Surface water quality of spring-fed tributaries arising from the floodplain of the lower Rakaia River: Boat Creek, Clear Stream and Mathias Stream

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INTRODUCTION

The Rakaia River is a large braided river that arises from the Southern Alps in Canterbury. As the river flows out of the steep upper catchment, an alluvial fan forms part of the Canterbury Plains. The active floodplain of the Rakaia River has multiple channels typical of a braided river complex which diverts into two branches near the coast as the gradient decreases. Braided river habitat is multi-dimensional, with strong links between the surface water and underlying alluvial groundwater of the floodplain. A number of small spring-fed tributaries arise from upwelling groundwater in the floodplain. These spring-fed streams often provide a more stable stream habitat compared to the main channels which are subject to physical disturbance from flooding flow. As a result, spring streams often have greater invertebrate species diversity and abundance than the main river braids (Gray *et al.* 2006; Gray and Harding, 2007; Gray and Harding, 2010).

Near the Canterbury coast, the Rakaia River floodplain spans up to 5km in width and forms alluvial islands amongst the river braids and branches. The greatest of these islands are Fereday Island and the larger Rakaia Island. Historically, dense riparian vegetation covered much of these islands. However, a substantial portion of the area has been cleared and large scale farming operations are now carried out on this reclaimed land. However, within these alluvial islands and riparian zones a number of spring streams arise. With changes to land use in the immediate groundwater catchments of some spring-fed streams, concerns have been raised by residents of the Rakaia Huts as to the possible impacts on surface water quality and aquatic ecology.

STUDY SITES

Water quality and ecology monitoring was carried out in three spring-fed streams within the Rakaia River floodplain at Boat Creek, Clear Stream and Mathias Stream. Boat Creek and Mathias Stream were each monitored for water quality at a single site, while a longitudinal study was carried out along Clear Stream at three monitoring sites (Figure 1).

Boat Creek and Clear Stream arise in the floodplain to the north of the Little Rakaia River, near the Rakaia Huts. Boat Creek is a short spring-fed stream that lies on the boundary of a number of hut holder properties and flows for approximately half a kilometre directly into the Lagoon below the hut settlement. The larger Clear Stream flows parallel to the Little Rakaia River amongst riparian scrub. Land use adjacent to this stream is low-moderate intensity grazing by sheep and calves, restricted by fencing and a wide riparian margin.

Mathias Stream arises from the floodplain of Rakaia Island to the south of the little Rakaia. Rakaia Island has undergone a progressive increase in land use intensity, with much of the island now used for dairy farming. A small riparian margin remains alongside the stream, however much of the shallow groundwater zone/drained wetland is converted pasture land.

Figure 1 and Figure 2 present the changes to the stream catchments over the last 18 years. Vegetation in both the Mathias Stream and Clear Stream catchments has been cleared to create more pasture and farmland.

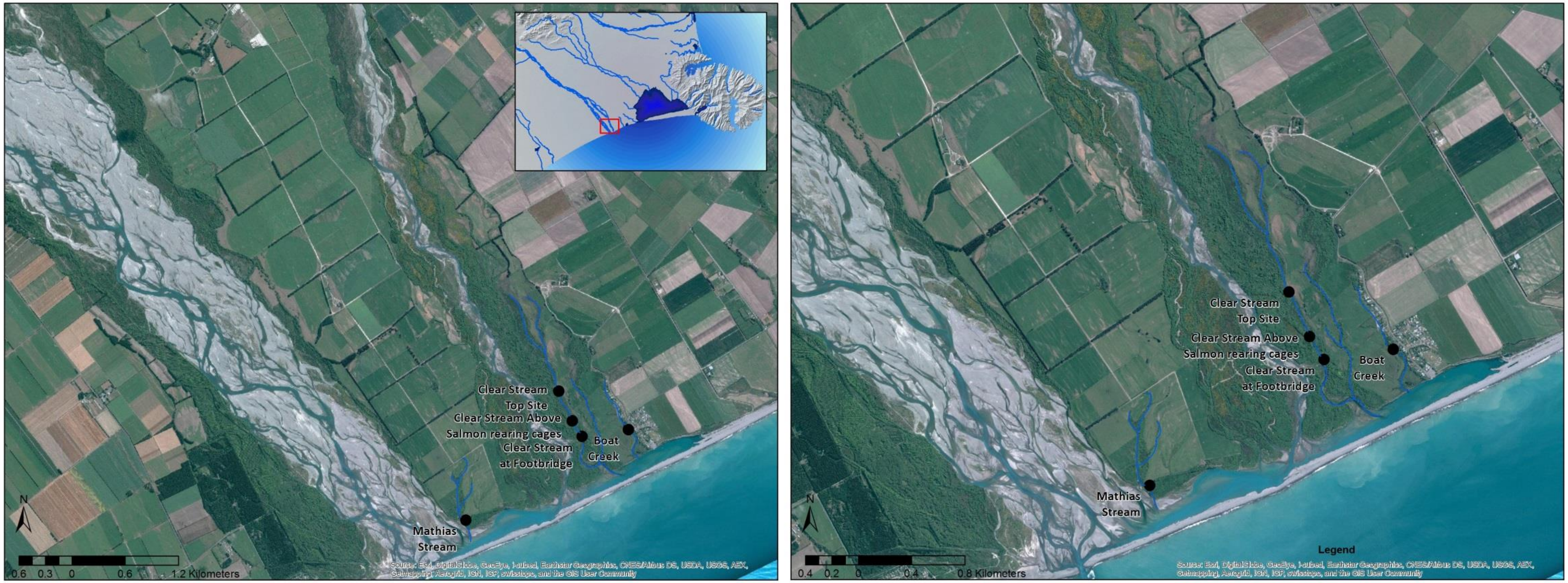

Figure 1: A; Broad-scale view the lower Rakaia River catchment including water quality monitoring sites for Boat Creek, Clear Stream and Mathias Stream tributary catchments. B; Water quality monitoring sites for Boat Creek, Clear Stream and Mathias Stream. N.B. This is the present aerial view of the catchment

Figure 2: the lower Rakaia River catchment in 1996 depicting changes to riparian margins and swamp land

METHODS

Boat Creek, Clear Stream and Mathias Stream were monitored for physical, chemical and microbiological parameters and aquatic ecology. Water quality samples for the 5 sites were collected according to the Procedures Manual: surface water quality and ecosystem health, Version 2 (ECan unpublished, 2013). Samples were taken monthly from 2009-14 for the physical, chemical and microbiological parameters detailed in Table 1. Samples were analysed by the Environment Canterbury laboratory and Hill Laboratories, while temperature and dissolved oxygen measurements were made in the field by the use of a calibrated handheld meter.

Table 1: Physio-chemical and microbiological water quality parameters measured for Boat Creek, Clear Stream and Mathias Stream

PHYSICAL PARAMETERS	CHEMICAL PARAMETERS	MICROBIOLOGICAL PARAMETERS:
pH Electrical conductivity @ 25^{O}c (mS/m) Temperature (^{O}C) Turbidity (NTU/100mL) Total Suspended Solids (TSS) (mg/L)	Dissolved Oxygen (DO) (mg/L) Dissolved Oxygen saturation (%) Nitrate and nitrite-nitrogen (NNN) (mg/L) Ammonium-nitrogen (NH4N) (mg/L) Dissolved inorganic nitrogen (DIN) (mg/L) Total nitrogen (TN) (mg/L) Dissolved reactive phosphorus (DRP) (mg/L) Total phosphorus (TP) (mg/L)	*Escherichia coli* (E. *coli*) - a faecal indicator bacteria (MPN/100mL)

Aquatic ecology monitoring was carried out in March and December 2009 to determine the invertebrate communities of each stream. A single kick-net sample was taken at each and preserved in 70% alcohol. Invertebrate samples were subsampled using a barrel splitter and invertebrates were identified and counted using a bogorov tray and the "100 fixed count + scan for rare taxa" method (Stark *et al.* 2001).

Data was analysed using Statistica (V12). Where individual water quality results were below analytical limits of detection, the detection limit result was halved. Water quality monitoring results are presented as box plots that portray the median as the middle line, the inter quartile range where 50% of central values fall within the box, the non-outlier minimum and maximum as whiskers, and outliers and extremes as discrete points. For nitrate-nitrite-nitrogen and *Escherichia coli* the whiskers are portrayed as 5^{th} and 95^{th} percentiles for direct comparison with 95^{th} percentile guideline values. Guideline values are portrayed as red lines where applicable to identify potential issues, and the regional spring-fed median (Stevenson *et. al* 2010) for each parameter is portrayed as a green line for comparison to similar streams in Canterbury. Individual guideline values are described in Appendix 1. The nitrate toxicity guidelines refer to grading nitrate concentrations and surveillance nitrate concentrations. The grading nitrate concentration is intended for comparison with median nitrate results to address the issue of long-term exposure. The surveillance nitrate concentration is intended for comparison with the 95^{th} %ile of nitrate results, to address seasonally high nitrate concentrations and species tolerance at conservative sub-lethal measures.

A long-term trend analysis was not carried out for this study due to an insufficient period of data collection. Long-term analysis of this data was not the intention of this study.

RESULTS

Nutrients

All single sample concentrations of both dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) exceed the recommended Ministry for the Environment (2000) 40 day accrual guideline thresholds of 0.019mg/L and 0.0017 mg/L for nuisance algal growth in Clear Stream, Boat Creek and Mathias Stream; indicating that under optimal conditions, algal and aquatic macrophytes may proliferate. In comparison to other spring-fed streams in Canterbury, all three streams are below the regional median for both DIN and DRP for the majority of the time, indicating lower dissolved nutrient concentrations (Figure 3 and Figure 4).

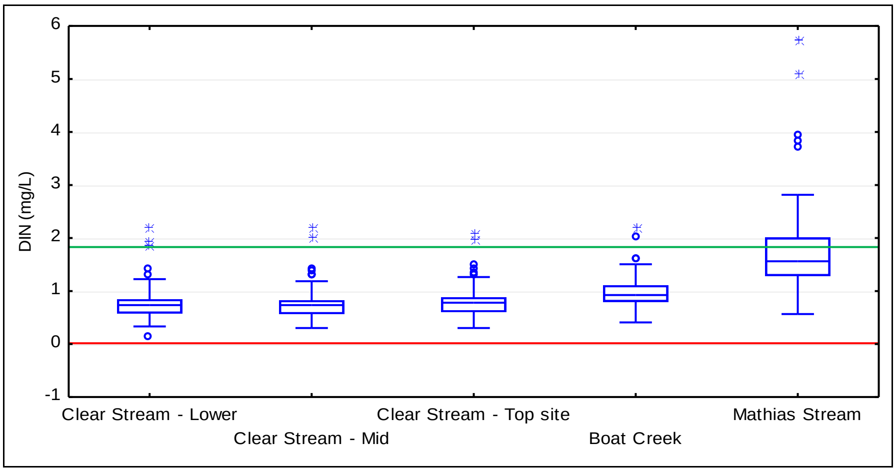

Figure 3: Dissolved inorganic nitrogen for Clear Stream, Boat Creek and Mathias Stream (Red line= 0.019mg/L, periphyton guideline adapted from MfE 2000)(Green line = 1.83mg/L, spring-fed plains regional median, Stevenson *et al*. 2010)

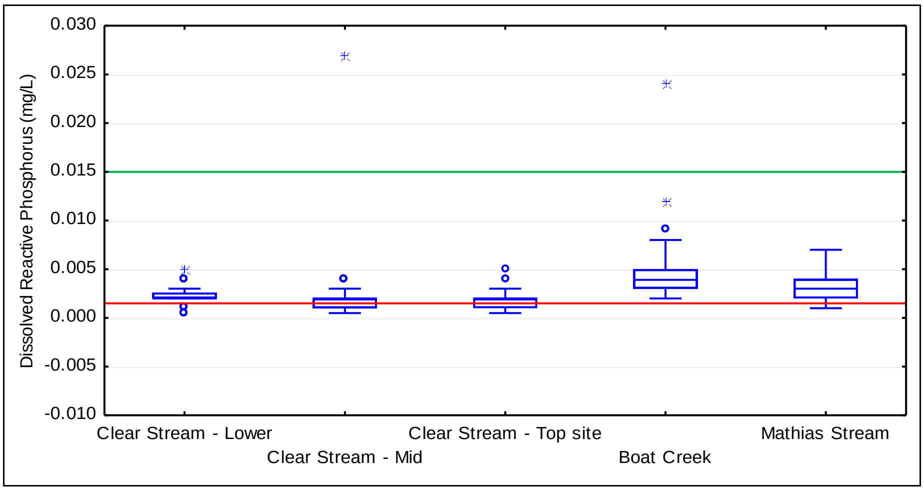

Figure 4: Dissolved reactive phosphorus for Clear Stream, Boat Creek and Mathias Stream (Red line = 0.0017mg/L, periphyton guideline adapted from MfE 2000)(Red line = 0.015mg/L, spring-fed plains regional median, Stevenson *et al*. 2010) N.B outlier omitted for Boat Creek of 0.064mg/L

Nitrate-nitrite-nitrogen (NNN) in the lower Rakaia River tributaries showed a similar pattern in space to dissolved inorganic nitrogen, with median concentrations below the regional spring-fed median indicating lower dissolved nutrient concentrations in comparison to other spring-fed streams in Canterbury. Median NNN concentrations in Clear Stream, Boat Creek and Mathias Stream were below the 95% aquatic species protection guideline value of 2.4mg/L used for grading nitrate toxicity in a stream (dashed red line). Additionally, the 95th percentiles for Clear Stream and Boat Creek were below the 95% aquatic species protection guideline value of 3.5mg/L used for nitrate toxicity surveillance (solid red line). However, the 95th percentile for NNN in Mathias Stream was above the surveillance guideline value, indicating NNN concentrations in Mathias Stream have the potential to pose toxic effects to some aquatic species if a further steady increase is observed (Hickey, 2013) (Figure 5).

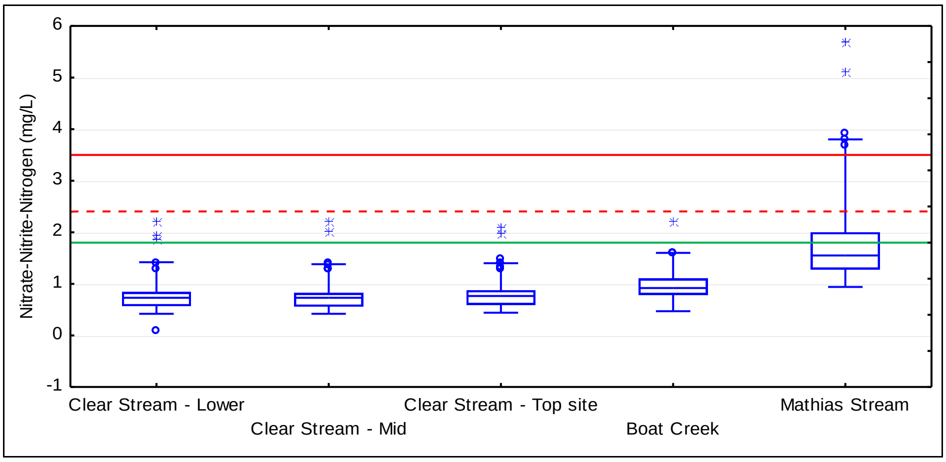

Figure 5: Nitrate-Nitrite-Nitrogen for Clear Stream, Boat Creek and Mathias Stream (Dashed red line=2.4mg/L (Nitrate toxicity grading – compare with median), Solid Red line= 3.5mg/L (Nitrate toxicity surveillance – compare with 95th %ile), Hickey, 2013) (Green line= 1.8mg/L, spring-fed plains regional median, Stevenson *et al*. 2010).

Ammonium-nitrogen concentrations in all three tributary streams are generally below the regional spring-fed median and well below the toxicity guideline of 0.9mg/L at a pH of 8 (Stevenson *et al*. 2010; ANZECC, 2000)(Figure 6).

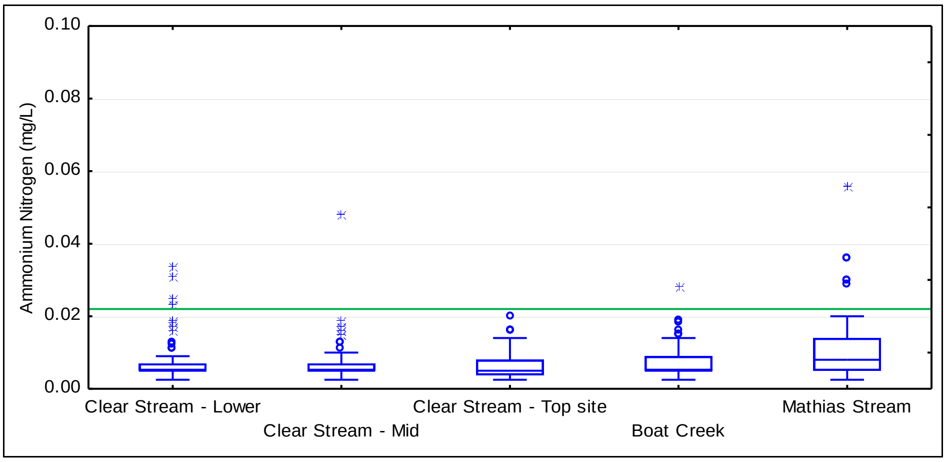

Figure 6: Ammonium-nitrogen for Clear Stream, Boat Creek and Mathias Stream (Green line = 0.022mg/L, spring-fed plains regional median Stevenson et al. 2010) N.B outlier omitted for Boat Creek of 0.41mg/L

Total nitrogen and phosphorus (TN and TP) concentrations are generally below their respective regional spring-fed medians of 2.1mg/L for TN and 0.03mg/L for TP. However, at times Mathias Stream exhibits high TN concentrations, while Boat Creek exhibits some highly elevated TP values (Figure 7 and Figure 8)

DIN, NNN and TN concentrations are greatest for Mathias Stream (Figure 3, Figure 5 and Figure 7) while DRP and TP concentrations are greatest for Boat Creek (Figure 4 and Figure 8).

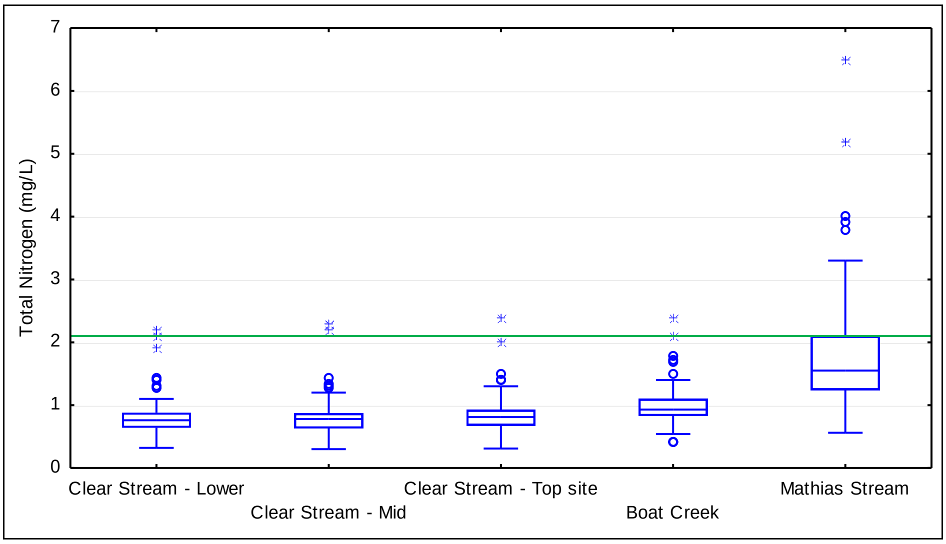

Figure 7: Total Nitrogen for Clear Stream, Boat Creek and Mathias Stream (Green line= 2.1mg/L, spring-fed plains regional median, Stevenson et al. 2010)

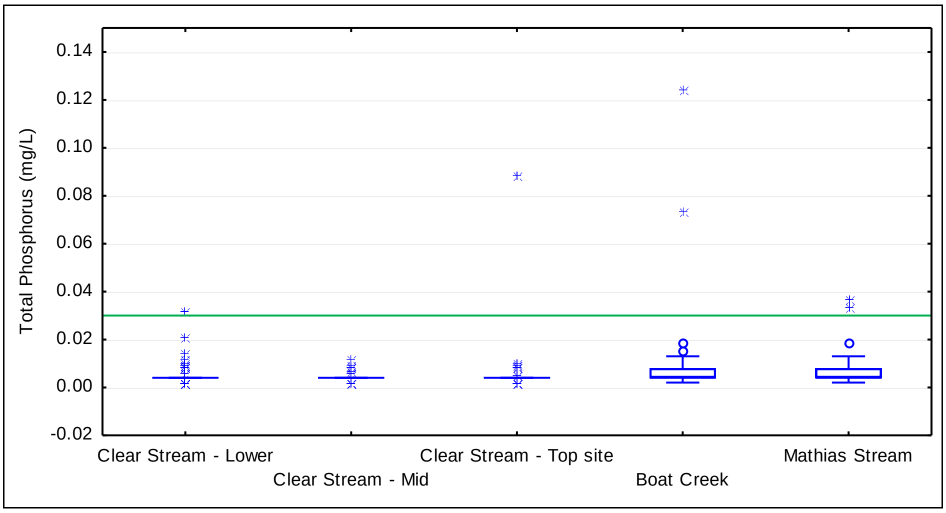

Figure 8: Total Phosphorus for Clear Stream, Boat Creek and Mathias Stream (Green line = 0.03mg/L, spring-fed plains regional median, Stevenson et al. 2010) N.B. two extremities have been omitted from this graph (2.6mg/L for Clear Stream – Mid, 3.7mg/L for Boat Creek)

Water Clarity, suspended solids and sedimentation

The water in Clear Stream, Boat Creek and Mathias Stream was generally clear. Both turbidity and suspended solids measurements were below the regional spring-fed medians of 1.6 NTU and 4mg/L, respectively (Stevenson *et al.* 2010). Turbidity measurements were generally below the recommended guideline value of 2 NTU for recreational water quality and aesthetics and 5.6 NTU for aquatic ecosystem health (Figure 9 and Figure 10) (ANZECC, 2000).

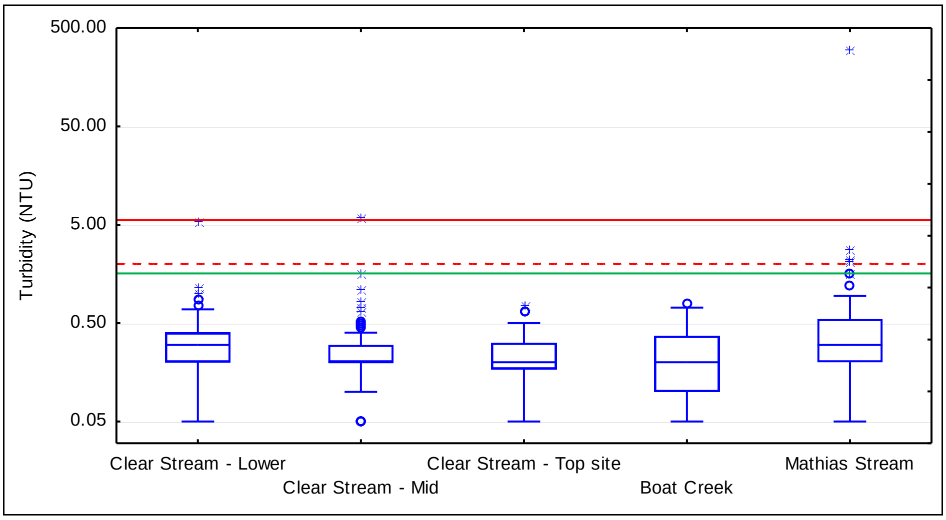

Figure 9: Turbidity concentrations for Clear Stream, Boat Creek and Mathias Stream (Dashed red line=2 NTU (Guideline for recreation and aesthetics), Solid Red line= 5.6 NTU (Guideline for aquatic ecosystem health), ANZECC, 2000) (Green line= 1.6 NTU, spring-fed plains regional median, Stevenson et al. 2010) N.B. the scale for this graph is logarithmic

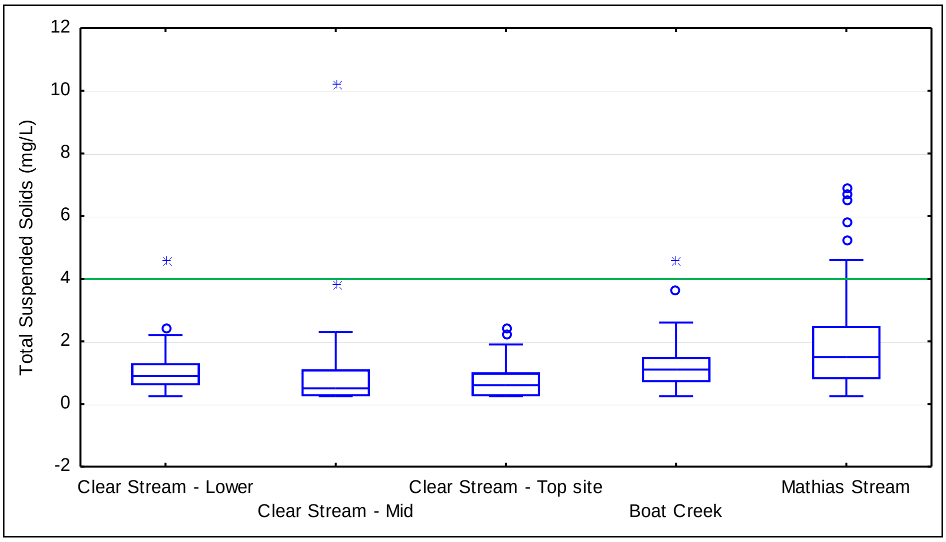

Figure 10: Total Suspended Solids for Clear Stream, Boat Creek and Mathias Stream (Green line= 4mg/L, spring-fed plains regional median, Stevenson et al. 2010)

Boat Creek had the highest levels of sediment cover on the stream bed, followed by Mathias Stream. Clear Stream was relatively free of sedimentation except at the lower site where particles settled out as the stream bed widened and water velocity reduced (Figure 11).

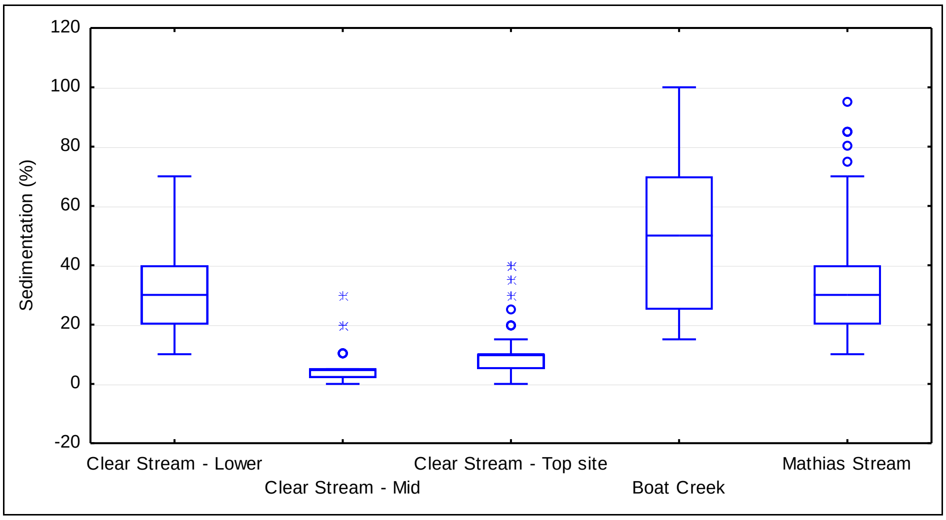

Figure 11: Sedimentation for Clear Stream, Boat Creek and Mathias Stream

Life supporting parameters

Water temperatures for Clear Stream, Boat Creek and Mathias Stream were relatively stable ranging between 9-14°C, and well below the recommended daily maximum guideline value of 20°C for fish migration and behaviour (Richardson *et al*. 1994). Water temperature in Clear Stream was comparable for all three sites to the regional spring-fed median of 11.7°C. However, water temperature for Boat Creek and Mathias Stream was generally above the regional spring-fed median (Figure 12) (Stevenson *et al*. 2010).

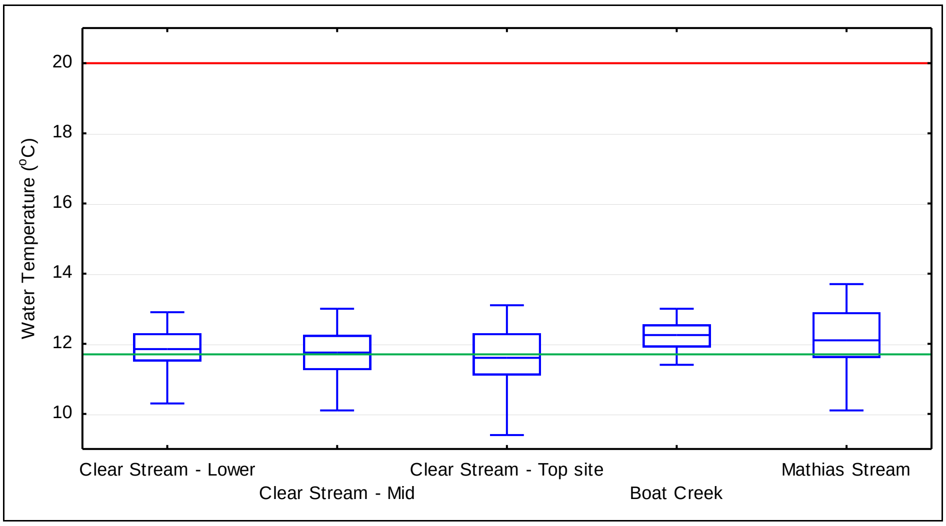

Figure 12: Water temperature for Clear Stream, Boat Creek and Mathias Stream (Red line= 20°C (Daily maximum guideline for fish), Richardson *et al.* 1994) (Green line = 11.7°C, spring-fed plains regional median, Stevenson et al. 2010)

Dissolved oxygen concentrations were typically above the recommended guideline value of 6mg/L. However, percent saturation of dissolved oxygen tended to be below the recommended minimum guideline of 80% indicating dissolved oxygen might be limiting for aquatic life in these three streams (ANZECC, 2000). Both dissolved oxygen concentration and percent saturation was below the regional spring-fed median of 9.3mg/L and 88.9% (Stevenson *et al.* 2010) (Figure 13 and Figure 14).

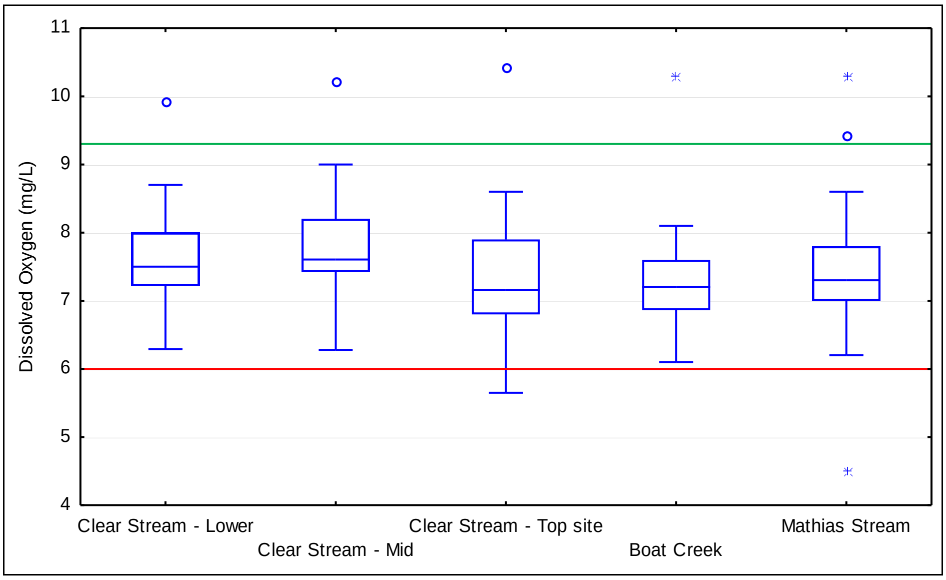

Figure 13: Dissolved oxygen for Clear Stream, Boat Creek and Mathias Stream (Red line= 6mg/L (minimum guideline for aquatic ecosystems), ANZECC, 2000) (Green line = 9.3mg/L, spring-fed plains regional median, Stevenson et al. 2010)

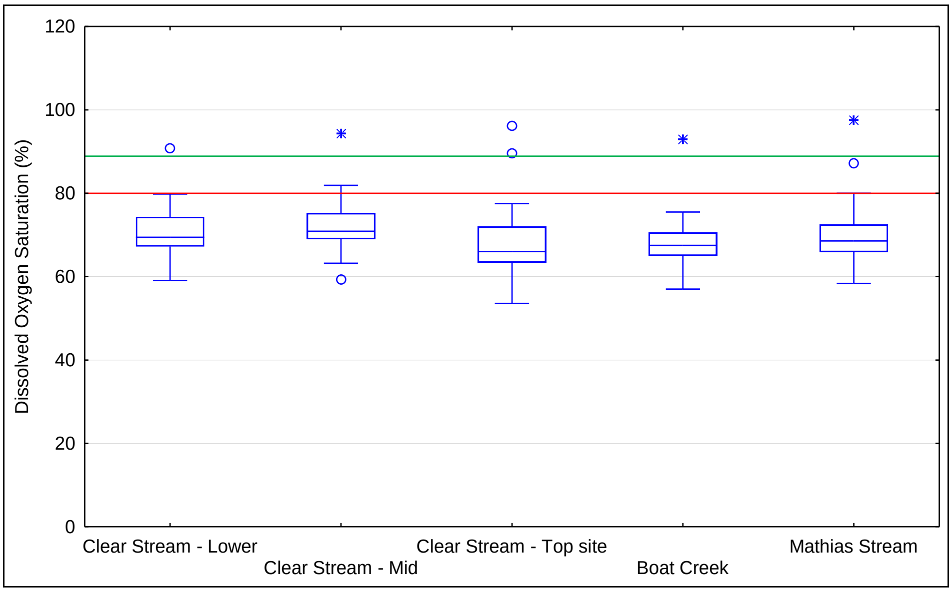

Figure 14: Dissolved oxygen saturation for Clear Stream, Boat Creek and Mathias Stream (Red line= 80% (minimum guideline for aquatic ecosystems), ANZECC, 2000) (Green line = 88.9%, spring-fed plains regional median, Stevenson et al. 2010)

The pH of Clear Stream, Boat Creek and Mathias Stream was reasonably buffered with a range of 6.8-7.5 for all streams and generally below the regional spring-fed median value of 7.4 (Stevenson *et al*. 2010) (Figure 15).

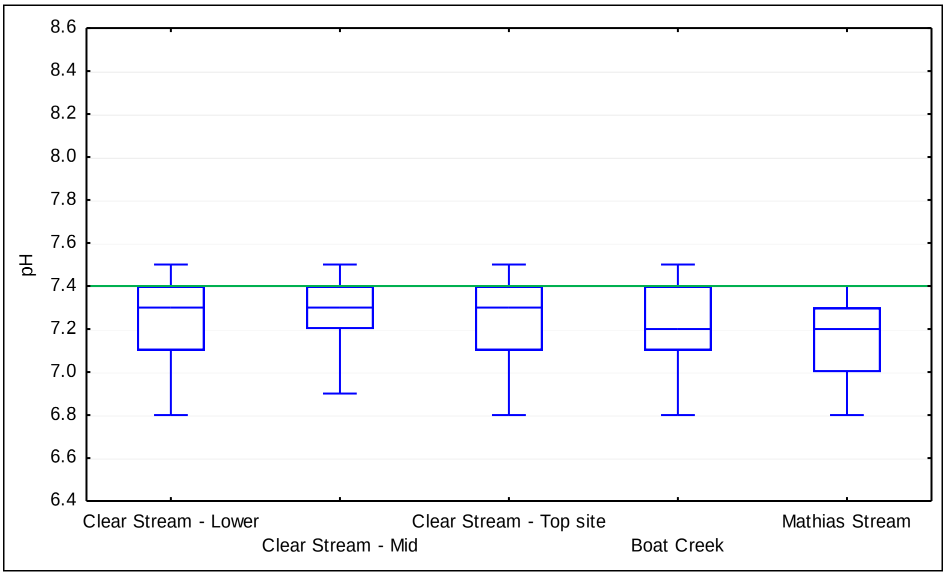

Figure 15: pH for Clear Stream, Boat Creek and Mathias Stream (Green line = pH 7.4, spring-fed plains regional median, Stevenson et al. 2010)

Conductivity in all three streams was lower than the spring-fed median of 19mS/m for streams in Canterbury (Figure 16).

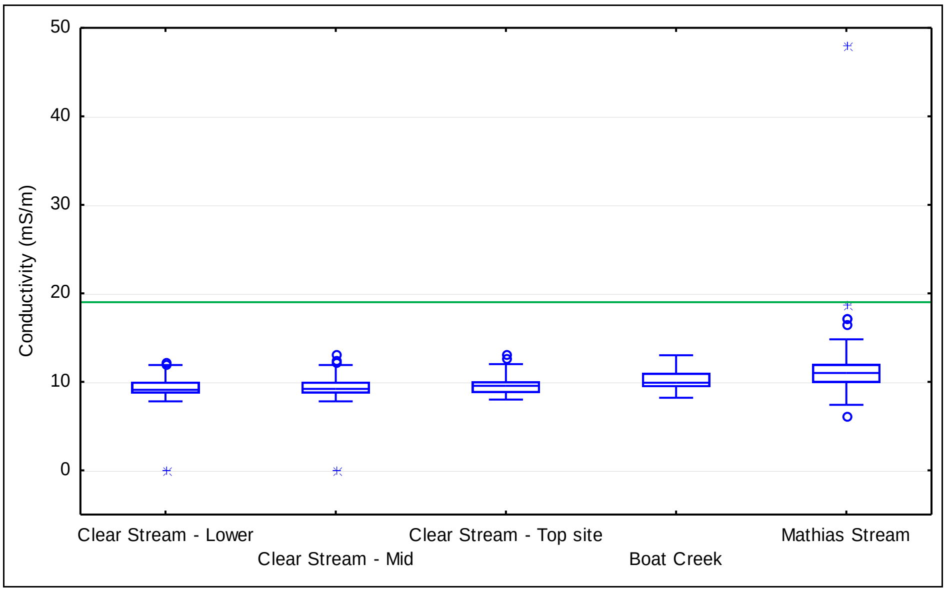

Figure 16: Conductivity for Clear Stream, Boat Creek and Mathias Stream (Green line = 19mS/m, spring-fed plains regional median, Stevenson et al. 2010)

Microbiological water quality

Microbiological water quality in Clear Stream and Boat Creek, as measured by the faecal indicator bacteria *Escherichia coli*, is compliant with the 95th percentiles for these sites below the recommended guideline of 550 MPN/100mL for primary contact recreation (MfE/MOH (2003). Mathias Stream does not meet this guideline. However, Mathias Stream does have a median *E.coli* concentration below the guideline value of 1000MPN/100mL which is the recommended bottom line for recreational activities involving partial immersion in the national objectives framework (MfE 2014) (Figure 17). Thus, Mathias Creek would be suitable non-immersion based activities, but not full immersion activities such as swimming.

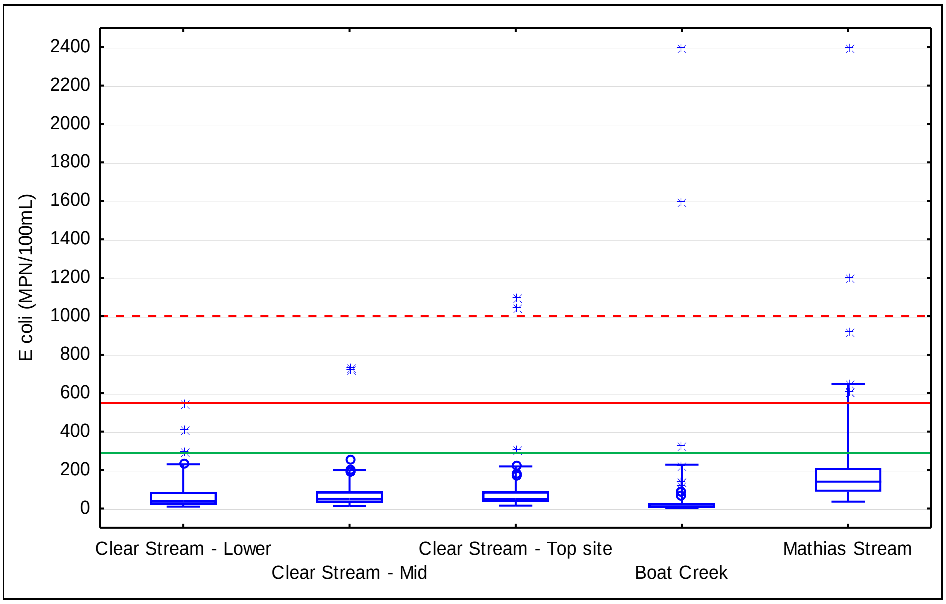

Figure 17: *Escherichia coli* concentrations for Clear Stream, Boat Creek and Mathias Stream (Dashed red line=1000MPN/100mL (Recommended median guideline value for recreational activities involving partial immersion) NPS, 2014), (Solid Red line=550MPN/100mL (Recommended 95th percentile guideline value for primary contact recreation, involving full immersion activities), MfE/MOH, 2003) (Green line = 290 MPN/100mL, spring-fed plains regional median, Stevenson et al. 2010)

Ecological indicators

Invertebrate Assessment

Species richness was greatest in the Clear Stream tributary of the lower Rakaia River, with a lower average species richness of 10 and 11 species identified in Mathias Stream and Boat Creek, respectively (Figure 18). Quantitative macroinvertebrate community index (QMCI) values were indicative of mild to moderate pollution in Clear and Mathias Streams, whereas the average QMCI value for Boat Creek is representative of severe pollution (Figure 19) (Boothroyd and Stark, 2000). As species richness decreased downstream in Clear Stream, the QMCI improved indicating a shift towards a greater relative abundance of more pollution-sensitive species (Figure 18 and Figure 19).

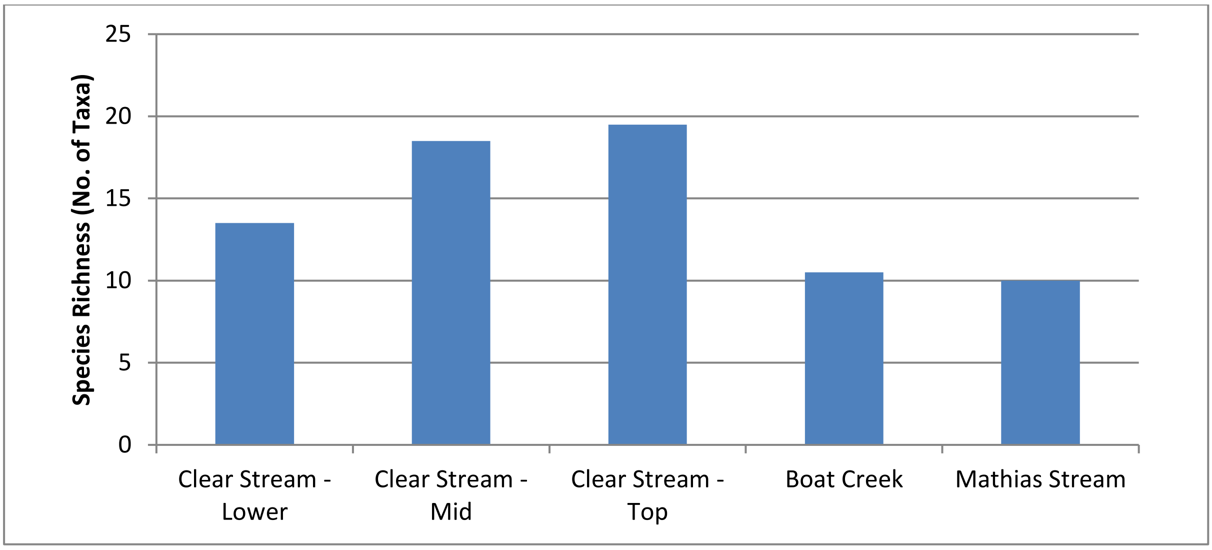

Figure 18: Invertebrate species richness for Clear Stream, Boat Creek and Mathias Stream

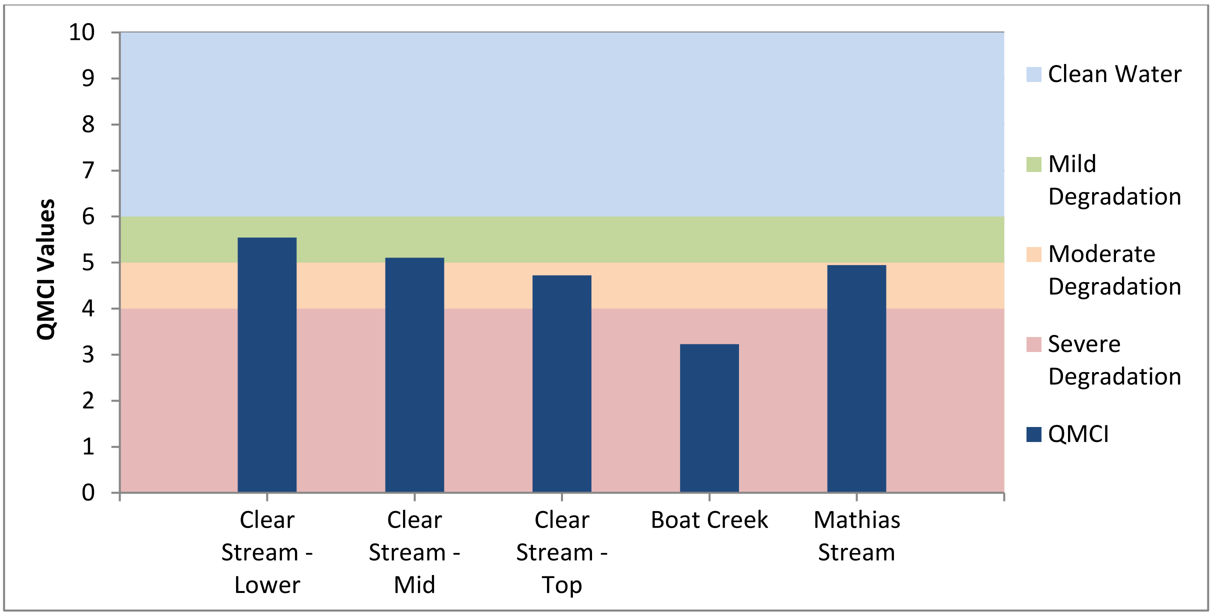

Figure 19: Quantitative Macroinvertebrate Community Index for Clear Stream, Boat Creek and Mathias Stream (pollution states are adopted from Boothroyd and Stark, 2000)

Trichoptera taxa dominated Clear Stream at the lower two sites, while the top site had a lower relative abundance of Trichoptera, but an increase in the abundance of Oligochatea and Chironomidae. Boat Creek was dominated by the more pollution-tolerant Oligochaetes, Crustacea and molluscs, while Mathias Stream was dominated by Trichoptera and molluscs (Figure 20).

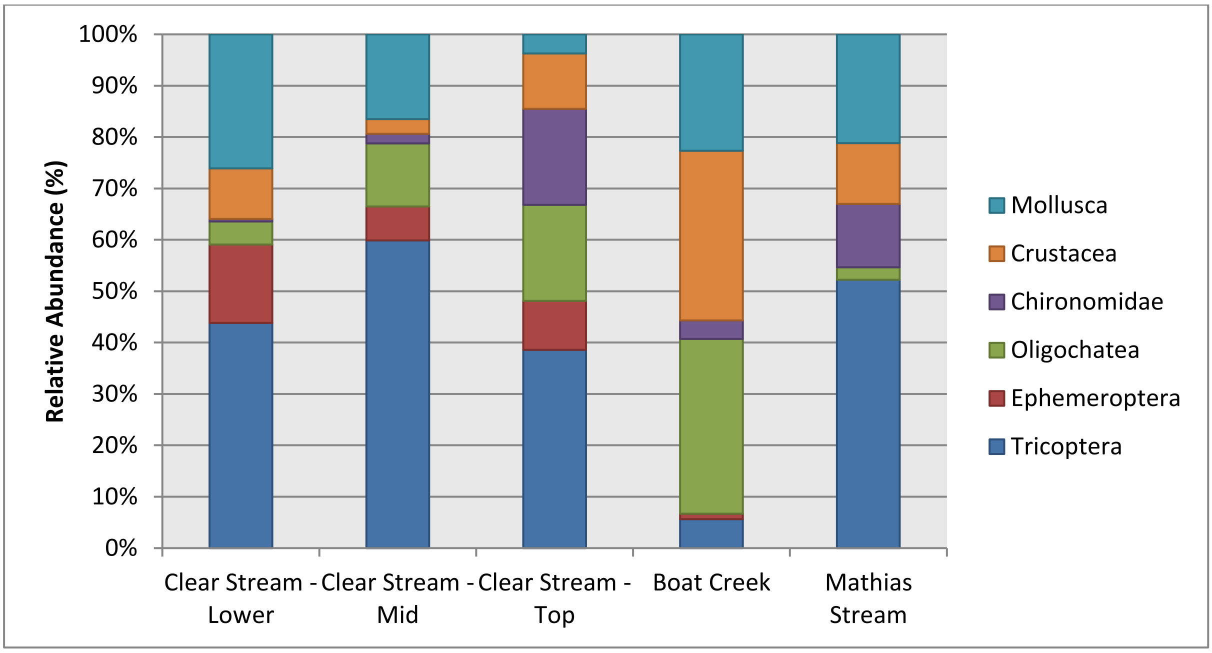

Figure 20: Relative abundance of taxa (%) for Clear Stream, Boat Creek and Mathias Stream

<u>In-Stream Habitat Assessment</u>

Monthly assessments of macrophyte and algal growth indicate that macrophyte growth can be elevated at the Clear Stream top site and Boat Creek ranging from 30-90% and 5-90% respectively (Figure 21). Periphyton growth was greatest at the middle Clear Stream site, at times exceeding 50% cover of thick mats and long filaments, with a presence of the potentially toxic cyanobacteria *Phormidium* sp. (Figure 22).

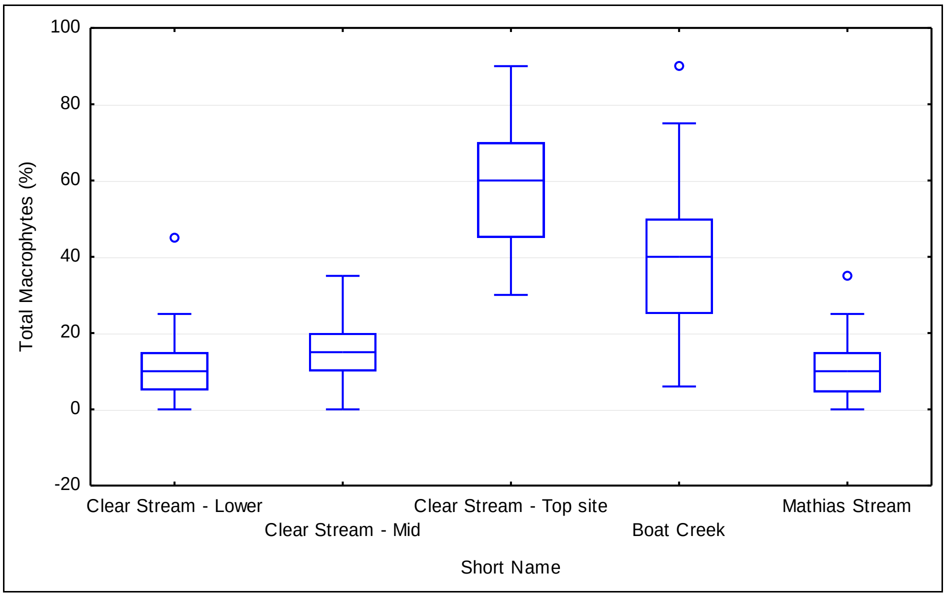

Figure 21: Total macrophyte cover (emergent and submerged) for Clear Stream, Boat Creek and Mathias Stream

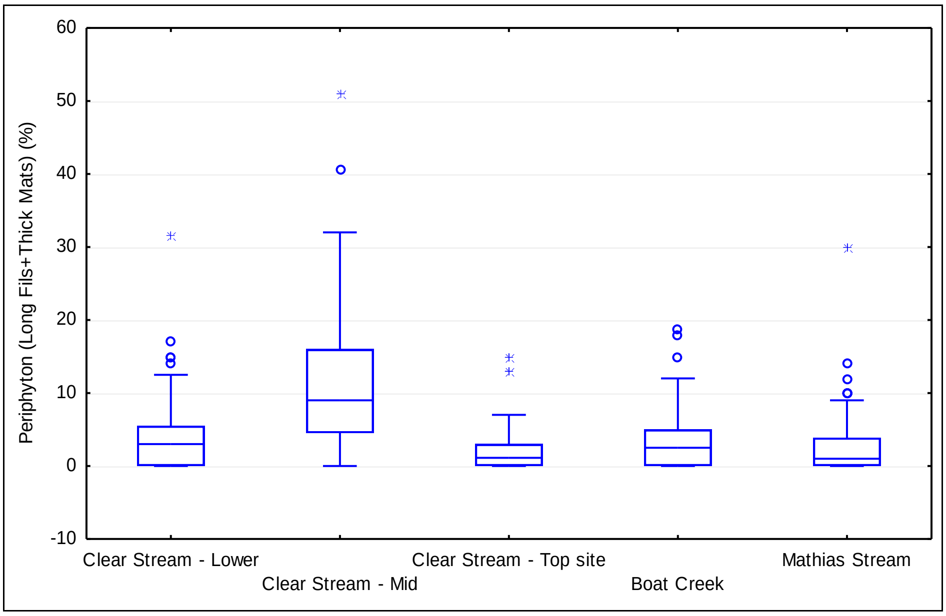

Figure 22: Long filament and thick mat periphyton cover for Clear Stream, Boat Creek and Mathias Stream

A comparison of habitat assessment and invertebrate community data in Boat Creek indicate that aquatic ecosystem health may have been impacted by macrophyte effects on flow velocity, sediment deposits and substrate embeddedness. At the other sites with higher QMCI's there was lower macrophyte growth, sedimentation and less impacted riparian margins (Table 2).

Table 2: Stream habitat assessment for the ecosystem health of Clear Stream, Boat Creek and Mathias Stream

Clear Stream - Lower	Low macrophyte cover not obstructing flow patterns, small areas of bank erosion but bank generally stable, riparian mostly introduced trees and scrub with occasional breaks and minimal impact from human activities
Clear Stream - Mid	Low macrophyte cover not obstructing flow patterns, small areas of bank erosion but bank generally stable, riparian mostly introduced trees and scrub with occasional breaks and minimal impact from human activities
Clear Stream - Top	Moderate-significant macrophyte growth, small areas of bank erosion but bank generally stable, riparian mostly introduced trees and scrub with occasional breaks and minimal impact from human activities
Boat Creek	Significant macrophyte growth that may reduce water flow in some areas. Small areas of bank erosion but bank generally stable. Riparian a mix of exotic grasses, trees and shrubs however riparian zone width is minimal with some impacts from human activities, heavy sediment deposits and embeddedness
Mathias Stream	Low macrophyte cover not obstructing flow patterns, small areas of bank erosion but bank generally stable, riparian mostly introduced trees and scrub with occasional breaks and minimal impact from human activities

DISCUSSION AND CONCLUSION

Nutrients such as nitrogen and phosphorus are essential for supporting the growth of aquatic macrophytes and algal communities. However, in excess nutrients can lead to nuisance macrophyte and algal growths and at even greater concentrations some forms of nitrogen may be toxic to aquatic species or pose a public health risk in drinking water (ANZECC 2000; MfE 2000; MOH 2005). Present day spring-fed streams on the Canterbury Plains are typically nitrate-rich due to leaching of nitrogen ions into groundwater across the surrounding catchment. However nutrient concentrations in Clear Stream, Boat Creek and Mathias Stream were generally lower than for many spring-fed streams of the Canterbury Plains. The source of flow to these spring-fed streams is groundwater derived primarily from the Rakaia River rather than land surface recharge. Due to the high degree of surface-groundwater interaction between the alpine-fed river, with low nutrient concentrations, and the groundwater beneath the floodplain it is reasonable to expect relatively low nitrogen concentrations in these stream (Kilroy *et al*. 2004; Gray and Harding, 2007).

Mathias Stream exhibited the greatest nitrate concentrations out of the three streams. Despite the influence of the Rakaia River on upwelling groundwater this stream was elevated for nitrate with a 95^{th} percentile that exceeds the surveillance guideline for aquatic species toxicity (95% protection level). Accordingly, this stream is at risk of a reduction in species diversity should nitrate concentrations in the stream increase further (Hickey, 2013). Of the three streams monitored, the Mathias Stream catchment has undergone the greatest development over 20 years with a large scale dairy operation occurring on the alluvial island. Given the free-draining nature of the alluvial soils, this stream would be susceptible to nitrate losses from land via leaching from urine patches, effluent, and nitrogen fertilisers. Mathias Stream also had elevated total phosphorus (TP) concentrations similar to those observed in Boat Creek, but DRP concentrations in Mathias Stream remained low. Boat Creek experienced the greatest dissolved reactive phosphorus (DRP) concentration. These results suggest that the predominant source of phosphorus to Mathias Stream is particulate and a likely result of entrainment of phosphorus bound to soil or other particles in run-off. This result is supported by the elevated suspended solids concentration in Mathias Stream in comparison to Boat Creek and Clear Stream. The elevated DRP and TP concentrations in Boat Creek may be attributable to bank erosion and release of DRP from benthic sediment under anoxic conditions. Given that the ammonium-nitrogen concentrations in this stream are low, it is unlikely that septic tanks are a major source of phosphorus.

While nutrient concentrations in all three streams are reduced in comparison to similar streams in Canterbury, both DIN and DRP (the dissolved fraction of nutrients that are available for uptake by macrophytes and algae) exceeded recommended guidelines for nuisance macrophyte and algal growth, and under favourable conditions could lead to prolific macrophyte or algal blooms. This can have implications for stream communities due to smothering or choking of the waterways and a reduction in suitable habitat for aquatic species. Large growths of aquatic macrophytes can deplete oxygen levels in water leading to illness and death in fish and invertebrates. Macrophytes can also cause sediment entrapment. Reduced dissolved oxygen saturation for these spring-fed streams, in particular Boat Creek, the top Clear Stream site, and at times Mathias Stream may be as a result of the excessive macrophyte growth observed in these streams. This is reflected by QMCI values representative of moderate to severe degradation, and species diversity loss for both Boat Creek and Mathias Stream. Boat Creek may be further impacted by increased sedimentation and substrate embeddedness, resulting in a QMCI value indicative of severe degradation, loss of species diversity, and the dominance of taxa such as the mollusc *Potamopyrgus*, Oligochaete worms and the crustacean *Paracalliope.* These taxa are commonly found in streams with high macrophyte growth and sedimentation (Gray 2005). In contrast, lower Clear Stream has relatively clean gravels free of excessive sedimentation and macrophyte growth. There is an increase in species richness, and QMCI values are indicative of mild to moderate degradation.

Microbiological water quality is generally good for Boat Creek, Clear Stream and Mathias Stream in comparison to other spring-fed in Canterbury. *Escherichia coli* concentrations are well below the recommended guideline for recreation involving partial immersion, such as wading. However Mathias Stream exceeds the recommended guideline for primary contact recreation, indicating an increased risk of illness from activities involving full or partial immersion (MfE/MOH 2003; NPS 2014).

In conclusion, water quality for tributary streams in the lower Rakaia River floodplain, was generally of good water quality in comparison to similar streams on the Canterbury Plains. Surface-groundwater interactions between the Rakaia River and underlying groundwater are likely to influence the nutrient status of these spring streams. However, nutrient concentrations are elevated and have the potential to promote for the growth of nuisance macrophyte and algal growth. Excessive macrophyte growth can lead to reduced oxygen concentrations and sediment entrapment, which may be an influencing factor on aquatic ecology. These streams therefore show signs of degradation of habitat and invertebrate communities.

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APPENDIX 1 GUIDELINE VALUES FOR SELECTED PARAMETERS OF SIGNIFICANCE TO SURFACE WATER QUALITY PROGRAMMES

Parameter	Water Use/Value	Guideline value	Reference
Turbidity	Recreational/Aesthetic Aquatic ecosystems	2 NTU 20% increase over ambient 5.6 NTU	MAF (1993) MfE (1994) ANZECC (2000)
Dissolved Reactive Phosphorus (DRP)	Aquatic Ecosystem (50day accrual periods)	0.0017mg/L (mean of monthly data over a 1 year period)	MfE (2000)
Dissolved Inorganic Nitrogen (DIN) (Nitrate + Ammonia)	Aquatic Ecosystem (50day accrual period) (30day accrual periods)	0.019 mg/L (mean of monthly data over a 1 year period) 0.075 mg/L (mean of monthly data over a 1 year period)	MfE (2000)
Nitrate N Toxicity	Aquatic ecosystems – Grading (for comparison against median water quality results) Aquatic ecosystems – Surveillance (for comparison against 95th %ile water quality results)	1.0 – High conservation value systems (99% protection) 2.4 – Slightly to moderately disturbed systems (95% protection) 3.8 – Highly disturbed systems (90% protection) 1.5 – High conservation value systems (99% protection) 3.5 – Slightly to moderately disturbed systems (95% protection) 5.6 – Highly disturbed systems (90% protection)	Hickey (2013)
E. coli	Recreational – Primary contact (for comparison to 95th %ile E.*coli* results) Partial immersion (for comparison to median E.*coli* results)	550 MPN/100mL (action mode) 1000 MPN/100mL	MoH (2003) MfE (2014)
Diurnally variable parameters – Spot measurements			
Dissolved Oxygen	Aquatic ecosystems	6 mg/L 80 % Saturation	ANZECC (2000)
Temperature	Aquatic ecosystems	Seasonal max 20 °C	Richardson *et al.* 1994

Appendix 2 QMCI "Pollution" States (adopted from Boothroyd and Stark, 2000)

This index allocates invertebrate taxa a score between 1 and 10 depending on each taxon's tolerance to organic enrichment. These scores are multiplied by the abundance of the taxa and divided by the total abundance then combined to give an overall QMCI value. Boothroyd and Stark (2000) provided an interpretation of QMCI values as follows:

QMCI	Definition
>6	clean water, abundant species are typically sensitive to pollution
5-6	doubtful quality of possible mild pollution
4-5	probable moderate pollution
<4	probable severe pollution, abundant species are typically pollution tolerant