RIVER LAKE

# Catchment water quality and loads to Maketū Estuary and Little Waihi Estuary

Prepared for:

**Bay of Plenty Regional Council**

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# Executive summary

Bay of Plenty Regional Council (BOPRC) is undertaking a Coastal Receiving Environments (CRE) Project to support the process of setting nutrient limits for the upstream catchments. This report summarises the water quality state and trends and calculates the contaminant load for surface water entering the Ongatoro /Maketū Estuary and the Little Waihi Estuary. The Estuarine Trophic Index (ETI) Screening Tool 1 was applied to classify the susceptibility of the estuaries to eutrophication.

The Kaituna River re-diversion project will change the hydraulic and nutrient loads entering the Ongatoro /Maketū Estuary, and is expected to improve the ecological condition of the estuary by increased flushing. The nutrient loads entering the estuary were calculated assuming inputs after the re-diversion project is complete.

Post re-diversion, about 93% of the catchment load of nitrogen (N) and phosphorus (P) to Maketū Estuary comes from the Kaituna River. Water quality in the lower Kaituna River is characterised by moderately high total nitrogen (TN) (0.8 g/m$^3$), moderately high total phosphorus (TP) (0.06 g/m$^3$) and low suspended solids (TSS). The concentration of *E.coli* bacteria are within bathing water guidelines at Te Matai but increase downstream to exceed the guidelines at Te Tumu.

Over the last 25 years there has been no significant trend in TN but the fraction in the form of nitrate has increased. There has been a weak decreasing trend in TP and DRP over the last 25 years at Te Matai, but an increasing trend at Te Tumu since 2007.

The total catchment load of nitrogen and phosphorus to the Maketū Estuary <u>post re-diversion</u> was calculated to be 267 t/yr and 20.1 t/yr respectively. This corresponds to an average areal load of nitrogen and phosphorus to the Maketū Estuary of 31 mg/m$^2$/day and 2.3 mg/m$^2$/day. The Estuarine Trophic Index Screening Tool classified the combined Physical and Nutrient Load Susceptibility of the Maketū Estuary as 'moderate'.

A priority sub-catchment for reducing nutrient inputs to Maketū Estuary is the Waitipuia Stream and Singletons Drain Pump Station. Although these inputs contribute only about 5% of the total N and P load to Maketū Estuary, they nevertheless have a considerable influence on the water quality in the southern part of the Maketū Estuary due to the limited flushing in this embayment.

The Little Waihi Estuary has four main inflows: Pukehina canal, Pongakawa canal, Wharere canal, and Kaikokopu canal. About half of the flow enters via the Pongakawa canal and a third from the Kaikokopu canal. The water quality of the inflowing stream is characterised by high concentrations of TN (1.6 g/m$^3$) and TP (0.14 g/m$^3$). The nutrient concentrations are high even in the headwaters springs of the Pongakawa Stream. A high proportion of nutrients are in the dissolved form (i.e. readily bioavailable).

Over the last 25 year the Pongakawa Stream has had a long-term increase in nitrate concentrations, a decrease in DRP since about 2009 but an increase in TP since about 2015.

The total catchment load of nitrogen and phosphorus to the Waihi Estuary was calculated to be 517 t/yr and 50.1 t/yr respectively. This corresponds to an average areal load of nitrogen and phosphorus to the Waihi Estuary of 52 mg/m$^2$/day and 5 mg/m$^2$/day. The ETI Screening Tool classified the combined Physical and Nutrient Load Susceptibility of the Waihi Estuary as just within the 'high' category.

# 1 Introduction

## 1.1 Background

Bay of Plenty Regional Council (BOPRC) is undertaking a Coastal Receiving Environments (CRE) Project to support the process of setting nutrient limits for the upstream catchments. Part of the CRE Project requires estimating the current load of contaminants entering the Ongatoro /Maketū Estuary and the Little Waihi Estuary (Figure 1.1).

The priority focus in on understanding loads to estuarine environments compared to the open coast because estuaries are considerably more sensitive to nutrient inputs, they have less flushing and dilution and are more susceptible to excessive algae accumulations.

River Lake Ltd was engaged to summarise the water quality and calculate the contaminant loads for surface water entering the Ongatoro /Maketū Estuary and the Little Waihi Estuary. In particular this required:

- Identify and describe the freshwater inputs of contaminants;
- Summarise surface water quality and quantity of inflows to the estuary;
- Summarise any trends in water quality where data is available;
- Estimated the catchment load from surface water inputs for total nitrogen (TN), dissolved inorganic nitrogen (DIN), total phosphorus (TP), dissolved reactive phosphorus (DRP), total suspended solids (TSS), and *E.coli* bacteria (*E.coli*).
- Delineate uncertainties around freshwater contribution of contaminant loads and hydrology.

The assessment provided in this report is based on the available information from the BOPRC and literature. No fieldwork was undertaken to fill any data gaps. The focus has been on characterising and estimating direct inputs to the estuaries rather than identifying different sources within the wider catchment.

Work is currently being undertaken to re-divert part of the Kaituna River back into the Ongatoro / Maketū Estuary. Consequently, this report compares loads to the Maketū Estuary both before and after the re-diversion.

Options are currently being considered for the long-term location of the Ford Road Pump Station. For the purpose of this report, it was assumed that Ford Road Pump Station discharge would remain in its current location.


**Figure 2.1:** Location of Maketū Estuary and Little Waihi Estuary (source NZ TopoMap).

# 2 Methods

## 2.1 Data sources

Water quality data and stream flow was obtained from Bay of Plenty Regional Council (BOPRC). Monitoring of drain inflows has occurred at different times over the years. For the purpose of assessing state this report uses all data available in the period.

River flow has been modelled at national level based on the River Environment Classification ("Geographic pattern of natural river flows" measure on the Environmental Indicators, Te taiao Aotearoa website, Ministry for the Environment). This dataset was used to provide a rough estimate of mean flow where other flow data was not available

## 2.2 Loads

The catchment load to the estuaries of each variable was calculated by summing the average of each inflow multiplied by the average concentration. This is a simple approach and has the potential to underestimate the actual load if there is a positive correlation between flow and concentrations. However, it is considered a reasonable approach to apply to the Kaituna River (96% of the flow to Maketū Estuary) and to the Pongakawa Stream (50% of the flow to the Waihi Estuary). In the Kaituna River TN and TP concentrations reduced with higher flow, and TSS concentrations increased, but the changes were relatively small (discussed in section 3.4). Furthermore, the flow volumes to the Maketū Estuary are modulated by relative tidal water levels at the Ford Road flap gates.

The Pongakawa Stream had no increase of TP with flow and very little increase in TN (about 6%). There may be positive relationships between TN and TP with flow in other streams but long-term continuous flow records were not available from other streams (section 4).

Apart from the Pongakawa Stream and Kaituna River, the other inflow volumes were based on a hydrological catchment analysis. The values are approximate because of the uncertainty in defining catchment area in the flat landscape with interconnected drainage systems.

## 2.3 Water quality trends

Water quality trends were assessed using the seasonal-Kendall test in the freeware “TimeTrends 6.3”. The seasonal-Kendall test calculates both whether a trend is statistically significant (i.e. its *p*-value) and the magnitude of change (i.e. the Sen slope). The Sen slope is the median annual slope of all possible pairs of values in each season. The Sen slope for each test was normalised by dividing the raw data median to give the relative Sen (RSEN) and this was expressed as a Percent Annual Change (PAC). In addition, 90% confidence limits were calculated for the Sen-slope and from these a probability was calculated to indicate confidence in the trend direction.

The lower the *p*-value the more likely it is that the trend is real (not due to change), and the larger the PAC the larger the magnitude of the trend. A trend test was considered to be statistically significant if the *p*-value was less than 0.05; and the test was considered meaningful (or practically important) if it had a PAC of more than 0.5% per year[1]. The trend analysis was based on 12 seasons per year (i.e. monthly data) using the median value per season, and with no adjustment for any serial correlation.

# 3 Ongatoro / Maketū Estuary and Kaituna River catchment

## 3.1 Maketū Estuary condition

### 3.1.1 Ecology

Ongatoro / Maketū Estuary (referred to as Maketū Estuary) has important ecological values for birds, fishing, shellfish gathering and biodiversity. The lower estuary is in reasonable ecological health with a relatively diverse range of macrofauna and dense populations of cockle / tuangi (*Austrovenus stutchburyi*), wedge shell / hanikura (*Tellina liliana*) and pipi (*Paphies australis*). However large areas of the inner estuary are highly degraded.

The degradation is due to dense accumulations of benthic algae that occur in the upper estuary, Papahikahawai Lagoon and margins of the mid-estuary and southern estuary. Reasonably dense algal accumulations (>50% cover) occurred over about 30% (71 ha) of Ongatoro / Maketū Estuary (Hamill 2014, Park 2014). The dominant algae species are *Gracilaria* sp. and to a less extent sea lettuce (predominantly *Ulva pertusa*).

The dense algal accumulations in parts of the estuary result in anoxic muds and a loss in the abundance and diversity of shellfish and other benthic fauna. In some parts of the upper estuary benthic macrofauna have been completely excluded. The dense algal accumulations also cause very low concentrations of dissolved oxygen (DO) at night in the mid and upper estuary.

The reason for the excessive algal accumulations is because there are sufficient nutrients (nitrogen and phosphorus) in the estuary to sustain algae growth and because there is currently little flushing of algae from the mid- and upper-estuary. Estuaries with more flushing are less susceptible to eutrophication because nutrients move through more quickly and there is less ability for algae to accumulate.

### 3.1.2 Nutrients

The mean concentrations of total nitrogen in the Ongatoro / Maketū Estuary are currently: 0.5 to 0.7 mg/L in the upper estuary, 0.1 to 0.3 mg/L in the lower estuary and 0.7 to >1 mg/L in the southern estuary. Mean concentrations of total phosphorus are currently: 0.05 to 0.06 mg/L in the upper estuary, 0.01 to 0.03 mg/L in the lower estuary and 0.06 to 0.1 mg/L in the southern estuary (DHI 2014).

The main sources of nutrients to the Ongatoro / Maketū Estuary is the Kaituna River, Waitipuia Stream and internal release of nitrogen (N) and phosphorus (P) from anoxic muds associated with algae accumulations. The highest nutrient concentrations in the Ongatoro / Maketū Estuary are in isolated pockets near drain inputs, and in the southern estuary due to the influence of Waitipuia Stream (Figure 2.1).

[1] A value of 1% per year is more often used but for this report a lower value has been applied to reflect the long time series.

There is a significant internal nutrient load from anoxic muds under dense algal accumulations and, in the Papahikahawai lagoon, from nitrogen-fixing by cyanobacteria. These internal nutrient loads can partially decouple the estuary algae from short term changes in external nutrient loads.

There is some evidence from intracellular nutrient concentrations to indicate that sea lettuce in the Ongatoro / Maketū Estuary is replete in N and P, and its growth rate may not be limited by these nutrients (Hamill 2015). This suggests that small increases in N concentration will have little impact on sea lettuce growth rates in the lower estuary, and that more work is needed to reduced nutrients in the estuary to improve ecological condition. It also suggests that reduction in N and P could be beneficial.

### 3.1.3 Microbial water quality

The lower Ongatoro / Maketū Estuary is commonly used for recreational bathing and is regularly monitored near the boat ramp. The microbial water quality in the lower estuary near the boat ramp consistently meets bathing water guidelines. Bimonthly monitoring found 95-percent of samples with less than 74 enterococci/100mL (Hamill 2014b).[2]

The Maketū Estuary is also commonly used for shellfish gathering, particularly pipi in the lower estuary and cockle / tuangi from the lower to mid-estuary. Annual monitoring of shellfish flesh are within microbial criteria most of the time but occasionally exceed maximum criteria, i.e. the maximum criteria was exceeded 23% and 26% of the time for pipi and cockle respectively[3]. The results of monitoring shellfish waters give a similar message i.e. shellfish gathering guidelines are met most of the time but the frequency of high results borderline to exceeding what is allowed under the guidelines (Hamill 2014b).

Elevated levels of bacteria in the estuary were mostly associated with rain events. For the period 2011 – 2013 the median faecal coliform concentration at the boat ramp was 10 MPN/100mL during base flow and 185 MPN/100mL during rain events [4] (Hamill 2014b).

### 3.1.4 Sources of microbial contamination

Microbial contamination of Ongatoro / Maketū Estuary occurs from multiple sources. The main load of faecal indicator bacteria (e.g. faecal coliforms, *enterococci* bacteria) to the estuary comes via the Kaituna River, Waitipuia Stream, and drains. The impact of these sources was modelled to predict the effects of the re-diversion (DHI 2014, Hamill 2014b). However, there are also other sources such as wildfowl, septic tanks and direct stormwater runoff that were not included in the model but can have a significant impact in localised parts of the estuary. Hamill (2014b) estimated that birds contribute 33% of the current median faecal coliform load to the estuary entering via Ford's Cut, although the relative contribution from birds reduces to about 10% after the Kaituna River Re-diversion and Ongatoro/Maketū Estuary Enhancement Project diverts more water to the estuary.

[2] The recreational bathing water guidelines (MfE and MoH 2003) required that in order for a marine site to be graded as 'good' or better it must have a 95-percentile value of <200 enterococci/100mL and a Sanitary Inspection Category of 'moderate'.

[3] The Ministry of Health criteria for shellfish flesh allow two out of five samples to have a faecal coliform concentration >230 MPN/100mL, and no sample in a batch to exceed 330 MPN/100 g (MoH 1995).

[4] The 90th percentile concentration at the boat ramp was 64 MPN/100mL during base flow and 828 MPN/100mL during rain events.

## 3.2 Kaituna River Re-Diversion

The Kaituna River re-diversion project is currently underway to increase the volume of water (particularly freshwater) flowing from the Kaituna River into Ongatoro/Maketū Estuary so as to maximises the ecological and cultural benefits. The project will increase the total volume of water entering the estuary via Ford's Cut during a mean tidal cycle from about 153,700 $m^3$ to 574,500 $m^3$. There will be an overall increase of freshwater entering the estuary (133,700 $m^3$ to 436,600 $m^3$), but a decrease in the fraction of freshwater (0.87 to 0.76). When converted to an average 24-hour equivalent flow, the volume of water entering the Ongatoro / Maketū Estuary via Ford's Cut will increase from 3.43 $m^3/s$ to 12.82 $m^3/s$ and the volume of freshwater from the Kaituna River will increase from 2.98 $m^3/s$ to 9.74 $m^3/s$ (during a mean tide cycle during a mean river flow).

A dilution model developed for the re-diversion project predicts that the re-diversion will increase the external load of nutrients to the estuary which will cause an overall increase in nutrient concentrations. This will range from a 4% reduction in nutrients in the upper estuary because of increased seawater from Te Tumu, to a 10% increase in the mid-estuary, and up to a 25% increase in the lower estuary because of increased load relative to seawater from the Maketū mouth (Figure 3.1).

This effect is expected to be balanced by a reduction in internal nutrient loads due to the increased flushing of mud. The reduced internal load is unlikely to fully balance the additional load of N from the river but the reduction is likely to exceed the additional load of P from the river (Hamill 2014). Overall, the re-diversion project is expected to improve the ecological condition of the estuary by considerably increasing the flushing of benthic algae and associated muds.

In a similar way, the re-diversion project will reduce the load of microbes from sediment re-suspension (by increased flushing), but it will also increase the external load of microbial contamination from the Kaituna River. It is uncertain as to whether internal loading or external loading is more important in driving microbial contamination of shellfish in the Ongatoro / Maketū Estuary, so it is unclear whether the re-diversion will improve or worsen the microbial contamination shellfish in the estuary.

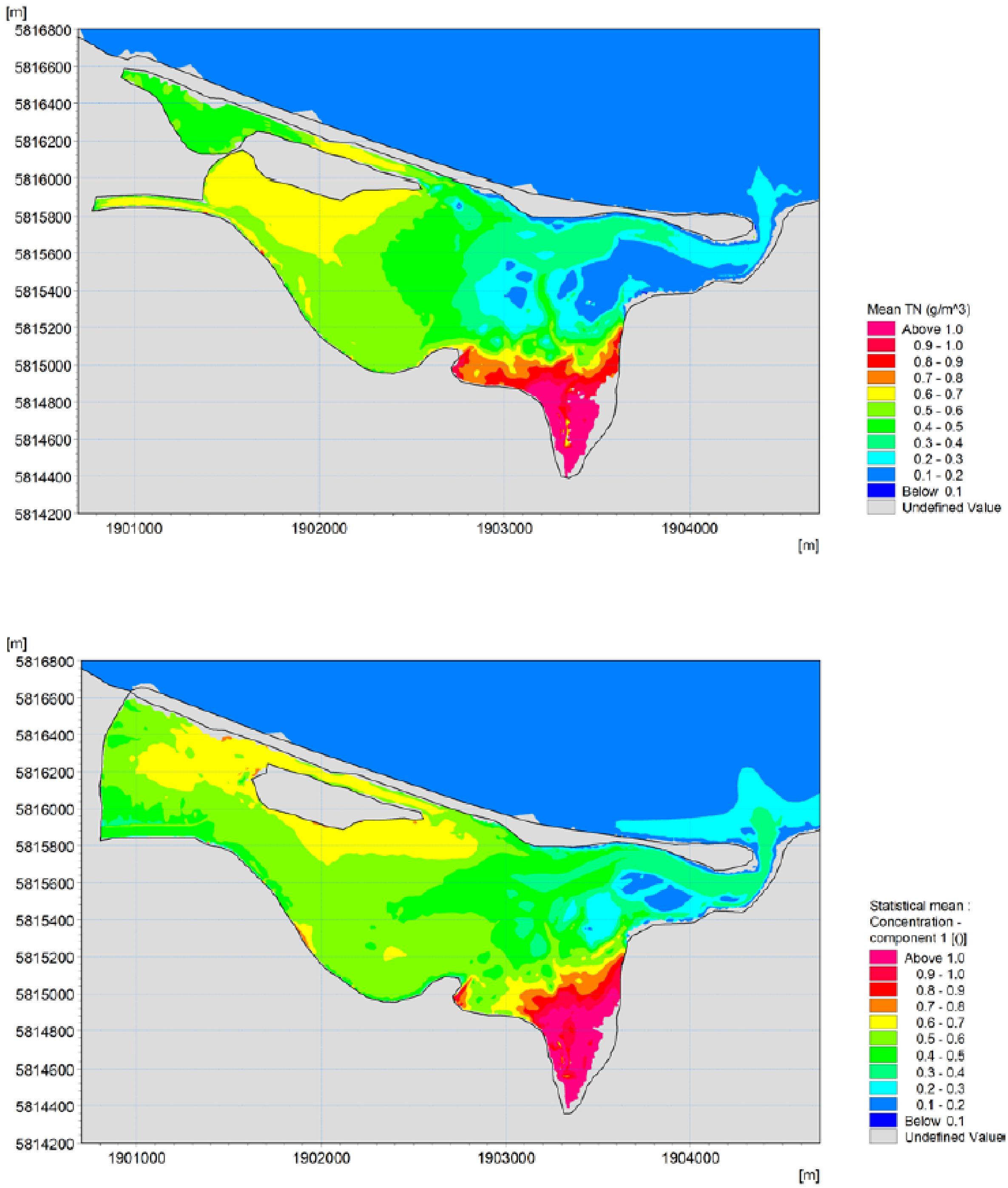



**Figure 3.1**: Mean total nitrogen concentration in the Ongatoro / Maketū Estuary modelled for the existing situation (top) and after the re-diversion (bottom) scenario. Modelled for a mean river flow and averaged over a neap spring tidal cycle (DHI 2014).

## 3.3 Maketū Estuary Inflow hydrology

### 3.3.1 Location of inflows

The main surface water inflows to Ongatoro / Maketū Estuary are the Kaituna River, Waitipuia Stream[5], Singletons Drain pump station, Ford Road drain, and Kaituna Road drain. In addition, there are numerous smaller drains entering the estuary from Maketū Township and adjacent farmland. There are small geothermal inputs in the wetland adjacent to the Waitipuia Stream and from a bore discharging to the Ford Road drain.

Diagonal Drain discharges to the Kaituna River upstream of the estuary and may have more influence on the estuary following the re-diversion which will involve shifting the inlet upstream, which, incidentally, is closer to the Diagonal Drain outlet.

The drainage network of Maketū Estuary is shown in Figure 3.2, including the Kaituna River and key sampling sites. This network[6] has been ground-truthed and is more accurate than the REC network.


**Figure 3.2**: Location of drains entering Maketū Estuary and key water quality sampling sites (source Google, Earth, DHI)

### 3.3.2 Fraction of water entering Ongatoro / Maketū Estuary

The total volume of water entering Ongatoro / Maketū Estuary via Ford's cut is currently 3.43 $m^3/s$ of which 2.98 $m^3/s$ is freshwater from the Kaituna River. Following the re-diversion the total volume of water entering Maketū Estuary via Ford's cut will be 12.83 $m^3/s$ of which 9.74 $m^3/s$ will be freshwater

[5] Also known as Singleton's Drain gravity outlet.
[6] Sourced from BOPRC drainage team and DHI models.

from the Kaituna River (based on a mean tide cycle during a mean river flow). The mean flow in Kaituna River near Diagonal Drain is about 41.4 $m^3/s$ (DHI 2014)[7], so during a mean flow, about 7.2% and 24% of the river water will enter the Ongatoro / Maketū Estuary before and after the re-diversion project respectively. On some parts of the tidal cycle no river water enters the Ongatoro / Maketū Estuary[8] and at other parts of the tidal cycle more than 24% of the river water will enter the Ongatoro / Maketū Estuary. The Kaituna River flow to the Maketū Estuary increases during flood events but is limited by the capacity of the inlet culverts to about 21 $m^3/s$, although this does vary with flood and tide heights.

Currently the water from Ford Road Pump Station is discharged directly in front of the inlet to Ongatoro / Maketū Estuary. Most of this water will enter the estuary. Water flows through the Ford Road gates towards the estuary about 70% of the time during a tidal cycle, but I assumed 85% of the drain water could enter the estuary because the limited flow past the gate may allow contaminant concentrations to increase. After the re-diversion it is likely that 100% of any discharge from Ford Road Pump Station will enter the estuary because of the salinity block that will be constructed in the current channel.

Diagonal Drain Pump Station discharges upstream of the estuary. Currently, Diagonal Drain has negligible input to the Maketū estuary because it is fully mixed with the Kaituna River water before entering the estuary. However, after the re-diversion project the entrance will be further upstream and the Diagonal Drain discharge will be only partially mixed with the Kaituna River before reaching the new entrance to the Kaituna River re-diversion.

Hamill (2018) estimated the proportion of water entering Ongatoro / Maketū Estuary from Diagonal Drain to be, 0.07 and 0.34 for the scenarios of before and after the re-diversion. This was calculated by dividing the fraction of river water that enters the estuary (i.e. 0.07 and 0.24 over a tidal cycle before and after re-diversion respectively) by proportion of river water that the Diagonal Drain discharge mixes with the river (i.e. 1 and 0.7 over a tidal cycle before and after re-diversion respectively).

### 3.3.3 Hydraulic load to Maketū Estuary

The annual average freshwater inflow to Maketū Estuary before and after re-diversion is estimated to be 3.4 $m^3/s$ and 10.1 $m^3/s$ respectively (Table 3.1). About 96% of the inflow is from the Kaituna River via Fords Cut. However, the Kaituna River has a disproportionate influence on the concentrations in the southern section of the estuary as shown in Figure 3.1.

The inflow of the Kaituna River via Ford's cut (including contribution form Diagonal Drain and Fords Road Drain) was based on modelling by DHI (2014) described above. The base flow from Waitipuia Stream, Kaituna Road Drain and other small drains was estimated based on catchment area and rainfall. Estimates of baseflow were multiplied by 1.3 in order to estimate annual average flows (Peter West pers. comm.)

[7] Comprised of 35.5 $m^3/s$ from the Kaituna at Te Matai, 4.0 $m^3/s$ from Waiari Stream, and 1.9 $m^3/s$ from Raparapahoe Cannel.

[8] This occurs for about seven hours a day when water height in the estuary is higher than on the river side of the tide gates (based on gaugings done reported in Putt 2013).

**Table. 3.1:** Annual average freshwater inflow to Ongatoro / Maketū Estuary. Ford Road drain enters upstream of Ford's Cut and comprises part of the Kaituna River inflow.

| Stream | Total | Entering Maketū Estuary | |
|---|---|---|---|
| | | Before re-diversion | After re-diversion |
| Kaituna River | 41.4 | 2.98 | 9.74 |
| Waitipuia Stream | 0.255 | 0.255 | 0.255 |
| Kaituna Rd | 0.071 | 0.071 | 0.071 |
| other drains | 0.062 | 0.062 | 0.062 |
| Ford Rd | 0.140 | 0.119 | 0.14 |
| **Total** | **41.8** | **3.37** | **10.13** |

## 3.4 Maketū Estuary Inflows water quality

### 3.4.1 Data

BOPRC has undertaken monthly long-term water quality monitoring data from the Kaituna River at Te Matai (at the state highway) and Te Tumu (100m upstream of the entrance). During summer weekly samples are collected at Te Matai for microbiological water quality. Regular water quality data is also collected from sites in the Ongatoro / Maketū Estuary (e.g. at the boat ramp). The monitoring of drain inflows to the Ongatoro / Maketū Estuary has been irregular, but a reasonable dataset is available from 2011 to 2013, 2016 and during late 2017 (Hamill 2018).

The dataset includes targeted rain event sampling that occurred during 2011, 2012 and in 2017. To minimise the bias associated with specific rain event sampling, the statistics and trend analysis is based on median monthly concentrations, i.e. Table 3.2 shows the average of monthly median concentrations.

### 3.4.2 Water quality

The average water quality for key inflows to Ongatoro / Maketū Estuary are shown in Table 3.2. The water quality of the lower Kaituna River is characterised by moderately high TN (75% in the form of nitrate), moderately high TP (45% to 60% in the form of DRP) and low TSS. The concentration of *E.coli* bacteria are within bathing water guidelines at Te Matai but increase downstream to exceed the guidelines at Te Tumu (i.e. a 95 percentile of 400 and 1890 cfu/100mL respectively)[9]. The higher bacteria concentrations at Te Tumu compared to Te Matai points to localised inputs from the Waiari Stream and drains (Figure 3.3).

A Spearman rank correlation was performed on data from the Kaituna River at Te Matai to assess the relationship between water quality variables and flow. Flow had a statistically significant negative correlation with TN, NNN, DIN, TP and DRP. Flow had a statistically significant positive correlation with TSS and turbidity (0.75 and 0.63 respectively) (Figure 3.4 and Figure 3.5). However even at high flows the TSS concentration in the Kaituna River is relatively low (generally less than 20 $g/m^3$).

There was no significant correlation between Kaituna River flow and *E.coli* bacteria or enterococci bacteria (Figure 3.6). Analysis of rain event sampling of the lower Kaituna River has previously found

[9] At the Te Matai site additional weekly samples are collected for E. coli and enterococci bacteria during November to March.

elevated turbidity, *E.coli* bacteria and enterococci bacteria, but little change in nitrogen (N) or phosphorus (P) (Hamill 2018).

In general, the drain inflows are characterised by low dissolved oxygen (DO), high ammoniacal nitrogen, TN, TP and turbidity relative to the Kaituna River sites. The response of water quality within drains is variable. Suren (2018) found that there was a correlation between rain in the previous month and elevated $NH_4$-N, but no significant correlation with TN or TP. In contrast, targeted sampling of drains in the Kaituna catchment during rain events has found elevated concentrations of turbidity, *E.coli* bacteria and enterococci bacteria, TP, TN and ammoniacal nitrogen (Hamill 2014b, Hamill 2018).

**Table 3.2**: Water quality in the lower Kaituna River and drains to Maketū Estuary and lower Kaituna. Average of monthly median concentration in Kaituna River for period 2010-2018, drains for period 2011 -2013, 2016 – 2017.

| Site | EC (mS/cm | *E.coli* cfu/100mL | *Enterococci* cfu/100mL | $NH_4$-N (mg/L) | NNN (mg/L) | TN (mg/L) | DRP (mg/L) | TP (mg/L) | TSS (mg/L) | Turbidity (NTU) |
|---|---|---|---|---|---|---|---|---|---|---|
| Kaituna at Te Matai | 0.185 | 105 | 120 | 0.047 | 0.55 | 0.74 | 0.030 | 0.051 | 9.3 | 3.2 |
| Kaituna at Te Tumu | 2.45 | 291 | 203 | 0.049 | 0.59 | 0.81 | 0.027 | 0.061 | 10.4 | 4.2 |
| Waitipuia Stream | 1.84 | 1424 | 1573 | 0.227 | 0.78 | 1.59 | 0.032 | 0.103 | 7.3 | 8.0 |
| Singletons Pump Drain | 3.34 | 1087 | 2110 | 0.094 | 0.10 | 0.68 | 0.033 | 0.127 | | 11.3 |
| Kaituna Road drain | 7.09 | 836 | 999 | 0.618 | 0.21 | 1.35 | 0.047 | 0.1320 | 17.4 | 16.0 |
| Ford Rd Drain u/s Pump Station | 6.21 | 1953 | 1914 | 0.447 | 0.38 | 1.37 | 0.026 | 0.124 | 16.5 | 23.5 |
| Diagonal Drain at Control Gates | 0.637 | 907 | 876 | 0.150 | 0.62 | 1.16 | 0.058 | 0.152 | 10.9 | 6.9 |

EC = electrical conductivity, Temp. = temperature, DO = dissolved oxygen, ENT = enterococci bacteria, $NH_4$-N = ammoniacal nitrogen, NNN = nitrate nitrite nitirgen, TN = total nitrogen, DRP = dissolved reactive phosphorus, TP = total phosphorus

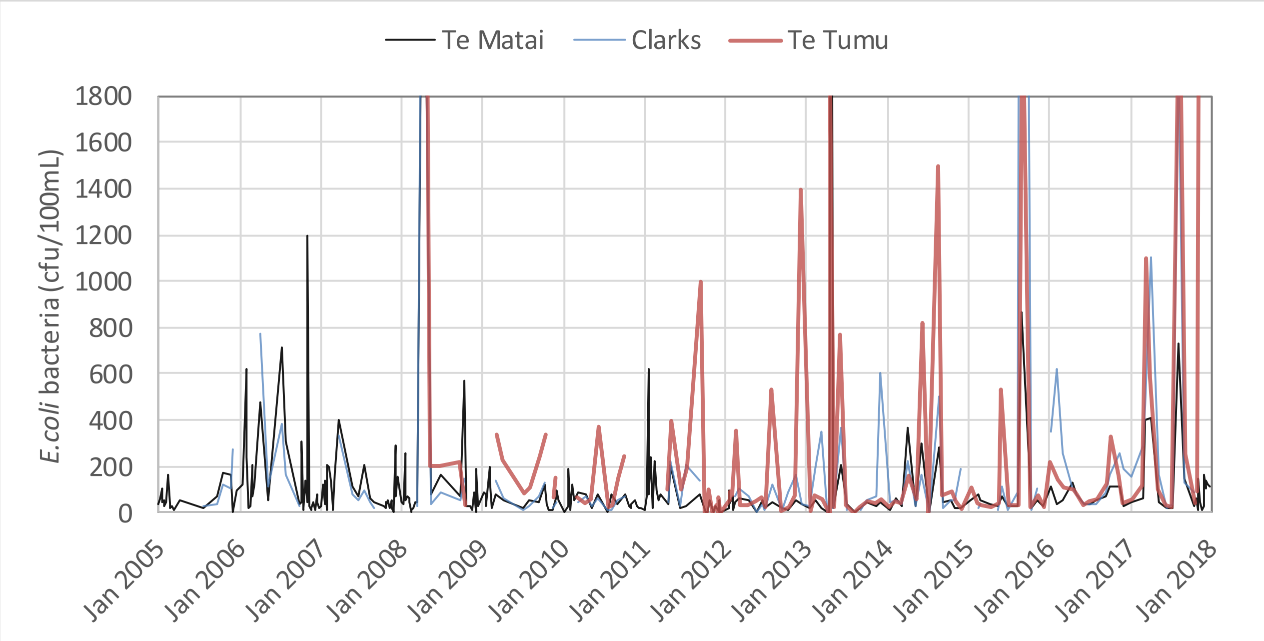



**Figure 3.3**: Comparison of *E.coli* bacteria in the Kaituna River at Te Matai, Clarks (downstream of Waiari) and at Te Tumu. The Y-axis is truncated for clarity.

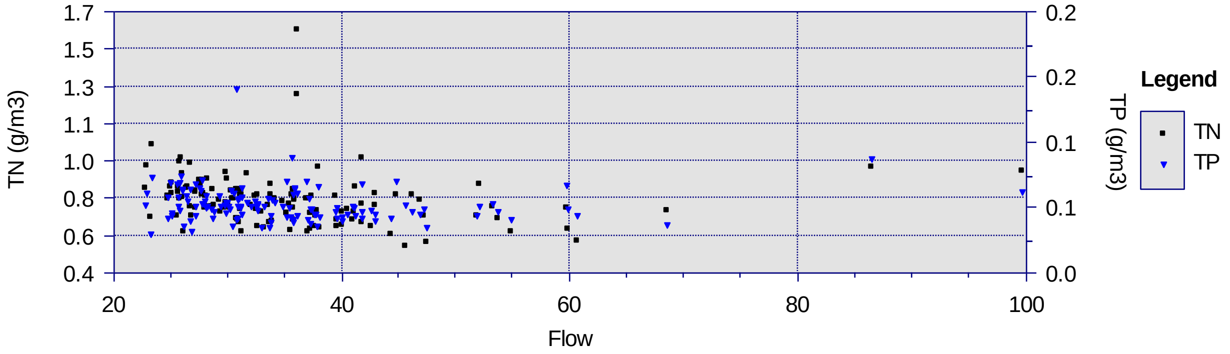



**Figure 3.4**: Change in TN and TP concentration with increasing flow in the Kaituna River at Te Matai.

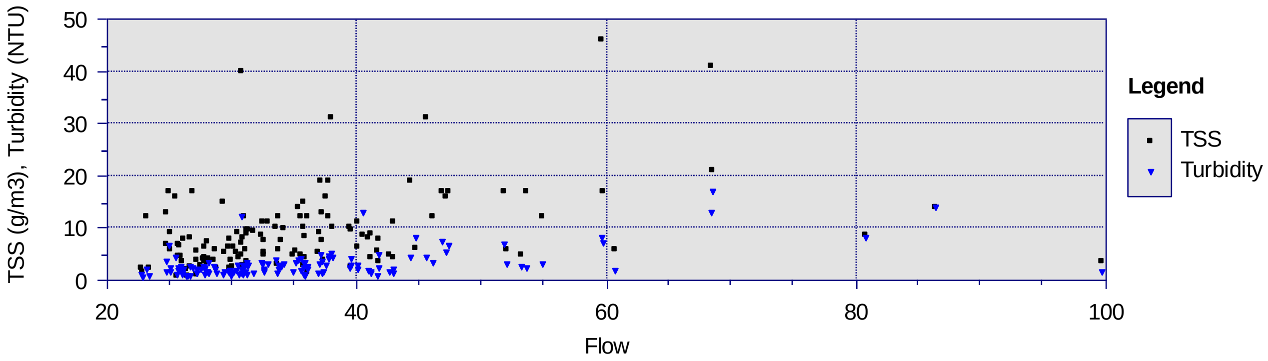



**Figure 3.5**: Change in TSS and turbidity with increasing flow in the Kaituna River at Te Matai.

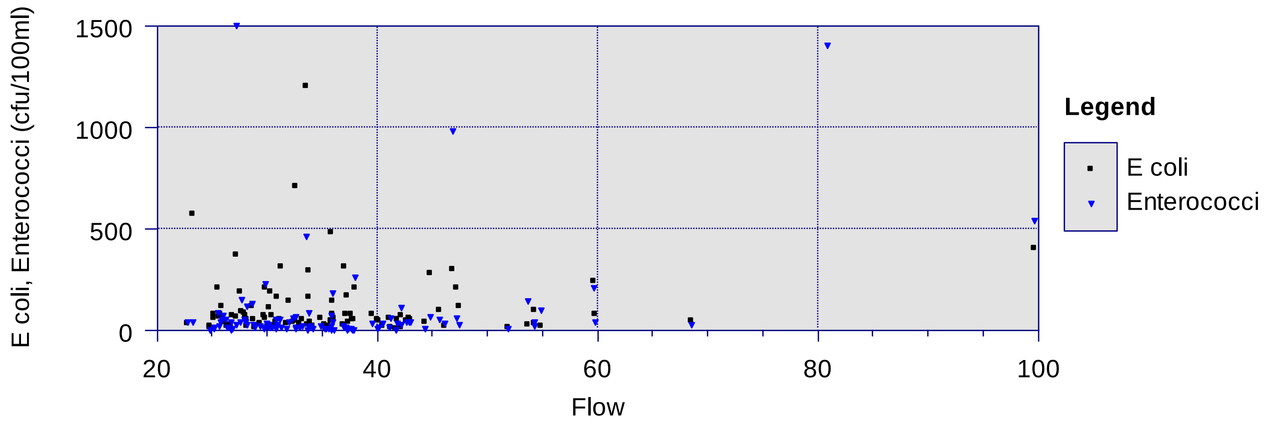



**Figure 3.6**: Change in *E.coli* bacteria and Enterococci bacteria concentration with increasing flow in the Kaituna River at Te Matai.

## 3.5 Maketū Estuary Inflows: Water quality trends

Water quality trends in the Kaituna River at Te Matai were assessed for the 25-year period March 1993 to December 2017. A shorter, 13-year record was available for trend analysis at three sites: Kaituna River at Te Matai, Kaituna River at Clarks (downstream Waiari) and Kaituna River at Te Tumu (Figure 3.2). Key results of water quality trend analysis for Kaituna River are:

- At the Te Matai site, no significant trend in total nitrogen, but a significant increase in the component as nitrate (NNN) and a decrease in total ammonia ($NH_4$-N) (Figure 3.7, Tables 3.3). However, TN has been decreasing at the Clarks and Te Tumu site in the last 11 to 13 years. This has made the TN concentration at Te Tumu more similar to the what is measured at Te Matai (Table 3.4, Figure 3.8).

- There has been a weak decreasing trend in TP and DRP over the last 25 years at Te Matai, but an increasing trend at Te Tumu since 2007.

- Turbidity has decreased at all sites and there was a corresponding decrease in TSS at the sites Te Matai and Clarks (Table 3.4).

- *E. coli* bacteria and enterococci bacteria have decreased at Te Matai since 1993 but have no significant trends in the last 13 years (Table 3.3, Table 3.4).

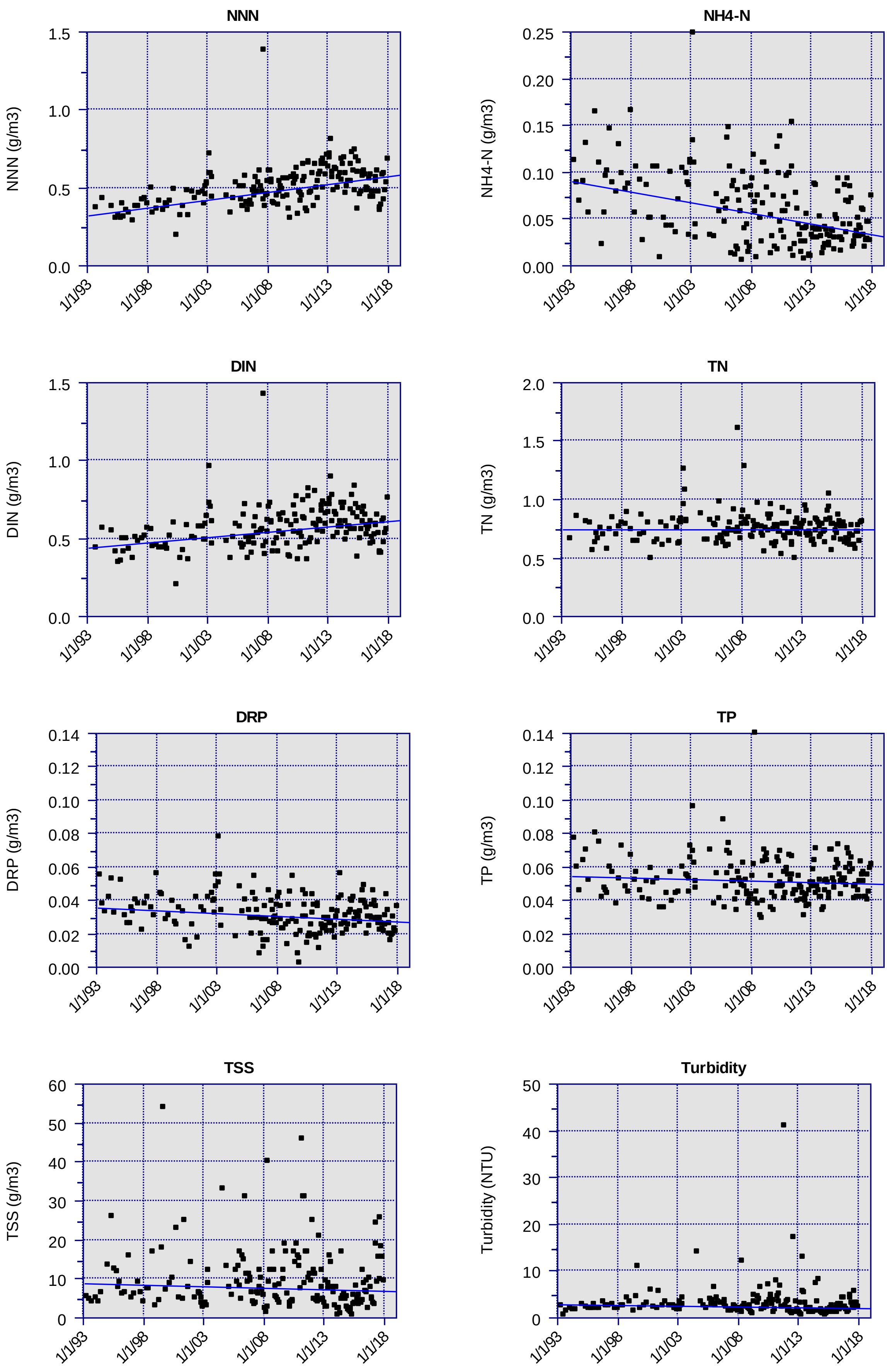



**Figure 3.7**: Water quality trends in the Kaituna River at Te Matai.

**Table 3.3**: Results of seasonal Kendell trend test, March 1993 to December 2017. Shaded cells indicate both 'significant' and 'meaningful' trends with a *p*-value >0.05 and a PAC>0.5. PAC = percent annual change. Prob. = probability.

| Site | Variable | Mean | Median | *p*-value | PAC | Trend direction | Prob. |
|---|---|---|---|---|---|---|---|
| 1 Kaituna at Te Matai | NNN ($g/m^3$) | 0.502 | 0.49 | **0** | 2.03 | **increasing** | 1 |
| 1 Kaituna at Te Matai | $NH_4$-N ($g/m^3$) | 0.06 | 0.052 | **0** | -4.44 | **decreasing** | 1 |
| 1 Kaituna at Te Matai | DIN ($g/m^3$) | 0.565 | 0.558 | **0** | 1.22 | **increasing** | 1 |
| 1 Kaituna at Te Matai | TN ($g/m^3$) | 0.752 | 0.74 | 0.742 | -0.03 | decreasing | 0.62 |
| 1 Kaituna at Te Matai | DRP ($g/m^3$) | 0.031 | 0.03 | **0.001** | -1.12 | **decreasing** | 1 |
| 1 Kaituna at Te Matai | TP ($g/m^3$) | 0.052 | 0.051 | 0.115 | -0.36 | **decreasing** | 0.96 |
| 1 Kaituna at Te Matai | TSS ($g/m^3$) | 9.6 | 7.4 | 0.118 | -1.14 | decreasing | 0.95 |
| 1 Kaituna at Te Matai | Turbidity (NTU) | 3.1 | 2.3 | 0.056 | -1.16 | **decreasing** | 0.97 |
| 1 Kaituna at Te Matai | *E. coli* (cfu/100mL) | 230 | 58 | **0** | -8.05 | **decreasing** | 1 |
| 1 Kaituna at Te Matai | Enterococci (cfu/100mL) | 111 | 39 | **0.004** | -4.34 | **decreasing** | 1.00 |
| 1 Kaituna at Te Matai | Flow ($m^3/s$) | 34.58 | 32.485 | 0.116 | 0.42 | increasing | 0.94 |

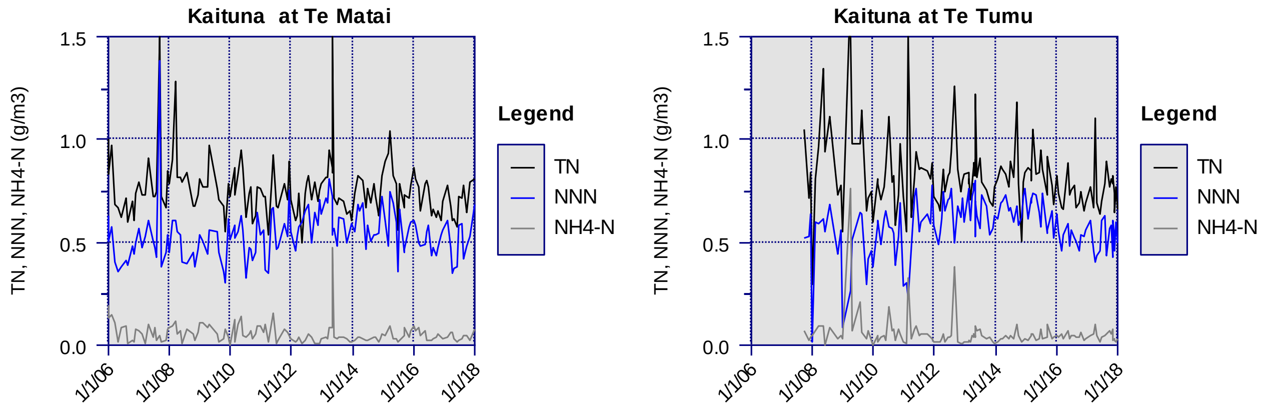



**Figure 3.8**: Nitrogen trends in the Kaituna River at Te Matai and Te Tumu.

**Table 3.4**: Results of seasonal Kendell trend test. Period for Te Matai and Clarks 2005 to 2017 (incl.) period for Te Tumu 2005 to 2017 (incl.). Shaded cells indicate both 'significant' and 'meaningful' trends with a *p*-value >0.05 and a PAC>0.5. PAC = percent annual change. Prob. = probability.

| Site | Variable | Mean | Median | *p*-value | PAC | Trend direction | Prob. |
|---|---|---|---|---|---|---|---|
| 1 Kaituna at Te Matai | NNN ($g/m^3$) | 0.531 | 0.534 | **0** | 1.90 | **increasing** | 1 |
| 1 Kaituna at Te Matai | $NH_4$-N ($g/m^3$) | 0.052 | 0.042 | **0.005** | -5.16 | **decreasing** | 1 |
| 1 Kaituna at Te Matai | DIN ($g/m^3$) | 0.586 | 0.577 | **0.013** | 1.05 | **increasing** | 0.99 |
| 1 Kaituna at Te Matai | TN ($g/m^3$) | 0.752 | 0.737 | 0.518 | -0.23 | decreasing | 0.75 |
| 1 Kaituna at Te Matai | DRP ($g/m^3$) | 0.029 | 0.029 | 0.806 | 0 | uncertain slope zero | 0.5 |
| 1 Kaituna at Te Matai | TP ($g/m^3$) | 0.052 | 0.05 | 0.777 | 0 | increasing | 0.67 |
| 1 Kaituna at Te Matai | TSS ($g/m^3$) | 9.5 | 7.7 | **0.012** | -2.86 | **decreasing** | 0.99 |
| 1 Kaituna at Te Matai | Turbidity (NTU) | 3.1 | 2.2 | **0.008** | -3.25 | **decreasing** | 0.99 |
| 1 Kaituna at Te Matai | *E. coli* (cfu/100mL) | 126 | 51.5 | 0.358 | -1.56 | decreasing | 0.82 |
| 1 Kaituna at Te Matai | Enterococci (cfu/100mL) | 119 | 27 | 0.904 | 0 | uncertain slope zero | 0.5 |
| 1 Kaituna at Te Matai | Flow ($m^3/s$) | 35.474 | 33.08 | 0.6 | 0.33 | increasing | 0.71 |
| 2 Kaituna at Clarks | NNN ($g/m^3$) | 0.519 | 0.498 | 0.829 | 0.15 | increasing | 0.62 |
| 2 Kaituna at Clarks | $NH_4$-N ($g/m^3$) | 0.038 | 0.03 | **0** | -6.60 | **decreasing** | 1 |
| 2 Kaituna at Clarks | DIN ($g/m^3$) | 0.557 | 0.537 | 0.527 | -0.39 | decreasing | 0.73 |
| 2 Kaituna at Clarks | TN ($g/m^3$) | 0.745 | 0.713 | **0** | -1.92 | **decreasing** | 1 |
| 2 Kaituna at Clarks | DRP ($g/m^3$) | 0.026 | 0.025 | 0.259 | -1.43 | decreasing | 0.88 |
| 2 Kaituna at Clarks | TP ($g/m^3$) | 0.051 | 0.046 | 0.059 | -0.93 | **decreasing** | 0.97 |
| 2 Kaituna at Clarks | TSS ($g/m^3$) | 8.0 | 5.4 | **0** | -8.81 | **decreasing** | 1 |
| 2 Kaituna at Clarks | Turbidity (NTU) | 3.1 | 2.3 | **0** | -6.24 | **decreasing** | 1 |
| 2 Kaituna at Clarks | *E. coli* (cfu/100mL) | 270 | 87 | 0.777 | 0.72 | increasing | 0.68 |
| 2 Kaituna at Clarks | Enterococci (cfu/100mL) | 164 | 35 | 0.454 | -1.06 | decreasing | 0.76 |
| 3 Kaituna at Te Tumu | NNN | 0.57 | 0.589 | 0.5 | 0.27 | increasing | 0.75 |
| 3 Kaituna at Te Tumu | $NH_4$-N | 0.057 | 0.041 | 0.196 | -2.10 | decreasing | 0.88 |
| 3 Kaituna at Te Tumu | DIN | 0.63 | 0.637 | 0.305 | -0.79 | decreasing | 0.85 |
| 3 Kaituna at Te Tumu | TN | 0.824 | 0.799 | **0.037** | -1.25 | **decreasing** | 0.98 |
| 3 Kaituna at Te Tumu | DRP | 0.026 | 0.027 | **0.032** | 2.52 | **increasing** | 0.99 |
| 3 Kaituna at Te Tumu | TP | 0.059 | 0.048 | **0.014** | 1.93 | **increasing** | 1.00 |
| 3 Kaituna at Te Tumu | TSS | 10.4 | 7.4 | 0.201 | 2.21 | increasing | 0.89 |
| 3 Kaituna at Te Tumu | Turbidity (NTU) | 4.7 | 3.1 | **0.024** | -3.22 | **decreasing** | 0.99 |
| 3 Kaituna at Te Tumu | *E. coli* (cfu/100mL) | 331 | 96.667 | 0.377 | -2.56 | decreasing | 0.80 |
| 3 Kaituna at Te Tumu | Enterococci (cfu/100mL) | 220 | 55 | 0.753 | -0.49 | decreasing | 0.62 |

## 3.6 Maketū Estuary Inflows loads

About 93% of the TN and TP load to the Maketū Estuary will be via the Kaituna River post-redivision, compared to about 81% before the re-diversion. The total catchment load of nitrogen and phosphorus to the Maketū Estuary post re-diversion was calculated to be 267 t/yr and 20.1 t/yr respectively. This corresponds to an average areal load of nitrogen and phosphorus to the Maketū Estuary of 31 $mg/m^2/day$ and 2.3 $mg/m^2/day$ (Table 4.5).

The Waitipuia Stream and Singletons drain Pump Station contribute only about 5% of the total nutrient load to Maketū Estuary, however they have a considerable influence on the water quality in the southern part of the Maketū Estuary due to the limited flushing (Figure 3.1).

The total hydraulic loading of water entering Maketū Estuary via Fords cut is about 50 m/yr and 174 m/yr before and after the re-diversion respectively. However, the freshwater component from the catchment is about 44 m/yr and 133 m/yr before and after the re-diversion respectively.[10]

**Table 3.3**: Load to Maketū Estuary of nutrients, sediment and bacteria after re-diversion (based on nutrient concentrations in Table 3.2)

| Site | Flow ($m^3/s$) | *E.coli* (cfu/s) | *Enterococci* (cfu/s) | $NH_4$-N (t/yr) | NNN (t/yr) | TN (t/yr) | DRP (t/yr) | TP (t/yr) | TSS (t/yr) |
|---|---|---|---|---|---|---|---|---|---|
| Kaituna at Te Tumu | 9.74 | 28,367,847 | 19,724,182 | 15.1 | 181 | 249 | 8.3 | 18.7 | 3189 |
| Waitipuia Stream | 0.255 | 3,630,308 | 4,010,345 | 1.8 | 6.2 | 12.8 | 0.26 | 0.83 | 59 |
| Kaituna Road drain | 0.071 | 593,738 | 709,415 | 1.38 | 0.47 | 3.03 | 0.10 | 0.30 | 39 |
| Other drains | 0.062 | 76,951 | 92,647 | 0.60 | 0.81 | 2.41 | 0.08 | 0.25 | 25 |
| **Total load** | **10.1** | **32,668,843** | **24,536,589** | **18.9** | **189** | **267** | **8.7** | **20.1** | **3312** |
| **Areial load ($mg/m^2/day$)** | | | | 2.2 | 21.6 | 30.6 | 1.0 | 2.3 | 379 |

Other' drains based on average concentrations of all drains.
Areial load based on the estuary being 240 ha

## 3.7 Uncertainties

The main uncertainties in estimating nutrient and sediment loads to Maketu Estuary is likely to come from modelled estimates of the load entering through the control gates at different tidal regimes and river flows.

There is a limited amount of water quality data available for drains but these make up only about 7% of the TN and TP load to the estuary, with the majority of the catchment load comes via the Kaituna River. The main uncertainty associated with the load estimate from drains is the hydraulic loading which has been modelled. Also, there is little data available to quantify the contribution from pump stations during rain events.

[10] Maketū Estuary covers an area of about 239.5 ha excluding Papahikahawai Island.

# 4 Little Waihi Estuary

## 4.1 Inflowing stream hydrology

Little Waihi Estuary covers an area of about 290 ha including 16ha of vegetated islands. The Pukehina sand spit encloses most of the estuary.

The main inflows to the Little Waihi Estuary are Pukehina canal, Pongakawa canal, Wharere canal (including tributaries Wharere Stream, and Puanene Stream), and Kaikokopu canal (including tributaries Pokopoko Stream and Mangatoetoe Stream) (Figure 4.1). A best estimate was made for the mean annual flow for each inflow based on modelled data from the Regional Environment Classification (REC) augmented by continuous flow measurements where available[11]. Continuous flow records are available for only two inflows - Pongakawa at Old Coach Road and Puanene Stream at SH2 (Figure 4.2).

The mean total annual inflow to Little Waihi Estuary was estimated to be 10.55 $m^3/s$ (Table 4.1). About half of the flow enters via the Pongakawa canal and about a third from the Kaikokopu canal. The measured long term mean flow from the Pongakawa Stream at Old Coach Road is about 1.35 $m^3/s$ higher than what is estimated by the REC because there are large springs at the headwaters. No account has been made for potential inflows or outflows from outside the surface water catchment. However, there are considerable irrigation takes from the catchment and four paired gaugings on the Oeuteheuheu Stream has indicated about 0.31 to 0.48 $m^3/s$ water loss in the lower reaches during periods of low flows.

[11] The REC drainage network is often inaccurate in flat landscapes. The REC showed the most western drainage system entering the estuary directly when in fact it enters the Kaikokopu canal. An adjustment was made to reflect this in the calculations and maps.


**Figure 4.1**: Location of drains entering Little Waihi Estuary and key water quality sampling sites (source Google Earth, REC).

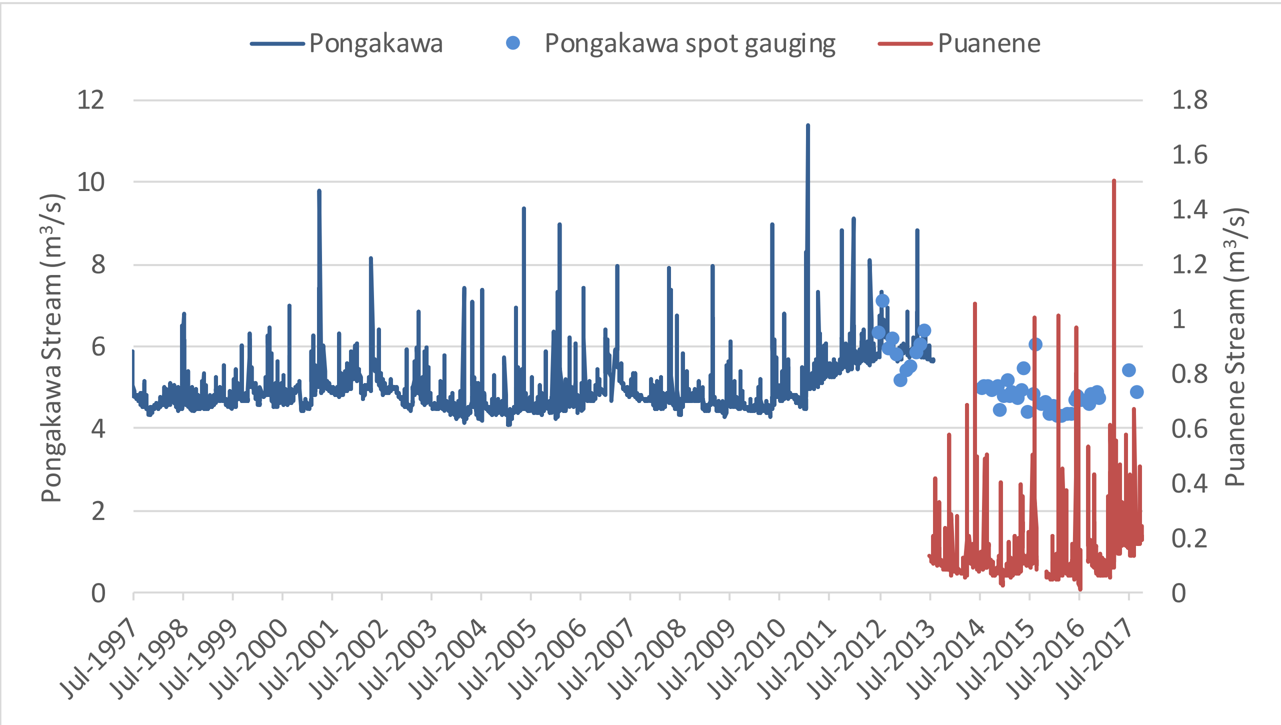



**Figure 4.2:** Flow record for Pongakawa Stream at Old Coach Road and Puanene Stream at SH2. Pongakawa spot gauging is from SH2.

**Table 4.1**: Best estimate of inflows to Little Waihi Estuary. Obs. mean flow = observed mean flow.

| Stream | REC mean flow ($m^3/s$) | Obs. mean flow ($m^3/s$) | Best est. flow | Comment |
|---|---|---|---|---|
| **Pukehina canal** | 0.343 | | 0.343 | |
| **Pongakawa canal** | 4.00 | | 5.35 | Obs. flow at Old Coach Road + 0.47m3/s (difference between REC flow at Old Coach Road and estuary). |
| Pongakawa at Old Coach Rd | | 4.88 | | Flow record period 1997-2013 |
| **Wharere canal** | 1.19 | | 1.19 | |
| Wharere Stream | 0.79 | | | |
| Puanene Stream | 0.29 | | 0.189 | Obs. flow at SH2 + 0.073 m3/s (difference between REC flow at SH2 and Wharere canal) |
| Puanene at SH2 | | 0.116 | | Flow record period 2013 - 2017 |
| **Kaikokopu canal** | 3.63 | | 3.63 | |
| Pokopoko Stream | 3.488 | | | |
| Mangatoetoe Stream | 0.266 | | | |
| Oeuteheuheu Stream | 1.867 | | | |
| Waiari Stream | 1.010 | | | |
| **Other** | 0.035 | | 0.035 | |
| **Total to estuary** | **9.20** | | **10.55** | |

REC = river flow model based on the River Environment Classification.
Location is at most downstream confluence unless otherwise stated

## 4.2 Inflowing stream water quality

Water quality variables have been regularly measured by BOPRC in the Pongakawa River, Puanene Stream Wharere Stream, Pokopoko Stream and in the Waihi Estuary, including a programme of drain water quality monitoring from November 2015 to March 2017. The number of samples and average results for the period July 2010 to July 2017 are in Table 4.2.

The results show inflowing streams had high concentrations of dissolved inorganic nitrogen (NNN+$NH_4$) typically in the range 1.15 to 1.55 g/$m^3$), and high concentrations of dissolved reactive phosphorus (DRP typically in the range of 0.06 to 0.11 g/$m^3$). These concentrations are well in excess of concentrations required to control periphyton growth in rivers.

**Table 4.2:** Number of samples and average results for inflows to Little Waihi Estuary (July 2010 to July 2017). Flow is gauged flow.

**Count**

| Site | Flow ($m^3/s$) | TN ($g/m^3$) | NNN ($g/m^3$) | $NH_4$-N ($g/m^3$) | TP ($g/m^3$) | DRP ($g/m^3$) | TSS ($g/m^3$) | Turbidity (NTU) | E coli (cfu/100ml) | Enterococci (cfu/100ml) |
|---|---|---|---|---|---|---|---|---|---|---|
| Pukehina at Wildlife Management Reserve | | 26 | 26 | 26 | 26 | 25 | 20 | 26 | 26 | |
| Pongakawa at Pumphouse | 79 | 43 | 44 | 44 | 43 | 44 | 44 | 44 | 44 | 19 |
| Pongakawa at Old Coach Rd | | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 21 |
| Pongakawa at SH2 | 89 | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 234 | 21 |
| Pongakawa Drain 8 at Cutwater Rd | | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | |
| Puanene at SH2 | | 16 | 16 | 16 | 16 | 14 | 16 | 16 | 15 | |
| Wharere at SH2 | 35 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | |
| Wharere Drain 5 at Pukehina | | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | |
| Pokopoko at Black Rd | 24 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | |
| Waihi Estuary at Main Channel | | 61 | 60 | 61 | 61 | 61 | 61 | 61 | 59 | 105 |

**Average**

| Site | Flow ($m^3/s$) | TN ($g/m^3$) | NNN ($g/m^3$) | $NH_4$-N ($g/m^3$) | TP ($g/m^3$) | DRP ($g/m^3$) | TSS ($g/m^3$) | Turbidity (NTU) | E coli (cfu/100ml) | Enterococci (cfu/100ml) |
|---|---|---|---|---|---|---|---|---|---|---|
| Pukehina at Wildlife Management Reserve | | 1.73 | 0.90 | 0.251 | 0.223 | 0.105 | 16.6 | 7.0 | 590 | |
| Pongakawa at Pumphouse | 3.36 | 1.38 | 1.36 | 0.002 | 0.137 | 0.108 | 19.9 | 3.7 | 49 | 125 |
| Pongakawa at Old Coach Rd | | 1.59 | 1.56 | 0.009 | 0.143 | 0.109 | 19.5 | 3.5 | 263 | 154 |
| Pongakawa at SH2 | 5.13 | 1.58 | 1.52 | 0.016 | 0.143 | 0.106 | 19.3 | 4.0 | 269 | 176 |
| Pongakawa Drain 8 at Cutwater Rd | | 1.50 | 1.37 | 0.032 | 0.149 | 0.108 | 12.0 | 4.1 | 100 | |
| Puanene at SH2 | | 2.29 | 1.29 | 0.334 | 0.272 | 0.092 | 69.2 | 16.3 | 1051 | |
| Wharere at SH2 | 0.43 | 1.81 | 1.58 | 0.059 | 0.161 | 0.089 | 23.3 | 4.8 | 838 | |
| Wharere Drain 5 at Pukehina | | 1.95 | 1.35 | 0.22 | 0.185 | 0.097 | 5.1 | 4.2 | 591 | |
| Pokopoko at Black Rd | 1.87 | 1.37 | 1.23 | 0.01 | 0.143 | 0.059 | 59.9 | 14.5 | 587 | |
| Waihi Estuary at Main Channel | | 0.47 | 0.178 | 0.056 | 0.049 | 0.024 | 25.0 | 6.3 | 128 | 111 |

A Spearman rank correlation was performed on the Pongakawa site data to assess the relationship between water quality variables and flow. Insufficient data was available for the analysis at other sites. The only variables that had a significant correlation with flow were TN, NNN and TSS. Although there was a significant increase in TN and NNN concentration with flow, the magnitude of increase in the Pongakawa was small (i.e. an increase of NN from about 1.5 $g/m^3$ to 1.6 $g/m^3$). In contrast, the Wharere Stream had considerably higher NNN at higher flows (1.4 $g/m^3$ to 2 $g/m^3$), and this appeared to be seasonal with a step change to higher flows during winter (Figure 4.3 and Figure 4.4)

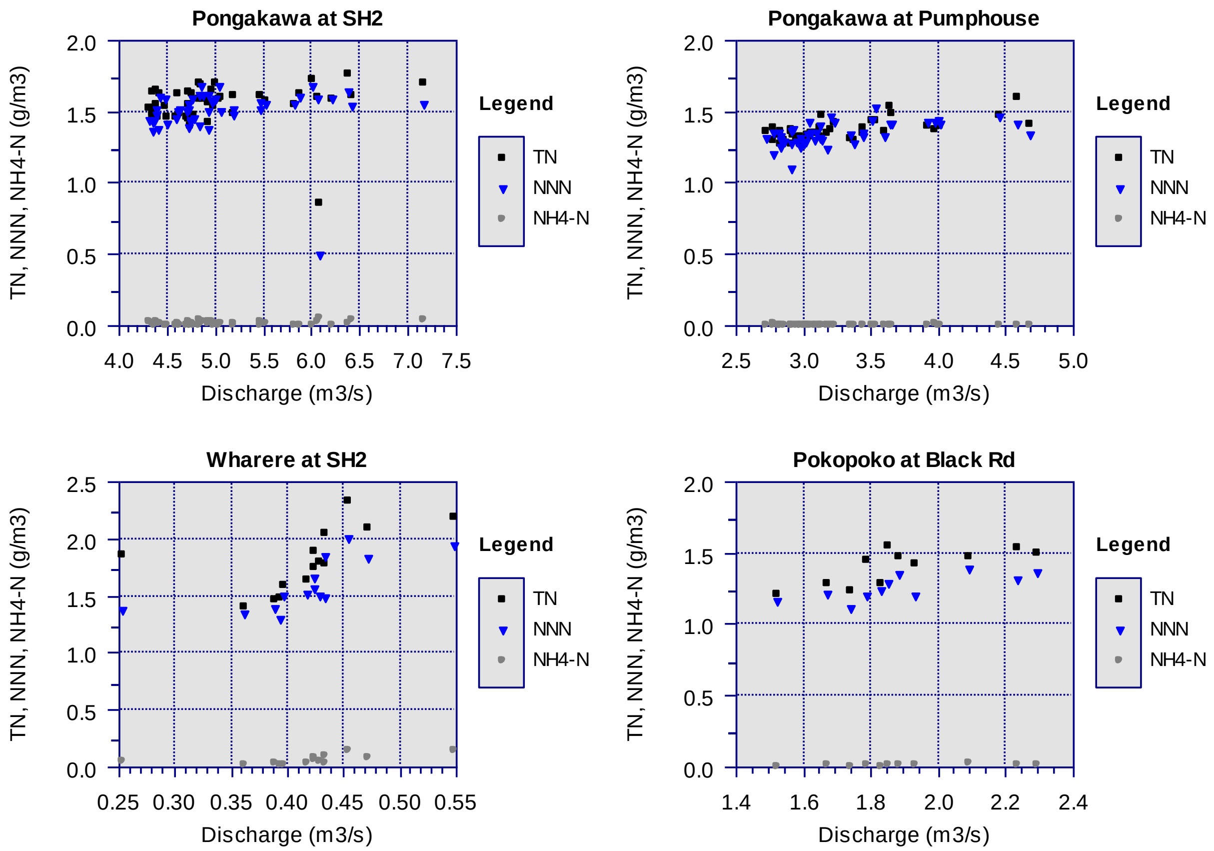



**Figure 4.3**: Change in TN, NNN and $NH_4$-N with increasing flow.

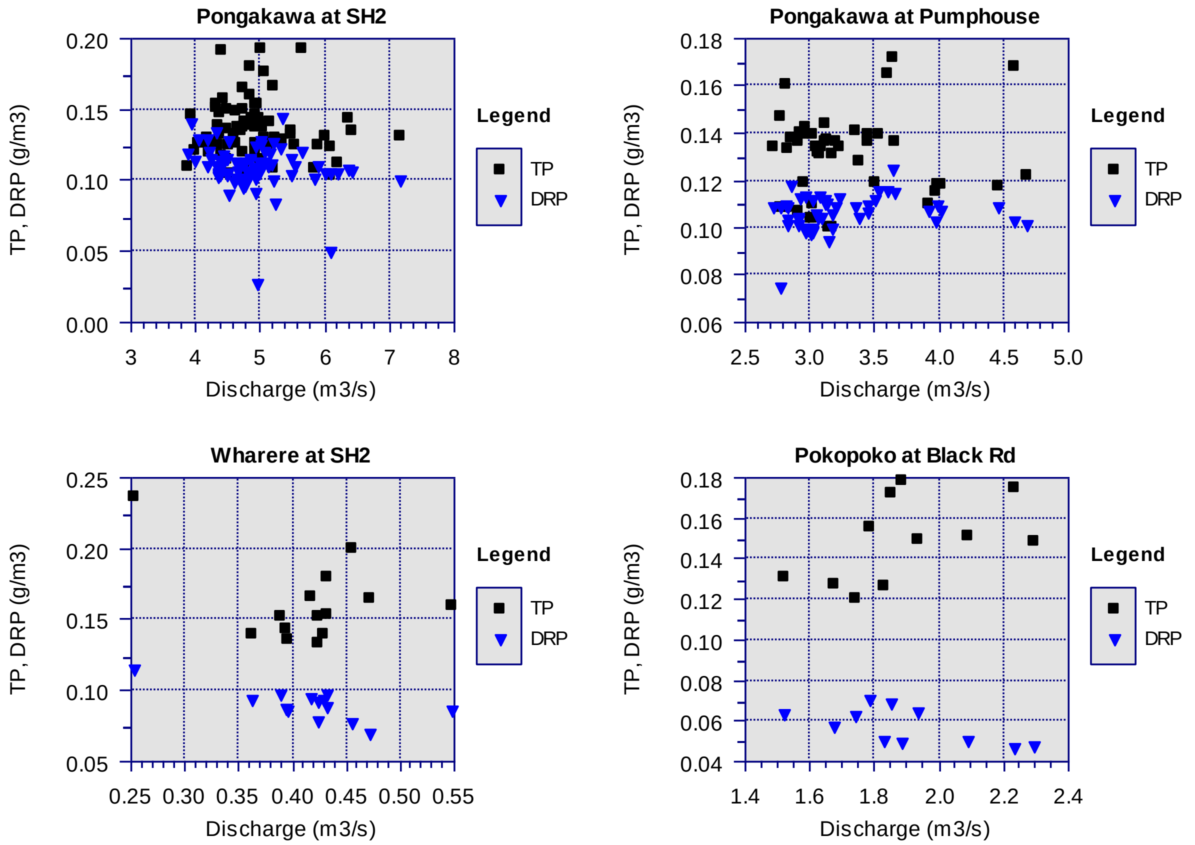



**Figure 4.4**: Change in TP and DRP with increasing flow.

## 4.3 Little Waihi Estuary Inflows: Water quality trends

Long term records sufficient to undertake a trend analysis were only available for the Pongakawa Stream (at three sites) and for the main channel of the Waihi Estuary itself. A trend analysis was undertaken using the longest record available at each site. Key features of the trend analysis for Pongakawa Stream are:

- A long-term increase in nitrate concentration at all Pongakawa sites but a recent improvement since 2013 – probably driven by climatic conditions (e.g. a wet year in 2017 diluting groundwater nitrate concentrations at the headwaters) (Figure 4.5, Table 4.3).
- A step change decrease in DRP since about 2009 but an increase in TP since about 2015 (Figure 4.6, Table 4.3).
- A recent increase in *E. coli* bacteria at Old Coach Road and an increase in Enterococci at SH2, but no corresponding increase at the headwater (pumphouse) site (Figure 4.7, Table 4.3).
- An increase TSS concentration at Pongakawa at SH2 (Figure 4.8)
- A decline in $NH_4$-N at all Pongakawa sites. This decline was particularly apparent at the Pumphouse site which had overall low $NH_4$-N concentrations (0.002 g/$m^3$) and it is possible that the trend reflects improvements in detection limits over time (i.e. the lower values have got lower (Table 4.3, Appendix 2).

The water quality in the Little Waihi Estuary itself shows an increasing trend of all variables, however for most variables this appeared to be driven by higher a step change increase in concentrations since about 2015. This may be associated with a change in sampling method to capture different tidal regimes. Trend results for Little Waihi Estuary are beyond the scope of this report and are not further investigated or reported here.

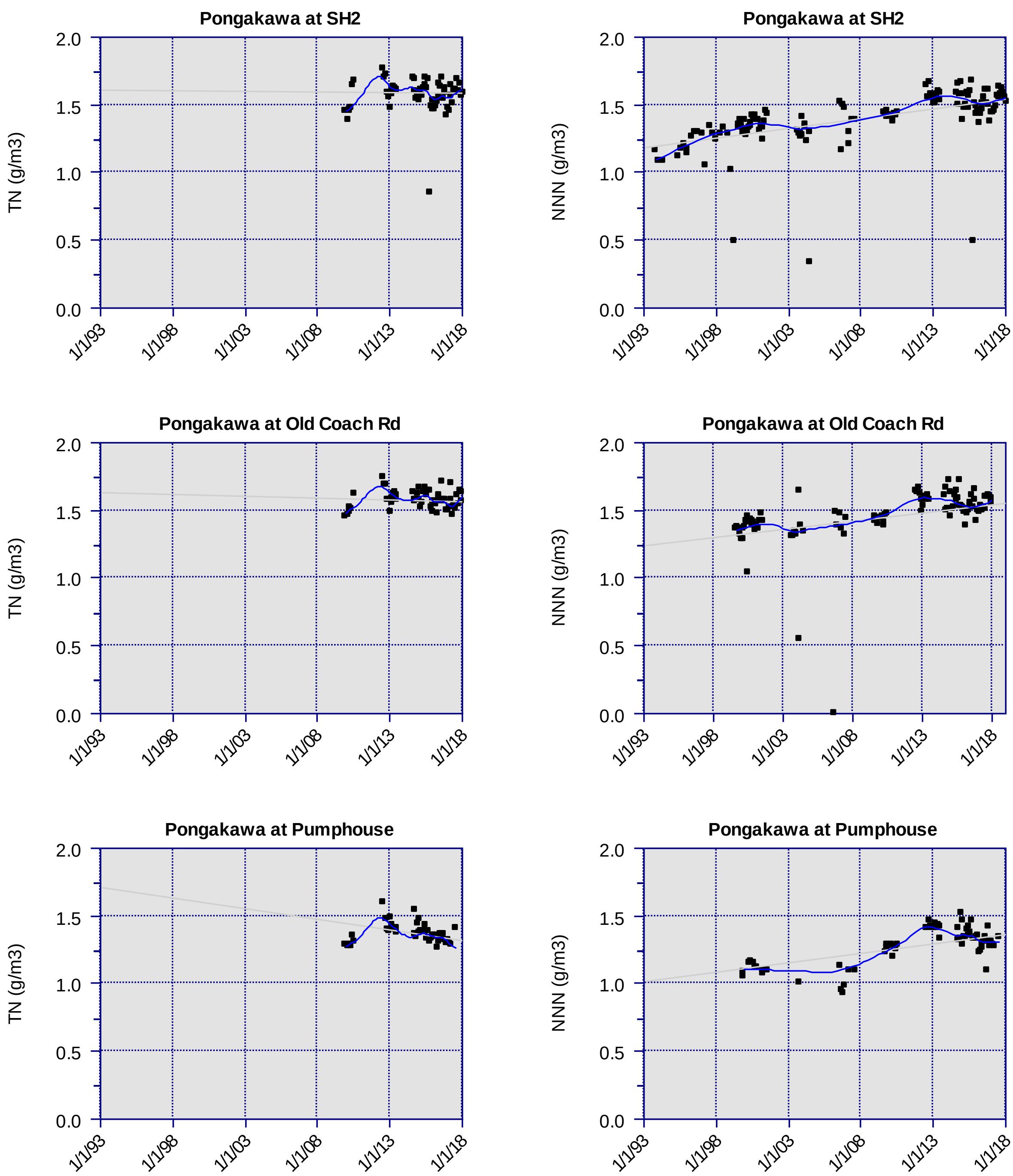



**Figure 4.5**: Pongakawa Stream trends in NNN and TN. This shows a long-term increase in nitrate concentration at all Pongakawa sites with a recent improvement since 2013.

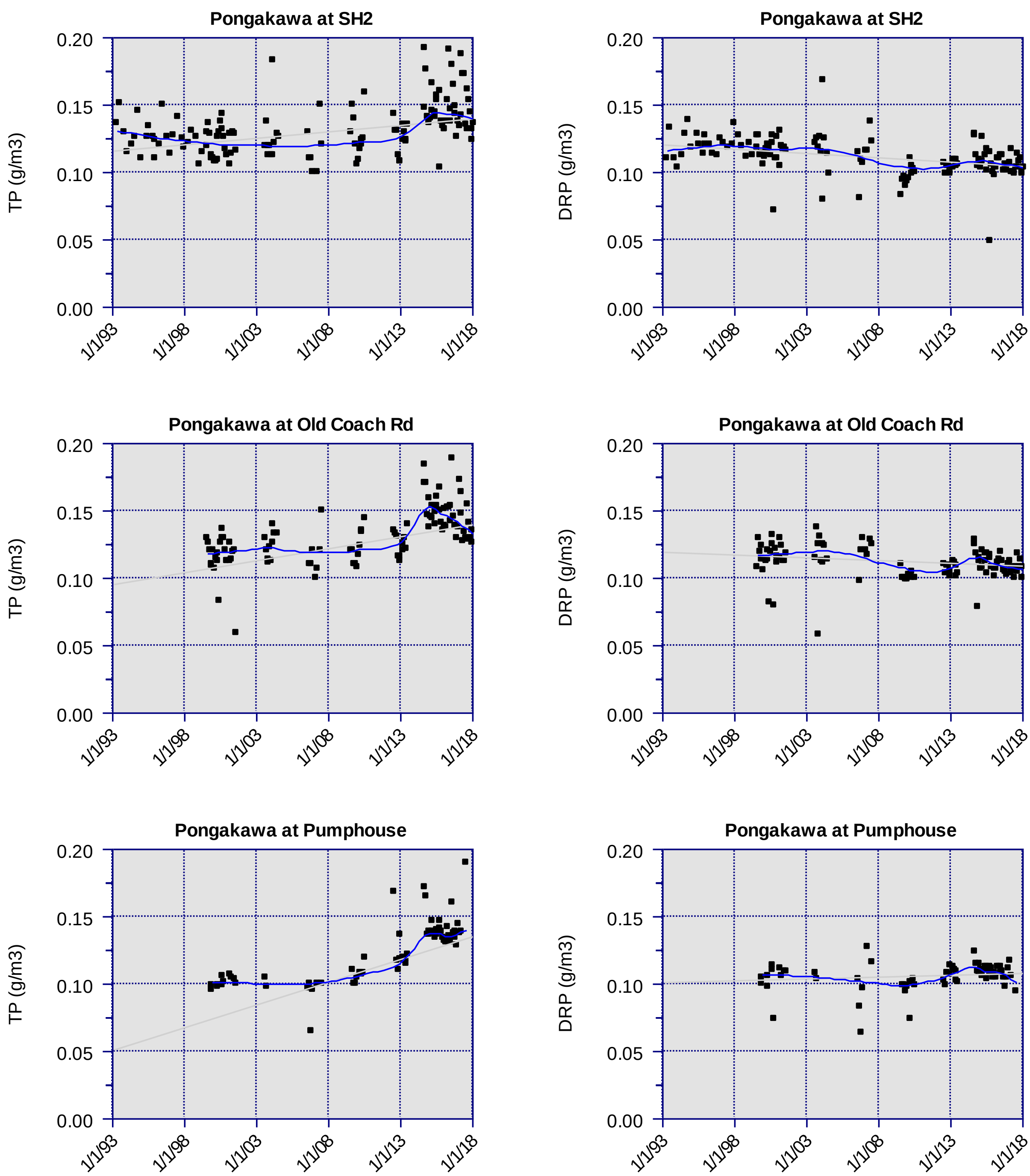



**Figure 4.6**: Pongakawa Stream trends in DRP and TP. This shows a decrease in DRP since about 2008 but an increase in TP since about 2015.

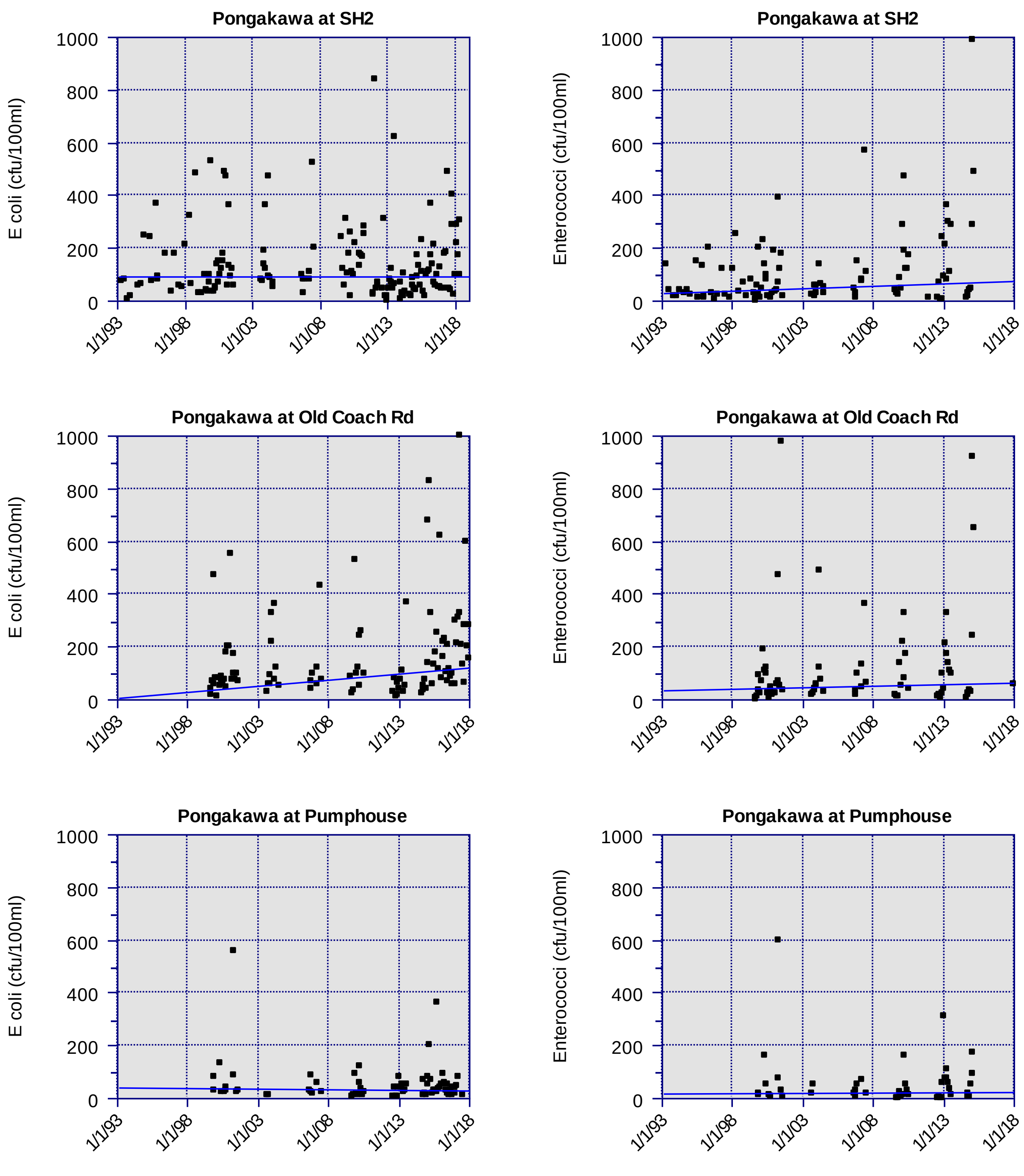
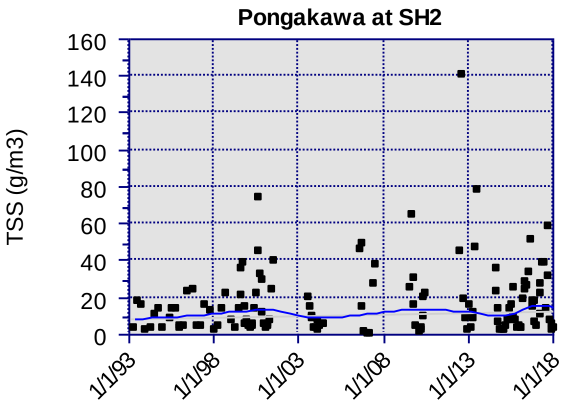
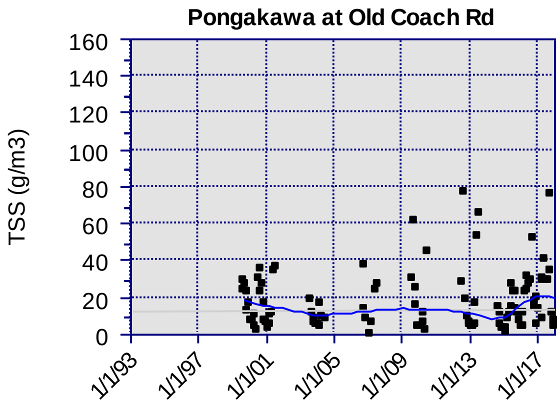



**Figure 4.7**: Pongakawa Stream trends in *E.coli* bacteria and Enterococci bacteria. This shows an increase in *E. coli* at Old Coach Road and an increase in Enterococci at SH2. (Data truncated at 1000 for clarity).



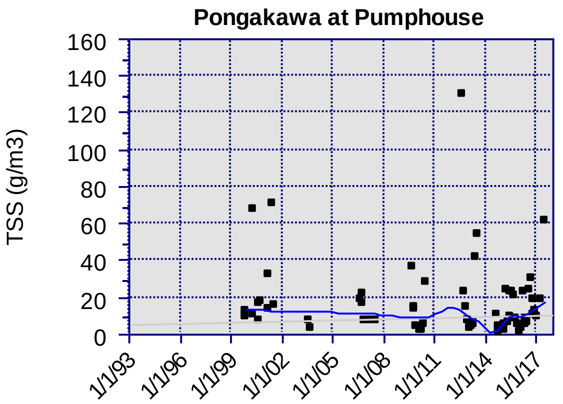




**Figure 4.8**: Pongakawa Stream trends in total suspended solids.

**Table 4.3**: Results of seasonal Kendell trend test. Shaded cells indicate both 'significant' and 'meaningful' trends with a *p*-value >0.05 and a PAC>0.5.

| Site | Variable | Count | Sampling period | Mean | Median | P | PAC | Trend direction | Prob. |
|---|---|---|---|---|---|---|---|---|---|
| Pongakawa at SH2 | Flow ($m^3/s$) | 88 | 15/12/70-16/4/18 | 4.94 | 4.90 | 0.91 | 0.0 | increasing | 0.58 |
| Pongakawa at SH2 | TN | 63 | 16/11/09-19/2/18 | 1.57 | 1.59 | 0.85 | -0.1 | decreasing | 0.58 |
| Pongakawa at SH2 | NNN | 132 | 16/9/93-19/2/18 | 1.39 | 1.42 | **0** | 1.0 | **increasing** | **1.0** |
| Pongakawa at SH2 | $NH_4$-N | 146 | 16/7/89-19/2/18 | 0.018 | 0.013 | 0.13 | -1.0 | **decreasing** | **0.96** |
| Pongakawa at SH2 | TP | 145 | 16/7/89-19/2/18 | 0.132 | 0.13 | **0** | 0.5 | **increasing** | **1.0** |
| Pongakawa at SH2 | DRP | 146 | 16/7/89-19/2/18 | 0.111 | 0.112 | **0** | -0.6 | **decreasing** | **1.0** |
| Pongakawa at SH2 | E coli | 162 | 25/2/91-3/4/18 | 188 | 91 | 0.26 | 1.1 | increasing | 0.88 |
| Pongakawa at SH2 | Enterococci | 110 | 25/2/91-2/2/15 | 117 | 47 | **0** | 4.2 | **increasing** | **1.0** |
| Pongakawa at SH2 | TSS | 145 | 16/7/89-19/2/18 | 16.4 | 11.0 | **0.02** | 1.2 | **increasing** | **1.0** |
| Pongakawa at SH2 | Turbidity | 145 | 25/2/91-19/2/18 | 3.5 | 2.6 | 0.15 | 0.7 | increasing | **0.96** |
| Pongakawa at Old Coach Rd | TN | 60 | 16/11/09-6/12/17 | 1.58 | 1.57 | 0.67 | -0.2 | decreasing | 0.69 |
| Pongakawa at Old Coach Rd | NNN | 105 | 14/7/99-6/12/17 | 1.45 | 1.48 | **0** | 0.8 | **increasing** | **1.00** |
| Pongakawa at Old Coach Rd | $NH_4$-N | 105 | 14/7/99-6/12/17 | 0.012 | 0.01 | **0** | -1.7 | **decreasing** | **1.00** |
| Pongakawa at Old Coach Rd | TP | 105 | 14/7/99-6/12/17 | 0.131 | 0.13 | **0** | 1.4 | **increasing** | **1.00** |
| Pongakawa at Old Coach Rd | DRP | 105 | 14/7/99-6/12/17 | 0.111 | 0.111 | **0.02** | -0.4 | **decreasing** | **1.00** |
| Pongakawa at Old Coach Rd | E coli | 105 | 14/7/99-6/12/17 | 200 | 97 | **0** | 4.8 | **increasing** | **1.00** |
| Pongakawa at Old Coach Rd | Enterococci | 72 | 14/7/99-6/11/17 | 119 | 51 | 0.13 | 2.0 | increasing | 0.94 |
| Pongakawa at Old Coach Rd | TSS | 105 | 14/7/99-6/12/17 | 18.0 | 13.0 | 0.56 | 0.3 | increasing | 0.75 |
| Pongakawa at Old Coach Rd | Turbidity | 105 | 14/7/99-6/12/17 | 3.4 | 2.4 | 1 | 0.0 | uncertain (median slope zero) | 0.5 |
| Pongakawa at Pumphouse | Flow ($m^3/s$) | 53 | 24/9/74-27/2/17 | 3.26 | 3.10 | 0.38 | -0.9 | decreasing | 0.8 |
| Pongakawa at Pumphouse | TN | 49 | 16/11/09-12/6/17 | 1.37 | 1.36 | **0.05** | -1.2 | **decreasing** | **1.0** |
| Pongakawa at Pumphouse | NNN | 71 | 7/10/99-12/6/17 | 1.27 | 1.30 | **0** | 1.0 | **increasing** | **1.0** |
| Pongakawa at Pumphouse | $NH_4$-N | 72 | 7/10/99-12/6/17 | 0.004 | 0.002 | **0** | -14.4 | **decreasing** | **1.0** |
| Pongakawa at Pumphouse | TP | 71 | 7/10/99-12/6/17 | 0.123 | 0.119 | **0** | 2.8 | **increasing** | **1.0** |
| Pongakawa at Pumphouse | DRP | 72 | 7/10/99-12/6/17 | 0.105 | 0.107 | 0.13 | 0.3 | increasing | **0.95** |
| Pongakawa at Pumphouse | E coli | 73 | 7/10/99-12/6/17 | 53 | 30 | 0.36 | -1.9 | decreasing | 0.82 |
| Pongakawa at Pumphouse | Enterococci | 47 | 7/10/99-2/2/15 | 83 | 21 | 0.86 | 0.8 | increasing | 0.65 |
| Pongakawa at Pumphouse | TSS | 72 | 7/10/99-12/6/17 | 18.8 | 9.7 | 0.19 | 2.5 | increasing | 0.91 |
| Pongakawa at Pumphouse | Turbidity | 72 | 7/10/99-12/6/17 | 3.3 | 1.8 | 0.88 | 0.9 | increasing | 0.65 |

All results units are $g/m^3$ except flow ($m^3/s$), *E. coli* and Enterococci (cfu/100mL, and turbidity (NTU).
P = *p*-value from student t-test, PAC = percent annual change. Prob. = probability (this indicates confidence in the trend direction based on the 90% confidence limits of the slope.

## 4.4 Little Waihi Estuary inflow loads

The total catchment load of nitrogen and phosphorus to the Waihi Estuary was calculated to be 517 t/yr and 50.1 t/yr respectively. This corresponds to an average areal load of nitrogen and phosphorus to the Waihi Estuary of 52 $mg/m^2/day$ and 5 $mg/m^2/day$ (Table 4.5). The total hydraulic loading of water entering Little Waihi Estuary from it's catchment is about 151 m/yr.

The nutrient concentrations used for calculating loads was the average data for the period July 2010 to July 2017 from the most downstream site Table 4.4. In the case of Wharere canal the average downstream concentration of TSS was less than the inflowing upstream tributaries (Wharere Stream and Puanene Stream).

The area of Little Waihi Estuary was measured to be about 274 ha, this consists of about 290.1 ha of estuary less about 15.7 ha of islands above the high tide level. Total load was divided by estuarine area to calculate the areal load to the estuary.

**Table 4.4**: Flow and nutrient concentrations used to calculate load to Little Waihi Estuary

| Site | Flow ($m^3/s$) | TN ($g/m^3$) | NNN ($g/m^3$) | $NH_4$-N ($g/m^3$) | TP ($g/m^3$) | DRP ($g/m^3$) | TSS ($g/m^3$) | Turbidity (NTU) | E coli (cfu/100ml) |
|---|---|---|---|---|---|---|---|---|---|
| Pukehina canal | 0.343 | 1.73 | 0.90 | 0.251 | 0.223 | 0.105 | 16.6 | 7.0 | 590 |
| Pongakawa canal | 5.35 | 1.58 | 1.52 | 0.016 | 0.143 | 0.106 | 19.3 | 4.0 | 269 |
| Wharere canal | 1.19 | 1.95 | 1.35 | 0.22 | 0.185 | 0.097 | 5.1 | 4.2 | 591 |
| Kaikokopu canal | 3.633 | 1.37 | 1.23 | 0.01 | 0.143 | 0.059 | 59.9 | 14.5 | 587 |
| Other | 0.035 | 1.73 | 0.90 | 0.25 | 0.22 | 0.11 | 16.58 | 6.99 | 590.20 |

Assume 'other' drains have the same water qualiyt as Pukehina canal

**Table 4.5**: Load to Little Waihi Estuary of nutrients, sediment and bacteria.

| Site | Flow ($m^3/s$) | TN (t/yr) | NNN (t/yr) | $NH_4$-N (t/yr) | TP (t/yr) | DRP (t/yr) | TSS (t/yr) | Turbidity (NTU) | E coli (cfu/s) |
|---|---|---|---|---|---|---|---|---|---|
| Pukehina canal | 0.343 | 19 | 10 | 2.7 | 2.4 | 1.1 | 179 | n.a. | 2,024,383 |
| Pongakawa canal | 5.35 | 266 | 256 | 2.7 | 24.1 | 17.9 | 3264 | n.a. | 14,374,006 |
| Wharere canal | 1.19 | 73 | 51 | 8.3 | 6.9 | 3.6 | 193 | n.a. | 7,027,295 |
| Kaikokopu canal | 3.633 | 157 | 141 | 1.1 | 16.4 | 6.8 | 6864 | n.a. | 21,313,612 |
| Other | 0.035 | 2 | 1 | 0.3 | 0.2 | 0.1 | 18 | n.a. | 206,570 |
| **Total load** | **10.55** | **517** | **459** | **15.1** | **50.1** | **29.5** | **10,518** | | **44,945,865** |
| **Areial load ($mg/m^2/day$)** | | 51.7 | 45.9 | 1.5 | 5.0 | 3.0 | 1052 | | |

Areial load based on the estuary being 274 ha

## 4.5 Uncertainties

The main uncertainties in estimating nutrient and sediment loads to Little Waihi Estuary comes from limited flow data. Long term flow records are available only from Pongakawa Stream. A model based on the REC was used to estimate flow from other catchments, but it is likely that these estimated could be considerably improved by developing a more catchment specific model and adjusting it for any known springs or water takes.

The Maketū / Little Waihi Wastewater Treatment Plant is located to the west of Little Waihi Estuary. This includes the discharge of treated wastewater to land by sub-surface irrigation. No account has been made of any loading (if any) to the Waihi Estuary of residual nitrogen and phosphorus after land disposal.

# 5 Discussion

## 5.1 Estuarine Trophic Index

This report has focused on external nutrient loads to the Maketū Estuary and Little Waihi Estuary, but it needs to be remembered that the response of estuaries to external nutrient loads is complex. Some estuaries are more susceptible to eutrophication than others. The susceptibility to eutrophication is influenced by the extent to which it is flushed (oceanic influence), and its depth.

The Estuarine Trophic Index (ETI) uses a simple four-category typology to help assess susceptibility of an estuary to eutrophication (Robertson et al. 2016). These categories are:

1. Shallow intertidal dominated estuaries (SIDEs)
2. Shallow, short residence time tidal river and tidal river with adjoining lagoon estuaries (SSRTREs)
3. Deeper subtidal dominated, longer residence time estuaries (DSDEs)
4. Coastal lakes (intermittently closed/open lakes and lagoons, (ICOLLs)).

Using this typology Maketū Estuary and Little Waihi Estuary are classed as 'shallow, intertidal dominated estuaries (SIDES)'. These types of estuaries are shallow (<3m), short residence time (<3 days), and predominantly intertidal (>40%). They are generally more likely to be limited by nitrogen rather than phosphorus. Overall their susceptibility to nutrient loads is considered to be moderate to high (Robertson et al. 2016).

The Estuarine Trophic Index Screening Tool 1 further refines SIDE type estuary susceptibility to eutrophication based on the ASSETS approach (Bickers et al. 1999). First it uses a matrix approach to determine Physical Susceptibility, i.e. the susceptibility based on the physical attributes of flushing potential[12] and dilution potential[13] (Figure 5.1). A second matrix is used to determine the Combined Physical and Nutrient Load Susceptibility. This combines the previously determined Physical Susceptibility with the Nitrogen Load Susceptibility (i.e. the aerial N load in $mg/m^2/day$) (Figure 5.2).

[12] Flushing potential (FP) = freshwater inflow ($m^3/d$) divided by estuary volume ($m^3$). For a microtidal estuary (<0.8m) categorise FP as: $0\text{-}10^{-1}$ High, $10^{-2}$ Moderate, $10^{-3}$ - $10^{-4}$ Low.
[13] Dilution potential (DP) = 1 ÷ estuary volume ($ft^3$). Categorise DP as: $10^{-12}$ - $10^{-13}$ = High; $10^{-11}$ = Moderate; $10^{-9}\text{-}10^{-10}$ = Low. Expressed in feet because the approach was adopted from ASSETS.

| | | Dilution potential | | |
|---|---|---|---|---|
| **Flushing Potential** | | High | Moderate | Low |
| | High | High EXP & Low Susceptibility | High EXP & Low Susceptibility | Moderate EXP & Moderate Susceptibility |
| | Mod | High EXP & Low Susceptibility | Moderate EXP & Moderate Susceptibility | Low EXP & High Susceptibility |
| | Low | Moderate EXP & Moderate Susceptibility | Low EXP & High Susceptibility | Low EXP & High Susceptibility |

**Figure 5.1**: Overall physical susceptibility of a shallow intertidal estuary (from Robertson et al. 2016)

| | | N load Susceptibility (mg/m²/d) | | | |
|---|---|---|---|---|---|
| **Physical Susceptibility** | | Very High >250 | High >50-250 | Moderate 10-50 | Low <10 |
| | High | Band D Very High | Band C High | Band C High | Band B Moderate |
| | Mod | Band D Very High | Band C High | Band B Moderate | Band A Low |
| | Low | Band C High | Band B Moderate | Band B Moderate | Band A Low |

**Figure 5.2**: Combined Physical and Nutrient Load Susceptibility of a shallow intertidal estuary (from Robertson et al. 2016)

Using this approach, the Maketū Estuary is classified as having 'moderate' Physical Susceptibility' based on it having a '*high'* flushing potential[14] and a '*low'* dilution potential[15]. The Nutrient Load Susceptibility is 'moderate' both before and after the re-diversion (31 mg/m$^2$/day), and thus the Combined Physical and Nutrient Load Susceptibility is also '*moderate'*.

Little Waihi Estuary has similar physical characteristics to Maketū Estuary after re-diversion in terms of flushing potential and dilution potential. It is likely to have '*moderate'* Physical Susceptibility', but the Nutrient Load Susceptibility is just within the '*high'* band due to the higher nitrogen concentrations in the inflows (specific N load of 52 mg/m$^2$/day). Thus, the Combined Physical and Nutrient Load Susceptibility of Little Waihi Estuary is '*high'*.

### 5.1.1 Interpreting the ETI in the context of the Kaituna River re-diversion

The ETI Screening Tool 1 described above provides a high-level risk assessment for estuaries. It has been applied to the whole estuary and does not account for localised effects or internal nutrient loading that can partially decouple the estuary algae from short term changes in external nutrient loads. Also, it only accounts for hydraulic loading and flushing by using coarse categories. More specific investigations or modelling are usually needed to understand estuary condition and response to external loads.

The Kaituna re-diversion project will substantially increase will increase the total load of nutrients and microbial contamination to the Ongatoro / Maketū Estuary. However, the direct effect on nutrient concentrations in the estuary will be relatively small (4% in upper estuary to 25% increase in the lower estuary), because of additional seawater entering with the re-diversion. Overall the re-diversion is expected to improve the ecological condition of the Maketū Estuary by considerably increasing the flushing of benthic algae and associated muds, and a consequent reduction of anoxic zones and internal loads (Hamill 2014).

[14] Flushing potential for Maketū Estuary (post re-diversion) is 'high', i.e. 0.7 (inflow 12.82 m$^3$/s, estuary volume = 1,516,400 m$^3$ (at mean high tide).
[15] Dilution Potential for Maketū Estuary = 1.9 x 10$^{-8}$ (1/53,528,920 ft$^3$) = 'low'.

The changes in Maketū Estuary that occurred after the original Kaituna River diversion in the mid-1950's was considerably more than what might be expected if looking at risk categories and bands in the ETI Screening Tool. There was widespread loss of freshwater wetland vegetation, almost complete loss of seagrass beds, and macro-algae accumulations covering large parts of the estuary (Hamill 2014, Park 2014). While the re-diversion project is expected to result in considerable improvements in the estuary, the degree of improvement is not clear. It is possible that reductions in upstream nutrient loads become more important because of increased connection with the catchment. Furthermore, it is likely that improvement in ecological conditions will not follow the same path as it degradation. There may be hysteresis, and additional interventions or nutrient reductions may be required to get to a desired ecological state.

## 5.2 Comparison between Maketū and Little Waihi Estuary

The Maketū Estuary (post re-diversion) and Little Waihi Estuary are a similar size (240 ha and 274 ha respectively) and have similar hydraulic loading (151 m/yr and 173 m/yr respectively). However, the specific load of TN to Maketū Estuary is only about 60% of that to the Little Waihi Estuary (i.e. 31 $mg/m^2/day$ compared to 52 $mg/m^2/day$), and the specific load of TP to Maketū Estuary is only about 45% of that to the Little Waihi Estuary (i.e. 2.3 $mg/m^2/day$ compared to 5 $mg/m^2/day$).

The major inflows entering Little Waihi Estuary have considerably higher concentrations of TN and TP compared to the Kaituna River inflow to Maketū Estuary. Furthermore, inflows to Waihi Estuary have a higher proportion of the total N and P load in a dissolved form compared to in the Kaituna River. These factors make the Little Waihi Estuary relatively more sensitive to eutrophication that the Maketū Estuary.

# 6 Conclusions

The total catchment load of nitrogen and phosphorus to the Maketū Estuary post re-diversion was calculated to be 267 t/yr and 20.1 t/yr respectively. This corresponds to an average areal load of nitrogen and phosphorus to the Maketū Estuary of 31 $mg/m^2/day$ and 2.3 $mg/m^2/day$. The ETI Screening Tool classified the combined Physical and Nutrient Load Susceptibility of the Maketū Estuary as 'moderate'.

A priority sub-catchment for reducing nutrient inputs to Maketū Estuary is the Waitipuia Stream and Singletons Drain Pump Station. Although these inputs contribute only about 5% of the total N and P load to Maketū Estuary, they nevertheless have a considerable influence on the water quality in the southern part of the Maketū Estuary due to the limited flushing in this embayment.

The total catchment load of nitrogen and phosphorus to the Waihi Estuary was calculated to be 517 t/yr and 50.1 t/yr respectively. This corresponds to an average areal load of nitrogen and phosphorus to the Waihi Estuary of 52 $mg/m^2/day$ and 5 $mg/m^2/day$. The ETI Screening Tool classified the combined Physical and Nutrient Load Susceptibility of the Waihi Estuary as just within the 'high' category.

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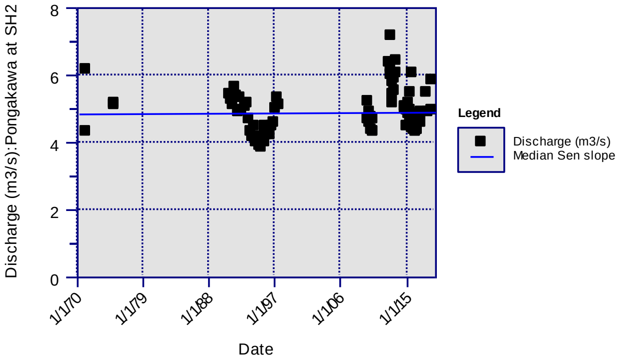
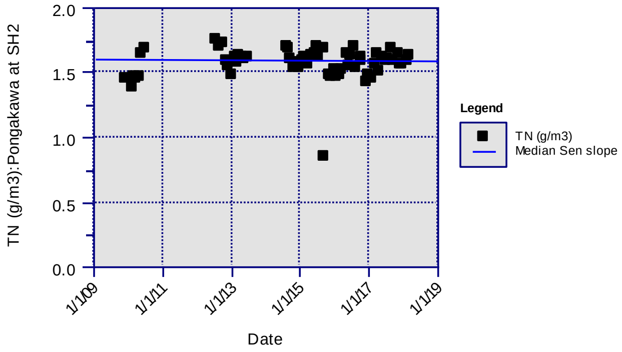
# Appendix 1: Graphs of trend analysis Little Waihi catchment

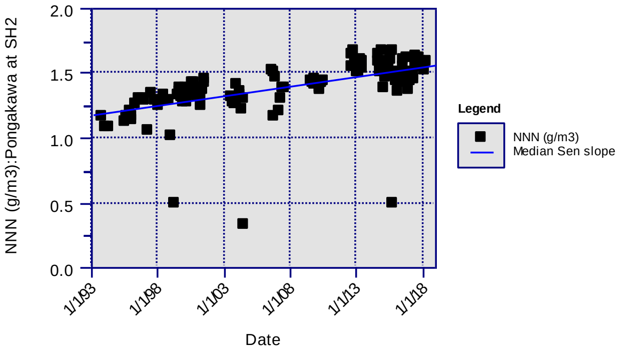
### Trend for Discharge (m3/s) for Pongakawa at SH2



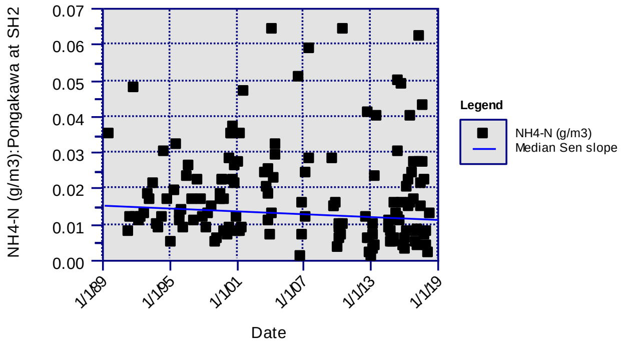

### Trend for TN (g/m3) for Pongakawa at SH2



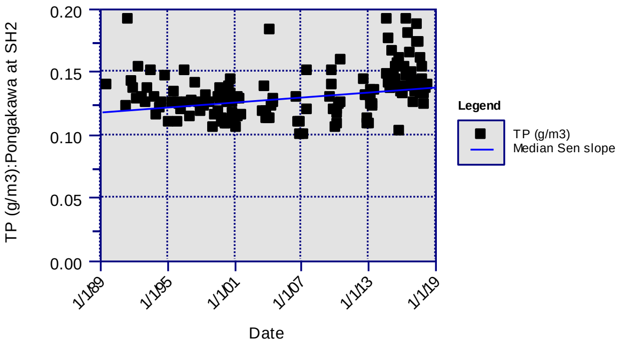

### Trend for NNN (g/m3) for Pongakawa at SH2



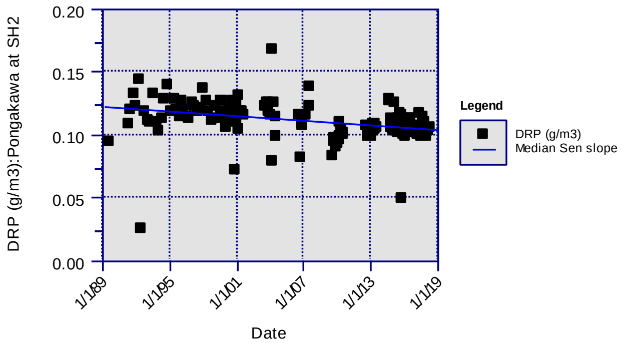

### Trend for NH4-N (g/m3) for Pongakawa at SH2



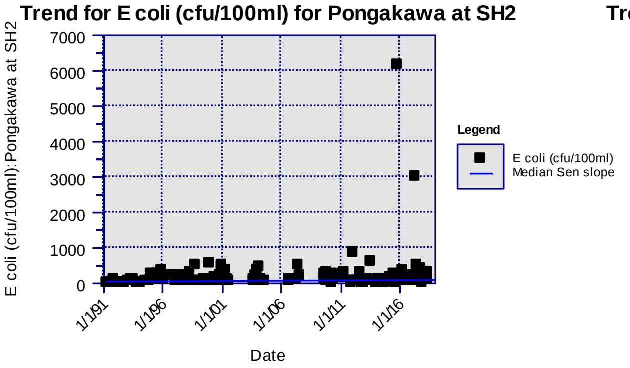

### Trend for TP (g/m3) for Pongakawa at SH2



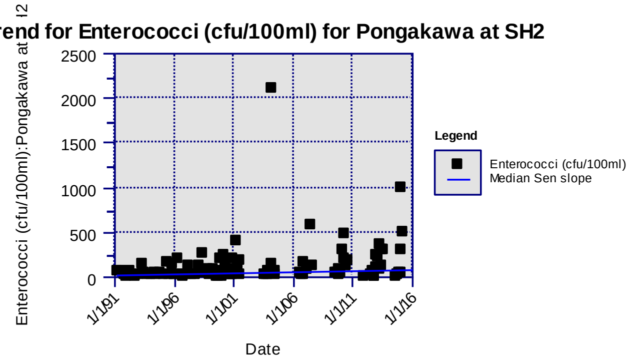

### Trend for DRP (g/m3) for Pongakawa at SH2

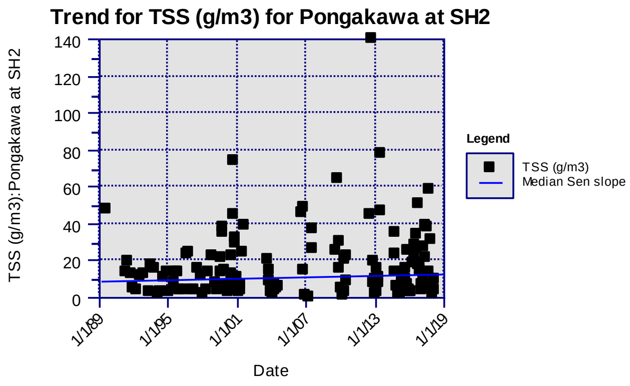


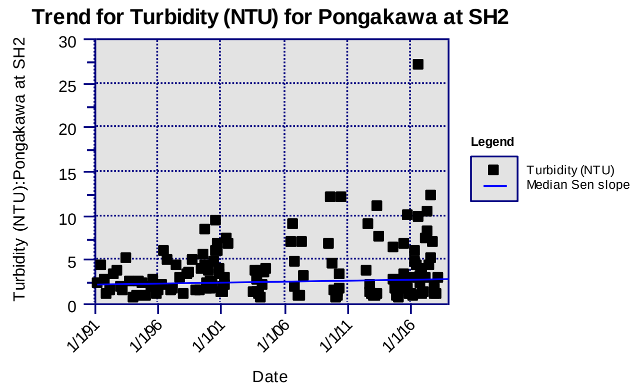

### Trend for E coli (cfu/100ml) for Pongakawa at SH2

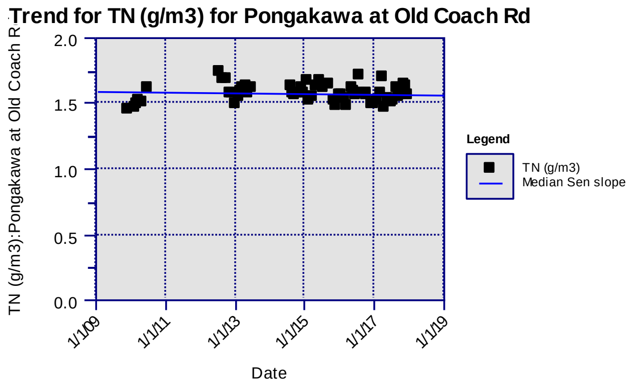


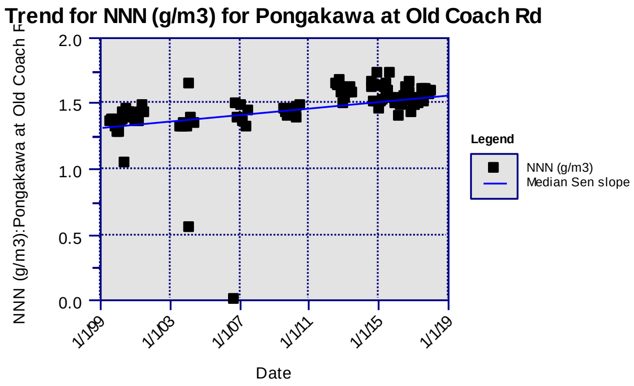

### Trend for Enterococci (cfu/100ml) for Pongakawa at SH2

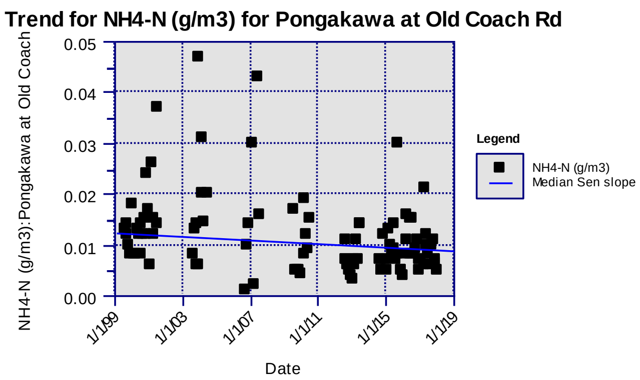


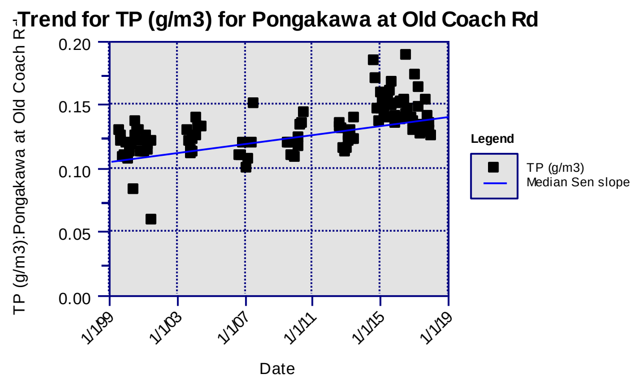

Trend for TSS (g/m3) for Pongakawa at SH2
TSS (g/m3):Pongakawa at SH2
Date
Legend
TSS (g/m3)
Median Sen slope

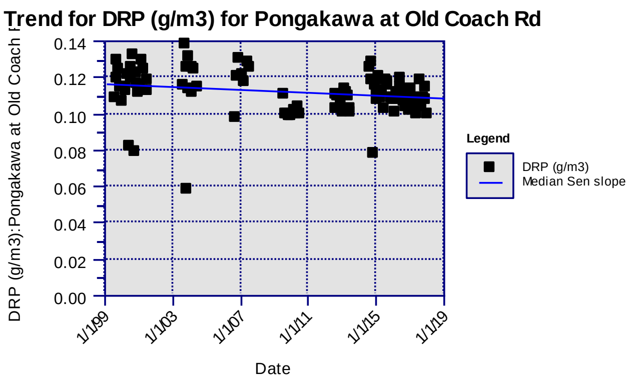

Trend for Turbidity (NTU) for Pongakawa at SH2
Turbidity (NTU):Pongakawa at SH2
Date
Legend
Turbidity (NTU)
Median Sen slope

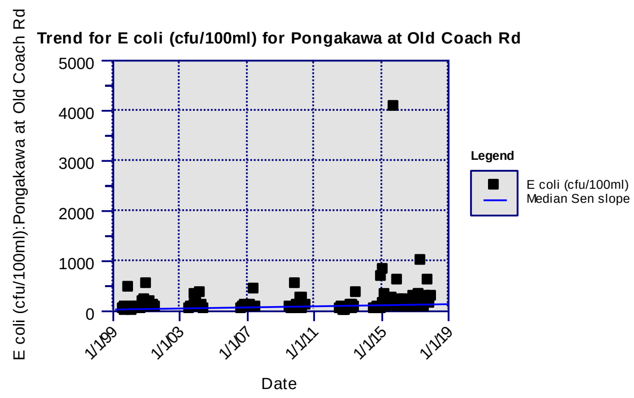

Trend for TN (g/m3) for Pongakawa at Old Coach Rd
Date
Legend
TN (g/m3)
Median Sen slope

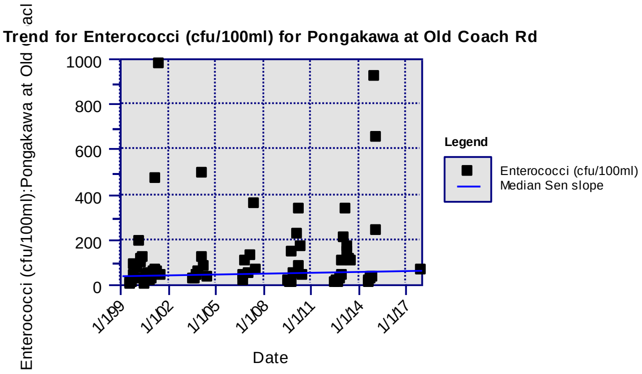

Trend for NNN (g/m3) for Pongakawa at Old Coach Rd
Date
Legend
NNN (g/m3)
Median Sen slope

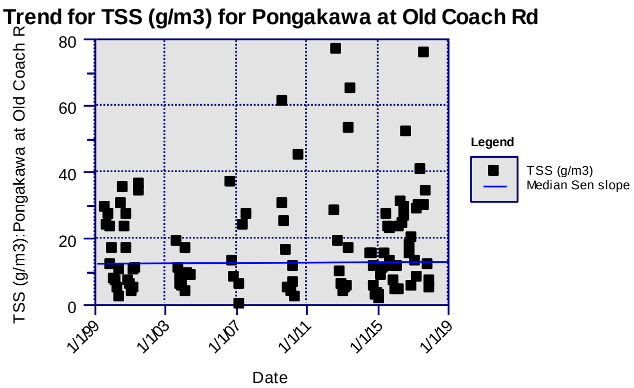

Trend for NH4-N (g/m3) for Pongakawa at Old Coach Rd
Date
Legend
NH4-N (g/m3)
Median Sen slope

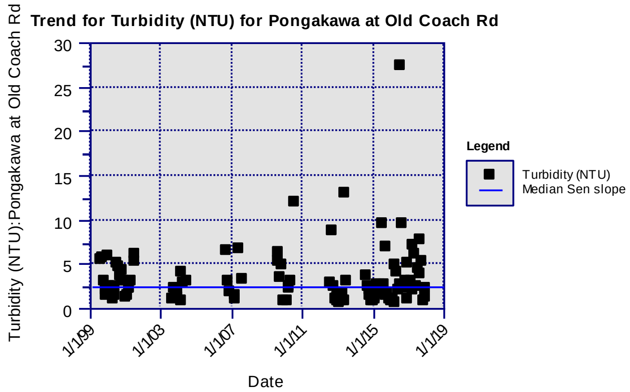

Trend for TP (g/m3) for Pongakawa at Old Coach Rd
Date
Legend
TP (g/m3)
Median Sen slope

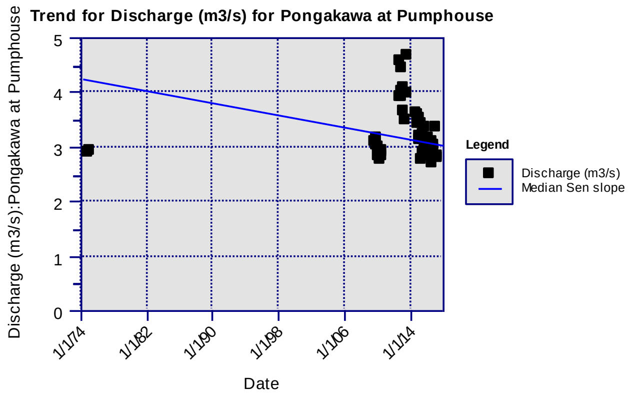

Trend for DRP (g/m3) for Pongakawa at Old Coach Rd
Date
Legend
DRP (g/m3)
Median Sen slope

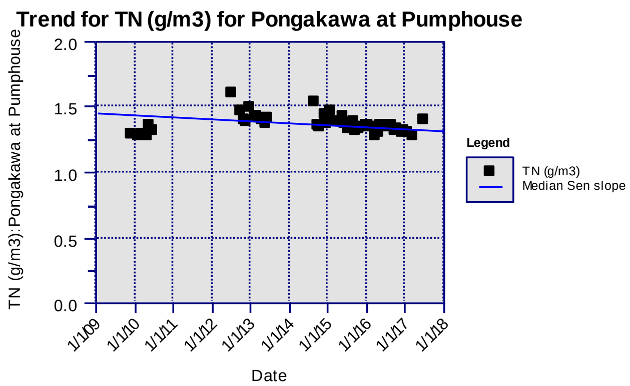

Trend for E coli (cfu/100ml) for Pongakawa at Old Coach Rd
E coli (cfu/100ml):Pongakawa at Old Coach Rd
Date
Legend
E coli (cfu/100ml)
Median Sen slope

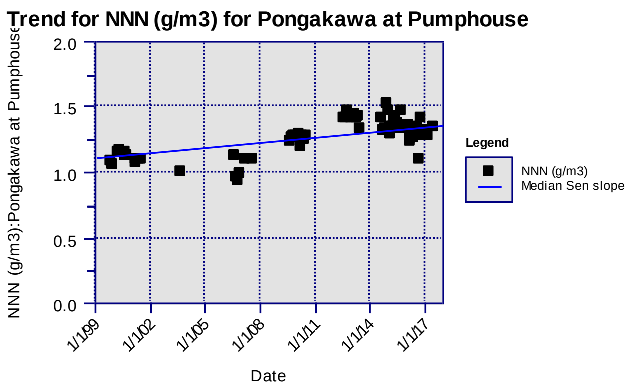

Trend for Enterococci (cfu/100ml) for Pongakawa at Old Coach Rd
Enterococci (cfu/100ml):Pongakawa at Old Coach Rd
Date
Legend
Enterococci (cfu/100ml)
Median Sen slope

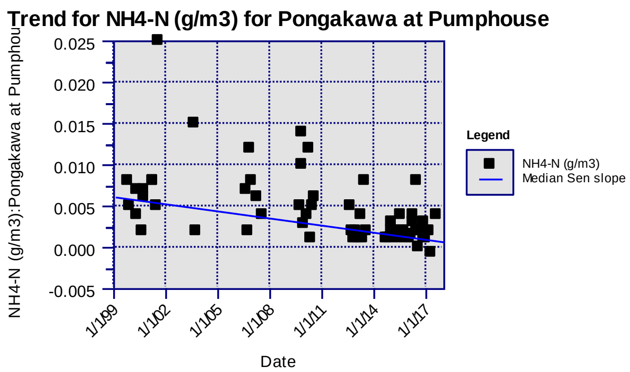

Trend for TSS (g/m3) for Pongakawa at Old Coach Rd
TSS (g/m3):Pongakawa at Old Coach Rd
Date
Legend
TSS (g/m3)
Median Sen slope

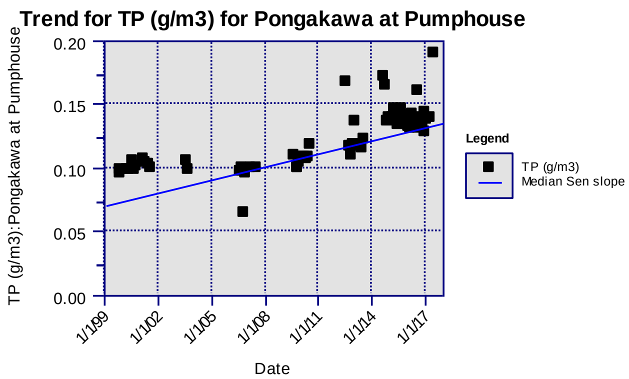

Trend for Turbidity (NTU) for Pongakawa at Old Coach Rd
Turbidity (NTU):Pongakawa at Old Coach Rd
Date
Legend
Turbidity (NTU)
Median Sen slope

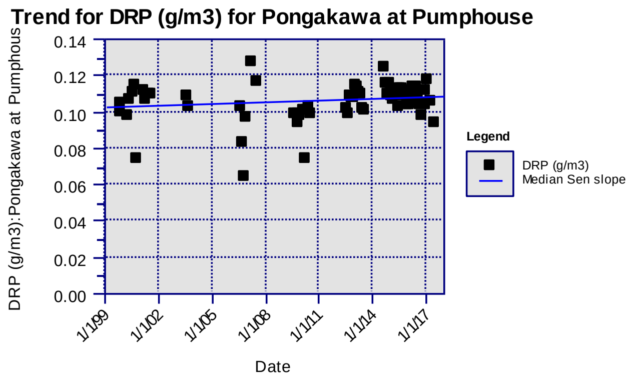

Trend for Discharge (m3/s) for Pongakawa at Pumphouse
Discharge (m3/s):Pongakawa at Pumphouse
Date
Legend
Discharge (m3/s)
Median Sen slope

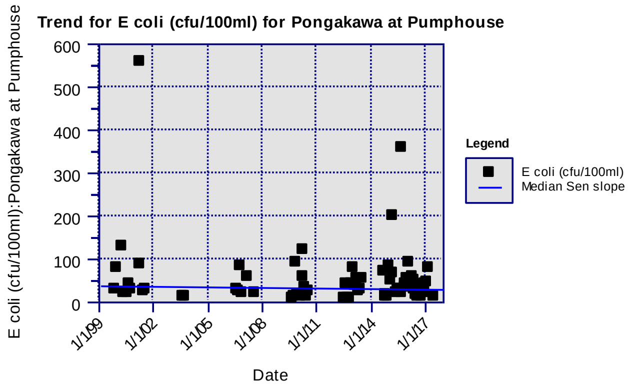

Trend for TN (g/m3) for Pongakawa at Pumphouse
TN (g/m3):Pongakawa at Pumphouse
Date
Legend
TN (g/m3)
Median Sen slope

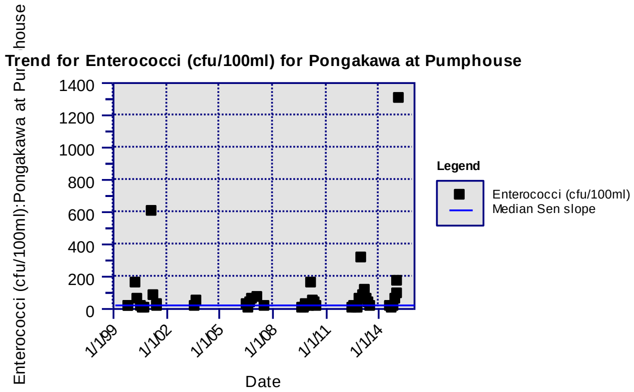

Trend for NNN (g/m3) for Pongakawa at Pumphouse
NNN (g/m3):Pongakawa at Pumphouse
Date
Legend
NNN (g/m3)
Median Sen slope

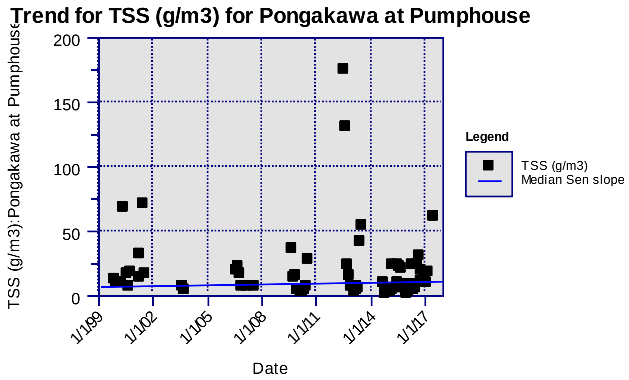

Trend for NH4-N (g/m3) for Pongakawa at Pumphouse
NH4-N (g/m3):Pongakawa at Pumphouse
Date
Legend
NH4-N (g/m3)
Median Sen slope

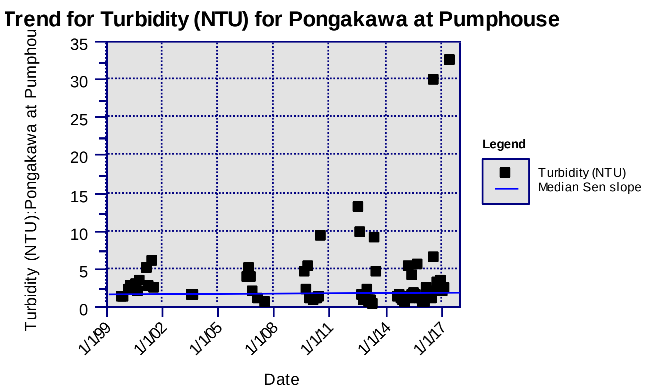

Trend for TP (g/m3) for Pongakawa at Pumphouse
TP (g/m3):Pongakawa at Pumphouse
Date
Legend
TP (g/m3)
Median Sen slope

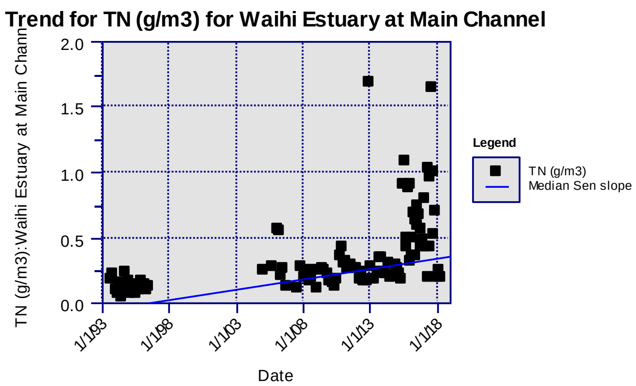

Trend for DRP (g/m3) for Pongakawa at Pumphouse
DRP (g/m3):Pongakawa at Pumphous
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1/1/99
1/1/02
1/1/05
1/1/08
1/1/11
1/1/14
1/1/17
Date
Legend
DRP (g/m3)
Median Sen slope

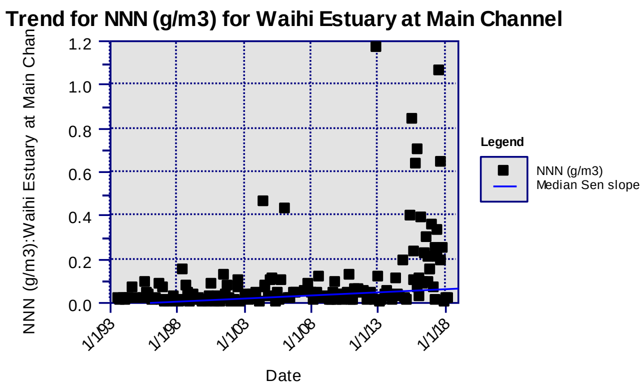

Trend for E coli (cfu/100ml) for Pongakawa at Pumphouse
E coli (cfu/100ml):Pongakawa at Pumphouse
600
500
400
300
200
100
0
1/1/99
1/1/02
1/1/05
1/1/08
1/1/11
1/1/14
1/1/17
Date
Legend
E coli (cfu/100ml)
Median Sen slope

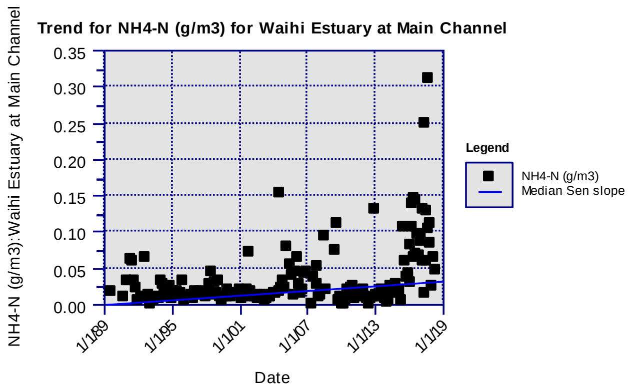

Trend for Enterococci (cfu/100ml) for Pongakawa at Pumphouse
Enterococci (cfu/100ml):Pongakawa at Pumphouse
1400
1200
1000
800
600
400
200
0
1/1/99
1/1/02
1/1/05
1/1/08
1/1/11
1/1/14
Date
Legend
Enterococci (cfu/100ml)
Median Sen slope


Trend for TSS (g/m3) for Pongakawa at Pumphouse
TSS (g/m3):Pongakawa at Pumphouse
200
150
100
50
0
1/1/99
1/1/02
1/1/05
1/1/08
1/1/11
1/1/14
1/1/17
Date
Legend
TSS (g/m3)
Median Sen slope


Trend for Turbidity (NTU) for Pongakawa at Pumphouse
Turbidity (NTU):Pongakawa at Pumphou
35
30
25
20
15
10
5
0
1/1/99
1/1/02
1/1/05
1/1/08
1/1/11
1/1/14
1/1/17
Date
Legend
Turbidity (NTU)
Median Sen slope


Trend for TN (g/m3) for Waihi Estuary at Main Channel
TN (g/m3):Waihi Estuary at Main Chann
2.0
1.5
1.0
0.5
0.0
1/1/93
1/1/98
1/1/03
1/1/08
1/1/13
1/1/18
Date
Legend
TN (g/m3)
Median Sen slope


Trend for NNN (g/m3) for Waihi Estuary at Main Channel
NNN (g/m3):Waihi Estuary at Main Chan
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1/1/93
1/1/98
1/1/03
1/1/08
1/1/13
1/1/18
Date
Legend
NNN (g/m3)
Median Sen slope


Trend for NH4-N (g/m3) for Waihi Estuary at Main Channel
NH4-N (g/m3):Waihi Estuary at Main Channel
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1/1/89
1/1/95
1/1/01
1/1/07
1/1/13
1/1/19
Date
Legend
NH4-N (g/m3)
Median Sen slope