | DRP | *E. coli* |
| | mg/l | mg/l | mg/l | mg/l | mg/l | cfu/100ml |
| 25-Sep-2012 | 4.000 | 3.200 | 0.016 | 0.200 | 0.002 | 1.00 |
| 09-Oct-2012 | 3.400 | 2.800 | 0.024 | 0.055 | 0.006 | 20.00 |
| 23-Oct-2012 | 4.500 | 3.000 | 0.050 | 0.100 | 0.008 | 620.00 |
| 06-Nov-2012 | 3.500 | 3.000 | 0.017 | 0.052 | 0.016 | 40.00 |
| 20-Nov-2012 | 2.800 | 2.200 | 0.022 | 0.070 | 0.002 | 80.00 |
| 04-Dec-2012 | 3.800 | 2.100 | 0.020 | 0.134 | 0.005 | 260.00 |
| 18-Dec-2012 | 2.900 | 1.500 | 0.017 | 0.230 | 0.006 | 4000.00 |
| 04-Jan-2013 | 3.200 | 2.500 | 0.025 | 0.098 | 0.009 | 390.00 |
| 15-Jan-2013 | 3.100 | 1.860 | 0.017 | 0.164 | 0.006 | 450.00 |
| 12-Feb-2013 | 2.400 | 1.500 | 0.025 | 0.410 | 0.004 | 1000.00 |
| 07-May-2013 | 5.500 | 5.100 | 0.068 | 0.020 | 0.010 | 110.00 |
| 20-May-2013 | 2.300 | 1.630 | 0.029 | 0.026 | 0.006 | 5.00 |
| 06-Jun-2013 | 5.400 | 5.000 | 0.025 | 0.023 | 0.004 | 18.00 |
| 2-Jul-2013 | 5.300 | 4.700 | 0.015 | 0.039 | 0.002 | 9 |
| 16-Jul-2013 | 4.800 | 4.500 | 0.019 | 0.019 | 0.002 | 39 |
| 30-Jul-2013 | 3.500 | 3.100 | 0.033 | 0.040 | 0.002 | 0.5 |
| 13-Aug-2013 | 2.900 | 2.300 | 0.064 | 0.022 | 0.008 | 10 |
| 27-Aug-2013 | 3.100 | 1.720 | 0.038 | 0.145 | 0.002 | 1 |
| 80%ile | 4.680 | 3.980 | 0.036 | 0.156 | 0.008 | |
| median | 3.450 | 2.650 | 0.025 | 0.063 | 0.006 | |

**Water quality results continued**

| | Stony Creek at Hillend Road | | | | | |
|---|---|---|---|---|---|---|
| | **TN** | **NNN** | **$NH_4$-N** | **TP** | **DRP** | ***E. coli*** |
| | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **cfu/100ml** |
| 09-Oct-2012 | 2.600 | 2.200 | 0.031 | 0.034 | 0.010 | 650.00 |
| 23-Oct-2012 | 3.000 | 2.200 | 0.024 | 0.106 | 0.011 | 1000.00 |
| 06-Nov-2012 | 2.900 | 1.660 | 0.055 | 0.210 | 0.013 | 1700.00 |
| 20-Nov-2012 | 2.200 | 1.770 | 0.011 | 0.048 | 0.007 | 1100.00 |
| 04-Dec-2012 | 1.690 | 1.010 | 0.039 | 0.070 | 0.010 | 2400.00 |
| 18-Dec-2012 | 1.920 | 1.070 | 0.055 | 0.135 | 0.017 | 6800.00 |
| 04-Jan-2013 | 3.700 | 2.700 | 0.076 | 0.139 | 0.019 | 600.00 |
| 15-Jan-2013 | 1.420 | 0.850 | 0.005 | 0.080 | 0.016 | 170.00 |
| 29-Jan-2013 | 0.860 | 0.360 | 0.005 | 0.094 | 0.012 | 32.00 |
| 12-Feb-2013 | 0.750 | 0.290 | 0.005 | 0.118 | 0.015 | 60.00 |
| 25-Feb-2013 | 0.900 | 0.270 | 0.038 | 0.166 | 0.025 | 80.00 |
| 23-Apr-2013 | 4.500 | 1.090 | 0.370 | 0.580 | 0.137 | 900.00 |
| 07-May-2013 | 5.000 | 4.200 | 0.058 | 0.042 | 0.021 | 950.00 |
| 20-May-2013 | 1.920 | 1.200 | 0.067 | 0.066 | 0.022 | 130.00 |
| 06-May-2013 | 4.000 | 3.500 | 0.031 | 0.030 | 0.011 | 150 |
| 02-Jul-2013 | 4.800 | 4.200 | 0.040 | 0.037 | 0.011 | 100 |
| 16-Jul-2013 | 4.000 | 3.600 | 0.028 | 0.040 | 0.011 | 70 |
| 30-Jul-2013 | 2.800 | 2.300 | 0.050 | 0.066 | 0.012 | 40 |
| 13-Aug-2013 | 2.600 | 1.900 | 0.053 | 0.054 | 0.018 | 300 |
| 27-Aug-2013 | 2.100 | 1.570 | 0.027 | 0.066 | 0.014 | 28 |
| 10-Sep-2013 | 2.800 | 2.300 | 0.020 | 0.051 | 0.006 | 280 |
| 80%ile | 4.000 | 3.340 | 0.055 | 0.132 | 0.019 | |
| median | 2.700 | 1.835 | 0.035 | 0.066 | 0.013 | |

**Water quality results continued**

| | Stony Creek at SH1 | | | | | | |
|---|---|---|---|---|---|---|---|
| | **TN** | **NNN** | **$NH_4$-N** | **TP** | **DRP** | ***E. coli*** | **Flow** |
| | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **cfu/100ml** | **l/s** |
| 25-Sep-2012 | 1.590 | 1.210 | 0.005 | 0.020 | 0.007 | 80.00 | 0.055 |
| 09-Oct-2012 | 1.870 | 1.520 | 0.005 | 0.023 | 0.011 | 200.00 | 0.118 |
| 23-Oct-2012 | 2.200 | 1.370 | 0.056 | 0.142 | 0.019 | 25000.00 | 0.126 |
| 06-Nov-2012 | 1.480 | 1.130 | 0.005 | 0.024 | 0.011 | 140.00 | 0.068 |
| 20-Nov-2012 | 1.560 | 1.050 | 0.005 | 0.038 | 0.011 | 300.00 | 0.084 |
| 04-Dec-2012 | 0.740 | 0.260 | 0.005 | 0.044 | 0.011 | 130.00 | 0.048 |
| 18-Dec-2012 | 0.920 | 0.310 | 0.005 | 0.074 | 0.018 | 4500.00 | 0.05 |
| 04-Jan-2013 | 3.600 | 2.800 | 0.005 | 0.061 | 0.018 | 1300.00 | 0.189 |
| 15-Jan-2013 | 0.690 | 0.210 | 0.005 | 0.048 | 0.017 | 2200.00 | 0.025 |
| 29-Jan-2013 | 0.480 | 0.021 | 0.005 | 0.084 | 0.027 | 70.00 | 0.003 |
| 12-Feb-2013 | 0.530 | 0.031 | 0.005 | 0.082 | 0.025 | 900.00 | 0.004 |
| 25-Feb-2013 | 0.410 | 0.033 | 0.005 | 0.014 | 0.007 | 19.00 | 0.01 |
| 12-Mar-2013 | 0.190 | 0.051 | 0.011 | 0.019 | 0.002 | 90.00 | 0.01 |
| 26-Mar-2013 | 0.400 | 0.031 | 0.005 | 0.021 | 0.002 | 32.00 | 0.01 |
| 23-Apr-2013 | 1.610 | 0.810 | 0.005 | 0.240 | 0.002 | 3400.00 | 0.001 |
| 07-May-2013 | 5.400 | 4.600 | 0.023 | 0.038 | 0.012 | 1900.00 | 0.552 |
| 20-May-2013 | 1.100 | 0.770 | 0.011 | 0.028 | 0.012 | 180.00 | 0.033 |
| 06-Jun-2013 | 3.700 | 3.000 | 0.020 | 0.027 | 0.008 | 190.00 | 0.321 |
| 02-Jul-2013 | 3.700 | 3.300 | 0.014 | 0.037 | 0.008 | 58 | 0.087 |
| 16-Jul-2013 | 3.300 | 2.900 | 0.022 | 0.024 | 0.008 | 120 | 0.279 |
| 30-Jul-2013 | 1.970 | 1.640 | 0.017 | 0.022 | 0.010 | 70 | 0.037 |
| 13-Aug-2013 | 1.410 | 1.050 | 0.011 | 0.026 | 0.014 | 230 | 0.034 |
| 27-Aug-2013 | 1.200 | 0.820 | 0.005 | 0.023 | 0.009 | 80 | 0.031 |
| 10-Sep-2013 | 2.800 | 1.810 | 0.012 | 0.026 | 0.010 | 120 | 0.121 |
| 80%ile | 3.000 | 2.206 | 0.015 | 0.066 | 0.017 | 1540.00 | |
| median | 1.520 | 1.050 | 0.005 | 0.028 | 0.011 | 160.00 | |

**Water quality results continued**

| | Stony Creek at Hillend Road d/s Farm | | | | | |
|---|---|---|---|---|---|---|
| | TN | NNN | $NH_4$-N | TP | DRP | *E. coli* |
| | mg/l | mg/l | mg/l | mg/l | mg/l | cfu/100ml |
| 20-Nov-2012 | 2.200 | 1.620 | 0.005 | 0.074 | 0.005 | 1200.00 |
| 04-Dec-2012 | 1.310 | 1.030 | 0.005 | 0.032 | 0.007 | 430.00 |
| 18-Dec-2012 | 1.350 | 0.620 | 0.005 | 0.104 | 0.020 | 7000.00 |
| 04-Jan-2013 | 2.600 | 2.100 | 0.005 | 0.050 | 0.012 | 850.00 |
| 15-Jan-2013 | 1.200 | 0.750 | 0.005 | 0.044 | 0.013 | 150.00 |
| 29-Jan-2013 | 0.610 | 0.280 | 0.005 | 0.034 | 0.012 | 400.00 |
| 12-Feb-2013 | 0.460 | 0.160 | 0.005 | 0.034 | 0.009 | 130.00 |
| 25-Feb-2013 | 1.150 | 0.081 | 0.005 | 0.025 | 0.014 | 21.00 |
| 12-Mar-2013 | 0.540 | 0.065 | 0.005 | 0.113 | 0.020 | 160.00 |
| 26-Mar-2013 | 0.360 | 0.105 | 0.005 | 0.034 | 0.018 | 220.00 |
| 09-Apr-2013 | 0.540 | 0.270 | 0.005 | 0.031 | 0.022 | 60.00 |
| 23-Apr-2013 | 1.680 | 1.040 | 0.005 | 0.075 | 0.049 | 3300.00 |
| 20-May-2013 | 1.560 | 1.130 | 0.013 | 0.079 | 0.018 | 58.00 |
| 06-Jun-2013 | 3.600 | 3.200 | 0.023 | 0.018 | 0.009 | 40.00 |
| 2-Jul-2013 | 4.500 | 4.000 | 0.030 | 0.026 | 0.009 | 70 |
| 16-Jul-2013 | 3.800 | 3.400 | 0.027 | 0.033 | 0.008 | 70 |
| 30-Jul-2013 | 2.800 | 2.300 | 0.025 | 0.042 | 0.008 | 40 |
| 13-Aug-2013 | 2.100 | 1.800 | 0.024 | 0.046 | 0.013 | 40 |
| 27-Aug-2013 | 1.940 | 1.550 | 0.005 | 0.050 | 0.009 | 27 |
| 10-Sep-2013 | 2.700 | 2.100 | 0.005 | 0.092 | 0.006 | 2000 |
| 80%ile | 2.720 | 2.140 | 0.023 | 0.076 | 0.018 | |
| median | 1.620 | 1.085 | 0.005 | 0.043 | 0.012 | |

| | Stony Creek at Hillend Road u/s Farm | | | | | |
|---|---|---|---|---|---|---|
| | TN | NNN | $NH_4$-N | TP | DRP | *E. coli* |
| | mg/l | mg/l | mg/l | mg/l | mg/l | cfu/100ml |
| 20-Nov-2012 | 2.500 | 1.740 | 0.005 | 0.113 | 0.010 | 2300.00 |
| 04-Dec-2012 | 4.100 | 1.270 | 0.028 | 0.620 | 0.012 | 2600.00 |
| 18-Dec-2012 | 1.970 | 1.230 | 0.040 | 0.210 | 0.015 | 3100.00 |
| 04-Jan-2013 | 2.100 | 1.380 | 0.061 | 0.104 | 0.022 | 600.00 |
| 15-Jan-2013 | 2.900 | 1.130 | 0.026 | 0.360 | 0.005 | 800.00 |
| 07-May-2013 | 3.800 | 3.300 | 0.025 | 0.048 | 0.031 | 1000.00 |
| 20-May-2013 | 1.490 | 0.820 | 0.041 | 0.072 | 0.021 | 90.00 |
| 06-Jun-2013 | 2.900 | 2.500 | 0.027 | 0.034 | 0.020 | 120.00 |
| 16-Jul-2013 | 2.800 | 2.400 | 0.023 | 0.033 | 0.011 | 200 |
| 30-Jul-2013 | 1.930 | 1.480 | 0.019 | 0.028 | 0.011 | 18 |
| 13-Aug-2013 | 1.650 | 1.180 | 0.021 | 0.038 | 0.016 | 5 |
| 27-Aug-2013 | 1.380 | 0.950 | 0.019 | 0.054 | 0.014 | 60 |
| 10-Sep-2013 | 2.100 | 1.670 | 0.023 | 0.048 | 0.012 | 220 |
| 80%ile | 2.900 | 2.136 | 0.035 | 0.171 | 0.021 | |
| median | 2.100 | 1.380 | 0.025 | 0.054 | 0.014 | |

**Water quality results continued**

| | Stony Creek at Farm Tile Drain | | | | | |
|---|---|---|---|---|---|---|
| | **TN** | **NNN** | **$NH_4$-N** | **TP** | **DRP** | ***E. coli*** |
| | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **mg/l** | **cfu/100ml** |
| 20-Nov-2012 | 5.200 | 4.800 | 0.036 | 0.008 | 0.002 | 210.00 |
| 04-Dec-2012 | 4.300 | 4.200 | 0.026 | 0.006 | 0.002 | 420.00 |
| 18-Dec-2012 | 3.500 | 3.300 | 0.014 | 0.027 | 0.002 | 1200.00 |
| 04-Jan-2013 | 3.800 | 3.500 | 0.038 | 0.010 | 0.002 | 510.00 |
| 15-Jan-2013 | 5.800 | 5.600 | 0.010 | 0.005 | 0.002 | 420.00 |
| 29-Jan-2013 | 3.600 | 3.500 | 0.005 | 0.008 | 0.002 | 180.00 |
| 12-Feb-2013 | 3.700 | 3.500 | 0.005 | 0.016 | 0.002 | 500.00 |
| 25-Feb-2013 | 3.400 | 3.300 | 0.005 | 0.012 | 0.002 | 60.00 |
| 12-Mar-2013 | 3.300 | 3.200 | 0.005 | 0.008 | 0.007 | 12.00 |
| 26-Mar-2013 | 3.400 | 3.000 | 0.005 | 0.011 | 0.005 | 800.00 |
| 09-Apr-2013 | 2.800 | 2.700 | 0.005 | 0.002 | 0.002 | 44.00 |
| 23-Apr-2013 | 6.300 | 4.100 | 0.005 | 0.310 | 0.002 | 27000.00 |
| 07-May-2013 | 7.300 | 6.600 | 0.068 | 0.028 | 0.010 | 1700.00 |
| 20-May-2013 | 5.000 | 4.800 | 0.012 | 0.015 | 0.008 | 320.00 |
| 06-Jun-2013 | 7.100 | 6.800 | 0.030 | 0.018 | 0.008 | 190.00 |
| 02-Jul-2013 | 7.200 | 6.900 | 0.010 | 0.013 | 0.008 | 80 |
| 16-Jul-2013 | 5.900 | 5.500 | 0.028 | 0.010 | 0.005 | 60 |
| 30-Jul-2013 | 5.700 | 5.500 | 0.005 | 0.004 | 0.002 | 3 |
| 13-Aug-2013 | 5.000 | 4.800 | 0.012 | 0.009 | 0.008 | 0.5 |
| 27-Aug-2013 | 4.700 | 4.500 | 0.005 | 0.007 | 0.002 | 3 |
| 10-Sep-2013 | 5.100 | 4.900 | 0.013 | 0.009 | 0.002 | 6 |
| 80%ile | 5.900 | 5.500 | 0.028 | 0.016 | 0.008 | |
| median | 5.000 | 4.500 | 0.010 | 0.010 | 0.002 | |

# Appendix 3 Macroinvertebrate results

Macroinvertebrate data (Ryder Consulting, October 2013).

| TAXON | MCI score | Frasers Stream | Lovells Stream |
|---|---|---|---|
| COLEOPTERA | | | |
| Elmidae | 6 | | R |
| Hydraenidae | 8 | | R |
| CRUSTACEA | | | |
| Isopoda | 5 | C | |
| Ostracoda | 3 | R | R |
| *Paracalliope fluviatilis* | 5 | VA | VA |
| *Paraleptamphopus* species | 5 | VA | |
| DIPTERA | | | |
| *Austrosimulium* species | 3 | A | R |
| *Mischoderus* species | 4 | | R |
| *Polypedilum* species | 3 | R | |
| EPHEMEROPTERA | | | |
| *Deleatidium* species | 8 | A | A |
| HIRUDINEA | 3 | R | R |
| MEGALOPTERA | | | |
| *Archichauliodes diversus* | 7 | | R |
| MOLLUSCA | | | |
| *Physa / Physella* species | 3 | | C |
| *Potamopyrgus antipodarum* | 4 | VVA | VA |
| Sphaeriidae | 3 | A | C |
| ODONATA | | | |
| *Xanthocnemis zealandica* | 5 | C | |
| OLIGOCHAETA | 1 | A | A |
| PLATYHELMINTHES | 3 | A | |
| PLECOPTERA | | | |
| *Zelandobius* species | 5 | VA | |
| TRICHOPTERA | | | |
| *Aoteapsyche* species | 4 | | R |
| *Hudsonema alienum* | 6 | C | R |
| *Hudsonema amabile* | 6 | R | C |
| Hydrobiosidae early instar | 5 | | R |
| *Hydrobiosis umbripennis* group | 5 | | C |
| *Olinga* species | 9 | | R |
| *Oxyethira albiceps* | 2 | | R |
| *Psilochorema* species | 8 | | C |
| *Pycnocentria* species | 7 | | VA |
| *Pycnocentrodes* species | 5 | | VA |
| *Triplectides* species | 5 | A | R |
| Number of taxa | | 17 | 24 |
| Number of EPT taxa | | 5 | 12 |
| MCI score | | 86 | 100 |
| SQMCI score | | 4.3 | 5.2 |

# Appendix 4 Habitat assessment results

Habitat data P2c

| Site | | Lovells Creek at Station | | | Frasers Stream at Station | | |
|---|---|---|---|---|---|---|---|
| | | Riffle | Run | Pool | Riffle | Run | Pool |
| Bed Substrate | % Concrete/artificial | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Bedrock (>4000mm) | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Boulder (256– | 10 | 10 | 0 | 20 | 2 | 0 |
| | % Cobble (64 - 255 | 60 | 60 | 30 | 40 | 45 | 40 |
| | % Gravel (2 – 63 mm) | 40 | 30 | 70 | 40 | 50 | 60 |
| | % Silt, sand, mud (< 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| | % embeddedness | 5 | 10 | 20 | 0 | 10 | 30 |
| | Substrate compactness | 2 | 2 | 3 | 0 | 2 | 2 |
| | % Deposition & | 0 | 0 | 10 | 0 | 10 | 10 |
| Organic Matter | % Macrophytes | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Moss | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Algae | 20 | 50 | 0 | 20 | 30 | 0 |
| | % Woody debris & leaf | 0 | 0 | 0 | 0 | 0 | 0 |
| Fish Habitat | % Obstructions to flow | 0 | 0 | 0 | 0 | 0 | 0 |
| | % Bank cover | 20 | 25 | 20 | 35 | 40 | 30 |