Water Quality in the Tutaekuri catchment

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State, trends and contaminant loads

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Cover Photograph: Tutaekuri at Puketapu.

All photographs by Olivier Ausseil

EXECUTIVE SUMMARY

Hawke's Bay Regional Council (HBRC) monitors water quality and river flow at a number of points across the Tutaekuri catchment and has produced a comprehensive report on the state and trends of water quality across the region, based on data collected between 1998 and 2003 (Stansfield 2004).

The present report was commissioned by HBRC to obtain an up-to-date and independent analysis of the state of the water quality in the Tutaekuri River catchment. This report is part of a series of technical reports covering all major catchments in the Hawke's Bay Region, currently being prepared to serve as a base for the upcoming 2009 Hawke's Bay Regional Council's state of the environment report.

The aim of this study is to analyse the water quality and biomonitoring data collected by Hawke's Bay Regional Council in the Tutaekuri catchment until August 2008. In particular, the study aims at investigating the following points:

- the state of the Tutaekuri River and its main tributaries;
- temporal trends, *i.e.* are the water quality or the ecological indicators getting better or worse over time?;
- the annual and daily nutrient loadings in the Tutaekuri River;

Most parameters indicate good water quality in the Tutaekuri catchment, which is consistent with the findings of the 2004 study (Stansfield, 2004). The microbiological water quality is generally excellent, indicating a low health risk to river users from pathogens of faecal origin. The generally low ammonia concentrations are unlikely to cause any acute or chronic toxic effects on the aquatic biota. Water clarity outside periods of high river flow is generally excellent at the top of the catchment (Lawrence Hut), and acceptable in the Mangaone River and the lower Tutaekuri River.

The key issue for the Tutaekuri catchment appears to be the common occurrence of nuisance levels of periphyton in the lower Tutaekuri River during extended periods of low river flows. During these periods, the nutrient (both SIN and DRP) concentrations and daily loads decrease the lower Tutaekuri River, probably as a result of utilisation by the abundant periphyton. In this context, the Mangaone River appears to contribute significant inputs of both DRP and SIN in the Tutaekuri main stem, possibly contributing to the excessive periphyton growths.

It is interesting to note that these excessive periphyton growths occur even as the nutrient concentrations at all monitoring sites in the Tutaekuri catchment are generally below the recommended guidelines (RRMP guideline for DRP and ANZECC guidelines for SIN), raising the question of the adequacy of these guidelines to prevent excessive periphyton growths. DRP concentrations were also found to be increasing over time, while SIN concentrations appear to remain stable.

There is no clear indication of one nutrient generally limiting periphyton growth in the Tutaekuri River. Thus, if a management objective is to reduce the frequency and duration of algal blooms in the Tutaekuri River, both SIN and DRP inputs to the system should be managed. This recommendation is consistent with those made by a panel of experts on limiting nutrients (Wilcock *et al.* 2007). As explained above, the current regional plan (RRMP) DRP guideline appears inadequate to prevent excessive periphyton growth in the Tutaekuri River. Further, the RRMP does not contain any specific water quality guidelines relating to SIN, and the planning implications of any nutrient control measure would need to be carefully assessed.

Further monitoring and investigations are recommended to better identify the sources of nutrients in the Tutaekuri catchment, and clarify the nutrient limitation status of the river during periods of active algal growth. It is also recommended to monitor water quality in the middle Tutaekuri River – upstream of the Mangaone River confluence- to provide information on the state of the middle Tutaekuri River, and its contribution to the nutrient loads in the lower river.

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1. Context

1.1. Introduction

Hawke's Bay Regional Council (HBRC) monitors water quality and river flow at a number of points across the Tutaekuri catchment and has produced a comprehensive report on the state and trends of water quality across the region, based on data collected between 1998 and 2003 (Stansfield 2004).

The present report was commissioned by HBRC to obtain an up-to-date and independent analysis of the state of the water quality in the Tutaekuri River catchment. This report is part of a series of technical reports covering all major catchments in the Hawke's Bay Region, currently being prepared to serve as a base for the upcoming 2009 Hawke's Bay Regional Council's state of the environment report.

1.2. Aim and scope of the study

The aim of this study is to analyse the water quality and biomonitoring data collected by Hawke's Bay Regional Council in the Tutaekuri catchment until August 2008. In particular, the study aims at investigating the following points:

- the state of the Tutaekuri River and its main tributaries;
- temporal trends, *i.e.* are the water quality or the ecological indicators getting better or worse over time?;
- the annual and daily nutrient loadings in the Tutaekuri River;

This report also makes recommendation for future water quality monitoring and management in the Tutaekuri catchment.

2. Methods

2.1. Original dataset

A complete extract of HBRC's water quality database for the Tutaekuri catchment was obtained from HBRC's Water Quality and Ecology teams.

As part of its State of the Environment (SOE) and contact recreation monitoring programmes, HBRC regularly monitors water quality at three sites in the Tutaekuri catchment. Two of these sites are on the Tutaekuri River main stem (Lawrence Hut, in the upper catchment, and Brookfields Bridge in the lower catchment), and one on a major tributary, the Mangaone River at Rissington.

All three sites are currently monitored quarterly, with year-long periods of monthly monitoring every five years. The lower river site (Brookfields Bridge) has been monitored since 1978. Water quality monitoring at the other two sites started in 1994. Due to changes in laboratory analysis procedures[1], only the data collected from January 1994 was used in this report. Average daily flow at each site for each day of sampling was obtained, either by direct measurement or by correlation with a flow recorder site. Table 1 and Table 2 Table 2provide a summary of the water quality and flow data used in this study.

[1] Prior to 1994, the laboratory quantification limit for DRP, ammonia-N and Nitrate N was 0.02 g/m^3. A large proportion of results fall below this limit. As a comparison, the RRMP defines a guideline DRP concentration of 0.015 g/m^3. Post 1994, the detection limits were 0.002 (DRP) and 0.005 g/m^3 (ammonia-N).

2.2. Water quality data preparation

2.2.1. Censored data

The dataset contained a small proportion of "less than detection limit" results. To conduct statistical analysis, such "censored" data should be replaced by numerical values. The "less than" values represented less than 10% of the total dataset for each parameter and were replaced by half of the detection limit, which is consistent with the recommendations of Scarsbrook and McBride (2007).

2.2.2. Bacterial indicators

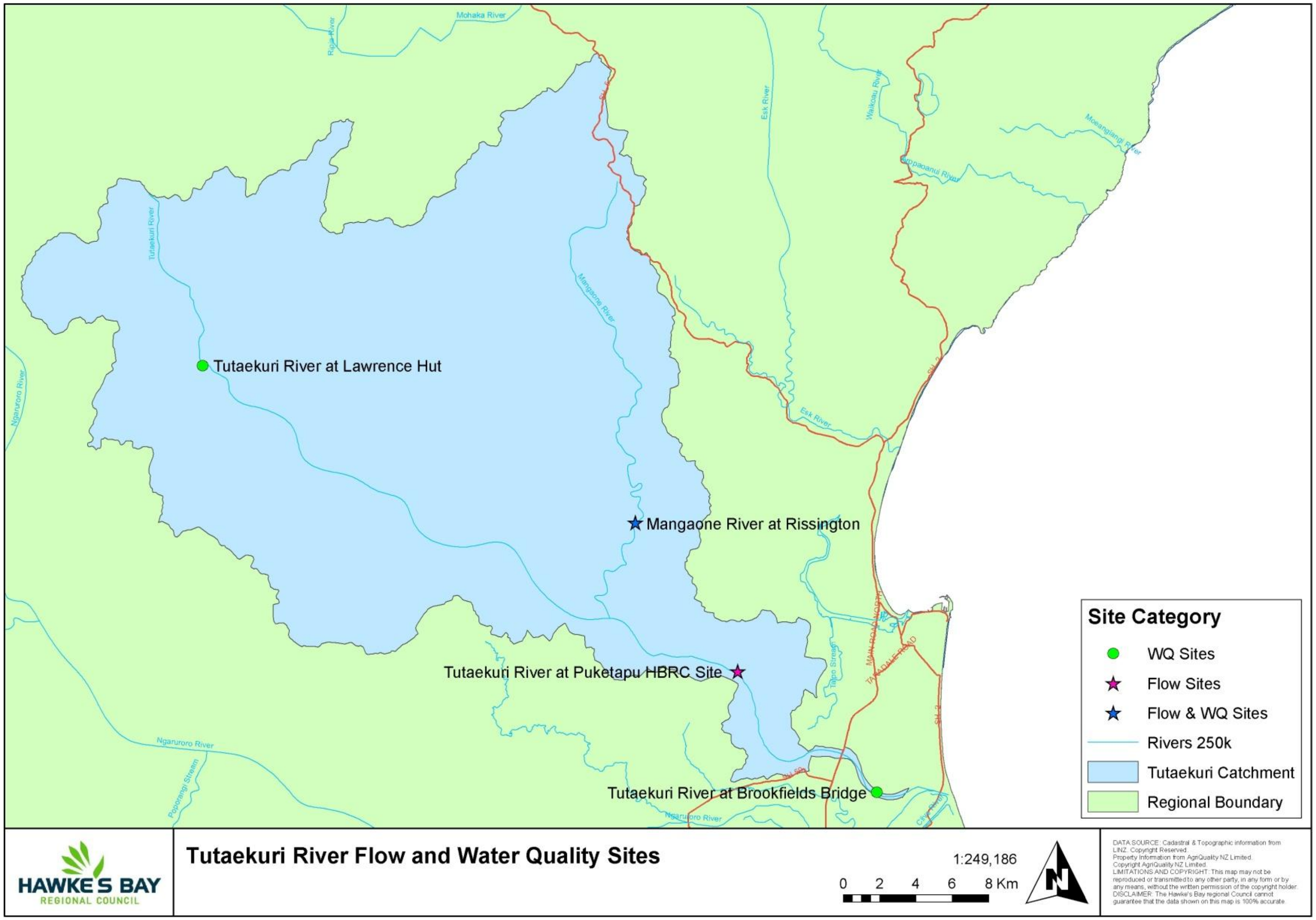
The dataset contained two indicators of bacteriological water quality: faecal coliforms (FC) and *Escherichia coli* (*E. coli*). As part of HBRC's state of the environment monitoring programme, FC was used between 1990 and 2007, and *E. coli* has been used since 2004. Typically, *E. coli* comprise 85-90 % of faecal coliforms in natural waters over several orders of magnitude (Wilcock, 2008), and good correlations can be obtained between the two parameters. Between 10 and 12 samples at each of the three sites were tested for both indicators. This number was considered insufficient to derive robust, site-specific correlations between *E. coli* and Faecal coliforms. Instead, all 33 samples were used to calculate a catchment –wide correlation between the two indicators. To obtain a more consistent dataset, covering a longer period of time, a synthetic *E. coli* data series ($correl^{td}$ *E. coli*) was created for each monitoring site. This dataset was used in particular in the time trends analysis.

2.2.3. Quarterly series

The current SoE monitoring programme for the Tutaekuri catchment comprises quarterly monitoring in February, May, August and November, with additional monthly monitoring every 5 years (Graham Sevicke-Jones, pers. comm.). However, the frequency and regularity of monitoring has varied somewhat between 1994 and 2008. The current quarterly monitoring regime is considered adequate for the Tutaekuri catchment, and will be maintained for the foreseeable future (Graham Sevicke-Jones, pers. Comm.). To maintain consistency with the current quarterly monitoring programme, and allow for comparison with future analysis, the time trend analysis was conducted using quarterly series.

2.3. River flow data

All flow data used in this report was provided by HBRC's Hydrology team. Continuous (15 min interval) flow data is available at two sites in the Tutaekuri catchment (Map 1): Tutaekuri at Puketapu and Mangaone River at Rissington. River flow data for the two Tutaekuri River water quality monitoring sites was obtained from either direct flow gauging or correlation with flow recorded at Puketapu (Table 1). All flow data used in this report was based on daily average flow.



Map 1: Water quality and flow monitoring sites in the Tutaekuri catchment.

Table 1: Flow statistics at the different monitoring sites in the Tutaekuri catchment.

Flow (L/s)	Mangaone River at Rissington	Tutaekuri at Lawrence Hut	Tutaekuri at Brookfields Bridge
3× Median	6,876	8,232	26,389
Median	2,292	2,744	8,796
Lower Quartile	1,737	1,800	5,895
7-day MALF	1,259	1,066	4,156
Minimum	634	321	1,346
Data record	1990 - 2008	1968-2008 (Correlation with Tutaekuri at Puketapu)	

Table 2: Summary of the water quality and flow data used in this study on the Tutaekuri catchment. Phy-Chem: Physico-chemical parameters (temperature, pH, conductivity and dissolved oxygen). Nutrients comprise dissolved reactive phosphorus (DRP) and soluble inorganic nitrogen (SIN). Bacto: bacteriological data (*E. coli* and faecal coliforms). Biom: Biomonitoring (macroinvertebrate and periphyton data

Monitoring site	HBRC Site ID	Water quality data					Flow data	Comments
		Record Period	Parameters					
			Phy-Chem	Nutrients	Bacto	Biom.		
Tutaekuri at Lawrence Hut	272	1994 – 2008	✓	✓	✓	✓	✓	Flow correlation with Tutaekuri at Puketapu
Mangaone at Rissington	266	1994 – 2008	✓	✓	✓	✓	✓	Flow recorder site
Tutaekuri at Brookfields Bridge	13	1994 – 2008	✓	✓	✓	✓	✓	Flow correlation with Tutaekuri at Puketapu

Table 3: Catchment area and vegetation land cover above monitoring sites in the Ngaruroro catchment. (Landcover source: land cover database 2 - LCDBII).

Monitoring site	Catchment area (km^2)	Landcover (% of surface water catchment area above each site)					
		Alpine(a)	Native forest	Native shrubland	Exotic forest	Pasture	Others
Tutaekuri at Lawrence Hut	98	6.3	17	8.2	66	0.6	<2
Mangaone at Rissington	218	<1	<1	<1	<1	99	<1
Tutaekuri at Brookfields Bridge	830	1.1	13	10	8.5	62	5.5

(a) Combination of Alpine gravel and rock, sub Alpine shrubland and tall tussock grassland

2.4. Data analysis

Descriptive statistics (mean, percentiles, confidence intervals), such as those provided in Appendix A and showed in different tables and figures in this report were calculated with a number of macros developed for Microsoft® Office Excel 2007.

To provide more in-depth analysis, water quality data was generally analysed:

- year-round at all flows (i.e. all data available),
- under 3* median flow, to remove the potential influence of flood flows;
- under the lower quartile (25th percentile) flow, to reflect low river flow conditions;

Wilcoxon paired rank tests were used to compare two groups of paired data (e.g. comparing contaminant concentration at two sites with the same sampling dates).

Temporal trend analysis (Kendall seasonal test) was carried out using NIWA's water quality trends software. Probability p- values were subsequently adjusted by False Discovery rate methodology (FDR). Trend analysis for *E. coli* was performed on Log-transformed data.

2.5. Annual Contaminant loads

Contaminant loads are the amount of contaminant carried by the river through one point, or more correctly one transversal section of the river in a given length of time. Calculation methods generally assume that the contaminant concentration is homogenous across the section of river. Annual loads were calculated for water years spanning 1 July-30 June.

When both continuous river flow and contaminant concentration data are available, instantaneous contaminant flux can be calculated at any point in time, and an estimate of the contaminant load during a given period of time can be calculated by simply integrating the instantaneous flux:

$$Load(year_i) = \int_{01/01/year_i}^{31/12/year_i} [Pollut](t) \cdot Flow(t)\, dt$$

When contaminant concentrations are known only at regular time intervals (e.g. monthly), the above formula can be approximated using a number of approaches. The "averaging approach" described below was used in this report. This method uses the average river flow and the average contaminant concentration over a given period of time (e.g. one month or 3 months) to estimate contaminant loads transported during that period of time. The annual load is then calculated by summing up the loads. This method is particularly applicable when the contaminant concentration and river flow are independent variables (Richards, 1998).

Quarterly load: $$Load(Quarter_i) = [Pollut](Quarter_i) \cdot \overline{Flow(Quarter_i)}$$

Annual load: $$Load(year_i) = \sum_{i=1}^{4} Load(Quarter_i)$$

The precision of annual contaminant load estimation based on quarterly sampling compared with monthly sampling was tested as part of the Ngaruroro Catchment study, part of the same series of technical reports (Ausseil, 2009). It was concluded that, whilst the absolute numbers still need to be taken with caution, it appears that annual loads calculated from quarterly sampling should be adequate to compare contaminant loads at different sites sampled concurrently within a given catchment.

Photo 1: Tutaekuri at Lawrence Hut.

Photo 2: Tukipo River at SH50.

3. Water quality in the Tutaekuri catchment

3.1. The Tutaekuri Catchment

The Tutaekuri headwaters are high in the Ruahine Ranges, dominated by Triassic-Jurassic greywacke, a hard sedimentary rock. The catchment headwaters, within the Ruahine Forest Park have predominantly native vegetation assemblages, dominated by native forest, with native shrubland and tussock associations above the tree line. Where it leaves the Forest Park, the Tutaekuri flows through predominantly commercial pine forest. At Lawrence Hut, the Tutaekuri is a clear, fast flowing river with a bed dominated by rocky outcrops, boulders and gravel. The catchment above Lawrence Hut is approximately two-thirds commercial exotic forest, and one-third native vegetation (Table 3).

The middle catchment, including the Mangaone River is dominated by typical Hill country dry stock farming.

Downstream of the Mangaone River confluence the Tutaekuri River valley widens and flattens, and the river takes a more semi-braided morphology. Landuse in the valley flats is dominated by vineyards and orchards, with typical dry stock farming in the surrounding hills.

The Tutaekuri catchment supports a regionally significant brown and rainbow trout fishery. The angling activity is spread throughout the catchment, with the Tutaekuri main stem the most sought after fishery. The trout populations in the catchment are self sustaining, with trout spawning occurring in a number of tributaries.

Recreational activities, such as swimming canoeing/kayaking and fishing occur throughout the catchment.

The Tutaekuri catchment also supports significant ecological values associated with the aquatic and riparian ecosystems and significant habitats of indigenous fauna and flora.

3.2. Water quality Standards and Guidelines

Hawke's Bay Regional Council's Regional Resource Management Plan (RRMP) defines a number of surface water quality guidelines applying to the Tutaekuri catchment. These have primarily a regulatory purpose, particularly in relation to resource consents for activities having a potential or actual effect on water quality.

Although they may not be directly applicable to a regulatory context, environmental guidelines are commonly used in describing the general state of a natural resource. In particular, this report makes extensive use of indicators based on the percentage of samples which comply with environmental guidelines or standards. The 2000 ANZECC Guidelines, the 2002 MfE guidelines for microbiological water quality and the NZ periphyton guidelines (Biggs, 2000) are three documents to consider in relation to surface water quality.

The paragraphs below briefly discuss water quality guidelines and standards for the main physical, chemical, microbiological and biological parameters commonly used in assessing the "health" of a river system, and their appropriateness for the Tutaekuri river system. Table 4 summarises the reference values used in this report for different parts of the Tutaekuri catchment.

3.2.1. Water temperature

The RRMP defines a maximum water temperature of 25°C. However, scientific evidence suggests that this limit may not be adequate to fully protect the Tutaekuri catchment's aquatic communities and trout fishery values.

Water temperatures above 19°C are likely to cause behavioural disturbances of trout, such as cessation of feeding (Hay *et al*. 2007) and may exclude stoneflies (Quinn and Hickey, 1990).

The incipient lethal temperature of brown trout increases with acclimation to a plateau at 24.7°C (Hay *et al*. 2007). A number of field and laboratory studies indicate that a maximum daily temperature of 21 to 23°C will adequately protect most common macroinvertebrate and native fish species (Ausseil and Clark, 2007). Recent research also indicates that stoneflies may be present at occasional temperatures of 22-23°C if other water quality and habitat parameters are suitable for these sensitive species (Dr. John Quinn, pers. comm.).

A maximum water temperature of 19°C is recommended for the Upper Tutaekuri catchment to avoid behavioural disturbances of trout and exclusion of sensitive invertebrate taxa such as stoneflies observed at higher temperatures. A maximum water temperature of 23°C is recommended for the middle and lower catchment to protect most macroinvertebrate species and avoid the potential lethal effects of high temperature on trout.

In this report, compliance with these limits is assessed against the 95th percentile of the data collected at the monitoring sites. It is noted however, that, due to the natural diurnal fluctuation of water temperature, “spot” monitoring data may not adequately capture daily maximum temperature, and continuous monitoring is preferable.

3.2.2. Water pH

Background information on the effects of pH on New Zealand native aquatic biota is scant. One study indicates that a number of native fish species show a definite avoidance of pH values below 6.5, and that pH range of 7 to 9.5 should not be toxic to most NZ fish species (West *et al.*, 1997).

Raleigh *et al.* (1986) suggest the tolerable range of water pH for brown trout is 5 to 9.5, with an optimal range of 6.7 to 7.8. Both the tolerable and optimal pH ranges for trout have been used as benchmark values in this report.

3.2.3. Dissolved oxygen (DO)

The RRMP sets a minimum dissolved oxygen concentration of 80% saturation, applying at all river flows. This is consistent with the RMA S69 standard for waters being managed for fishery purposes. This guideline is used in this report.

It should be noted, however, that instantaneous measurements taken as part of the SOE monitoring programme may have limited value in terms of assessing compliance with the guideline. DO concentration varies diurnally, with maximum values generally late afternoon and minimum values at dawn. Thus, only measurements taken early in the morning, or with continuous monitoring, can provide some useful measure of the daily minimum DO concentration actually occurring in the river.

3.2.1. Organic load

A common cause of deleterious DO depletion is the instream degradation of organic matter by heterotrophic bacteria. Biochemical oxygen demand (BOD) and total organic carbon (TOC) are commonly used indicators of the organic load carried by the water.

TOC is routinely measured as part of HBRC’s state of the environment monitoring programme. This indicator was selected by HBRC to provide better information in waterways with relatively low organic enrichment. BOD is not regularly monitored in the Tutaekuri catchment.

There is no general formula to directly link BOD or TOC with DO. Only site-specific modelling can assist in understanding how the dissolved oxygen concentration reacts to instream organic loads. For this reason, it is difficult to define acceptable TOC concentration thresholds, and this indicator was only used as an indicator of spatial and temporal trends in this report.

3.2.2. Water clarity and suspended solids

The RRMP defines a maximum suspended solids (SS) concentration of 10 mg/l upstream of Redclyffe Bridge and 25 mg/l downstream of that point. Redclyffe Bridge is located downstream of the Mangaone River confluence and upstream of Brookfields Bridge. This guideline applies at all river flows. However, high suspended solids concentrations are expected naturally during floods, thus it is generally recommended to exclude flood flows from a "state of the resource" assessment. Accordingly compliance with the SS standard was assessed at river flows at or below three times the median flow in this report.

The RRMP defines a minimum water clarity of 1.6 m for areas used for contact recreation, which is consistent with the 2002 ANZECC Guidelines for recreational waters. This threshold is used in this report, at flows at or below three times the median flow.

However, a water clarity of 1.6 m may not be sufficient to maintain the foraging efficiency of drift feeding trout, and Hay *et al.* (2007) recommend minimum water clarity of 5 m for regionally significant trout fisheries and 3.5 m for trout fisheries of lesser importance. These limits should apply only under base flow conditions (i.e. under median flow). The same report notes that there may be situations where these guidelines may be unattainable due to the catchment's natural characteristics.

3.2.3. Ammonia

Ammonia can be toxic to many aquatic species, and is a common pollutant in treated domestic, agricultural and industrial wastewater discharges. In aqueous solution, ammonia exists in two chemical forms: the ammonium cation (NH_4^+) and un-ionised ammonia (NH_3). The respective proportion of these forms is determined by a chemical equilibrium governed by pH and temperature. The higher the pH and temperature, the higher the proportion of unionised ammonia. Unionised ammonia being by far the most toxic form to aquatic life, the toxicity of ammonia increases with pH and temperature.

The 2000 ANZECC guidelines define a maximum unionised concentration of 0.035 mg/L (35 ppb) for the 95% protection level. The guidelines also provide tables and formulas to calculate the concentration of total ammonia corresponding to this threshold under different temperature and pH conditions.

The approach taken in this report was to use the 95th percentile of the pH and temperature data distribution observed at different monitoring sites to calculate the total ammonia concentration corresponding to the ANZECC 95% protection level (35 ppb unionised ammonia). The results are summarised in Table 4. The lowest value obtained was retained as the recommended overall guideline for the catchment. Both this guideline and the RRMP guideline (0.1 mg/l) are used in this report.

Table 4: Maximum total ammonia-nitrogen (NH_4-N) concentration recommended by the 2000 ANZECC guidelines for the protection of 95% of aquatic species. Calculations based on ANZECC Guidelines table 8.3.6, 95% protection level (0.035 mg/l un-ionised ammonia), and 95th percentile of water temperature and pH data recorded at monitoring sites in the Tutaekuri catchment.

Site	Temperature (°C) 95th %ile	pH 95th %ile	Recommended Total NH_4-N guideline (mg/l)	
Tutaekuri at Lawrence Hut	17.5	8.1	0.877	0.240
Mangaone at Rissington	22.0	8.8	0.240	
Tutaekuri at Brookfields Bridge	20.0	8.4	0.480	

3.2.4. Bacteriological water quality

Two indicators of the microbiological water quality have been routinely monitored in the Tutaekuri catchment, faecal coliforms (FC) and *Escherichia coli* (*E. coli*). Both are used as indicators of the presence of pathogens of faecal origin in the water, in turn linked with the level of health risk to water users.

The RRMP defines guideline values of 50 faecal coliforms/100mL in the Tutaekuri catchment above Redclyffe bridge (applicable to Tutaekuri at Lawrence Hut and Mangaone at Rissington), 100 FC/100ml between Redclyffe and SH50 bridges, and 150 FC/100ml downstream of SH50 Bridge (applicable to Brookfields Bridge). This guideline applies at river flows at or below median flow.

The 2002 microbiological water quality guidelines (MfE, 2002) define a three-mode management system for recreational freshwaters: Acceptable/green (*E. coli* < 260/100mL); Alert/Amber (*E. coli* < 550/100mL) and Red/Action (*E. coli >550*/100mL). The red mode indicates an unacceptable level of health risks to contact recreation users (*e.g.* swimmers). These are single-value criteria, designed to trigger further investigation and additional sampling (amber mode) and positive action to identify the source(s) of contamination and warn recreational users (red mode).

The 550 *E. coli*/100mL has been used in this report to assess suitability for swimming at all river flows. As *E. coli* are a subset of total faecal coliforms, the RRMP guideline is more stringent than the MfE guideline.

3.2.5. Periphyton biomass, DRP and SIN

Periphyton is the brown or green slime or filaments coating stones, wood or any other stable surfaces in streams and rivers. In some situations, periphyton can proliferate and form thick mats of green or brown filaments on the river bed. The proliferation of periphyton can affect a number of water body values, including life-supporting capacity, recreational and aesthetic values and trout fishery.

Periphyton biomass in a stream or river is forever changing, as result of a dynamic equilibrium between periphyton growth and biomass loss (chiefly through hydrological influence and invertebrate grazing). Generally speaking, floods re-set periphyton biomass at a low level. The flow recession and low flow periods following a flood are termed “accrual period” during which periphyton biomass increases to reach a “peak biomass”. Both the peak biomass and the speed at which it is reached can be increased by high available nutrient concentration in the water.

As part of HBRC’s monitoring programme, periphyton biomass is monitored only once in any given year, after a stable flow (i.e. 2 to 3 weeks without any major hydrological disturbance). As such, a once-per-year sample is not intended to capture the full range of periphyton biomass occurring in a year. Rather, the timing of the monitoring (after a period of stable flow), makes it suitable to provide an indication of the peak biomass likely to be reached during this accrual period. It should be noted however, that very long accrual periods (i.e. a long time between two significant floods) are known to allow the development of high periphyton biomass even with low nutrient concentrations (Biggs, 2000).

The New Zealand periphyton guidelines (Biggs, 2000) recommend a maximum periphyton biomass of 120 mg *chlorophyll a*/m^2 for the protection of trout habitat and recreational values. This biomass level is also suitable to protect a wide range of biodiversity values in slightly enriched systems (Dr Barry Biggs, NIWA, pers. comm.), and was used in this report.

Periphyton growth is generally controlled by a number of physical (e.g. river flow, sunlight, temperature) chemical (e.g. bioavailable nutrient concentration – DRP and SIN) and biological (e.g. grazing by invertebrates) phenomena. In situations when other factors are favourable, particularly during periods of low/stable river flows, high nutrient concentrations are likely to result in undesirable periphyton

proliferation. The setting of nutrient concentrations guidelines or standards is generally used as a way of maintaining periphyton growth below unacceptable levels.

The RRMP defines a maximum DRP concentration of 0.015 mg/l when flow in the river is at or below median flow. This guideline was used in this report. The RRMP does not set maximum concentrations for the other macronutrient, nitrogen. As default values, the ANZECC guidelines for dissolved nitrogen oxides (NO_x – nitrate + nitrite) are recommended for soluble inorganic nitrogen (SIN): 0.167 mg/l in the upper catchment and 0.444 mg/l in the middle and lower catchment, applying when the flow in the river is at or below median flow.

3.2.6. Macroinvertebrate communities

Macroinvertebrate communities are commonly used as an indicator of water quality and ecosystem health. A macroinvertebrate community index (MCI) guideline of 120 (indicative of clean water) is recommended for the upper catchment, and 100[2] (indicative of possible mild pollution) for the Mangaone River and the lower Tutaekuri River site. These recommendations are consistent with the advice provided in (Hay *et al.* 2007) to protect trout fisheries.

Table 5: Summary of recommended guidelines for the Tutaekuri catchment monitoring sites for physical, chemical and biological parameters.

Parameter	River flow	Tutaekuri at Lawrence Hut	Mangaone River at Rissington	Tutaekuri at Brookfields Bridge
Temperature (°C)	All	19	23	23
pH (tolerance range)	All	5.0 – 9.5	5.0 – 9.5	5.0 – 9.5
pH (optimum range)	All	6.7 – 7.8	6.7 – 7.8	6.7 – 7.8
DO (% saturation)	All	80	80	80
Clarity - contact recreation (m)	< 3* median	1.6	1.6	1.6
Clarity (m) (trout)	< 3* median	5	3.5	3.5
SS (mg/l)	< 3* median	10	10	25
Ammonia-N (mg/l)	All	0.24	0.24	0.24
Periphyton biomass (mg *Chlo a*/m^2)	All	120	120	120
SIN (mg/l)	< Median	0.167	0.167	0.444
DRP (mg/l)	< Median	0.015	0.015	0.015
E. coli (/100mL)	All	550	550	550
Faecal coliforms (/100mL)	< Median	50	50	150
MCI	All	120	100	100

[2] Scores above 120 are indicative of clean water; scores of 100 to 119 are indicative of possible mild pollution, scores between 80 and 100 are indicative of probable moderate degradation, and scores less than 80 are indicative of severe pollution.

3.3. Water Quality in the Tutaekuri catchment

3.3.1. Biological monitoring

Macroinvertebrate community index (MCI) results indicate that the upper Tutaekuri River at Lawrence Hut generally complies with the 120 guideline, indicative of clean water. The Mangaone River also complies with the guideline recommended for this site- a score of 100, indicative of possible mild pollution. However, MCI scores at the lower Tutaekuri River site are consistently between 80 and 100, a range indicative of probable moderate pollution (Table 6 and Figure 1).

Periphyton biomass monitoring indicates that nuisance periphyton growths (Table 6 and Figure 2):

- have never been recorded at Lawrence Hut,
- have been recorded on one occasion in the Mangaone River;
- are a common occurrence at Brookfields Bridge.

Table 6: Summary of biomonitoring results at the three Tutaekuri catchment monitoring sites. Sites are presented in the upstream to downstream order.

Parameter	Monitoring Site	Average	Minimum	Maximum	N. of Samples	% Compliance with standard	Standard/ Guideline
Periphyton biomass *Chlorophyll a* (mg/m^2)	Tutaekuri at Lawrence Hut	24	17	72	6	100 (6/6)	120
	Mangaone River	123	10	548	6	83% (5/6)	
	Tutaekuri at Brookfields	129	27	193	6	33% (2/6)	
Macroinvertebrate Community Index (MCI)	Tutaekuri at Lawrence Hut	131	114	155	12	83% (11/12)	120
	Mangaone River	112	70	129	12	92% (11/12)	100
	Tutaekuri at Brookfields	98	86	115	8	38% (3/8)	

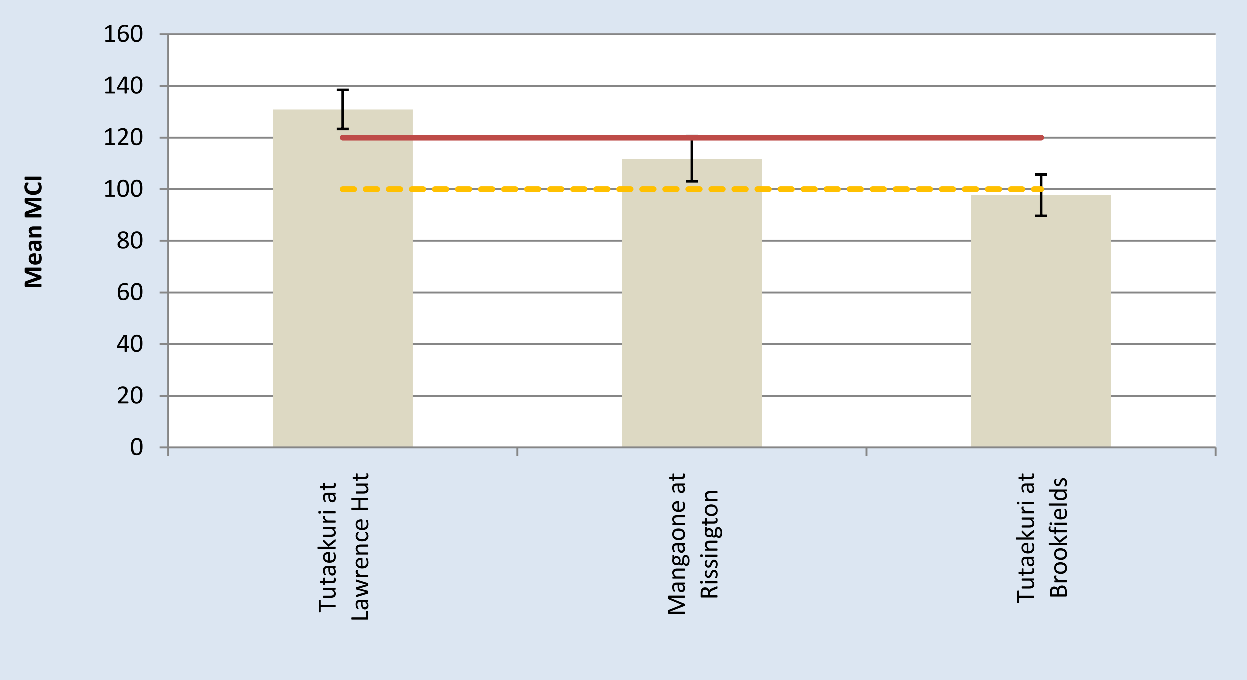


Figure 1: Mean macroinvertebrate community index (MCI) ± 95% confidence interval. Sites in the upper catchment are in clear brown, sites in the middle and lower catchment are in dark brown. The solid red line represents the recommended guideline for the upper catchment; the dotted orange line represents the guideline for the middle and lower catchment.

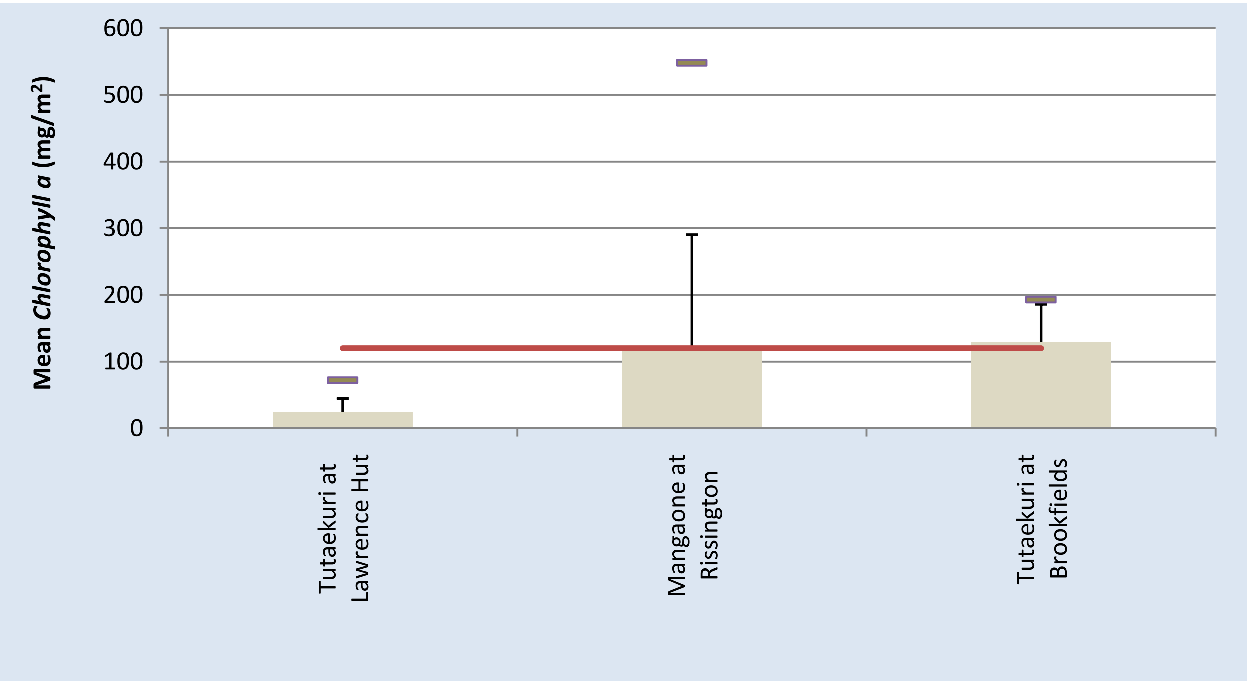


Figure 2: Maximum (rectangles) and mean (columns) periphyton biomass (mg chlorophyll a/m^2) ± 95% confidence interval. The solid red line represents the recommended periphyton biomass guideline for the protection of recreational and trout fishery values.

3.3.2. Nutrients (DRP and SIN)

Concentrations of both nutrients at Lawrence Hut are very low, and always comply with the recommended guidelines (Figure 3 and Figure 4).

Both SIN and DRP concentrations at Mangaone at Rissington and Tutaekuri at Brookfields Bridge occasionally exceed guideline levels, but these exceedances are generally confined to periods of relatively high river flows. Nutrient concentrations generally decrease at lower river flows, and compliance rates with the nutrient guidelines at river flows below median are generally excellent (Table 7).

It is interesting to note that the Mangaone River has generally higher nutrient concentrations than the Tutaekuri at Brookfields, whilst nuisance periphyton growth seems to be a regular occurrence at Tutaekuri at Brookfields, but not at Mangaone at Rissington. This is probably due to differences in channel morphology and shading: the lower Tutaekuri has a wide, flat, mostly shallow and unshaded bed (i.e. ideal conditions for periphyton growth), whilst the Mangaone River is more deeply entrenched and heavily shaded.

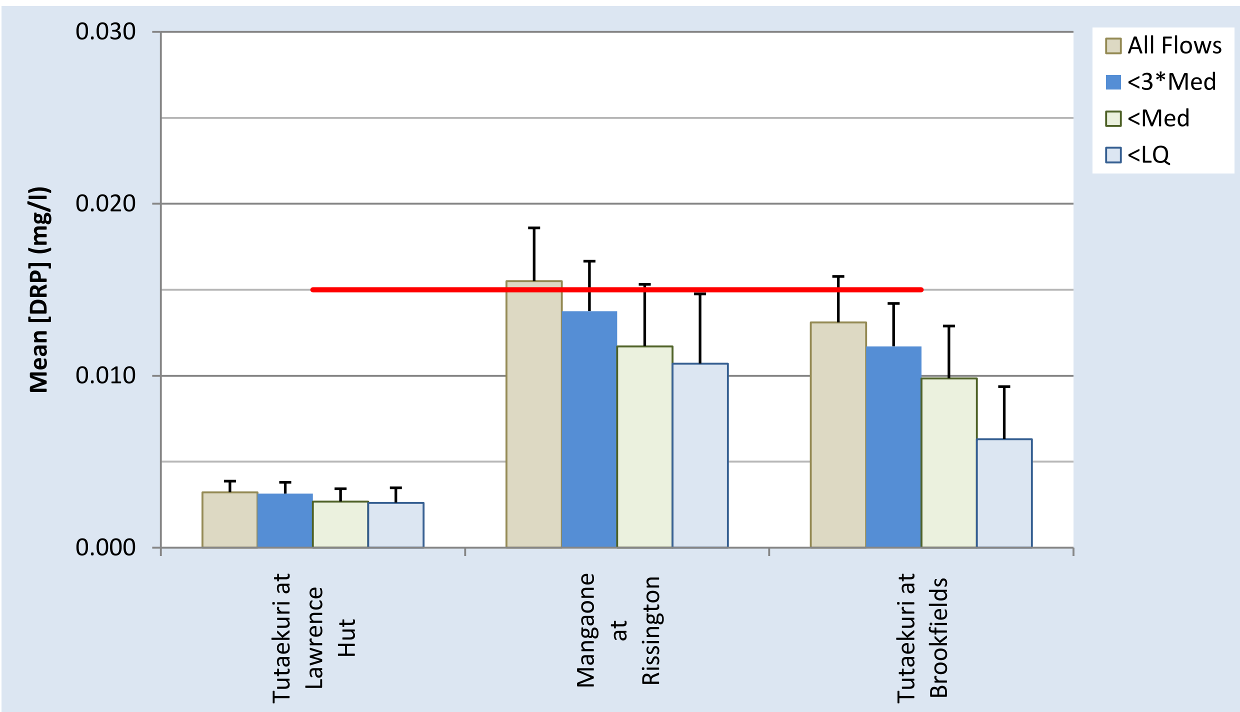


Figure 3: Mean DRP concentrations (mg/L) ± 95% confidence interval under different flow conditions: at all river flows (All flow), below three times the median flow (<3*Med), below median flow (<Med) and below the lower quartile flow (<LQ). The red line indicate the RRMP guideline (0.015 mg/L).

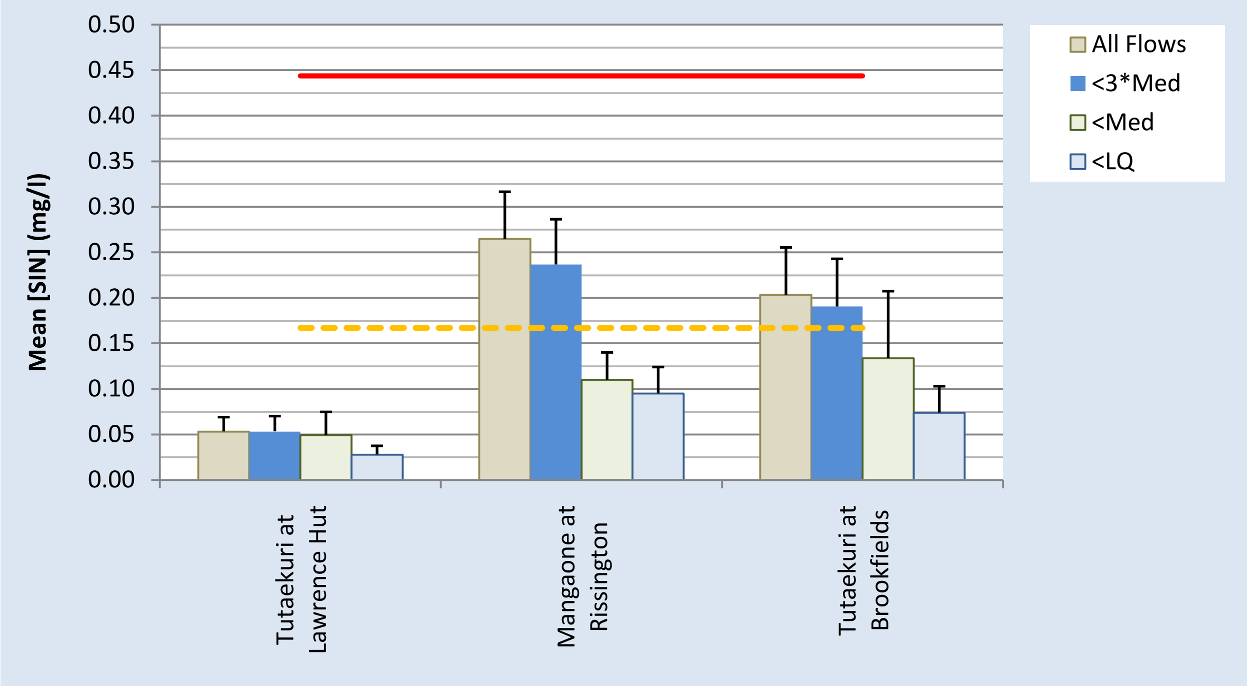


Figure 4: Mean SIN concentrations (mg/l) ± 95% confidence interval under different flow conditions: at all river flows (All flow), below three times the median flow (<3*Med), below median flow (<Med) and below the lower quartile flow (<LQ). The dotted orange line the recommended guideline for the upper catchment (0.167 mg/L) and the plain red line indicates the recommended guideline for the middle and lower catchment (0.444mg/l).

3.3.1. Nutrient limitation

Both nitrogen and phosphorus are needed for periphyton growth in an average weight ratio of 7.5:1, as defined in the Redfield equations (Stumm and Morgan, 1996 in Wilcock *et al.*, 2007). A ratio of approximately 7.5 is the theoretical limit between N-limited (ratio<7.5) and P-limited (Ratio >7.5) conditions.

The SIN/DRP ratio can be a useful indicator of which of SIN or DRP is the likely limiting nutrient for periphyton growth. Generally, elevated SIN/DRP ratios (above 20) are indicative of P-limited conditions, and low ratios (<4) indicate of N-limited conditions. Ratios between 4 and 20 are generally inconclusive or may indicate that the nutrient limitation may "switch" between the two nutrients at different times of the year/ flows. It is important to note that nutrient limitation may only occur when other factors controlling periphyton growth, such as sunlight, hydrological regime and biological activity are favourable and nutrient concentrations (at least one of them) are sufficiently low to limit periphyton growth. When both nutrients are in sufficient supply, nutrient concentration is unlikely to limit algal growth. For this study, this meant using the SIN:DRP ratios only outside flood flows (i.e. below three times median) and when the DRP concentration was below the RRMP standard (0.015 mg/l) or the SIN concentration was below 0.167 mg/l.

It should be stressed that, although a useful indicator, SIN:DRP ratios do not provide a definite answer, and bioassays, such as nutrient diffusing substrates, are generally viewed as a more reliable method to determine nutrient limitation.

Plots of SIN/DRP ratios (Figure 5) do not provide any strong indication of one nutrient being generally likely to be limiting at all times/river flows. There is a pattern of conditions tending towards P-limited conditions at higher river flows and N-limited conditions at lower river flows. This pattern is relatively weak however, and should not be used to recommend management options based on a single nutrient.

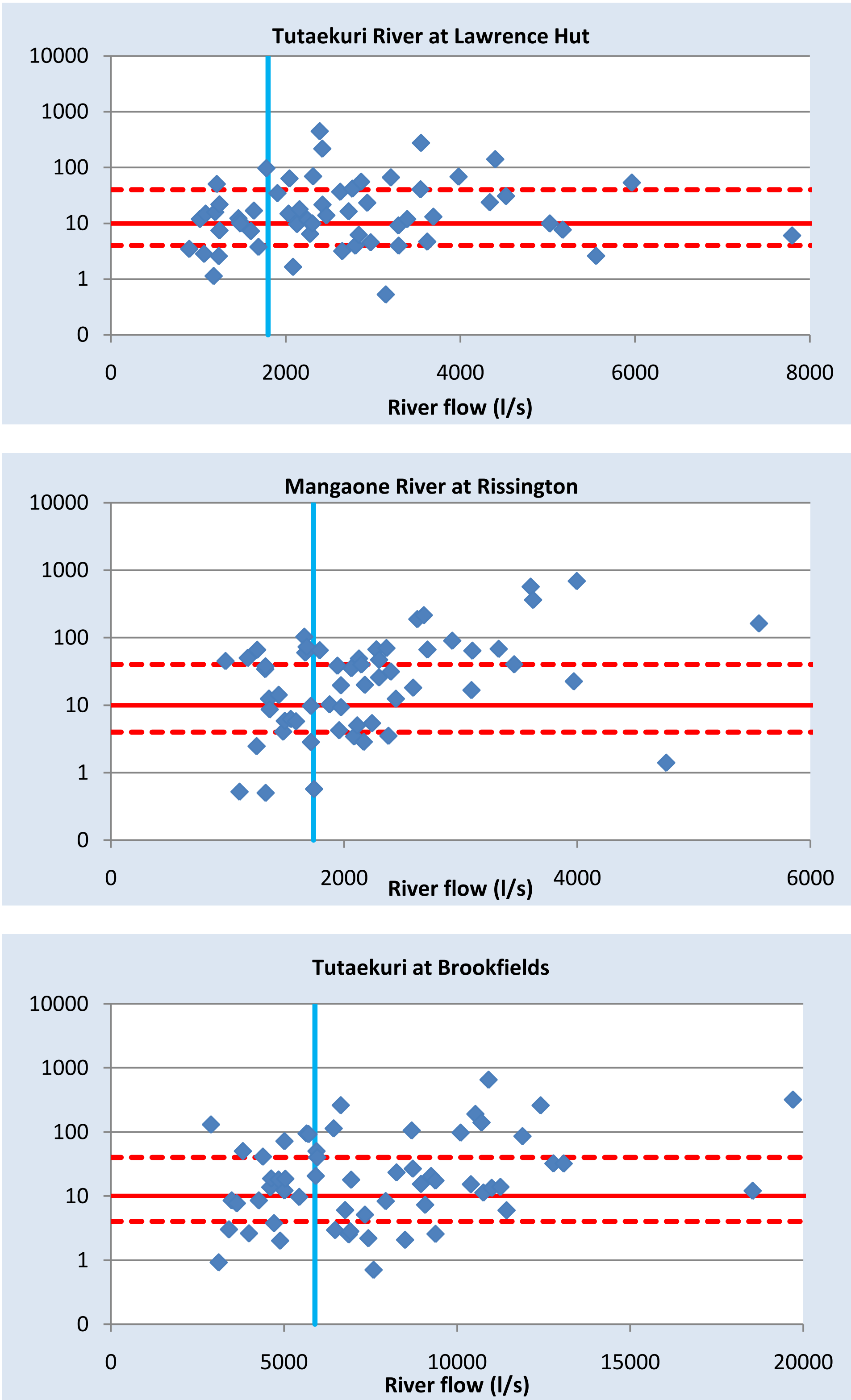


Figure 5: SIN:DRP ratio at monitoring sites in the Tutaekuri. Data for river flows below 3* median flow and when either or both SIN and DRP concentrations are below guideline level (0.015 mg/l for DRP and 0.167 mg/l for SIN. The vertical blue line indicates the Lower quartile flow. Points above the top dashed horizontal red line are indicative of P- limited conditions. Points below the bottom red dashed line are indicative of N-limited conditions.

3.3.2. Microbiological water quality

Figure 6 presents a summary of the dataset obtained by correlating and merging the *E. coli* and faecal coliform results, as explained in section 2.2 of this report.

The microbiological water quality is generally very good at all three sites in the Tutaekuri catchment. All three sites have a rate of compliance with the recreational water quality guideline (550 *E. coli*/100mL) in excess of 94%, based on data collected at all flows. At low flows (below lower quartile flow), the compliance rates was 100% at all three sites. In other words, the microbiological water quality was always suitable for swimming at low river flows, and nearly always at higher flows.

Faecal coliform data indicates relatively low levels of compliance with the RRMP guideline at both Lawrence Hut and in the Mangaone River at Rissington (Table 7). The compliance level is much improved at Brookfields Bridge, but only because the RRMP guideline is less stringent - the actual faecal coliform statistics are similar to those of the two other sites. The relatively high faecal coliforms concentrations at Lawrence Hut and Rissington may indicate a moderate level of faecal contamination. This explanation may be logical for the Mangaone River (which has a predominantly pastoral catchment), but would be surprising for the Tutaekuri at Lawrence Hut given the predominance of native vegetation above this site. Another other explanation is the possibility of "false positive" Faecal coliforms. Faecal coliforms, or bacteria which will be identified as such by laboratory analyses, are known to grow in natural conditions, like decaying leaf litter. This is the reason why *E. coli* in now the preferred indicator of faecal contamination for recreational freshwaters (MfE, 2002).

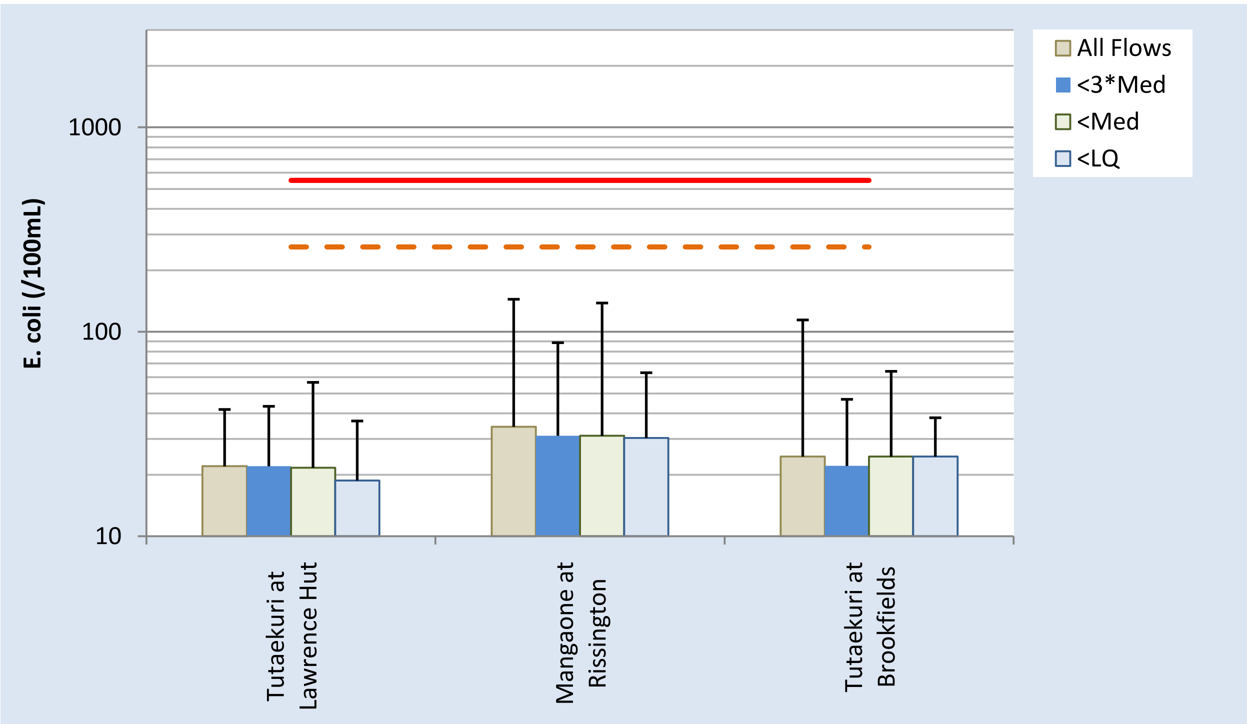


Figure 6: Median *E. coli* concentrations (/100mL) ± 95% confidence interval under different flow conditions: at all river flows (All flow), below three times the median flow (<3*Med), below median flow (<Med) and below the lower quartile flow (<LQ). The dotted orange line represents the recommended guideline for the threshold between Green and Amber modes (260 *E. coli*/100 mL); the solid red line represents the threshold between Amber and Red modes (260 *E. coli*/100 mL) as defined in the MfE microbiological water quality guidelines (2002).

Table 7: Summary of water quality state at three monitoring sites in the Tutaekuri catchment. pH: two guideline ranges have been used, corresponding to (a) tolerable and (b) optimal range for trout. Water clarity: two guideline ranges have been used 3.5m (c) and 5m (d) corresponding to different levels of protection of the trout fishery values. ID: Insufficient data.

Parameter	Monitoring Site	Average	Median	10th / 90th percentile	5th / 95th percentile	N. of Samples	% Compliance with standard	Standard/ Guideline
DRP (g/m^3) Under median flow	Lawrence Hut	0.003	0.002	0.006	0.007	42	100	0.015
	Mangaone	0.012	0.009	0.025	0.028	40	70	
	Brookfields	0.010	0.006	0.023	0.031	42	76	
SIN (g/m^3) Under median flow	Lawrence Hut	0.049	0.028	0.075	0.165	37	95	0.167
	Mangaone	0.110	0.080	0.238	0.310	40	85	
	Brookfields	0.134	0.074	0.243	0.295	42	95	0.444
pH	Lawrence Hut	7.7	7.7	7.4 – 8.1	7.3 – 8.2	22	100(a) / 73(b)	5.0 to 9.5 (a) 6.7 to 7.8 (b)
	Mangaone	8.3	8.3	7.7 – 8.8	7.7 – 8.9	19	100(a) / 16(b)	
	Brookfields	8.1	8.1	7.7 – 8.4	7.7 – 8.5	17	100(a) / 24(b)	
Ammonia-N (g/m^3)	Lawrence Hut	0.021	0.009	0.055	0.092	66	100	0.240
	Mangaone	0.031	0.020	0.048	0.070	83	98	
	Brookfields	0.047	0.020	0.074	0.104	77	99	
Do saturation (%sat)	Lawrence Hut	94	94	88	75	57	91	80
	Mangaone	98	97	81	71	77	90	
	Brookfields	96	96	72	67	72	83	
Suspended Solids (mg/l) <3* Median flow	Lawrence Hut	3.6	1.5	4.5	6.9	76	97	10
	Mangaone	3.3	2.0	7.0	10	77	97	
	Brookfields	5.1	2.5	11	15.5	72	86	25
Water clarity (m) <3* Median flow	Lawrence Hut	4.3	4.3	1.6	1.0	72	90	1.6
	Mangaone	2.6	2.5	1.1	0.9	52	79	
	Brookfields	2.6	2.8	0.6	0.4	51	71	
Water clarity (m) < Median flow	Lawrence Hut	4.5	4.8	2.7	1.6	42	48	5
	Mangaone	3.1	3.0	1.9	1.8	27	30	3.5
	Brookfields	3.3	3.2	2.0	1.5	31	42	
E. coli (/100mL) All flows	Lawrence Hut	14	4	41	58	17	100	550
	Mangaone	144	25	281	750	16	94	
	Brookfields	152	10	240	716	17	94	
Faecal coliforms (/100mL) Under median flow	Lawrence Hut	78	37	140	297	27	67	50
	Mangaone	129	44	160	272	24	54	
	Brookfields	65	38	87	107	24	96	150

3.3.1. Water Clarity

Water clarity records indicate that all three sites comply with the guideline for recreational waters (1.6m at flows below 3* median) at least 71% of the time (Table 7 and Figure 7).

At all three sites, water clarity improves as river flow decreases, a normal, well documented pattern. At base flow conditions (under median flow), the Tutaekuri at Lawrence Hut has a median clarity of 4.8m, and complies with the 5 m clarity guideline for regionally significant trout fisheries about half of the time.

Although significantly lower that at Lawrence Hut, the average water clarity at Brookfields Bridge exceeds 3m at flows under median, and exceeds 3.5m (the guideline for the protection of trout fisheries) during periods of low flow (< lower quartile flow).

The average water clarity in the Mangaone River exceeds 3m, which is satisfactory for a low elevation hill country stream.

3.3.2. Total Organic Carbon (TOC) and Dissolved oxygen

TOC provides an indication of the amount of organic matter in the water column. Whilst relatively low levels are a normal, natural part of the ecosystem, elevated levels are a likely indicator of organic enrichment, either as a result of direct input of organic input (e.g. from a discharge) or as a result of accelerated primary production (e.g. algal growth).

Results presented in Figure 8 indicate very low TOC concentrations at Lawrence Hut, and higher, but still low, concentrations in the Mangaone River and the lower Tutaekuri River.

Compliance with the 80% DO saturation guideline (assessed at river flows below 3* median) is generally good across at Lawrence Hut and Mangaone at Rissington catchment, with at least 90% compliance. Whilst still acceptable, the rate of compliance at Brookfields Bridge (83%) is somewhat lower, and may require further investigation (by way of continuous dissolved oxygen monitoring for a period of time during low river flow).

3.3.1. Water temperature, pH and ammonia

Records indicate that water pH is always within the tolerance range of both native fish species and trout tolerance range (6.5 to 9.5) at all three sites. However, moderately high pH (above 8.5) is recorded on a regular basis at Brookfields and Rissington, and, to a lesser extent at Lawrence Hut. As such, the pH values observed should not be a significant stressor to aquatic life. However, the high pH values will increase ammonia toxicity. High pH values are also a likely indicator of active algal growth[3].

Ammonia concentrations are well below guideline level at all sites. These concentrations are not expected to cause any chronic or acute toxic effects on the aquatic biota. Water temperature in the Tutaekuri and Mangaone Rivers is also generally below guideline levels at all monitoring sites (results presented in Appendix A).

[3] During the day, algal production uses CO_2 faster than it can be replaced from the atmosphere, causing the dominant CO_2/HCO_3^- equilibrium to be displaced so that the pH is increased ($HCO_3^- + H^+ \leftrightarrow CO_2 + H_2O$).

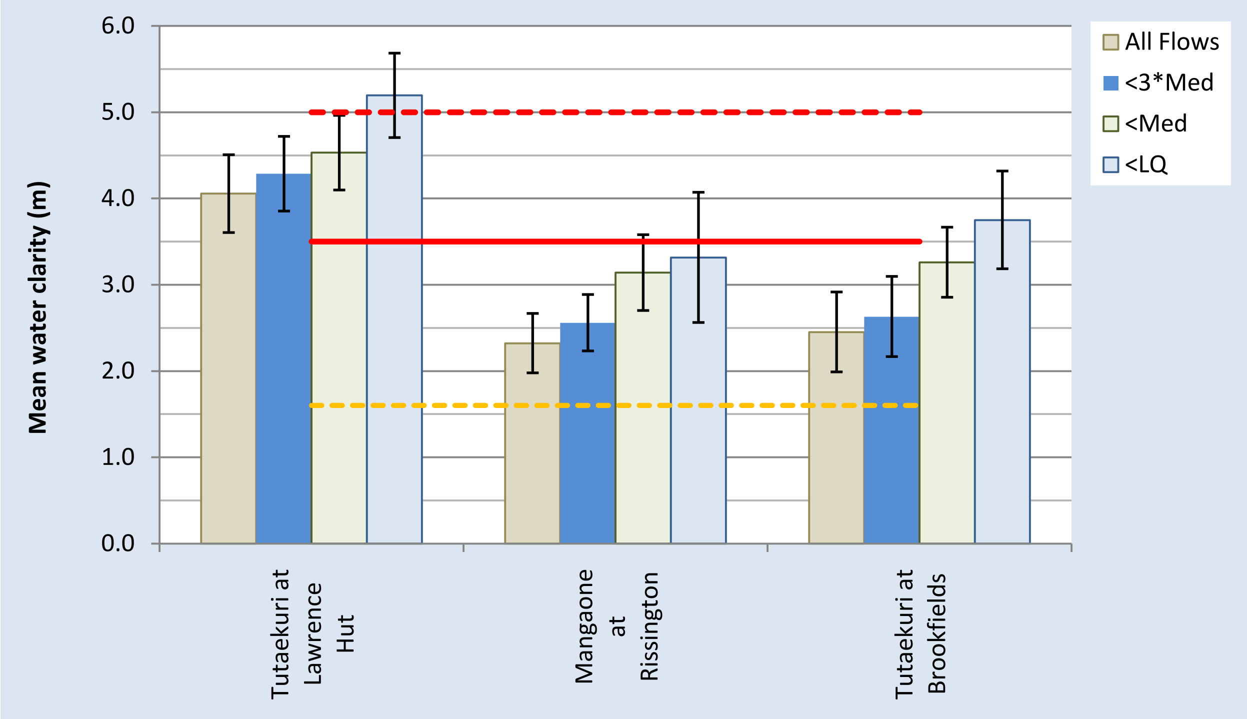


Figure 7: Mean water clarity (m) ± 95% confidence interval under different flow conditions: at all river flows (All flow), below three times the median flow (<3*Med), below median flow (<Med) and below the lower quartile flow (<LQ).The dotted yellow line represents the minimum clarity guideline for recreational waters (1.6m). The red lines represent the recommended water clarity guidelines for the protection of the trout fishery value: 3.5m (solid red line) and 5 m (dotted red line).

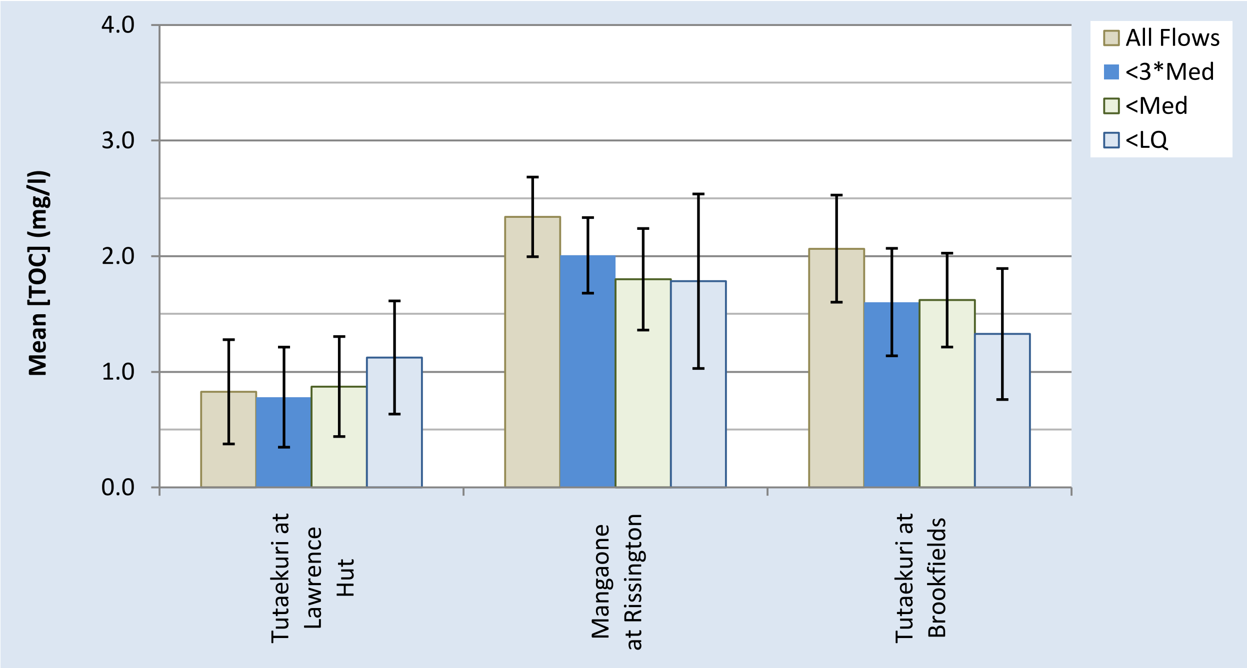


Figure 8: Mean total organic carbon (TOC) (mg/L) ± 95% confidence interval under different flow conditions: at all river flows (All flow), below three times the median flow (<3*Med), below median flow (<Med) and below the lower quartile flow (<LQ).

3.4. Comparison with national figures

A 2008 report prepared by NIWA for the ministry for the Environment to support the 2007 national state of the environment report presents a national summary of regional council data collected between 1996 and 2000. The report uses the River Environment Classification (REC) to define 5 broad classes, based on the source of flow (upland/lowland) and the dominant land cover (natural/pastoral), the fifth category being urban streams (NIWA 2008).

To provide a national perspective, the results obtained in the Tutaekuri catchment were compared to national figures. The comparisons with national figures were undertaken according to each site's REC classification:

- Tutaekuri at Lawrence Hut was compared with national medians for upland rivers with a dominant natural land cover;
- Mangaone at Rissington and Tutaekuri at Brookfields Bridge were compared with national medians for lowland rivers with a dominant pastoral land cover.
-

All sites in the Tutaekuri catchment have better water quality than comparable sites on nationally, for all four parameters considered: DRP, SIN, *E. coli* and water clarity (Table 8).

Table 8: Comparison of water quality statistics for the Tutaekuri catchment sites with national figures from (NIWA 2008). Green shading indicates better water quality than the national median, red shading indicate worse water quality than the national median.

Site	DRP (mg/l, median)		SIN (mg/l, median)		*E. coli* (/100ml, 95th percentile)		Clarity (m, median)	
	National median	Tutaekuri Site	National median	Tutaekuri Site	National median	Tutaekuri Site	National median	Tutaekuri Site
Tutaekuri at Lawrence Hut	0.006	0.002	0.068	0.035	117	58	2.9	4.2
Mangaone at Rissington	0.016	0.012	0.55	0.145	1,542	750	1.2	2.3
Tutaekuri at Brookfields		0.011		0.130		716		2.4

4. Temporal trends

The results of seasonal Kendall tests followed by false discovery rate adjustment performed on data collected at 3 sites across Tutaekuri catchment are presented in Table 9 (DRP, SIN) and Table 10 (SS, *E. coli*). Note that the trend analysis for *E. coli* was performed on Log-transformed data.

Of the three parameters of the dataset which relate directly to water clarity (black disc visibility, suspended solids and turbidity), suspended solids (SS) is the only one that has been monitored regularly since 1994. Black disc visibility readings were seldom taken between 1994 and 1996, then again taken irregularly in 1998 and 1999. Laboratory turbidity measurements were discontinued in 1997. For this reason, the trends analysis was performed on suspended solids.

MCI trends analysis was performed on all data available between 1994 and 2007, at all 3 sites, i.e. 12 consecutive yearly samples at Lawrence Hut and Rissington, and 8 at Brookfields. No significant trends were found at any of the 3 sites.

Significant increasing DRP trends were found at all three sites, with rates of increase ranging between 7 and 12 % per year.

Significant trends were also found at all three sites in relation to *E. coli*, but decreasing (i.e. improving) trends.

No significant trends were detected in relation to SIN or suspended solids.

Table 9: Summary of temporal trends at different monitoring sites in the Tutaekuri catchment. Seasonal Kendall Test, FDR-adjusted p values, Flow adjusted data, covariate adjustment method is LOWESS. NS: Not significant; N.D.; no data.

	DRP				SIN			
Site	Period analysed	Trend	p	Slope (%/year)	Period analysed	Trend	p	Slope (%/year)
Tutaekuri at Lawrence Hut	94 – 08	↗	0.02	+ 9	94 – 08	-	NS	-
Mangaone at Rissington	94 – 08	↗	<0.01	+ 12	94 – 08	-	NS	-
Tutaekuri at Brookfields	94 – 08	↗	<0.01	+ 7	94 – 08	-	NS	-

Table 10: Summary of temporal trends at different monitoring sites in the Tutaekuri catchment. Seasonal Kendall Test, FDR-adjusted p values, Flow adjusted data, covariate adjustment method is LOWESS. NS: Not significant; N.D.; no data.

	Suspended solids				E. coli			
Site	Period analysed	Trend	p	Slope (%/year)	Period analysed	Trend	p	Slope (%/year)
Tutaekuri at Lawrence Hut	94 – 08	-	NS	-	98 – 08	↘	<0.001	-5
Mangaone at Rissington	94 – 08	-	NS	-	97 - 08	↘	<0.05	- 14
Tutaekuri at Brookfields	94 – 08	-	NS	-	98 – 08	↘	<0.01	- 14

5. Contaminant loads analysis

This section of the report presents the results of an analysis of the contaminant loads in the Tutaekuri catchment. The aim is to provide an estimate of the contaminant loads transported in the upper and lower Tutaekuri, and to estimate the contribution from the Mangaone River, both on an annual and a daily low flow basis.

As identified in previous sections of the report, nutrient enrichment and associated periphyton growth in the lower Tutaekuri River appears to be the key issue in the Tutaekuri catchment, thus the annual and low flows daily loads analysis was restricted to DRP and SIN.

5.1. Annual Loads

Annual loads were estimated using the "averaging" approach described in section 2.5 of this report. Results are and summarised in Figure 9 and Figure 10. Full results are reported in Appendix F.

The average annual DRP load at Lawrence Hut is estimated at 0.6 Tonnes per year (T/Y), and 9.0 T/Y at Brookfields. The Mangaone at Rissington is estimated to carry 3.7 T/y, or 41% of the estimated load at Brookfields.

For the SIN, the average annual load is estimated to increase from 8 T/Y at Lawrence Hut to 119 T/Y at Brookfields. The Mangaone at Rissington is estimated to carry 53 T/y, or 44% of the estimated load at Brookfields.

To put these figures into perspective, the Mangaone River's median flow only represents 26% of the median flow at Brookfields.

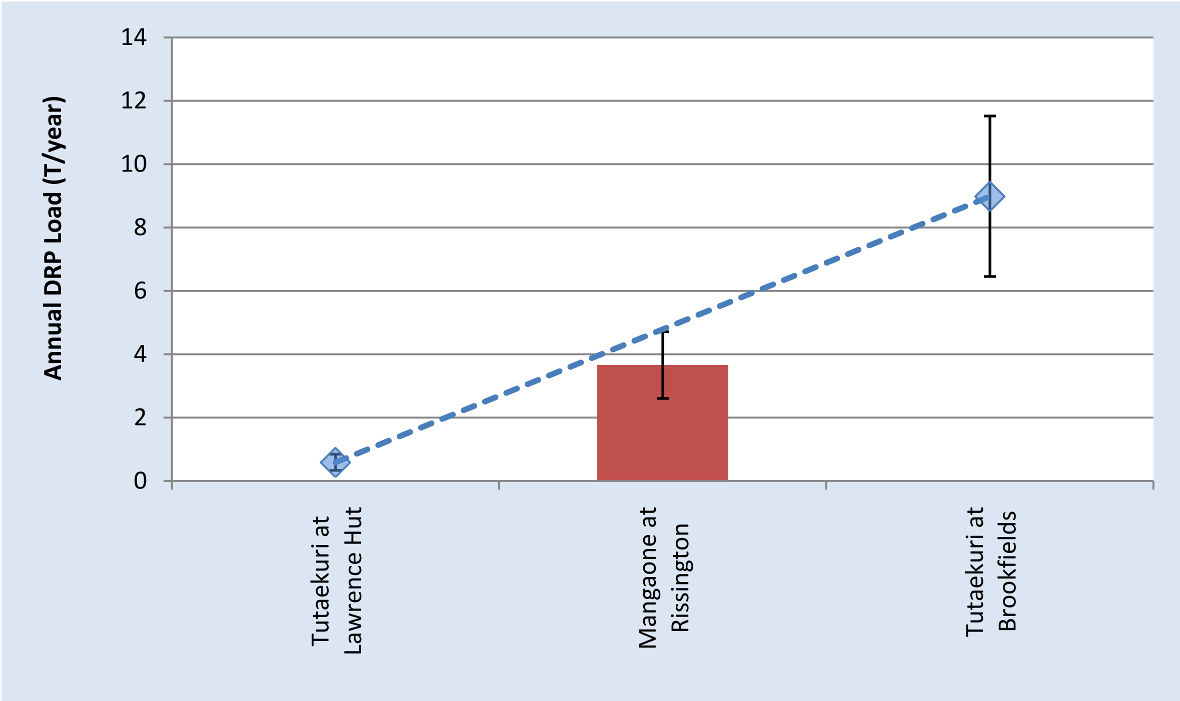


Figure 9: Annual DRP loads (Tonnes per year) at the three Tutaekuri catchment monitoring sites, calculated with the "averaging" approach.

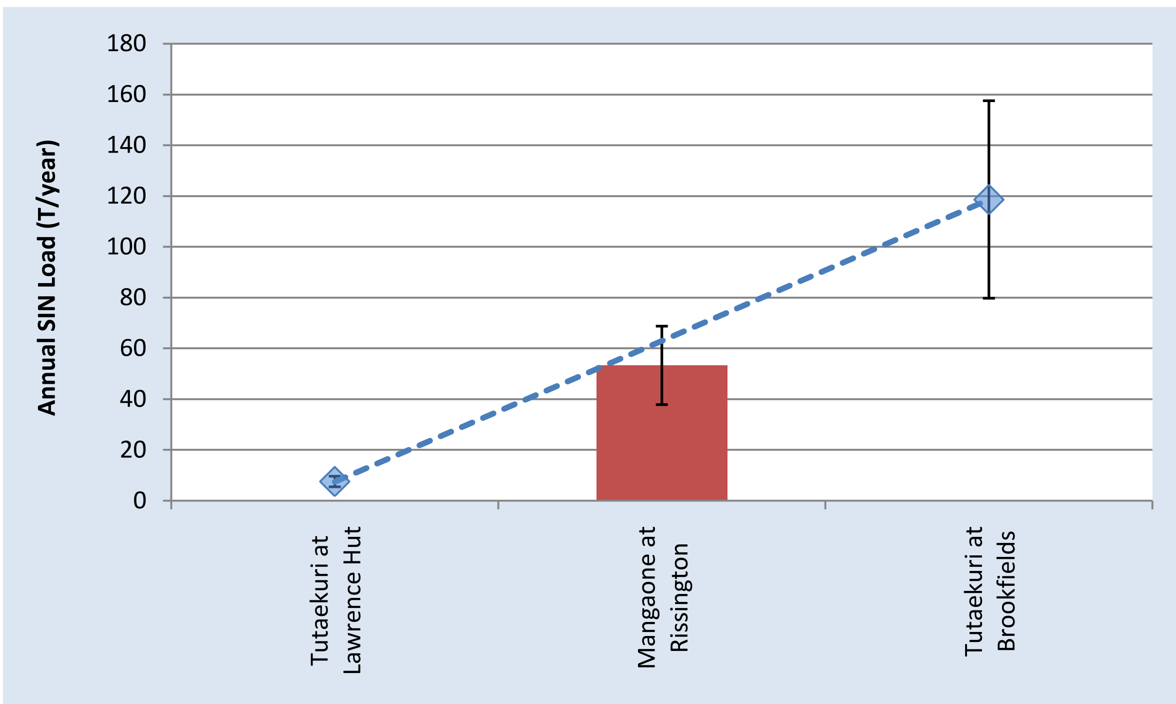


Figure 10: Annual SIN loads (Tonnes per year) at the three Tutaekuri catchment monitoring sites, calculated with the "averaging" approach.

5.2. Nutrient loads under low river flow conditions

5.2.1. Methodology

The approach taken was to estimate the DRP and SIN daily load at the different monitoring sites under different low river flow conditions: median flow, lower quartile flow and mean annual low flow (MALF). The nutrient concentrations at the different monitoring sites under each river flow condition were estimated from the actual dataset, as the average concentration recorded when the flow is at or close to the flow in each scenario.

The patterns observed are very similar for DRP and SIN (Figure 11 and Figure 12):

- The daily loads at Lawrence Hut are generally small in comparison with those estimated at Tutaekuri Brookfields or Mangaone at Rissington;
- At Brookfields, the daily loads decrease sharply with the river flow. The nutrient load at MALF represents only a fraction of the load at median flow (10% for DRP, 12% for SIN), although the river flow at MALF represents about 50% of the median flow. This is consistent with the decrease in nutrient concentrations with dropping river levels at this site described earlier in this report, which is probably explained by a combination of decreased nutrient inputs to the catchment under dry weather, low flow conditions and the utilisation of the available nutrients by the heavy periphyton biomass often present during low flows;
- In the Mangaone River at Rissington, the estimated daily load of both nutrients at MALF represents approximately 40 % of the estimated load at median flow, whilst the MALF represents about 54% of the median flow. The Mangaone River is quite entrenched and shaded, and generally does not have the excessive periphyton growths found in the Tutaekuri at Brookfields Bridge. Available nutrients are therefore much less likely to be utilised in the Mangaone River itself, and are transported to the Tutaekuri River main stem
- At MALF, the daily loads carried by the Mangaone River are estimated to be similar to those at Brookfields.

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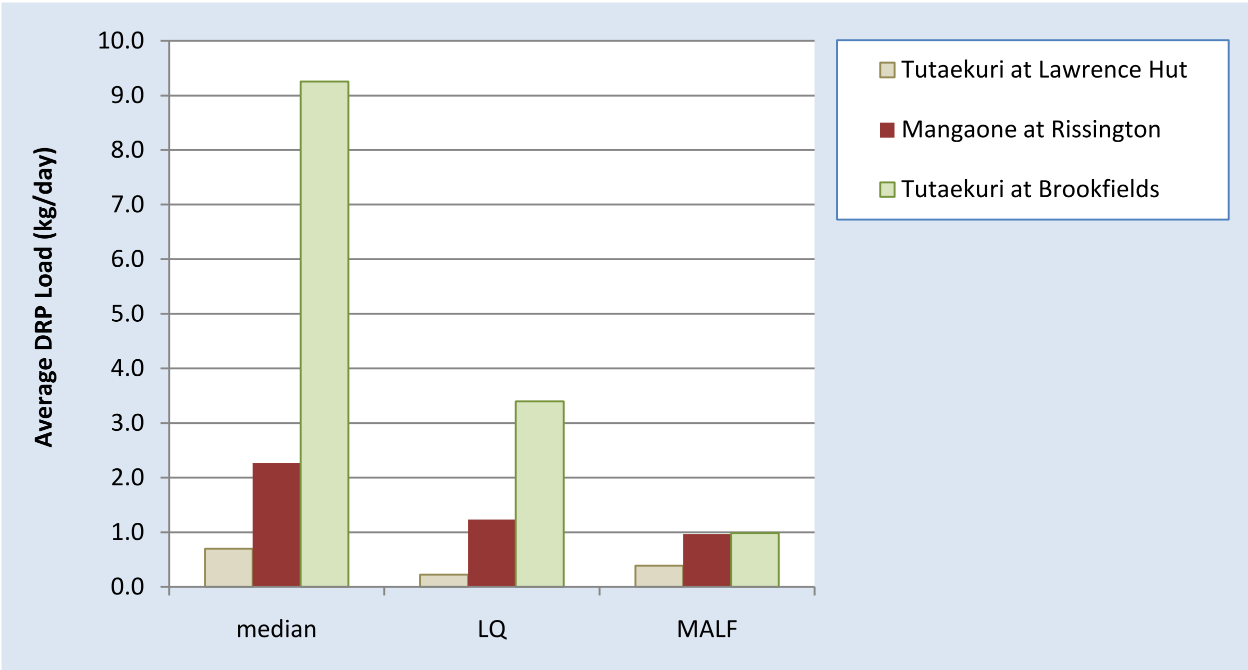

Figure 11: Estimated daily DRP loads (kg/day) in the Tutaekuri catchment under three river flow conditions: median flow, lower quartile flow and 7-day Mean Annual Low Flow (MALF).

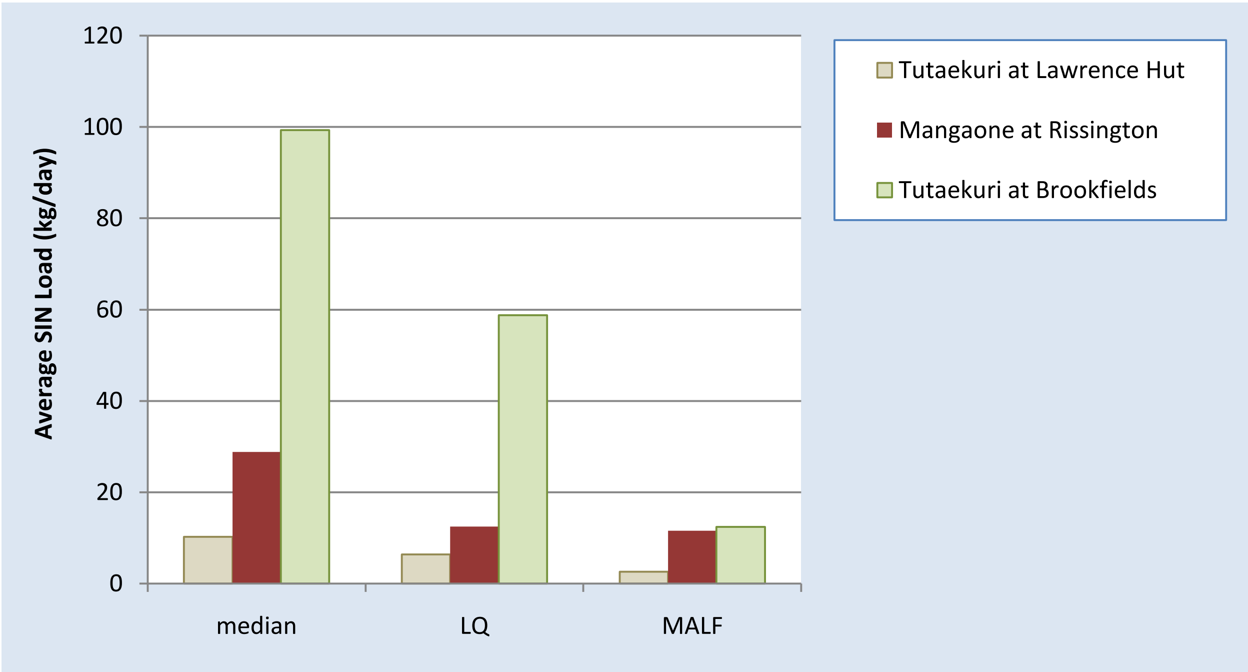

Figure 12: Estimated daily DRP loads (kg/day) in the Tutaekuri catchment under three river flow conditions: median flow, lower quartile flow and 7-day Mean Annual Low Flow (MALF).

6. Discussion and Conclusions

6.1. Water quality of the Tutaekuri River

Most parameters indicate good water quality in the Tutaekuri catchment, which is consistent with the findings of the 2004 study (Stansfield, 2004). The microbiological water quality is generally excellent, indicating a low health risk to river users from pathogens of faecal origin. The generally low ammonia concentrations are unlikely to cause any acute or chronic toxic effects on the aquatic biota. Water clarity outside periods of high river flow is generally excellent at the top of the catchment (Lawrence Hut), and acceptable in the Mangaone River and the lower Tutaekuri River.

The only issue which appears to be significant is the common occurrence of nuisance levels of periphyton in the lower Tutaekuri River during extended periods of low river flows. During these periods, the nutrient (both SIN and DRP) concentrations and daily loads decrease at Brookfields, probably as a result of utilisation by the abundant periphyton. In this context, the Mangaone River appears to contribute significant inputs of both DRP and SIN in the Tutaekuri main stem, possibly contributing to the excessive periphyton growths. It should be noted however, that there are no monitoring sites in the Tutaekuri River between Lawrence Hut and the Mangaone confluence, making it impossible to estimate the nutrient loads carried by the Tutaekuri River upstream of the Mangaone River confluence.

It is interesting to note that these excessive periphyton occur even as the nutrient concentrations are generally lower than similar catchments nationally, and below the recommended guidelines (RRMP guideline for DRP and ANZECC guidelines for SIN), raising the question of the adequacy of these guidelines to prevent excessive periphyton growths. This also indicates that the Tutaekuri River system is possibly particularly sensitive to periphyton growth.

DRP concentrations were also found to be increasing over time, while SIN concentrations appear to remain stable.

6.2. Recommendations

6.2.1. Management implications

There is no clear indication of one nutrient generally limiting periphyton growth in the Tutaekuri River. Thus, if a management objective is to reduce the frequency and duration of algal blooms in the Tutaekuri River, both SIN and DRP inputs to the system should be managed. This recommendation is consistent with those made by a panel of experts on limiting nutrients (Wilcock *et al.* 2007). As explained above, the current regional plan (RRMP) DRP guideline appears inadequate to prevent excessive periphyton growth in the Tutaekuri River. Further, the RRMP does not contain any specific water clarity guidelines relating to SIN, and the planning implications of any nutrient control measure would nee to be carefully assessed.

6.2.2. Further monitoring and investigations

The current monitoring regime is quarterly sampling, with monthly sampling every five years. This regime seems suitable for state of the environment monitoring and reporting purposes in the Tutaekuri catchment, and no change to the sampling frequency is recommended at this stage.

The monitoring network, made of only three sites appears generally sufficient, although the addition of a monitoring site upstream of the Mangaone River confluence would be very useful in providing information on the state of the middle Tutaekuri River and in better understanding the sources of nutrient inputs to the lower Tutaekuri River.

The Mangaone River appears to be a significant source of nutrients for the Tutaekuri River and an investigation aiming at identifying the sources of nutrients in the Mangaone River would be useful. There

does not appear to be any direct, point-source of nutrients in the Mangaone River, thus the investigation needs to focus on diffuse source of nutrients.

As indicated previously, the analysis of SIN:DRP ratios alone does not allow to draw any firm conclusion relating to the nutrient limitation status of the Tutaekuri River. A field investigation based on bioassays, such as nutrient diffusing substrates would probably shed some light on the matter, and would be very helpful in guiding any policy/management directions relating to nutrient management in the Tutaekuri catchment Such a study should be undertaken during periods of active periphyton growth at a number of sites in the catchment (i.e. not limited to the three current monitoring sites) as nutrient limitation in a catchment can vary spatially and temporally.

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APPENDICES

Appendix A: Summary of data – all river flows/year round

SiteID		pH	TEMP (°C)	DO (mg/L)	SDO (%)	BD (m)	TURB (NTU)	SS (mg/L)	TN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	SIN (mg/L)	DRP (mg/L)	SIN/ DRP	SIN Ld (kg/day)	DRP Ld (kg/day)	TP (mg/L)	FC (/100mL)	Coreltd Ecoli	TOC (mg/L)	MCI (Unit)	CHLA (mg/m²)
Tutaekuri River at Brookfields Bridge	Average	8.0	14.4	10	95	2.5	13	20	0.411	0.047	0.003	0.158	0.203	0.013	45	282	18	0.044	407	110	2.1	98	129
	Min	7.3	6.5	5	11	0.0	0	1	0.040	0.003	0.001	0.001	0.006	0.001	1	2	0	0.003	5	1	0.3	86	27
	5%ile	7.5	8.6	7	67	0.3	0	1	0.072	0.003	0.001	0.005	0.015	0.001	2	6	0	0.010	10	2	0.7	87	35
	10%ile	7.5	9.0	8	72	0.4	0	2	0.092	0.004	0.001	0.008	0.026	0.001	3	14	1	0.011	11	5	0.8	87	43
	25%ile	7.8	11.0	9	86	1.0	1	2	0.144	0.010	0.002	0.030	0.050	0.002	8	26	1	0.016	25	9	0.9	88	77
	Median	8.0	14.2	10	95	2.4	2	3	0.328	0.020	0.003	0.096	0.130	0.011	14	85	6	0.025	40	25	1.3	94	155
ALL DATA	75%ile	8.2	18.0	11	104	3.4	4	7	0.517	0.029	0.003	0.240	0.264	0.023	32	259	16	0.035	64	49	1.8	108	185
	90%ile	8.4	19.5	12	117	4.4	10	15	0.782	0.074	0.005	0.413	0.474	0.031	108	623	36	0.053	166	110	3.7	112	190
	95%ile	8.4	20.0	12	129	4.7	27	70	1.137	0.104	0.008	0.474	0.552	0.034	204	969	70	0.103	656	504	5.9	113	191
	Max	8.6	22.0	14	152	9.2	330	442	1.878	1.470	0.012	0.590	1.560	0.051	650	4615	209	0.450	13000	1900	13.9	115	193
	StDev	0.3	4.0	2	21	1.8	52	71	0.384	0.167	0.002	0.156	0.232	0.012	93	612	38	0.080	2002	314	2.5	12	71
	95% C.I.	0.1	0.9	0	5	0.5	12	16	0.105	0.037	0.001	0.035	0.052	0.003	21	137	8	0.018	606	90	0.6	8	57
	Guideline	6.5-9.5	23	8	80	1.6	15	25	0.614	0.24			0.444	0.015	7			0.033	150	550		100	120
	%compliance	100	100	88	82	65	93	81	82	99			87	65	21			73	88	96		38	33
	N	31	82	77	77	55	72	77	51	77	48	78	77	78	77	77	78	78	42	47	72	8	6
	Average	8.2	14.0	10	97	2.3	4.8	7.9	0.540	0.031	0.006	0.234	0.265	0.015	50	104	6	0.041	449	159	2.3	112	123
Mangaone river at Rissington	Min	7.6	5.0	6	54	0.1	0.2	0.5	0.079	0.003	0.001	0.001	0.003	0.001	1	0	0	0.005	1	0	0.4	70	10
	5%ile	7.7	7.3	8	72	0.2	0.4	0.5	0.128	0.003	0.002	0.014	0.025	0.001	2	5	0	0.011	5	2	1.2	89	13
	10%ile	7.7	8.0	8	80	0.5	0.4	1.0	0.146	0.005	0.003	0.029	0.047	0.001	4	7	0	0.013	18	5	1.2	104	16
	25%ile	8.0	9.5	9	91	1.3	0.7	1.5	0.199	0.007	0.003	0.060	0.074	0.002	10	12	0	0.020	26	18	1.3	107	26
ALL DATA	Median	8.2	13.0	10	97	2.3	1.6	2.0	0.490	0.020	0.003	0.140	0.145	0.012	18	31	2	0.028	63	34	1.7	116	47
	75%ile	8.4	18.0	11	104	3.1	2.3	4.0	0.725	0.030	0.006	0.420	0.450	0.024	44	116	5	0.040	132	98	2.3	119	63
	90%ile	8.7	21.0	12	112	4.1	4.2	10.0	0.940	0.048	0.008	0.573	0.633	0.037	72	237	11	0.056	310	233	3.8	128	307
	95%ile	8.8	22.0	12	116	4.5	9.8	24.3	1.360	0.070	0.011	0.649	0.689	0.045	185	428	21	0.076	1291	856	5.4	129	428
	Max	9.1	24.0	15	144	5.9	103.0	155.0	2.883	0.464	0.063	0.891	0.906	0.053	690	924	88	0.464	13000	2291	13.0	129	548
	StDev	0.4	4.9	2	15	1.3	15.1	22.2	0.481	0.060	0.009	0.222	0.240	0.014	106	186	13	0.058	1907	409	2.2	15	209
	95% C.I.	0.1	1.0	0	3	0.3	3.3	4.8	0.132	0.013	0.003	0.048	0.052	0.003	23	40	3	0.012	539	110	0.5	9	167
	Guideline	6.5-9.5	19	8	80	1.6	15	10	0.295	0.24			0.167	0.015	7			0.026	50	550		120	120
	%compliance	100	82	95	90	71	95	92	37	98			53	57	19			48	44	94		25	83
	N	39	88	78	77	58	78	83	51	83	47	81	83	84	83	83	84	84	48	53	78	12	6

SiteID		pH	TEMP (°C)	DO (mg/L)	SDO (%)	BD (m)	TURB (NTU)	SS (mg/L)	TN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	SIN (mg/L)	DRP (mg/L)	SIN/ DRP	SIN Ld (kg/day)	DRP Ld (kg/day)	TP (mg/L)	FC (/100mL)	Coreltd Ecoli	TOC (mg/L)	MCI (Unit)	CHLA (mg/m²)
Tutaekuri at	Average	7.7	11.0	10	94	4.1	4.2	5.5	0.154	0.021	0.003	0.029	0.053	0.003	37	16	1	0.010	63	40	0.8	131	24
Lawrence Hu	Min	7.1	4.0	5	44	0.2	0.2	0.5	0.040	0.003	0.001	0.002	0.008	0.001	1	1	0	0.001	1	1	0.2	114	4
	5%ile	7.2	6.0	8	75	0.6	0.3	0.5	0.055	0.003	0.001	0.005	0.013	0.001	3	2	0	0.001	9	1	0.3	115	5
ALL DATA	10%ile	7.4	6.7	9	88	1.2	0.3	0.5	0.066	0.003	0.001	0.007	0.016	0.001	4	2	0	0.002	10	1	0.3	116	5
	25%ile	7.5	8.0	9	90	2.8	0.4	1.0	0.103	0.005	0.001	0.011	0.021	0.001	6	3	0	0.003	16	9	0.4	121	8
	Median	7.7	11.0	10	94	4.2	0.6	1.5	0.121	0.009	0.002	0.018	0.035	0.002	12	7	0	0.006	36	22	0.6	129	17
	75%ile	7.9	13.4	11	99	5.4	1.3	2.0	0.148	0.020	0.003	0.034	0.052	0.005	34	19	1	0.009	71	38	1.0	141	29
	90%ile	8.0	15.5	12	103	6.2	3.8	6.8	0.307	0.055	0.003	0.045	0.122	0.007	69	46	2	0.018	103	72	2.0	149	51
	95%ile	8.1	17.5	12	108	6.8	18.5	23.2	0.391	0.092	0.010	0.062	0.150	0.009	140	53	4	0.041	153	101	2.4	152	62
	Max	8.3	20.0	15	136	10.0	85.0	108.0	0.495	0.190	0.054	0.440	0.451	0.012	451	100	9	0.102	660	476	3.1	155	72
	StDev	0.3	3.7	2	12	2.0	14.4	17.1	0.104	0.034	0.008	0.050	0.065	0.003	72	21	2	0.017	105	73	0.7	13	26
	95% C.I.	0.1	0.8	0	3	0.5	3.2	3.7	0.029	0.008	0.002	0.011	0.016	0.001	18	5	0	0.004	30	20	0.2	8	20
	Guideline	6.5-9.5	19	8	80	1.6	15	10	0.295	0.24			0.167	0.015	7			0.026	50	550		120	120
	%compliance	100	99	96	91	84	94	94	88	100			95	100	27			94	69	100		83	100
	N	37	86	77	57	77	78	82	50	66	48	78	65	75	62	65	75	83	48	53	65	12	6

Appendix B: Summary of data – river flows under 3* median flow (<3*med)

Site		pH	TEMP (°C)	DO (mg/L)	SDO (%)	BD (m)	TURB (NTU)	SS (mg/L)	TN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	SIN (mg/L)	DRP (mg/L)	SIN/ DRP	SIN Ld (kg/day)	DRP Ld (kg/day)	TP (mg/L)	FC (/100mL)	Coreltd Ecoli	TOC (mg/L)	MCI (Unit)	CHLA (mg/m²)
	Average	8.0	14.6	10	96	2.6	3	5	0.338	0.047	0.003	0.143	0.163	0.190	0.012	48	173	10	0.026	60	43	98	129
Tutaekuri River at Brookfields Bridge	Min	7.3	6.5	5	11	0.3	0	1	0.040	0.003	0.001	0.001	0.001	0.006	0.001	1	2	0	0.003	5	1	86	27
	5%ile	7.5	8.6	8	67	0.4	0	1	0.071	0.003	0.001	0.004	0.002	0.015	0.001	2	6	0	0.010	10	2	87	35
	10%ile	7.5	9.0	8	72	0.6	0	2	0.087	0.003	0.001	0.008	0.007	0.024	0.001	3	13	1	0.011	11	5	87	43
	25%ile	7.8	11.3	9	88	1.2	1	2	0.130	0.010	0.002	0.028	0.026	0.049	0.002	8	24	1	0.016	23	9	88	77
<3*median (26,389 l/s)	Median	8.0	14.5	10	96	2.8	2	3	0.318	0.020	0.003	0.087	0.110	0.118	0.009	15	80	5	0.022	37	22	94	155
	75%ile	8.2	18.0	11	104	3.6	3	6	0.464	0.029	0.003	0.230	0.240	0.248	0.020	34	198	13	0.033	59	45	108	185
	90%ile	8.4	19.6	12	118	4.5	7	11	0.642	0.069	0.005	0.368	0.420	0.450	0.027	112	456	25	0.042	102	80	112	190
	95%ile	8.4	20.0	12	129	4.8	10	15	0.750	0.098	0.006	0.451	0.470	0.527	0.032	221	624	35	0.052	130	102	113	191
	Max	8.6	22.0	14	152	9.2	23	44	1.171	1.470	0.012	0.578	0.582	1.560	0.040	650	1266	67	0.089	660	540	115	193
	StDev	0.3	4.0	2	21	1.7	4	6	0.254	0.173	0.002	0.147	0.160	0.227	0.011	96	233	12	0.015	105	83	12	71
	95% C.I.	0.1	0.9	0	5	0.5	1	1	0.073	0.040	0.001	0.034	0.047	0.052	0.002	22	54	3	0.003	33	25	8	57
	Guideline	6.5-9.5	23	8	80	1.6	15	25	0.614	0.24				0.444	0.015	7			0.033	150	550	100	120
	%compliance	100	100	90	83	71	99	86	87	99				89	70	21			78	95	100	38	33
	N. Samples	30	77	72	72	51	68	72	47	72	44	73	44	72	73	72	72	73	73	39	43	8	6
Mangaone river at Rissington	Average	8.2	14.3	10	98	2.6	1.6	3.3	0.442	0.029	0.005	0.208	0.241	0.237	0.014	52	62	3	0.031	116	83	112	123
	Min	7.6	5.0	6	54	0.4	0.2	0.5	0.079	0.003	0.001	0.001	0.002	0.003	0.001	1	0	0	0.005	1	0	70	10
	5%ile	7.7	7.3	8	71	0.9	0.4	0.5	0.126	0.003	0.002	0.014	0.007	0.024	0.001	2	4	0	0.011	4	2	89	13
	10%ile	7.7	8.0	8	81	1.1	0.4	1.0	0.144	0.004	0.003	0.028	0.025	0.042	0.001	3	6	0	0.013	13	5	104	16
	25%ile	8.0	9.6	9	92	1.8	0.6	1.5	0.184	0.007	0.003	0.056	0.067	0.067	0.002	9	11	0	0.019	25	18	107	26
<3*median (6,876 l/s)	Median	8.2	14.3	10	97	2.5	1.4	2.0	0.377	0.020	0.003	0.120	0.146	0.140	0.010	19	23	2	0.026	52	31	116	47
	75%ile	8.4	18.0	11	105	3.1	2.2	4.0	0.604	0.030	0.006	0.331	0.400	0.363	0.024	47	85	4	0.036	113	65	119	63
	90%ile	8.7	21.0	12	112	4.1	2.8	7.0	0.810	0.039	0.007	0.519	0.597	0.609	0.034	80	161	9	0.050	204	156	128	307
	95%ile	8.8	22.0	12	116	4.7	4.0	10.0	0.915	0.067	0.008	0.612	0.646	0.684	0.037	193	224	11	0.055	286	230	129	428
	Max	9.1	24.0	15	144	5.9	6.8	25.0	1.196	0.464	0.063	0.891	0.896	0.906	0.053	690	495	19	0.200	1700	1391	129	548
	StDev	0.4	4.9	2	15	1.2	1.3	3.5	0.280	0.059	0.009	0.208	0.233	0.223	0.013	110	84	4	0.023	257	203	15	209
	95% C.I.	0.1	1.1	0	3	0.3	0.3	0.8	0.080	0.013	0.003	0.047	0.067	0.050	0.003	25	19	1	0.005	76	58	9	167
	Guideline	6.5-9.5	19	8	80	1.6	15	10	0.295	0.24				0.167	0.015	7			0.026	50	550	120	120
	%compliance	100	80	95	90	79	100	97	40	97				57	62	21			51	48	98	25	83
	N. Samples	37	82	73	72	52	73	77	47	77	43	75	46	77	78	77	77	78	78	44	48	12	6

Site		pH	TEMP (°C)	DO (mg/L)	SDO (%)	BD (m)	TURB (NTU)	SS (mg/L)	TN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	SIN (mg/L)	DRP (mg/L)	SIN/ DRP	SIN Ld (kg/day)	DRP Ld (kg/day)	TP (mg/L)	FC (/100mL)	Coreltd Ecoli	TOC (mg/L)	MCI (Unit)	CHLA (mg/m²)
Tutaekuri at Lawrence Hut	Average	7.7	11.1	10	94	4.3	2.4	3.6	0.155	0.022	0.002	0.028	0.035	0.053	0.003	38	13	1	0.008	65	42	131	24
	Min	7.1	4.0	5	44	0.2	0.2	0.5	0.040	0.003	0.001	0.002	0.002	0.008	0.001	1	1	0	0.001	1	1	114	4
	5%ile	7.2	6.0	8	75	1.0	0.3	0.5	0.055	0.003	0.001	0.005	0.005	0.013	0.001	3	2	0	0.001	8	1	115	5
	10%ile	7.4	6.7	9	88	1.6	0.3	0.5	0.066	0.003	0.001	0.006	0.007	0.016	0.001	3	2	0	0.002	13	2	116	5
	25%ile	7.5	8.0	9	90	3.0	0.4	1.0	0.100	0.005	0.001	0.011	0.012	0.020	0.001	6	3	0	0.003	17	9	121	8
<3*median (8,232 l/s)	Median	7.7	11.3	10	94	4.3	0.5	1.5	0.118	0.009	0.003	0.017	0.023	0.035	0.002	13	7	0	0.005	37	22	129	17
	75%ile	7.9	13.4	11	99	5.5	1.0	2.0	0.153	0.020	0.003	0.030	0.038	0.052	0.005	37	16	1	0.008	70	38	141	29
	90%ile	8.0	15.5	12	103	6.2	3.3	4.5	0.333	0.068	0.003	0.044	0.051	0.138	0.007	69	40	2	0.012	106	74	149	51
	95%ile	8.1	17.6	12	108	6.8	3.9	6.9	0.391	0.092	0.007	0.062	0.066	0.152	0.008	154	47	2	0.020	160	108	152	62
	Max	8.3	20.0	15	136	10.0	85.0	108.0	0.495	0.190	0.014	0.440	0.445	0.451	0.012	451	93	8	0.080	660	476	155	72
	StDev	0.3	3.7	2	13	1.9	10.2	12.6	0.107	0.035	0.003	0.052	0.064	0.067	0.003	74	17	1	0.013	108	76	13	26
	95% C.I.	0.1	0.8	0	3	0.4	2.3	2.8	0.031	0.009	0.001	0.012	0.018	0.017	0.001	19	4	0	0.003	31	21	8	20
	Guideline	6.5-9.5	19	8	80	1.6	15	10	0.295	0.24				0.167	0.015	7			0.026	50	550	120	120
	%compliance	100	99	96	91	90	97	97	87	100				95	100	28			96	69	100	83	100
	N. Samples	34	80	72	54	72	73	76	47	62	44	73	47	61	69	58	61	69	77	45	49	12	6

Appendix C: Summary of data – river flows under median flow (<med)

Site		pH	TEMP (°C)	DO (mg/L)	SDO (%)	BD (m)	TURB (NTU)	SS (mg/L)	TN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	SIN (mg/L)	DRP (mg/L)	SIN/ DRP	SIN Ld (kg/day)	DRP Ld (kg/day)	TP (mg/L)	FC (/100mL)	Coreltd Ecoli	TOC (mg/L)	MCI (Unit)	CHLA (mg/m²)
Tutaekuri	Average	8.1	16.2	10	97	3.3	2	4	0.242	0.057	0.002	0.075	0.134	0.010	32	75	6	0.023	65	48	2	97	139
River at	Min	7.3	8.0	5	11	0.4	0	1	0.040	0.003	0.001	0.001	0.006	0.001	1	2	0	0.003	9	1	0	86	59
Brookfields	5%ile	7.7	10.0	8	67	1.5	0	1	0.059	0.003	0.001	0.001	0.013	0.001	2	5	0	0.009	10	5	1	86	70
Bridge	10%ile	7.7	11.4	8	71	2.0	0	1	0.077	0.003	0.001	0.005	0.015	0.001	2	6	0	0.010	10	6	1	87	80
	25%ile	7.9	14.4	9	88	2.8	1	2	0.102	0.010	0.002	0.016	0.036	0.002	4	16	1	0.015	13	8	1	88	112
	Median	8.1	17.0	10	97	3.2	1	2	0.189	0.020	0.003	0.047	0.074	0.006	13	32	3	0.020	38	25	1	94	155
<median	75%ile	8.2	19.0	11	110	4.0	2	3	0.337	0.026	0.003	0.102	0.137	0.014	37	79	8	0.029	58	46	2	105	182
	90%ile	8.4	19.8	12	124	4.5	3	8	0.453	0.058	0.003	0.207	0.243	0.023	94	149	13	0.035	87	70	3	111	184
	95%ile	8.5	20.0	12	130	4.8	5	11	0.536	0.090	0.005	0.240	0.295	0.031	113	182	22	0.039	107	85	3	113	185
	Max	8.6	22.0	14	152	6.0	10	23	1.060	1.470	0.006	0.361	1.560	0.040	260	895	26	0.072	660	540	14	115	186
	StDev	0.3	3.4	2	24	1.2	2	4	0.213	0.224	0.001	0.085	0.244	0.010	50	143	7	0.013	130	103	2	12	59
	95% C.I.	0.1	1.0	1	7	0.4	1	1	0.079	0.068	0.000	0.026	0.074	0.003	15	43	2	0.004	52	40	1	9	58
	Guideline	6.5-9.5	23	8	80	1.6	15	25	0.614	0.24			0.444	0.015	7			0.033	150	550		100	120
	%compliance	100	100	93	86	94	100	93	96	98			95	76	31			88	96	100		33	25
	N. Samples	17	45	42	42	31	39	41	28	42	26	42	42	42	42	42	42	42	24	26	39	6	4
Mangaone	Average	8.3	16.6	10	102	3.1	1.4	2.9	0.283	0.017	0.003	0.090	0.110	0.012	24	17	2	0.030	129	95	1.8	116	45
river at	Min	7.6	8.0	6	54	1.2	0.2	0.5	0.079	0.003	0.001	0.001	0.003	0.001	1	0	0	0.005	1	0	0.6	104	21
Rissington	5%ile	7.7	9.0	7	77	1.8	0.3	0.5	0.109	0.003	0.001	0.009	0.013	0.001	1	1	0	0.011	4	1	1.2	104	24
	10%ile	7.7	9.5	8	88	1.9	0.4	0.9	0.127	0.003	0.002	0.019	0.025	0.001	3	4	0	0.013	13	5	1.2	105	27
	25%ile	8.1	13.3	9	93	2.3	0.5	1.5	0.150	0.005	0.003	0.030	0.055	0.002	5	7	0	0.019	24	18	1.3	108	35
<median	Median	8.3	17.2	10	103	3.0	0.8	2.0	0.215	0.019	0.003	0.067	0.080	0.009	11	13	1	0.025	44	31	1.5	117	47
	75%ile	8.5	20.0	11	110	4.0	1.6	3.0	0.370	0.027	0.003	0.096	0.139	0.020	39	18	3	0.032	73	57	1.7	125	57
	90%ile	8.8	22.0	12	115	4.7	3.0	5.4	0.495	0.031	0.005	0.204	0.238	0.025	65	39	4	0.041	160	97	3.6	129	62
	95%ile	8.9	22.6	12	129	5.2	4.1	8.2	0.521	0.035	0.006	0.280	0.310	0.028	67	53	5	0.047	272	212	3.9	129	64
	Max	9.1	24.0	15	144	5.9	6.8	11.0	0.940	0.046	0.006	0.420	0.433	0.053	103	85	10	0.200	1700	1391	4.7	129	66
	StDev	0.4	4.5	2	17	1.2	1.4	2.4	0.190	0.012	0.001	0.091	0.097	0.012	26	17	2	0.030	340	274	0.9	10	19
	95% C.I.	0.2	1.4	1	5	0.4	0.4	0.8	0.074	0.004	0.001	0.029	0.030	0.004	8	5	1	0.009	136	107	0.3	8	19
	Guideline	6.5-9.5	19	8	80	1.6	15	10	0.295	0.24			0.167	0.015	7			0.026	50	550		120	120
	%compliance	100	67	92	95	96	100	97	64	100			85	70	35			60	54	96		43	100
	N. Samples	19	42	37	37	27	38	39	25	40	22	37	40	40	40	40	40	40	24	25	36	7	4

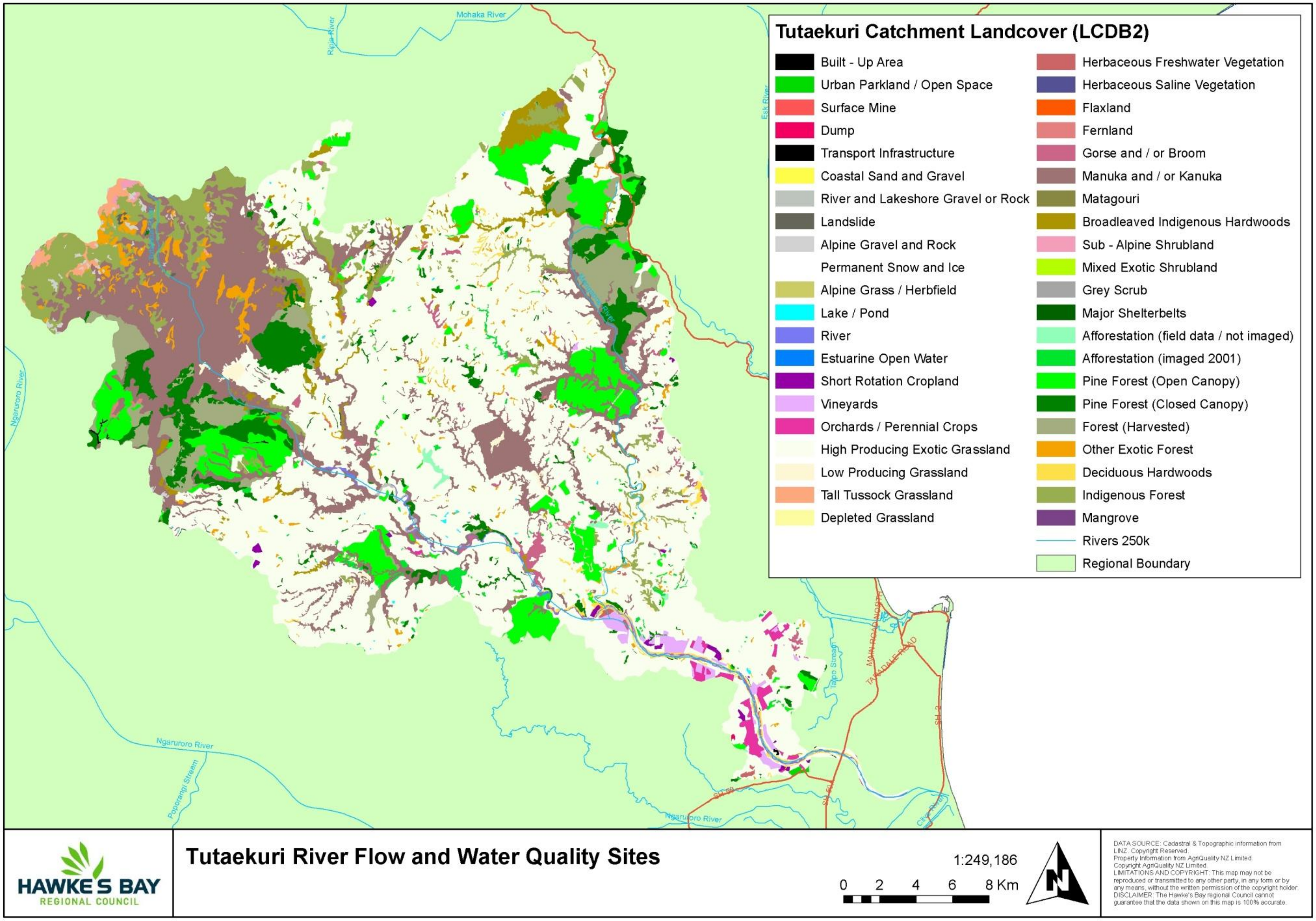
Site		pH	TEMP (^oC)	DO (mg/L)	SDO (%)	BD (m)	TURB (NTU)	SS (mg/L)	TN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	SIN (mg/L)	DRP (mg/L)	SIN/ DRP	SIN Ld (kg/day)	DRP Ld (kg/day)	TP (mg/L)	FC (/100mL)	Coreltd Ecoli	TOC (mg/L)	MCI (Unit)	CHLA (mg/m^2)
Tutaekuri at	Average	7.7	12.0	10	92	4.5	2.7	3.9	0.150	0.020	0.002	0.027	0.049	0.003	38	9	0	0.008	78	52	0.9	135	17
Lawrence Hut	Min	7.1	4.0	5	44	1.0	0.2	0.5	0.040	0.003	0.001	0.003	0.008	0.001	1	1	0	0.001	1	1	0.2	115	4
	5%ile	7.3	5.4	7	69	1.6	0.3	0.5	0.053	0.003	0.001	0.005	0.014	0.001	2	2	0	0.001	5	1	0.3	117	5
<median	10%ile	7.4	6.4	8	81	2.7	0.3	0.5	0.055	0.003	0.001	0.005	0.016	0.001	3	2	0	0.001	11	2	0.3	119	5
	25%ile	7.6	9.0	9	89	3.9	0.3	0.5	0.088	0.005	0.001	0.009	0.020	0.001	7	2	0	0.003	16	9	0.4	123	8
	Median	7.7	12.1	10	93	4.8	0.5	1.5	0.113	0.006	0.003	0.015	0.028	0.002	13	4	0	0.005	37	22	0.5	136	17
	75%ile	7.9	15.0	10	100	5.5	0.7	2.0	0.161	0.016	0.003	0.023	0.037	0.004	22	7	1	0.007	77	60	0.9	144	26
	90%ile	8.1	17.5	11	103	6.2	1.8	3.0	0.305	0.032	0.003	0.038	0.075	0.006	68	11	1	0.012	140	94	2.3	152	28
	95%ile	8.2	18.8	12	107	6.3	3.8	4.0	0.389	0.120	0.003	0.053	0.165	0.007	140	35	1	0.019	297	201	2.7	153	29
	Max	8.3	20.0	15	110	6.9	85.0	108.0	0.495	0.190	0.003	0.440	0.451	0.012	451	93	2	0.080	660	476	3.1	155	30
	StDev	0.3	3.9	2	13	1.4	12.6	15.7	0.111	0.039	0.001	0.064	0.079	0.002	83	17	0	0.015	136	96	0.8	14	12
	95% C.I.	0.1	1.1	0	4	0.4	3.7	4.5	0.041	0.012	0.000	0.019	0.025	0.001	28	5	0	0.004	51	35	0.3	10	12
	Guideline	6.5-9.5	19	8	80	1.6	15	10	0.295	0.24			0.167	0.015	7			0.026	50	550		120	120
	%compliance	100	98	93	89	95	98	98	89	100			95	100	24			96	67	100		88	100
	N. Samples	22	49	45	35	42	45	46	28	38	26	45	37	42	34	37	42	47	27	29	35	8	4

Appendix D: Summary of data – river flows under lower quartile flow (<LQ)

Site		pH	TEMP (°C)	DO (mg/L)	SDO (%)	BD (m)	TURB (NTU)	SS (mg/L)	TN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)	SIN (mg/L)	DRP (mg/L)	SIN/ DRP	SIN Ld (kg/day)	DRP Ld (kg/day)	TP (mg/L)	FC (/100mL)	Coreltd Ecoli	TOC (mg/L)	MCI (Unit)	CHLA (mg/m²)
Tutaekuri River at Brookfields Bridge	Average	8.1	17.7	10	102	3.8	2	3	0.185	0.025	0.002	0.047	0.074	0.006	30	30	2	0.023	39	27	1	93	125
	Min	7.8	13.5	5	49	2.0	0	1	0.080	0.003	0.001	0.001	0.006	0.001	1	2	0	0.003	9	5	0	86	59
	5%ile	7.8	14.4	7	67	2.1	0	1	0.094	0.003	0.001	0.001	0.012	0.001	2	4	0	0.009	10	5	1	86	66
	10%ile	7.8	14.6	8	69	2.3	0	1	0.102	0.005	0.001	0.001	0.013	0.001	3	5	0	0.011	10	5	1	87	73
	25%ile	7.9	15.8	8	88	3.0	0	2	0.103	0.008	0.001	0.008	0.034	0.002	8	13	1	0.013	21	7	1	87	95
<LQ	Median	8.1	18.0	10	101	3.9	1	2	0.133	0.020	0.003	0.027	0.050	0.003	14	19	1	0.018	30	25	1	89	130
	75%ile	8.2	19.3	11	116	4.2	2	2	0.199	0.029	0.003	0.058	0.094	0.006	41	45	3	0.032	52	38	1	94	158
	90%ile	8.3	20.0	12	130	4.8	3	8	0.339	0.036	0.005	0.077	0.143	0.020	92	51	6	0.035	60	49	3	102	175
	95%ile	8.3	21.4	12	138	5.2	5	9	0.392	0.080	0.005	0.135	0.161	0.021	94	62	7	0.039	85	65	3	104	180
	Max	8.4	22.0	14	152	6.0	10	15	0.487	0.100	0.006	0.281	0.297	0.024	130	142	10	0.072	110	90	3	107	186
	StDev	0.2	2.3	2	25	1.1	2	4	0.120	0.024	0.002	0.063	0.068	0.007	37	31	3	0.015	29	25	1	10	64
	95% C.I.	0.1	0.9	1	10	0.6	1	2	0.063	0.010	0.001	0.027	0.029	0.003	16	13	1	0.006	17	13	0	10	72
	Guideline	6.5-9.5	23	8	80	1.6	15	25	0.614	0.24			0.444	0.015	7			0.033	150	550		100	120
	%compliance	100	100	91	86	100	100	95	100	100			100	86	24			86	100	100		25	33
	N. Samples	9	23	22	22	14	19	20	14	21	13	21	21	21	21	21	21	21	11	13	20	4	3
Mangaone river at Rissington	Average	8.3	18.8	10	103	3.3	1.6	2.8	0.234	0.020	0.003	0.067	0.095	0.011	27	12	1	0.038	63	46	1.8	120	44
	Min	7.8	9.0	6	61	1.2	0.2	0.5	0.079	0.003	0.001	0.001	0.003	0.001	1	0	0	0.011	3	2	1.1	110	21
	5%ile	7.9	11.0	8	88	1.5	0.3	0.5	0.116	0.005	0.002	0.023	0.012	0.001	1	1	0	0.019	13	7	1.2	111	23
	10%ile	8.1	16.0	8	93	1.9	0.5	0.5	0.146	0.005	0.002	0.029	0.032	0.001	2	5	0	0.019	21	11	1.2	112	26
	25%ile	8.2	17.5	8	95	2.9	0.6	1.5	0.167	0.009	0.003	0.037	0.059	0.002	5	7	0	0.024	28	20	1.3	115	32
<LQ	Median	8.4	20.0	9	104	3.1	1.0	2.0	0.199	0.021	0.003	0.060	0.083	0.010	11	10	1	0.029	40	30	1.6	120	44
	75%ile	8.4	21.0	11	110	4.1	1.9	3.0	0.269	0.029	0.003	0.095	0.125	0.016	46	16	2	0.037	71	42	1.7	125	55
	90%ile	8.6	22.0	12	116	4.4	3.9	5.2	0.371	0.031	0.003	0.120	0.144	0.024	67	19	3	0.042	87	70	2.5	127	62
	95%ile	8.7	22.6	12	127	5.1	5.3	7.2	0.428	0.036	0.004	0.134	0.169	0.025	75	20	3	0.054	179	139	3.9	128	64
	Max	8.8	23.0	12	142	5.9	6.8	10.0	0.490	0.046	0.005	0.149	0.308	0.026	103	35	3	0.200	290	237	4.7	129	66
	StDev	0.3	3.6	2	16	1.3	1.8	2.3	0.114	0.012	0.001	0.040	0.066	0.009	30	8	1	0.039	76	60	0.9	10	32
	95% C.I.	0.2	1.5	1	7	0.8	0.8	1.0	0.064	0.005	0.001	0.019	0.029	0.004	13	3	0	0.017	43	33	0.4	11	44
	Guideline	6.5-9.5	19	8	80	1.6	15	10	0.295	0.24			0.167	0.015	7			0.026	50	550		120	120
	%compliance	100	43	95	95	91	100	100	75	100			95	75	40			40	58	100		67	100
	N. Samples	11	21	19	19	11	19	20	12	20	10	17	20	20	20	20	20	20	12	13	18	3	2

Tutaekuri at Lawrence Hut	Average	7.8	14.2	9	92	5.2	0.8	1.7	0.124	0.015	0.002	0.017	0.028	0.003	17	3	0	0.008	47	30	1.1	128	12
	Min	7.3	8.5	5	44	1.6	0.2	0.5	0.040	0.003	0.001	0.003	0.008	0.001	1	1	0	0.001	1	1	0.3	115	4
	5%ile	7.4	9.0	7	72	3.4	0.2	0.5	0.049	0.003	0.001	0.003	0.013	0.001	2	1	0	0.001	2	1	0.3	116	4
	10%ile	7.5	10.0	8	76	4.0	0.3	0.5	0.053	0.003	0.001	0.005	0.014	0.001	3	2	0	0.001	5	1	0.3	118	5
	25%ile	7.6	12.5	9	89	4.6	0.3	0.8	0.061	0.005	0.001	0.007	0.018	0.001	4	2	0	0.003	16	4	0.4	121	6
<LQ	Median	7.7	13.5	9	94	5.4	0.4	1.5	0.110	0.006	0.002	0.011	0.020	0.002	11	2	0	0.006	30	19	0.6	123	9
	75%ile	8.0	15.8	10	100	6.1	0.7	2.0	0.116	0.013	0.003	0.017	0.028	0.004	16	3	0	0.007	53	36	2.2	140	17
	90%ile	8.2	18.8	11	103	6.3	1.9	3.0	0.225	0.031	0.003	0.044	0.053	0.006	34	5	1	0.011	110	76	2.7	141	21
	95%ile	8.2	19.0	11	107	6.3	3.5	3.9	0.305	0.039	0.003	0.055	0.064	0.007	60	7	1	0.012	140	97	3.0	142	23
	Max	8.3	20.0	12	107	6.9	4.0	4.0	0.385	0.120	0.003	0.062	0.098	0.007	98	15	1	0.080	170	123	3.1	142	24
	StDev	0.3	3.2	2	14	1.2	1.0	1.0	0.091	0.026	0.001	0.016	0.021	0.002	24	3	0	0.016	49	35	1.0	12	10
	95% C.I.	0.2	1.3	1	6	0.5	0.4	0.4	0.046	0.011	0.000	0.007	0.010	0.001	11	1	0	0.006	27	18	0.5	11	12
	Guideline	6.5-9.5	19	8	80	1.6	15	10	0.295	0.24			0.167	0.015	7			0.026	50	550		120	120
	%compliance	100	96	92	86	100	100	100	93	100			100	100	29			96	69	100		80	100
	N. Samples	12	25	24	21	23	22	23	15	20	13	22	19	22	17	19	22	24	13	15	17	5	3

Appendix E: Tutaekuri catchment landcover map (Source: LCDB2).



Appendix F: Annual load calculation results

Table 11: Estimated annual DRP load in tonnes per year (T/Y).

Monitoring site	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008
Tutaekuri at Lawrence Hut	0.1	0.2	0.6	0.2	1.5	0.7	0.9	0.9	0.5	0.4
Mangaone at Rissington	1.6	1.0	3.3	2.4	3.3	5.4	4.8	6.5	4.2	4.2
Tutaekuri at Brookfields	5.4	2.2	8.7	4.6	13	9.9	9.4	16.2	10.1	10.2

Table 12: Estimated annual SIN load in tonnes per year (T/Y).

Monitoring site	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008
Tutaekuri at Lawrence Hut	9.2	13	6.1	3.2	8.3	4.4	9.5	11	3.6	6.2
Mangaone at Rissington	17	11	59	42	65	67	72	94	52	53
Tutaekuri at Brookfields	59	29	115	224	188	58	108	182	108	116