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Memorandum

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Date	6 May 2016
Attention	Ruamahanga Whaitua Committee
From	Michelle Sands, Phil Pedruco
Subject	**Surface water quality modelling E.coli and sediment**

This memo summarises the E.coli and sediment modelling methodologies and presents existing situation E.coli results and interim sediment modelling results.

1. E.coli

The purpose of this memo is to outline the approach to modelling E.coli in the Ruamahanga catchment. The approach has been informed by the available data and recent catchment scale modelling of Escherichia coli (E. coli) undertaken in New Zealand.

1.1 Background

E. coli can be generated from a variety of sources within a catchment including (after Dymond, 2016):

- Direct access of cattle to waterways;
- Overland flow through grazed paddocks entraining E. coli;
- Application of sprayed dairy effluent; and
- Waste water discharge to streams,
- As well as wildfowl and other domestic and feral animals.

1.1.1 Previous Studies

A number of studies have recently been completed in New Zealand that investigate the E. coli concentrations the catchments these studies have been used to inform our methodology, these studies include:

- Mapping of Escherichia coli sources connected to waterways in the Ruamahanga catchment, New Zealand. (Dymond et al. 2016)
- Assessment of the CLUES Model for the Implementation of the National Policy Statement on Freshwater Management in the Auckland Region (Semadeni-Davies et al., 2015)
- Modelling E. coli in the Waikato and Waipa River Catchments (Semadeni-Davies et al., 2015)
- Catchment models for nutrients and microbial indicators Modelling application to the upper Waikato River catchment (Elloit et al. 2014)
- Water quality of the Pomahaka River catchment: scope for improvement (McDowell et al., 2011)

1.2 Data

Monthly monitoring data has been collected at a number of sites in the Ruamahanga catchment and these have been extracted from Hilltop database. The site with concurrent streamflow data are listed in Table 1 below and shown in Figure 1below.

This table lists the start and end dates as well as the number of observations and the median concentration. Note that the data was inspected for spurious data, which was removed from the analysis.

These samples are biased towards fine weather and low flows. While these biases could be problematic for many water quality constituents this is less so for E.coli. The main risk from E.coli occur from recreational activities such as swimming, boating and fishing as these are naturally biased towards fine weather and low flows. For these reasons this is not considered a limitation to the study.

Table 1 : Sites with E. coli and flow data

Site	Start	End	No. observations	Median Concentration cfu/100mL	CLUES load (10^15 org/yr)
Waiohine River at Gorge†	2002-01-30	2014-06-26	149	4	0.26
Mangatarere River at SH2	2000-01-12	2014-06-26	174	145	4.03
Ruamahanga at Gladstone Bridge	2000-01-11	2014-06-25	174	30	16.7
Taueru River at Gladstone	2000-01-11	2014-06-18	174	110	4.01
Waipoua River at Colombo	2000-01-11	2014-06-19	174	46	4.27
Kopuaranga River at Stuarts	2000-01-11	2014-06-25	173	240	3.14
Ruamahanga River at Mt Bruce†	2000-02-08	2003-06-24	37	5	0.47
Parkvale Stream at Renalls Weir	2003-09-22	2014-06-26	130	500	0.71
Ruamahanga at McLays	2003-09-18	2014-06-25	130	5	0.23
Taueru River at Castlehill	2003-09-25	2014-06-17	130	100	0.18
Beef Creek at headwaters	2003-09-22	2014-06-26	128	6	0.004
Tauanui River at Whakatomotomo	2003-10-02	2014-06-27	128	4	0.002
Ruamahanga River at Waihenga Bridge	2000-01-12	2003-06-25	43	30	29.7

† Truncated record, as some values from the beginning of the monitoring record are zero values (and these are excluded for this analysis).

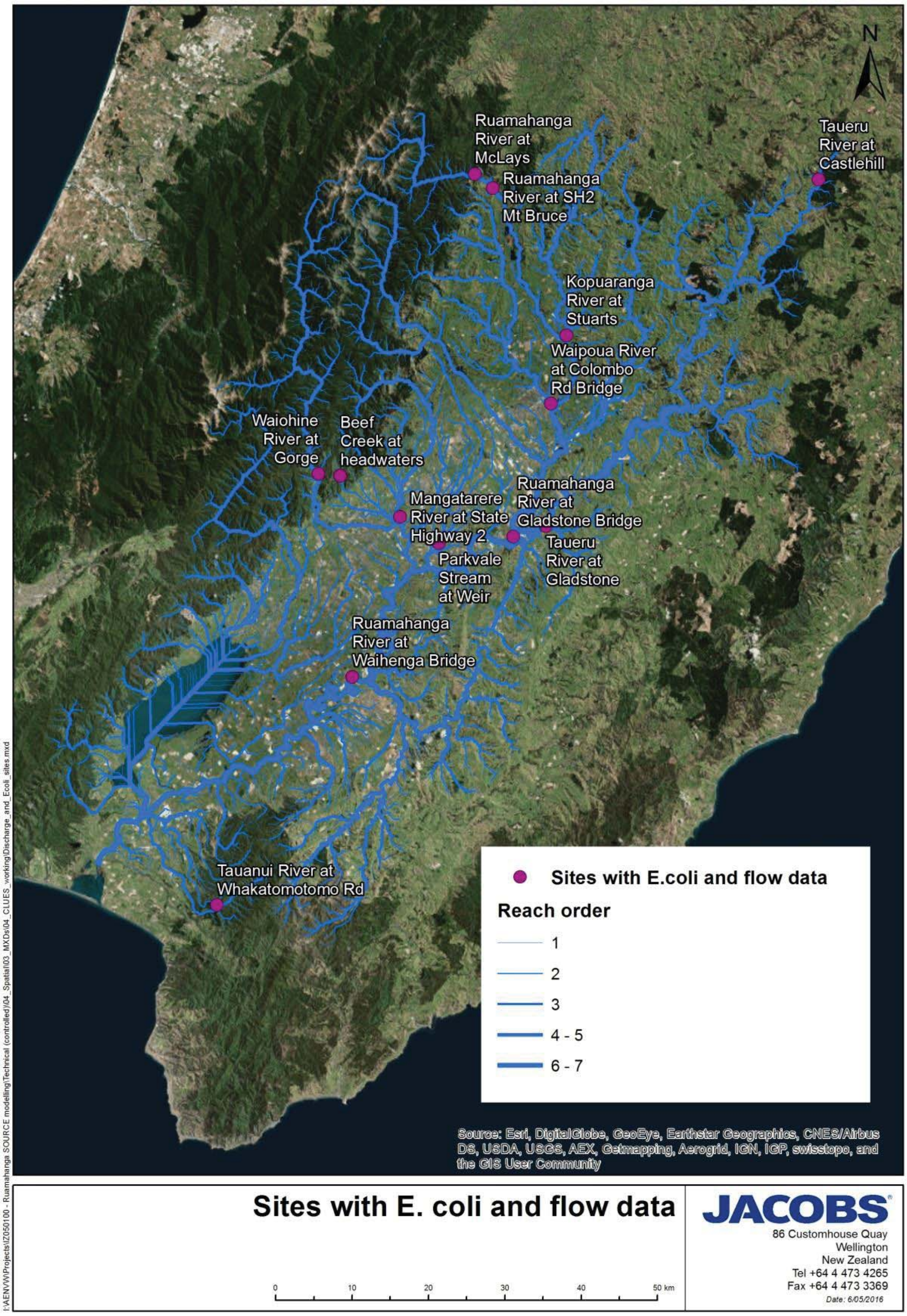


Figure 1 Flow sites with E.coli measured data

1.2.1 Relationship of CLUES load and measured concentration

The CLUES models is a combination of a number of existing models within a GIS framework, including a SPARROW component. SPARROW predicts annual average stream loads of total nitrogen, total phosphorus, sediment and number of organisms of E. coli. This framework includes stream routing and loss (or decay) processes. SPARROW has been applied to the whole New Zealand (Elliott et al. 2005). Further details on the CLUES modelling framework can be found in Semadeni-Davies et al. (2011) and Woods et al. (2006a).

The average annual instream numbers of E. coli organisms for the Ruamahanga catchment has been extracted from CLUES. The numbers of organisms calculated by CLUES at each of the sites listed in Table 1 has been extracted and are shown in this table.

A relationship between the CLUES instream loads and median monthly concentrations is presented in

Figure 2 below. In this figure the CLUES concentrations are calculated the estimated in-stream annual load in the estimated mean annual flow for that stream reach in the River Environmental Classification (REC1) data layer.

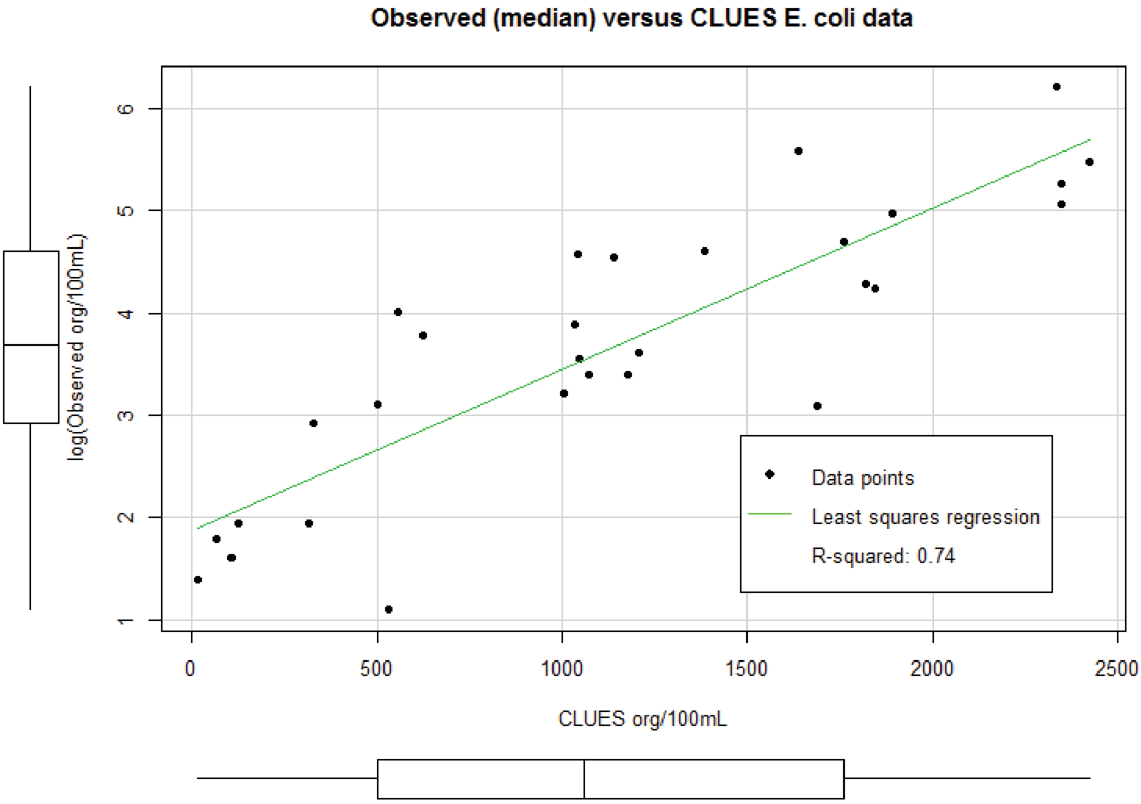


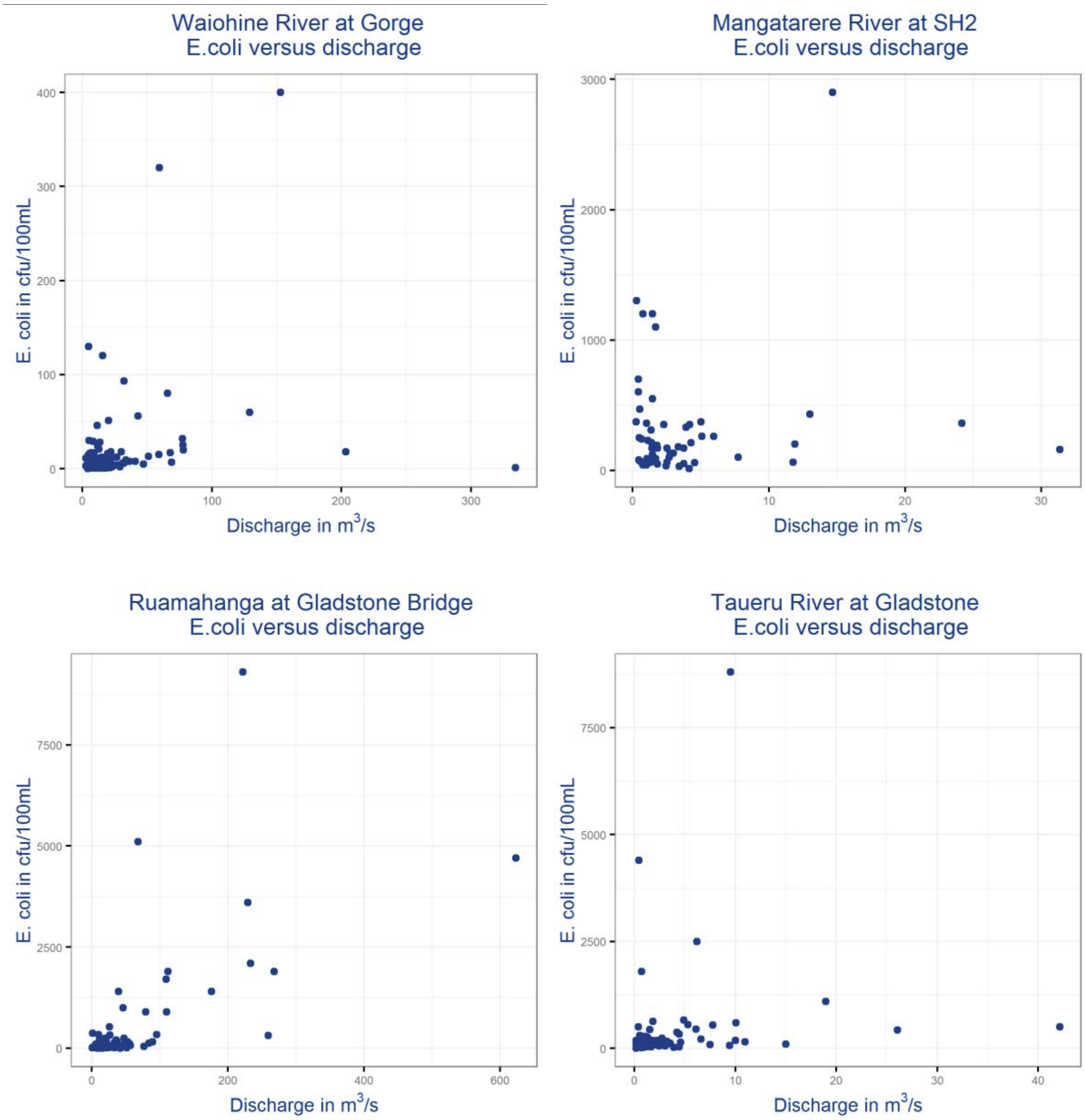
Figure 2 Relationship between observed median and CLUES instream loads

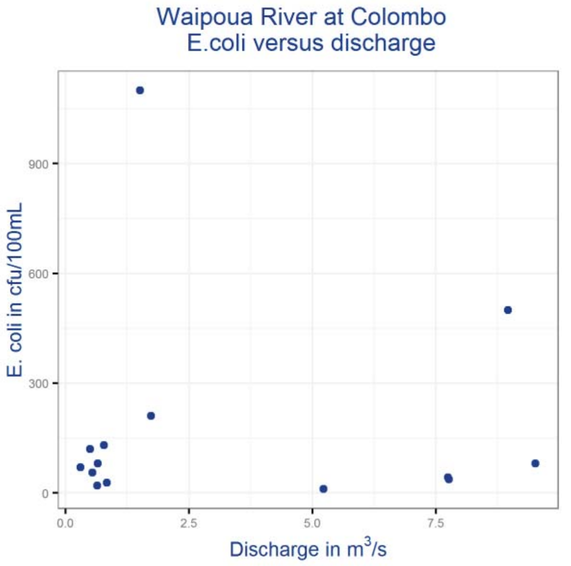
1.3 Analysis

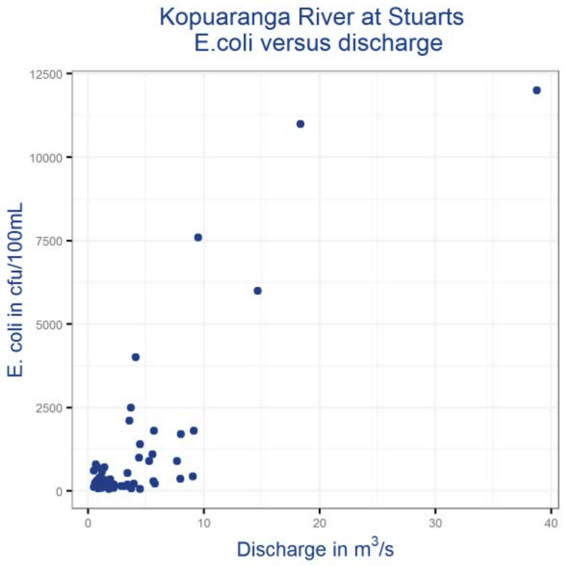
The purpose of the analysis was to investigate what are the key drivers for producing estimates of instream E.coli concentrations. Both discharge and time of the year were investigated. In addition, changes through time or trends were also considered.

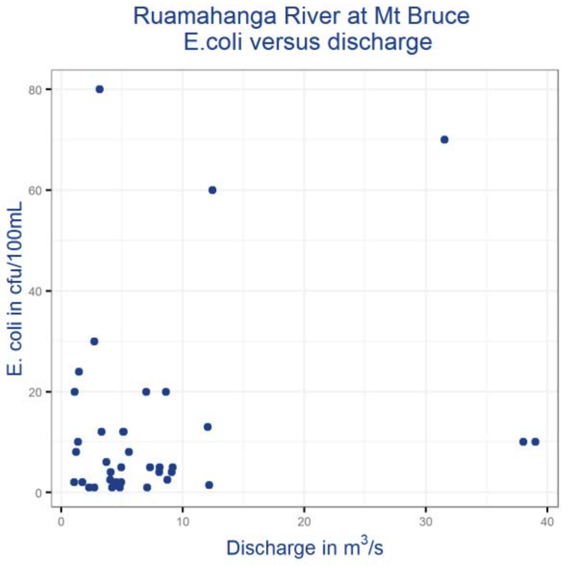
1.3.1 Flows

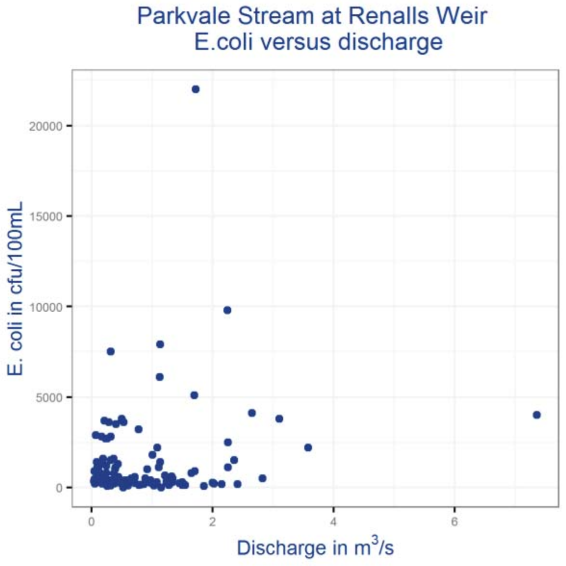
Plots of observed E.coli concentrations and instantaneous discharge were prepared. These are presented in Figure 3. Inspection of these figures indicates there is only a weak relationship between discharge and E.coli (cfu per 100 ml) at most sites. Therefore, this was not considered feasible to develop a rating type approach for the Ruamahanga catchment.

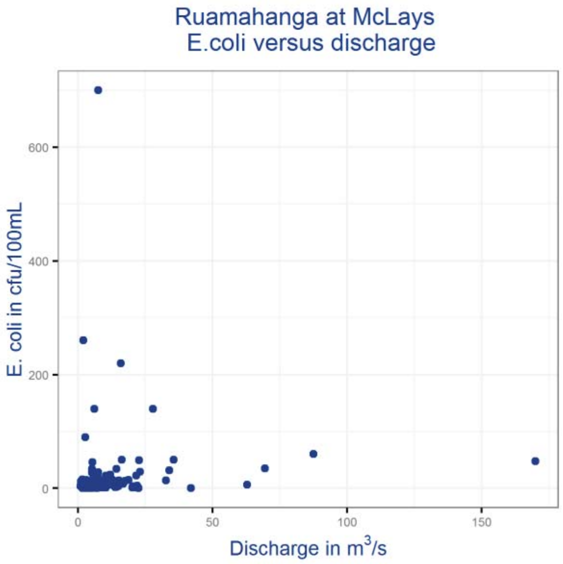


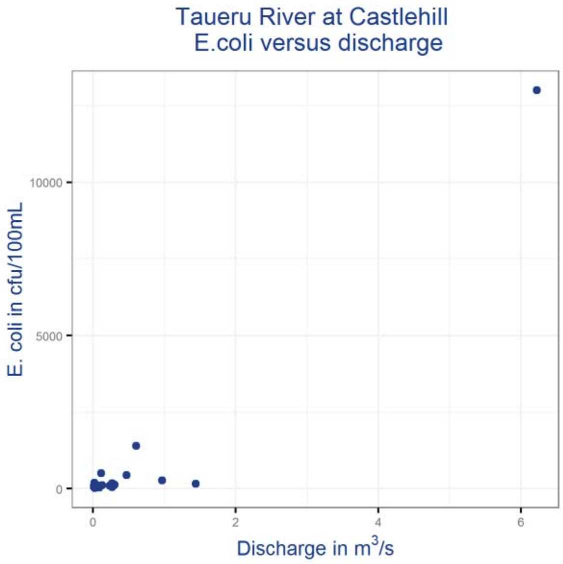

Waipoua River at Colombo
E.coli versus discharge
E. coli in cfu/100mL
Discharge in m^3/s

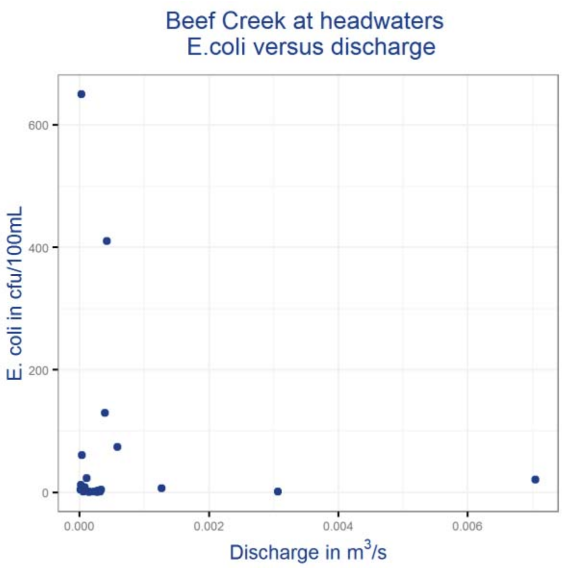

Kopuaranga River at Stuarts
E.coli versus discharge
E. coli in cfu/100mL
Discharge in m^3/s

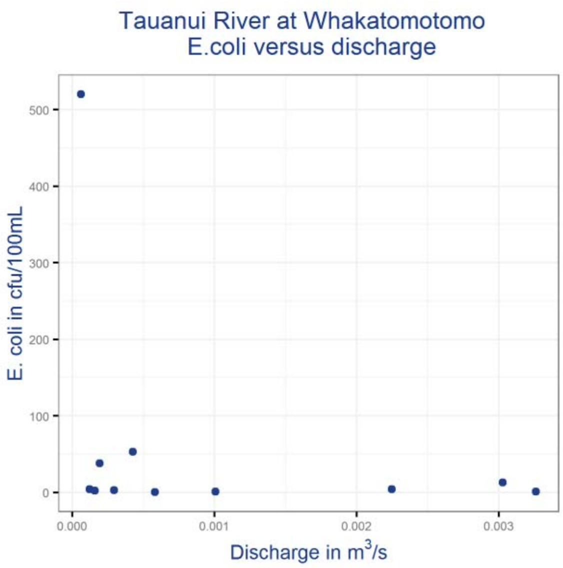

Ruamahanga River at Mt Bruce
E.coli versus discharge
E. coli in cfu/100mL
Discharge in m^3/s


Parkvale Stream at Renalls Weir
E.coli versus discharge
E. coli in cfu/100mL
Discharge in m^3/s


Ruamahanga at McLays
E.coli versus discharge
E. coli in cfu/100mL
0
200
400
600
0
50
100
150
Discharge in m3/s


Taueru River at Castlehill
E.coli versus discharge
E. coli in cfu/100mL
0
5000
10000
0
2
4
6
Discharge in m3/s


Beef Creek at headwaters
E.coli versus discharge
E. coli in cfu/100mL
0
200
400
600
0.000
0.002
0.004
0.006
Discharge in m3/s


Tauanui River at Whakatomotomo
E.coli versus discharge
E. coli in cfu/100mL
0
100
200
300
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500
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0.002
0.003
Discharge in m3/s

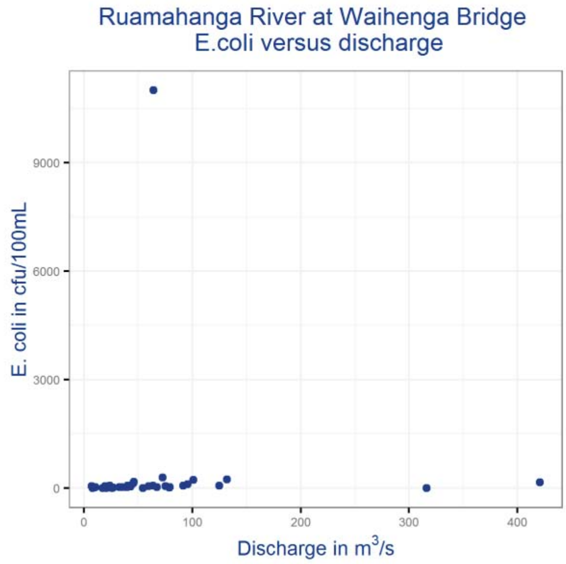


Figure 3: Plots of E.coli concentration verses discharge at each site with observed flow and E.coli

1.3.2 Time of the year

The hypothesis that E.coli concentration varies by month was investigated by preparing log-transformed box-plots at each of the sites. The sites were pooled by normalising by the median E.coli concentration. The resulting plot is shown in Figure 4.

Figure 4 does not present any significant monthly pattern of E.coli concentrations throughout the Ruamahanga catchment. It is of note that some individual sites present evidence of monthly patterns, but overall there is no consistent pattern throughout the catchment.

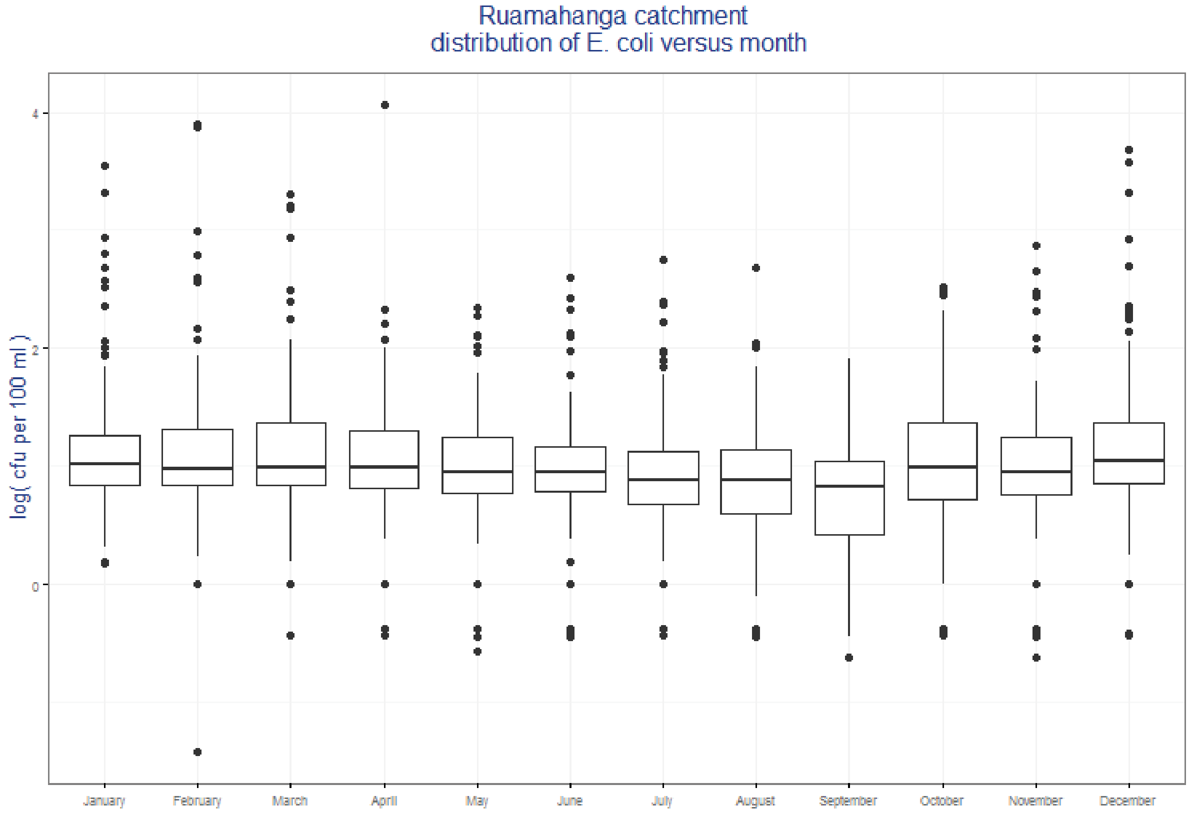


Figure 4 : Distribution of E coli concentration by month for the Ruamahanga catchment

1.3.3 Trend

The time series of E coli monitoring data was visually inspected for trends. This was completed on the raw values as well as log transformed values. No obvious trends were noted.

1.3.4 Distributions of sample concentrations

The distribution of sample concentrations was investigated. The raw data series appeared to be log-normally distributed. This was investigated by fitting a normal distribution to the log-normalised E. coli samples from all sites. The results of this are shown in Figure 5. This figure indicates that log-normal distribution is a reasonable fit to the data. It is of note that the Q_Q plot (top right hand corner of Figure 5) illustrates correlation waves for smaller quantile. These are due to the discrete nature of the smaller values in the samples.

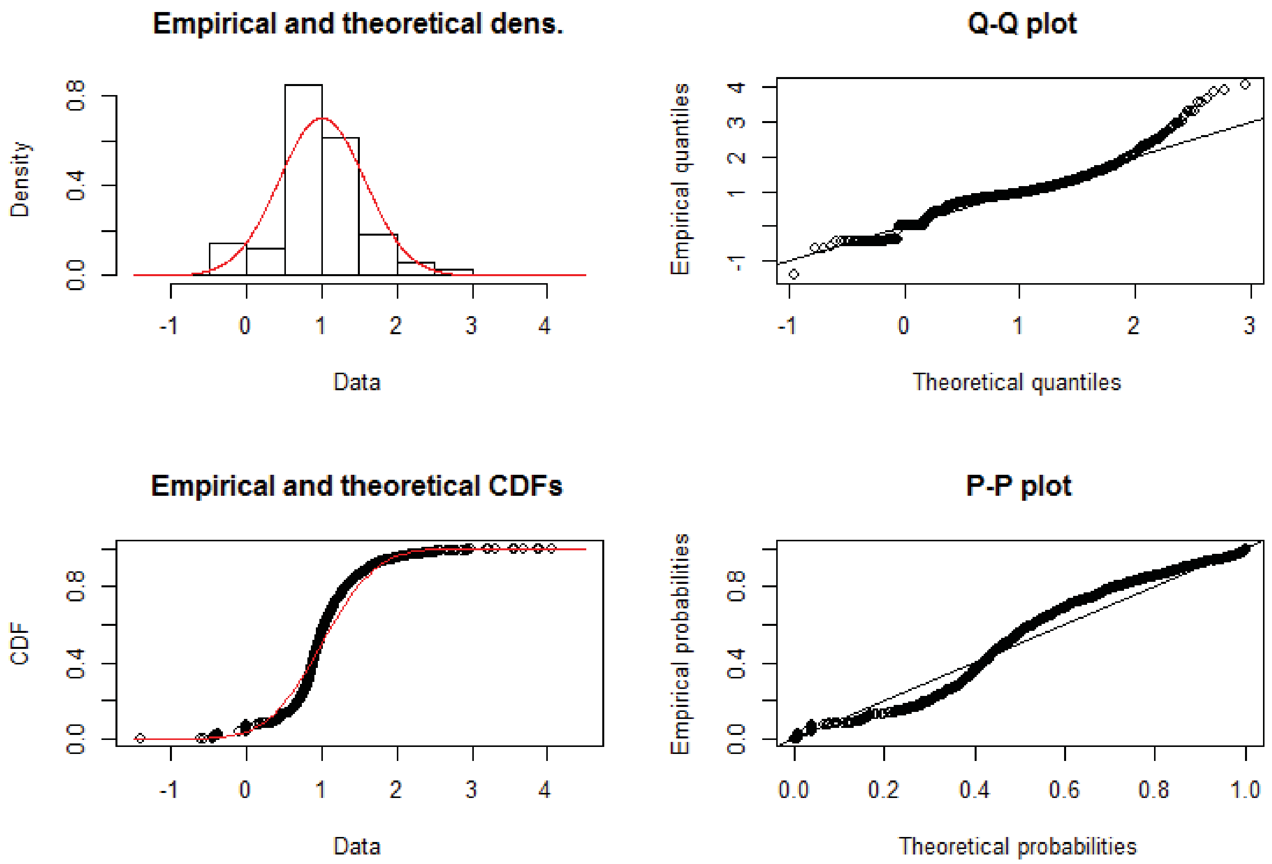


Figure 5 : Log translated E. coli sample concentrations fitted to normal distribution

1.4 Findings

- There is no strong evidence that there is a relationship between E.coli concentrations and discharge, that is, E.coli concentrations do not necessarily increase with discharge.
- There is no strong evidence that E.coli concentrations are temporarily based throughout the catchment, although there is some evidence of temporal dependence at individual sites.
- There is a relationship between measured instream concentration and the CLUES predicted instream loads. Changes in predicted load in CLUES can be used to predict changes in concentrations
- A log normal distribution represents the sample population and can be used to characterise the sample sets in locations where measured data is not available.

1.5 Adopted Method

The method of using the reductions from CLUES scenario runs to be translated to in-stream concentrations is similar to previous methods such as Semadeni-Davies et al. (2015) and Semadeni-Davies and Elliott (2012).

1. When scenarios are developed, the CLUES model will be run to predict the changes in-stream load at the sites of interest

2. Relationships will be developed between CLUES annual number of organisms and the observed median cfu per 100 mL at sites with observed data
3. Log normal distributions will be fitted to the observed data which has two parameters; a mean and standard deviation
4. The CLUES annual number of organisms for scenarios at each site will be determined
5. The relationship between CLUES and the observed median will be used to determine the median concentration at sites for each scenario
6. The log normal relationship from each site will be used to determine the median and 95th percentiles using the median value from each scenario (step 6) and standard deviation from step 3
7. A similar process would be followed for sites without measured data, but using a pooled relationship between the catchment observed median instream concentration and CLUES and pooled log normal curve
    a. CLUES scenario will be used to calculate the scenario median instream concentration
    b. The pooled log normal standard deviation will be used to predict the 95th percentile in the scenario

Figure 6 below illustrates the instream CLUES load for six sites, these sites have measured E.coli data. The probability distributions for these sites are shown in Figure 7

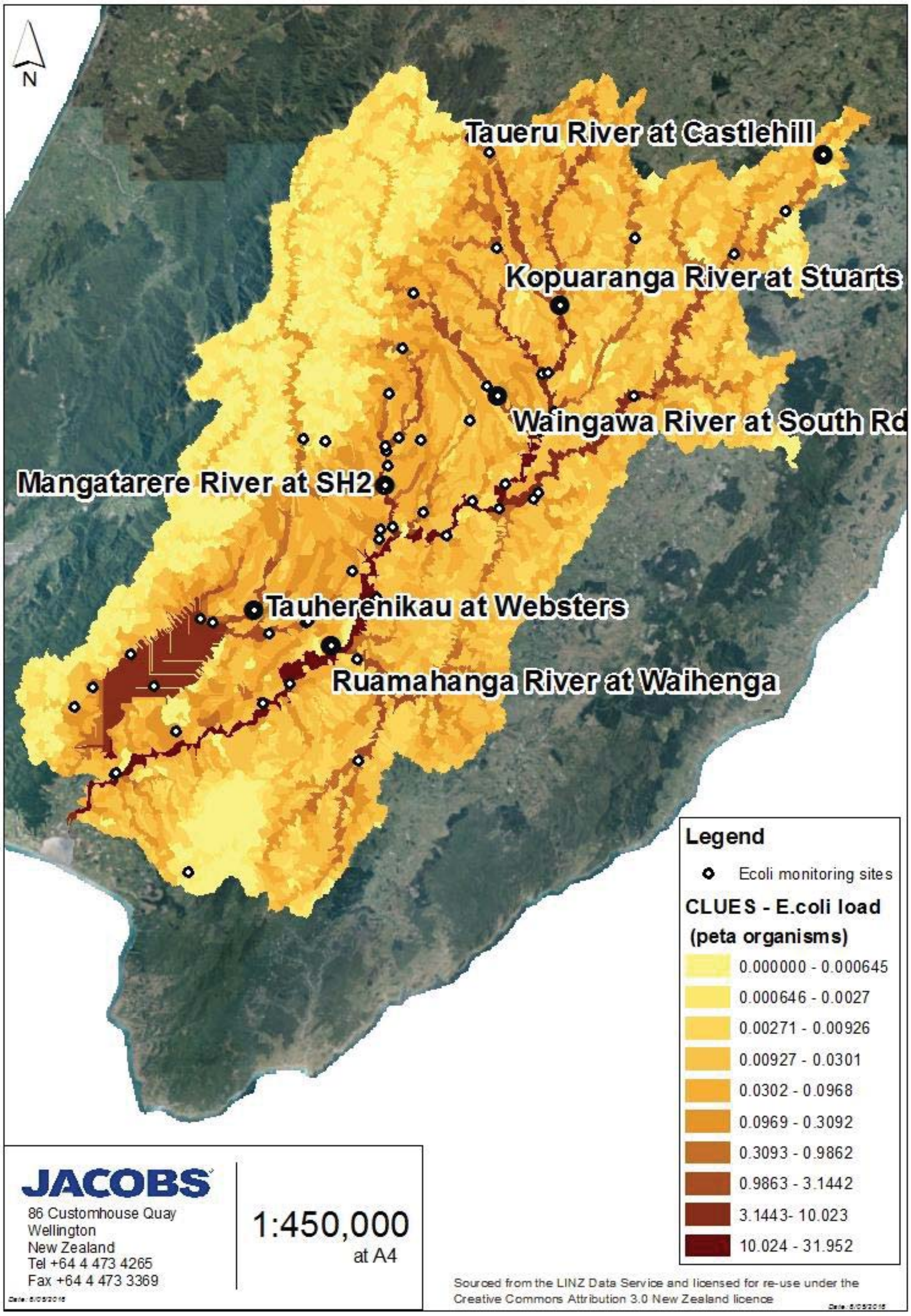
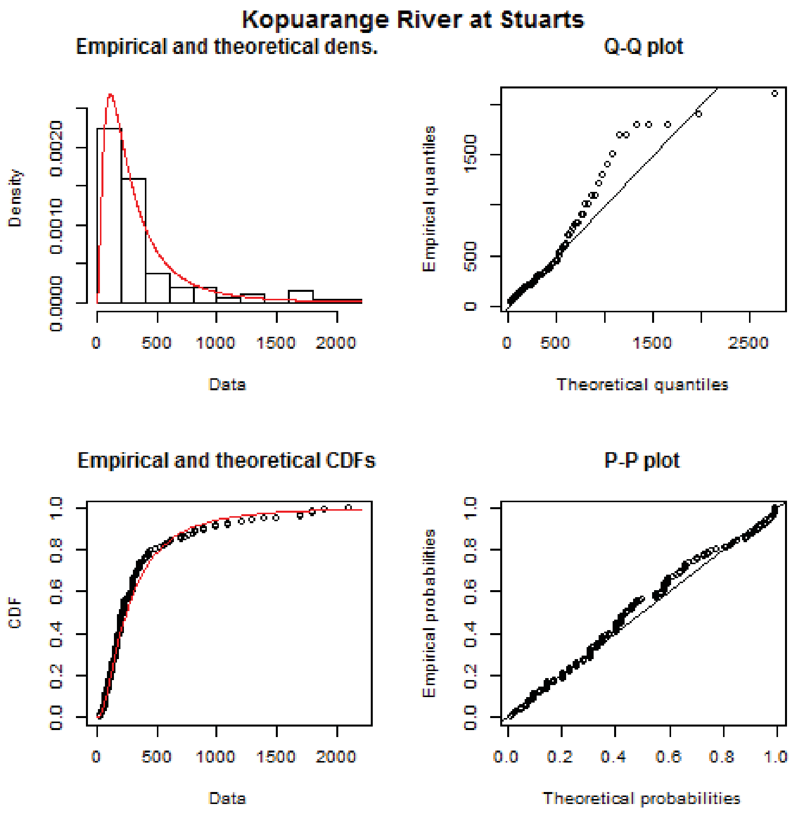
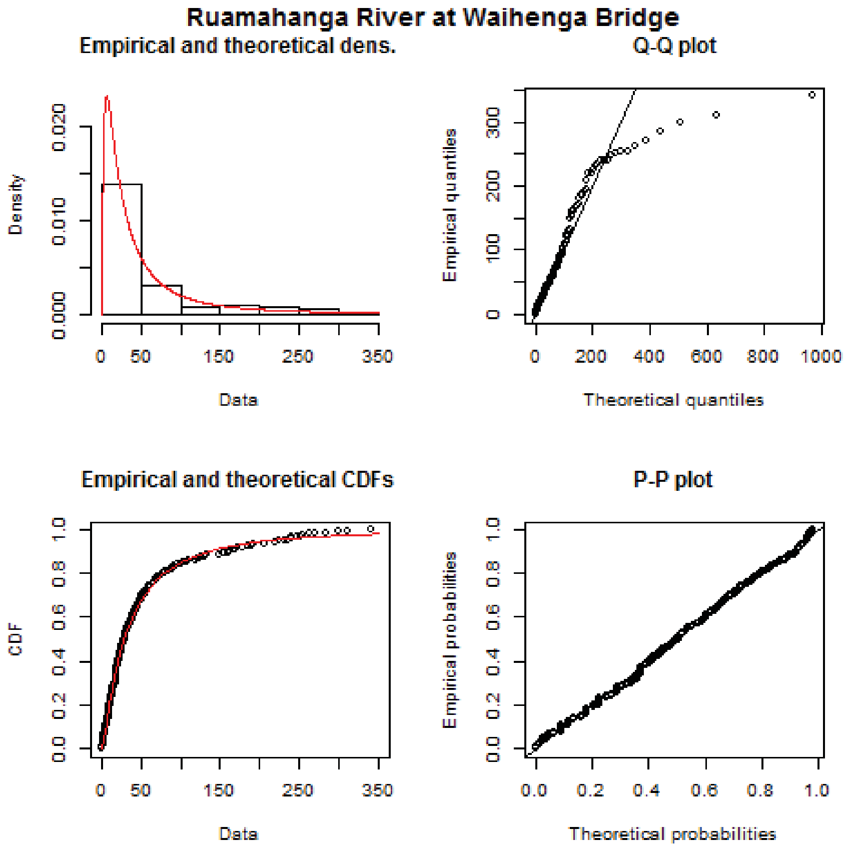
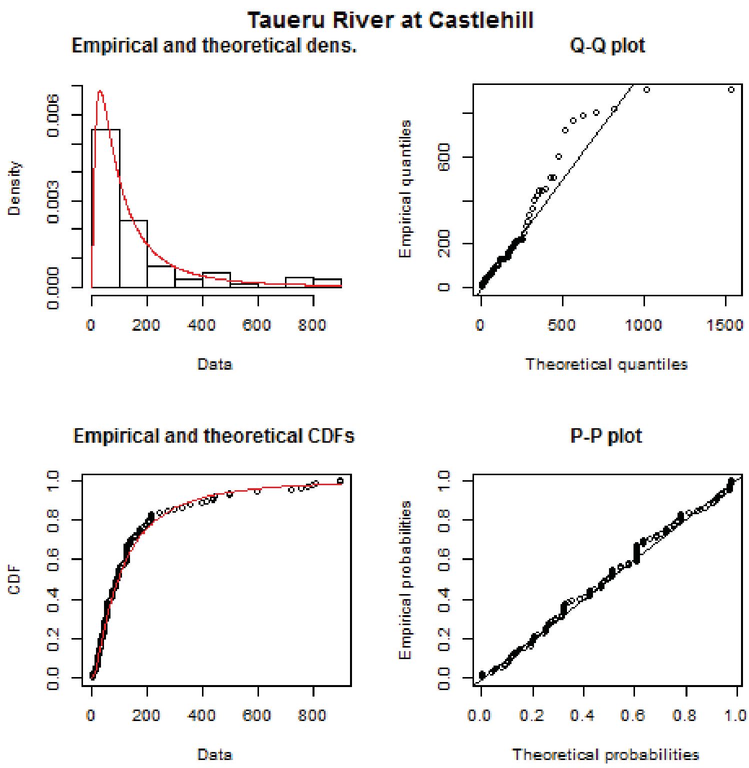
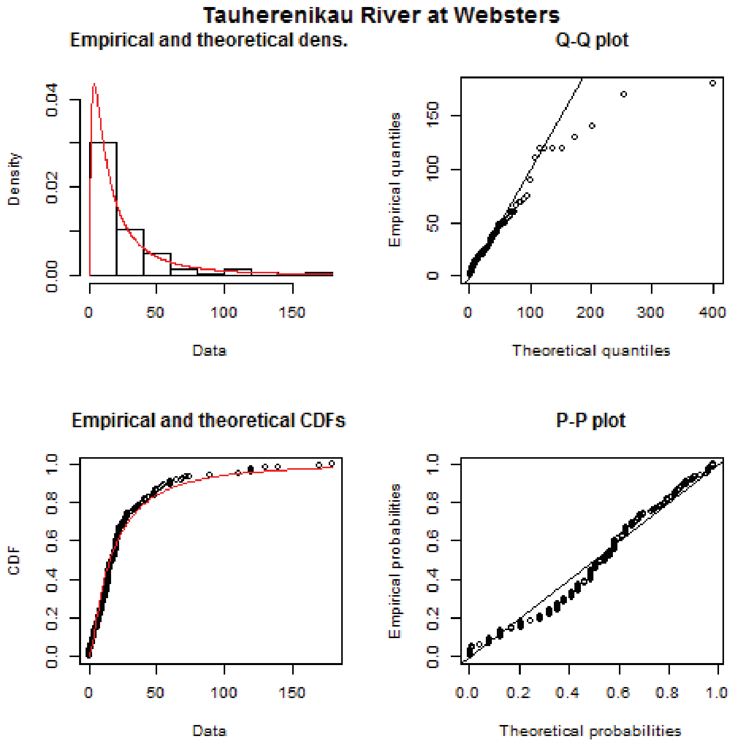


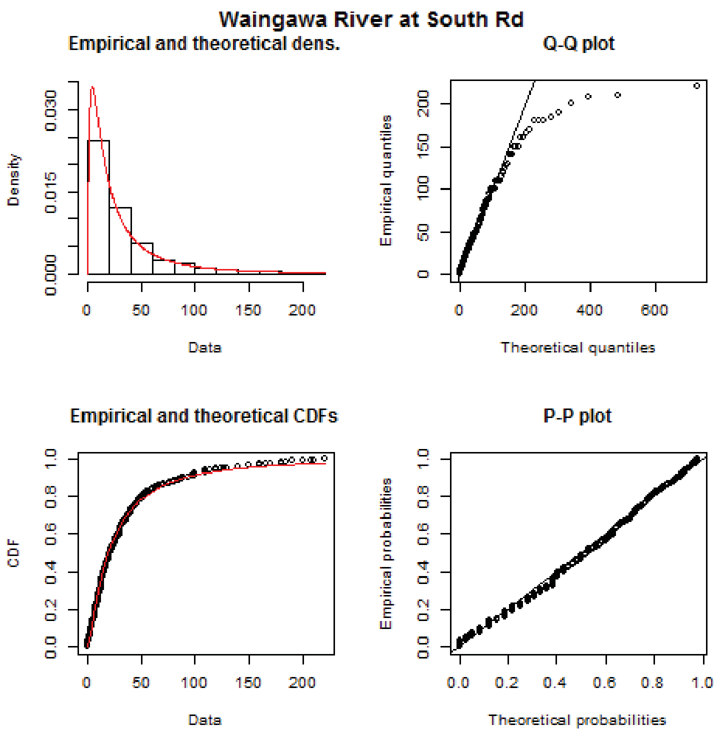
Figure 6 Selection of sites with measured E.coli data and instream CLUES loads


Kopuarange River at Stuarts
Empirical and theoretical dens.
Density
Data
Q-Q plot
Empirical quantiles
Theoretical quantiles
Empirical and theoretical CDFs
CDF
Data
P-P plot
Empirical probabilities
Theoretical probabilities


Ruamahanga River at Waihenga Bridge
Empirical and theoretical dens.
Q-Q plot
Density
Data
Empirical quantiles
Theoretical quantiles
Empirical and theoretical CDFs
P-P plot
CDF
Data
Empirical probabilities
Theoretical probabilities


Taueru River at Castlehill
Empirical and theoretical dens.
Q-Q plot
Density
Data
Empirical quantiles
Theoretical quantiles
Empirical and theoretical CDFs
P-P plot
CDF
Data
Empirical probabilities
Theoretical probabilities


Tauherenikau River at Websters
Empirical and theoretical dens.
Density
Data
Q-Q plot
Empirical quantiles
Theoretical quantiles
Empirical and theoretical CDFs
CDF
Data
P-P plot
Empirical probabilities
Theoretical probabilities


Waingawa River at South Rd
Empirical and theoretical dens.
Density
Data
Q-Q plot
Empirical quantiles
Theoretical quantiles
Empirical and theoretical CDFs
CDF
Data
P-P plot
Empirical probabilities
Theoretical probabilities

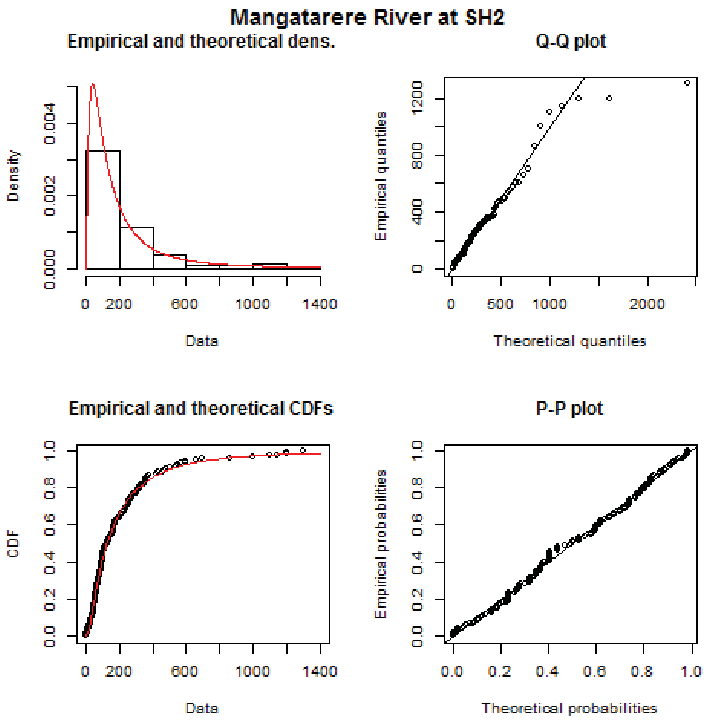


Figure 7 Probability distributions of six sites with measured E.coli

2. Sediment

The modelling results presented in this section are interim. The flows that these results are based have not been updated for the recent revision of Topnet flows and the subsequent update to Modflow flux. The final modelled results will differ to those presented in this memo.

2.1 Data

The analysis utilises the following data:

- Suspended Sediment Yield Estimator (SSYE), used to predict average annual sediment loads (Hicks 2011)
- Sednet NZ used to predict average annual sediment loads (Dymond 2016)
- Suspended sediment concentration and high flow gaugings from Ministry of Works and supplied by NIWA, used to fit the power curve (Equation 1)
- Water quality monthly water quality data including total suspended sediment and turbidity data from GWRC used to determine the dry weather concentrations
- Flow data for Ruamahanga catchment gauges from Greater Wellington

2.1.1 Sediment Load

Two models that estimate sediment load were analysed, the SSYE and SedNetNZ. SedNetNZ estimates the average annual sediment yield including the contribution from surficial erosion, gully erosion, earthflow and landslides. The SedNetNZ model enables scenarios to be modelled by changing landcover or by applying percentage reductions to account for mitigation measures including stream bank erosion mitigation. The SedNetNZ model was calibrated for the Manawatu and also covers the Wellington Region.

The SSYE is a national tool that estimates sediment yield based a on statistical analysis of measured sediment concentration data, including data collected in the Wairarapa.

Figure 8 below compares the SSYE and SedNetNZ estimates of average annual sediment yield. The estimates of are generally similar where surficial erosion dominates, but in locations where landslide potential is identified in SedNetNZ, the SedNetNZ model tends to predict higher yields. The predicted sediment load for the Ruamahanga catchment as a whole is larger using SedNetNZ than SSYE.

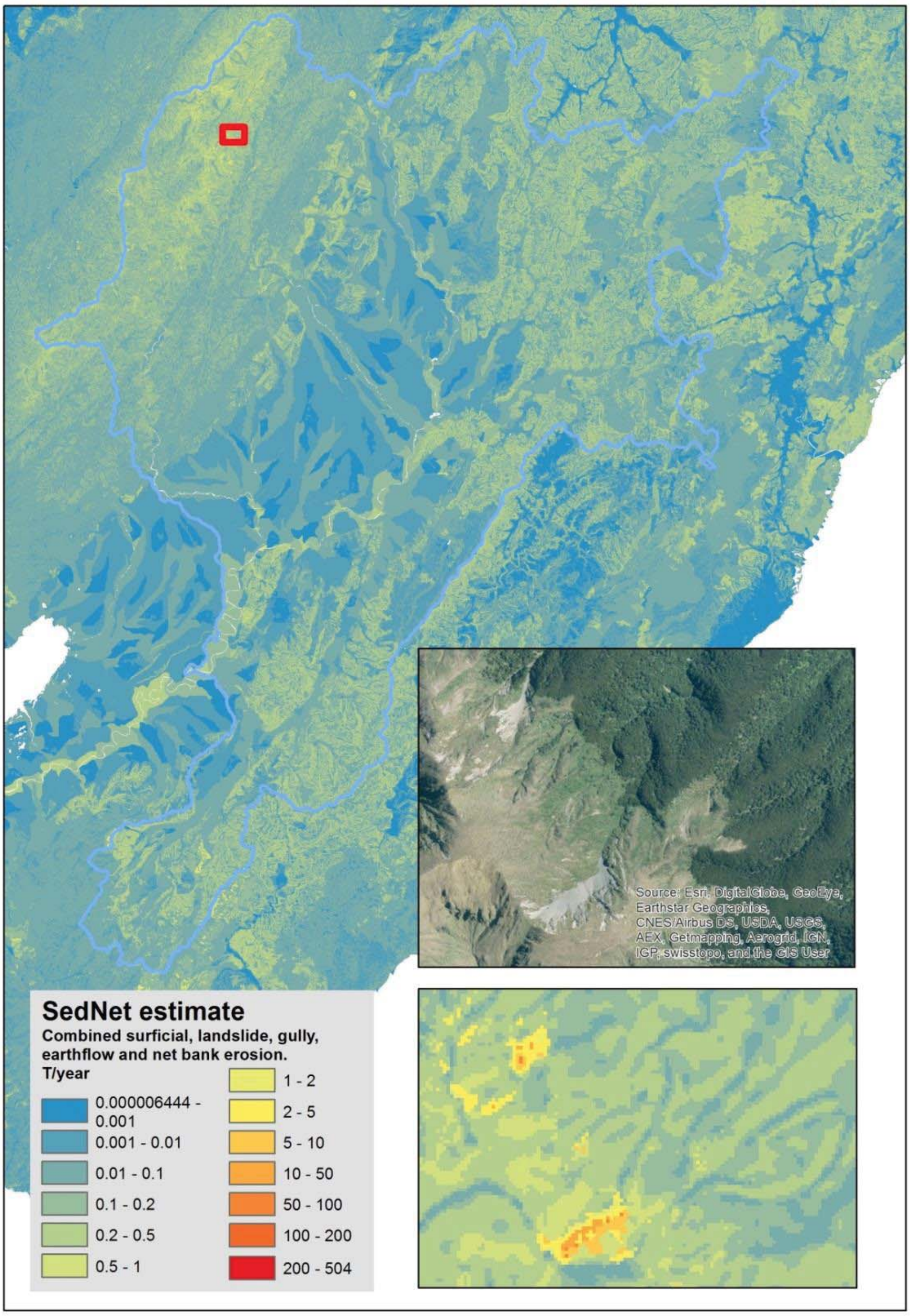


Figure 8 Comparison of SSYE and SedNetNZ

2.2 Analysis

2.2.1 Power Curves

There are three sites in the Ruamahanga catchment (see Figure 1) with high flow suspended sediment data, namely:

- Ruamahanga River at Waihenga
- Taueru River at TeWeraiti
- Ruakokopatuna River at Iraia

From this data the following individual suspended sediment concentration power curves have been fitted as shown in Figure 2, Figure 3 and Figure 4 for the Waihenga, Te Weraiti and Iraia datasets respectively. In addition, data has been pooled between all sites as well as Waihenga and Te Weraiti sites. These relationships are presented in Figure 5 and Figure 6.

Sites were pooled by taking the ratio of the mean daily flow.

The results of the power curve analysis are presented in Table 1. These results together with Figure 2 through Figure 7 demonstrate the following:

- The power curve relationship for Waihenga reasonably predicts suspended sediment concentrations
- The power curve relationship for TeWeraiti reasonably predicts suspended sediment concentrations
- The power curve relationship for Iraia does not predicts suspended sediment concentrations well
- The power curve relationship for all sites pooled does not predicts suspended sediment concentrations well
- The power curve relationship for the pooled Waihenga and Te Weraiti site reasonably predicts suspended sediment concentrations

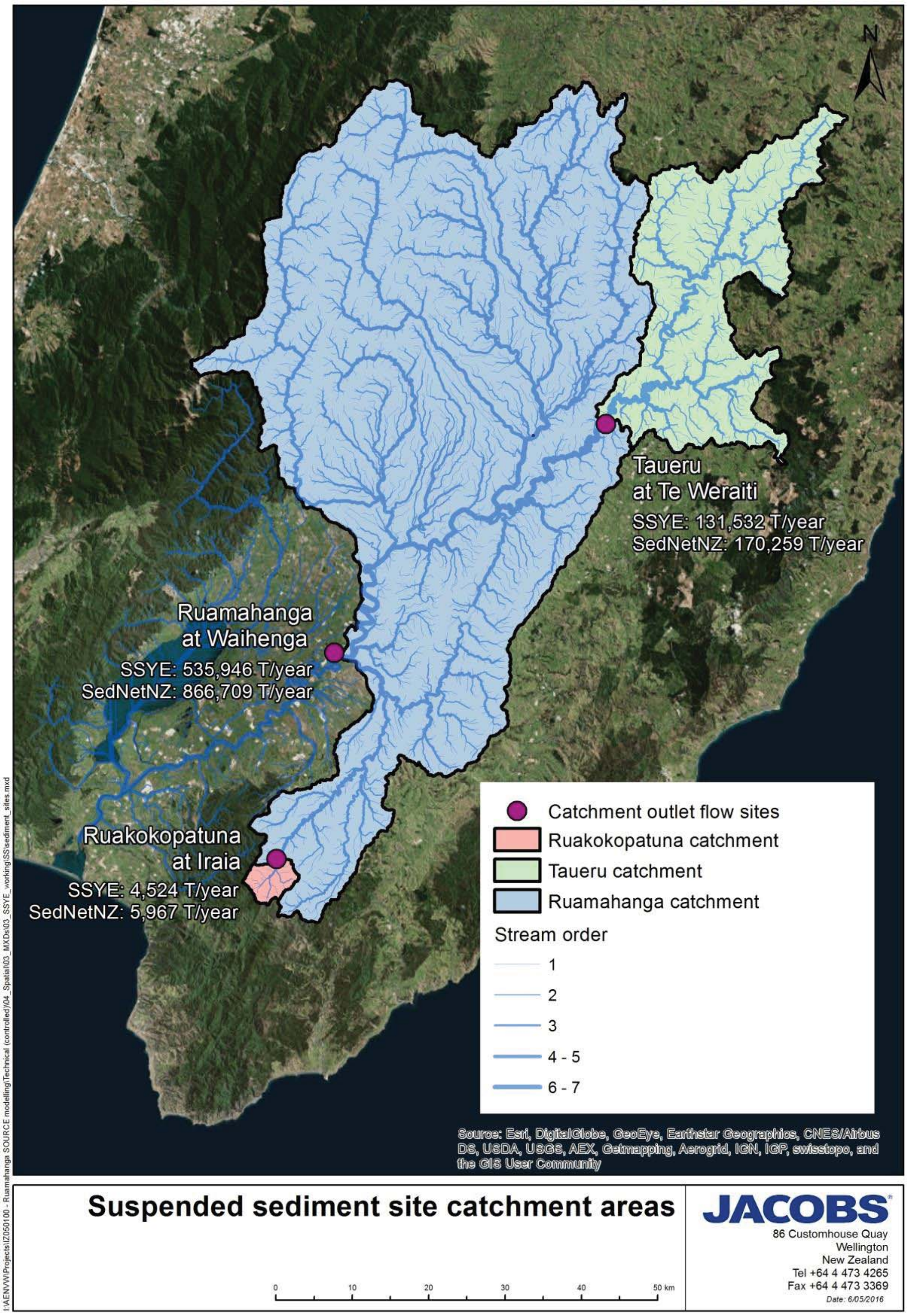


Figure 9 Catchments for the three Ministry of Works suspended sediment concentration sites in the Ruamahanga

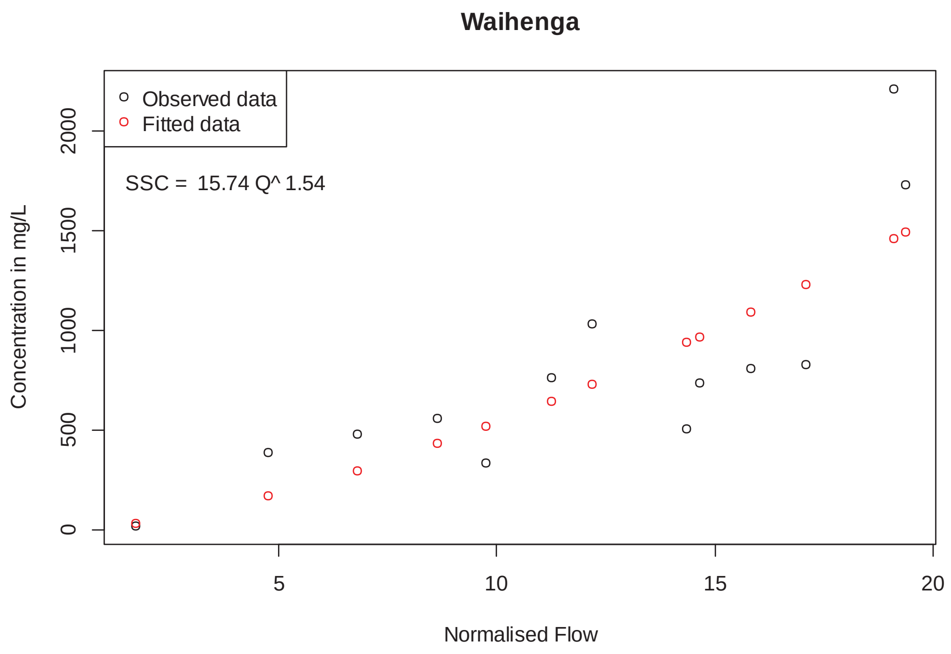


Figure 10 Sediment-flow power curve relationships for Ruamahanga at Waihenga

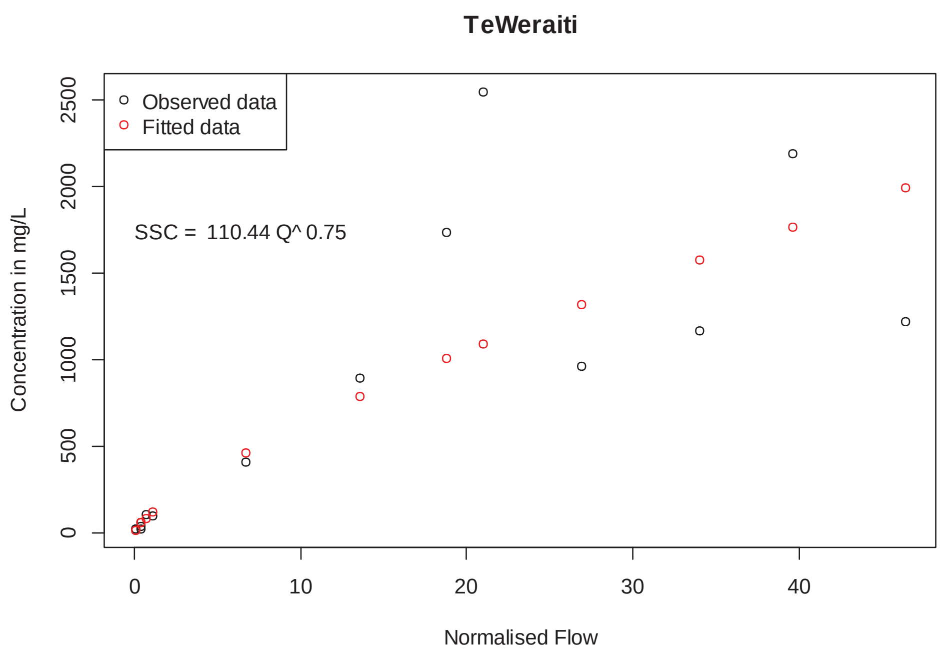


Figure 11 Sediment-flow power curve relationships for Taueru at Te Weraiti

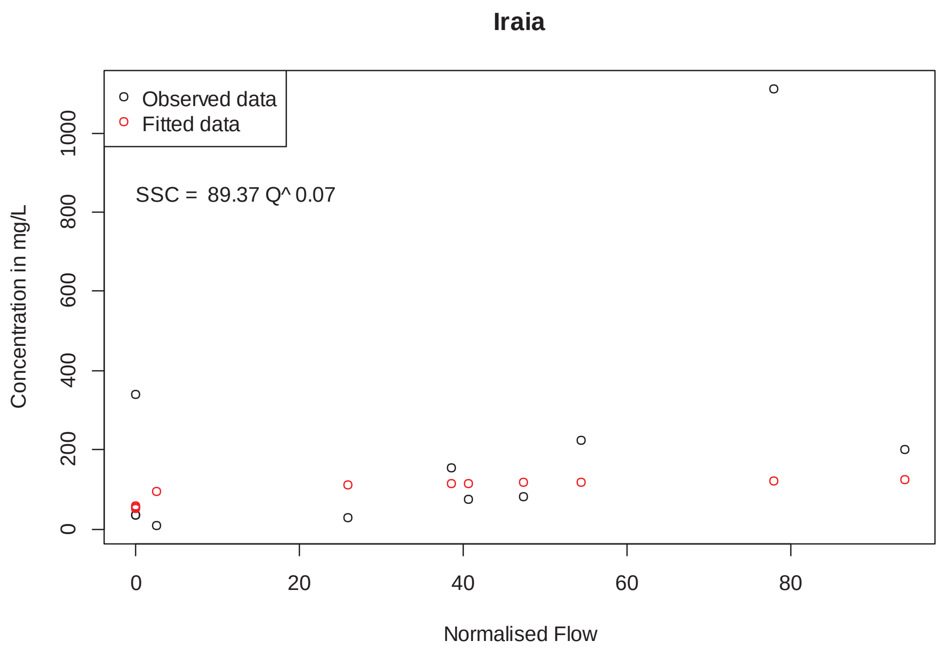


Figure 12Sediment-flow power curve relationships for Ruakokopatuna River at Iraia

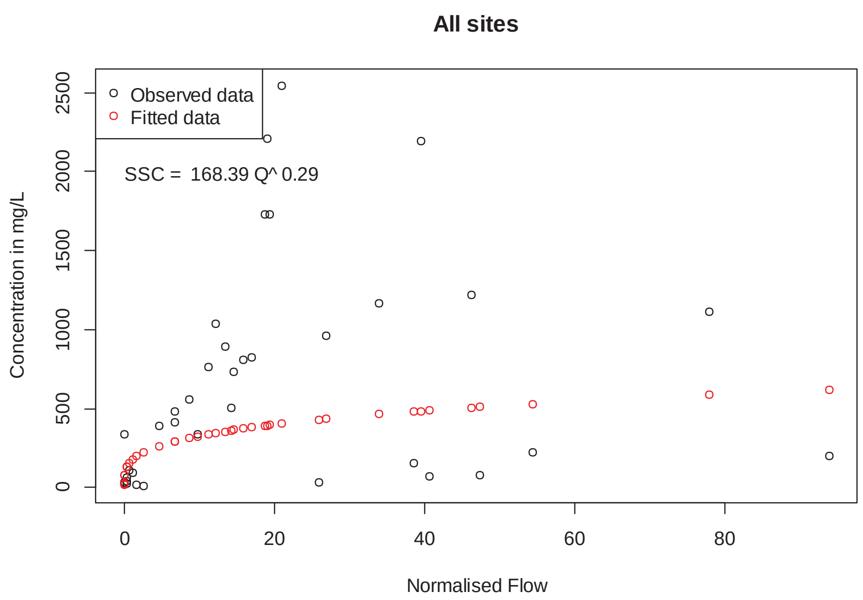


Figure 13. Sediment-flow power curve for all sites

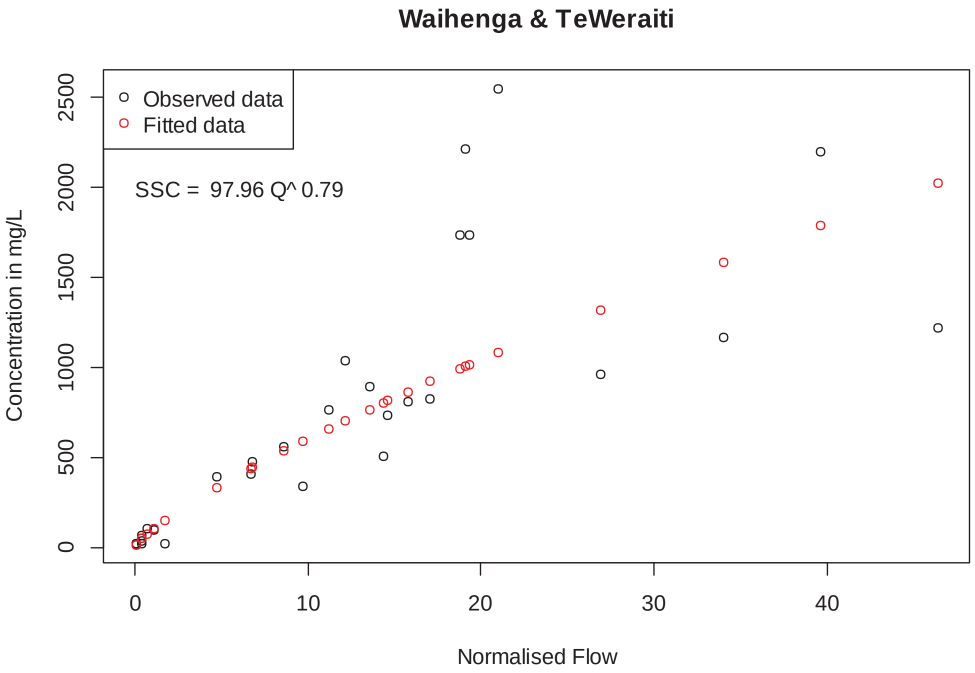


Figure 14 Sediment-flow power curve relationships for Waihenga & Te Weraiti

In order to determine whether the instantaneous power curve relationships could be applied at a daily time-step (the Source model is a daily model) we calculated the instantaneous concentration from the instantaneous flow data using the instantaneous power curve. We then calculated the daily average flow and the daily average concentration from the calculated instantaneous data-set and calculated the power curve exponent for this daily average data set. The exponents for the daily average data were very similar to the power curves for the instantaneous data.

2.2.2 Disaggregating Sediment load

The approach presented here disaggregates the annual average sediment load for each sub-catchment in the Source model. The disaggregation is based on a power curve relationship (Equation 1):

$$SSC = bQ^a \qquad \text{(Equation 1)}$$

where SSC is the suspended sediment concentration in milligrams per litre, Q is peak flow in litres per second, *a* and *b* are parameters.

The power law relationship was based on the data collected by the Ministry of Works, with the power curve exponent calculated from the calculated daily average flow and daily concentration data.

In order to maintain the average annual loads between the SedNetNZ estimate and the power curve relationship, the b parameter of the power curve relationship (Equation 1) was adjusted.

The analysis been done on gauge and sample data supplied by Greater Wellington. Where the actual gauged data has had gaps or spurious values, these have been removed without attempt to infill.

Figures 7 and Figure 8 show the disaggregation for the Ruamahanga at Waihenga and the Taueru at TeWeraiti sites respectively. Both exponents of 1.5 and 0.75 were trialled at both sites.

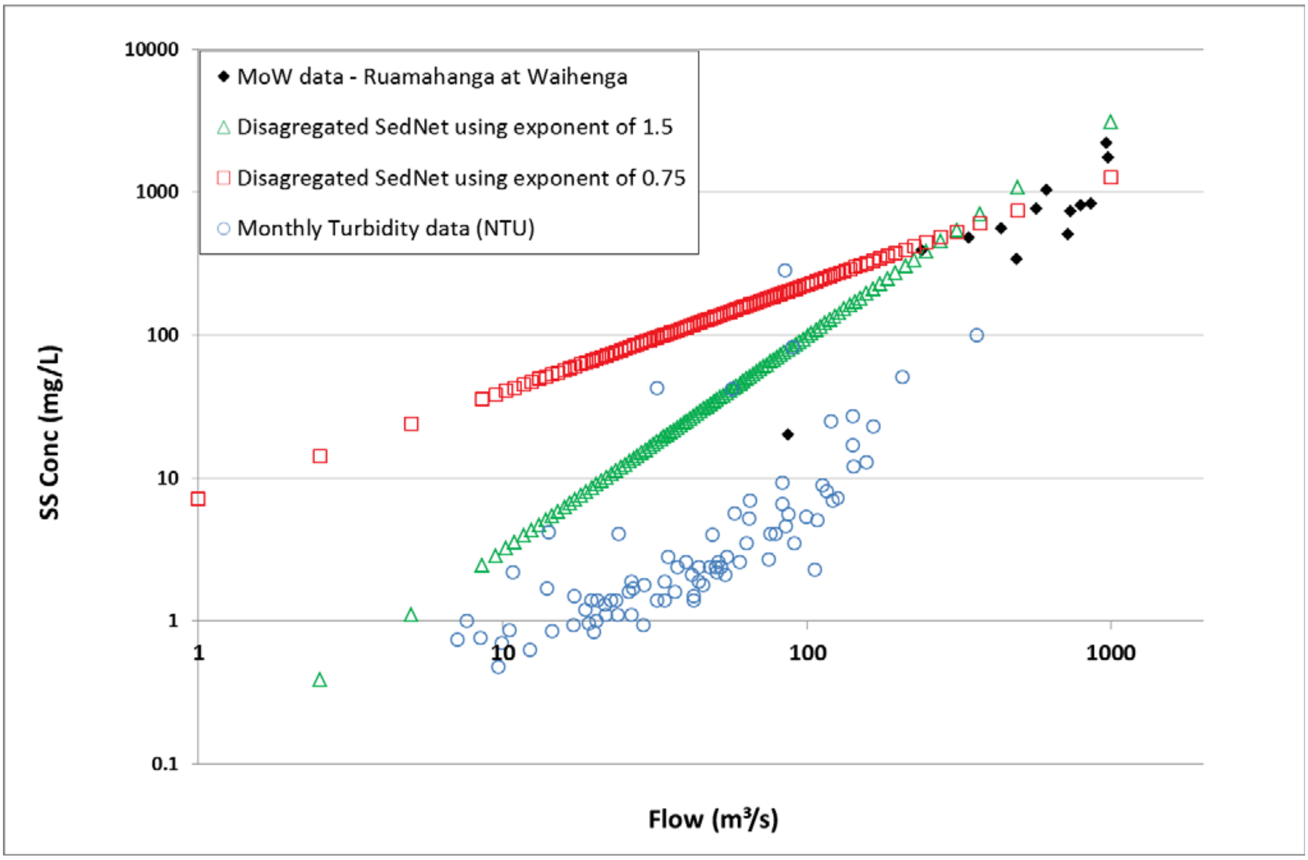


Figure 15. Disaggregation of average annual SedNetNZ sediment load into daily average flow for Ruamahanga at Waihenga

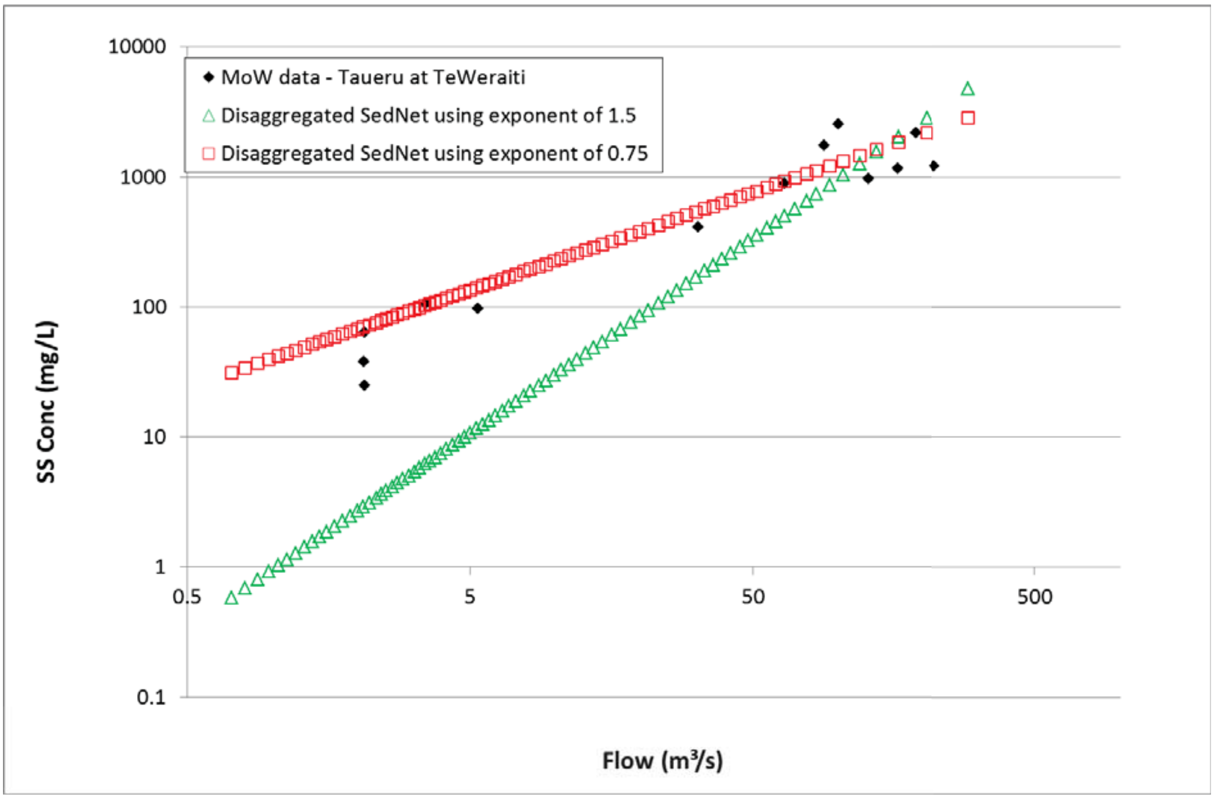


Figure 16 Disaggregation of average annual SedNetNZ sediment load into daily average flow for Taueru at Te Weraiti

The exponent adopted for modelling was 1.5, this is because the expoenent of 0.75 would return much higher sediment concentrations in low and moderate flows than indicated by the monthly monitoring data collected at these sites.

Findings

- The SedNetNZ model is preferred as the estimate of baseline sediment load because it will enable sediment scenarios to be modelled spatially, the average annual sediment load predicted by SedNetNZ is larger than SSYE overall, but in most locations is very similar.
- A exponent of 1.5 was adopted in order to return the catchment sediment load in larger flows. The higher exponent allows for a better fit with both the high flow and low flow data. The monthly data, which is measured in low and moderate flows, has much lower concentrations than the Ministry of Works high flow data.
- The sediment load data in SSYE and SedNetNZ uses geology and rainfall to predict load. These loads seem high when compared to the monthly measured data, but there is better agreement for those sites where high flow sediment concentration data exisits.

2.3 Sediment modelling in Source – Interim Results

The results presented in this section are interim. The Source model has not yet been updated to reflect the revised Topnet flows and the subsequent revision of the Modflow flux.

The power curve relationship determined above (shown below in Equation 2) was incorporated into the Source model on each Source sub-catchment (237 sub-catchment). The suspended sediment concentration was determined by the runoff from each sub-catchment, that is, either the Irrical flows or the Topnet flows.

$$SSC = b_{scaled}\, Q^{1.5} \qquad \text{(Equation 2)}$$

Where SSC is the suspended sediment concentration, b_{scaled} is the b parameter from Equation 1 selected to find the average annual sediment load, Q is the daily discharge and 1.5 is the exponent.

By using the same rating curve (scaled by different b parameter) across the whole Ruamahanga catchment the cumulative load from individual upstream sub-catchments is similar to the average annual load calculated from SedNetNZ for the Ruamahanga where it discharges to the sea.

Figure 17 below shows the interim results modelled in Source at the Ruamahanga at Waihenga. The model tends to overestimate in low and moderate flows, and predicts reasonably well in high flows.

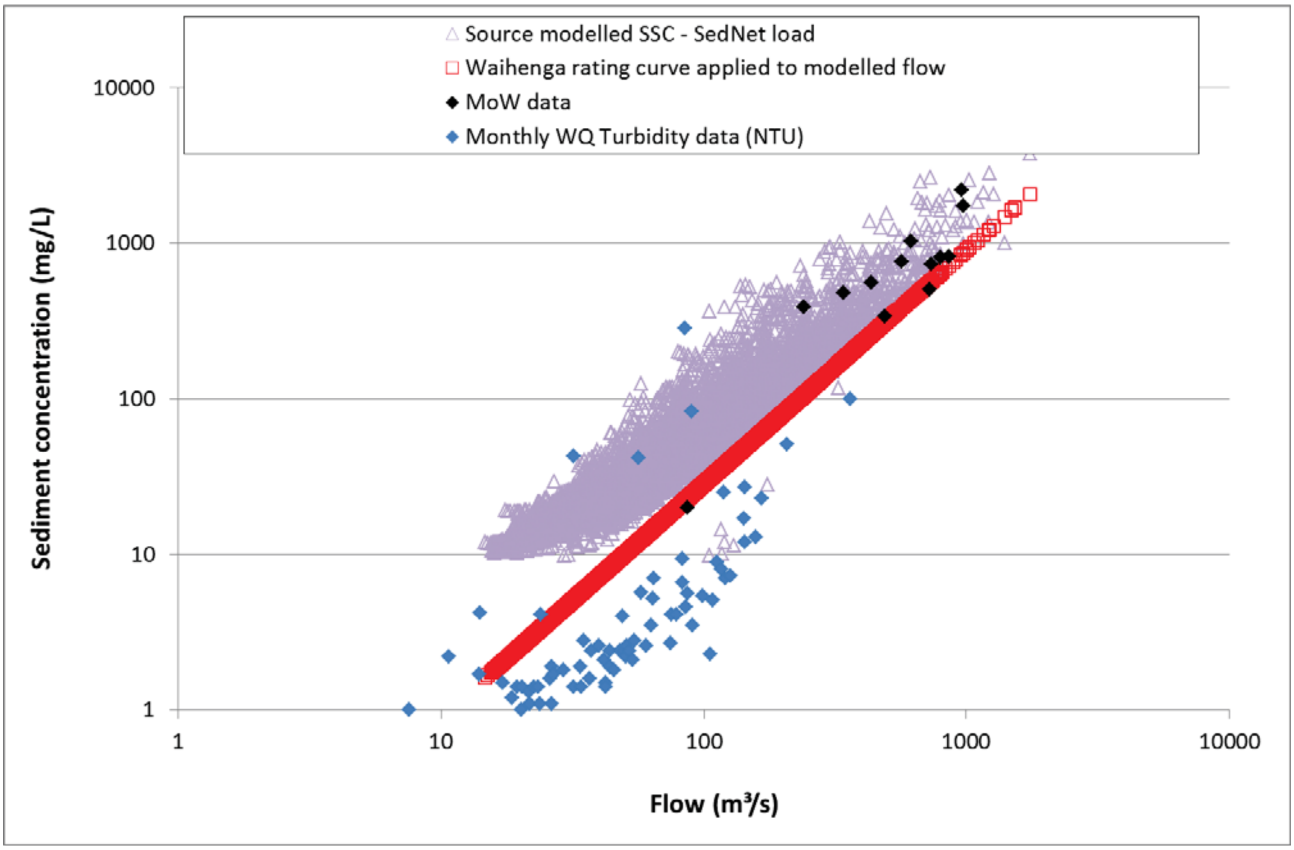


Figure 17 Interim modelled suspended sediment concentration at Waihenga

Figure 18 below shows interim modelled concentrations at Waiohine at Gorge. The model overestimates the sediment concentration at this site compared to the measured data. The data at this site was collected in low and moderate flows during monthly routine monitoring. There is no sediment concentration data in high flows. The water quality at this site is very good. We analysed the erosion sources, about 8% of the annual sediment load is attributed to landslides, however the predicted surficial estimate of sediment load is very high in this catchment in both the SSYE and SedNetNZ.

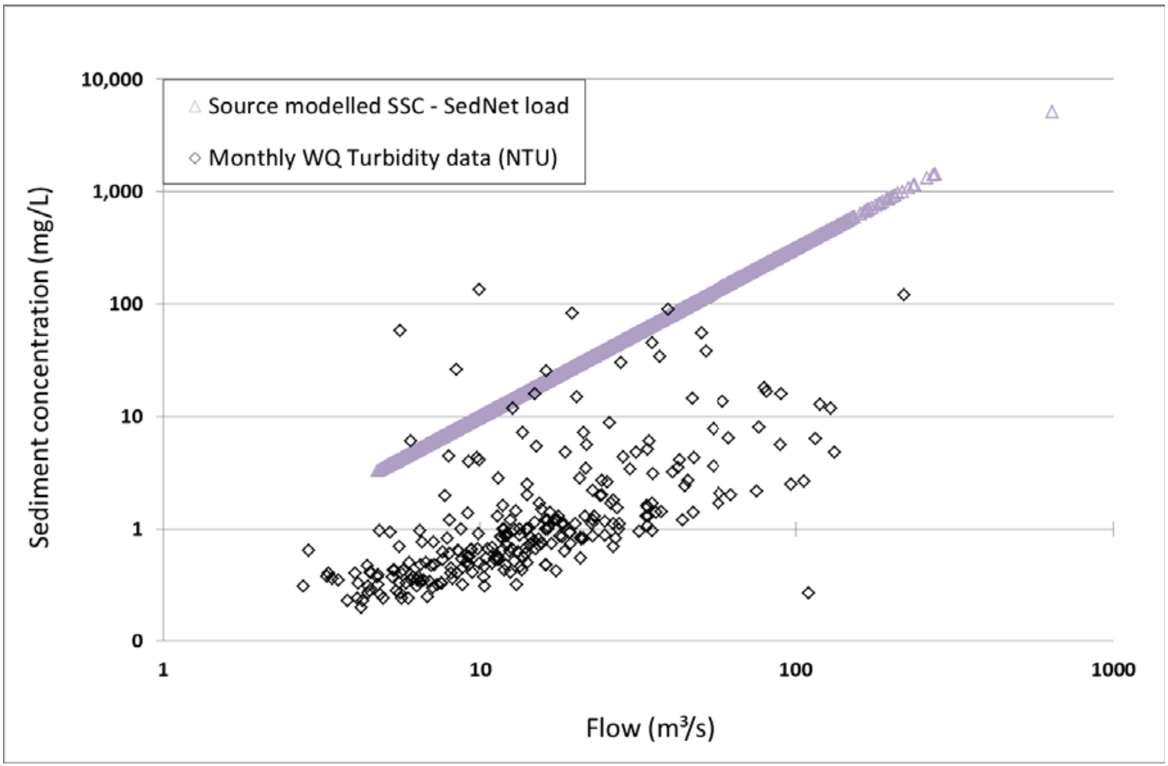


Figure 18 Interim modelled suspended sediment concentration at Waiohine at Gorge

Figure 19 below shows interim modelled results of concentrations at Kopuaranga at Stuarts. The data at this site was collected in low and moderate flows during monthly routine monitoring. There is no data on the sediment concentration in high flows. The sediment concentrations are higher at Kopuaranga at Stuarts compared with Waiohine at Gorge. The model overestimates the concentration at this site, but not to the same degree as at Waiohine at Gorge.

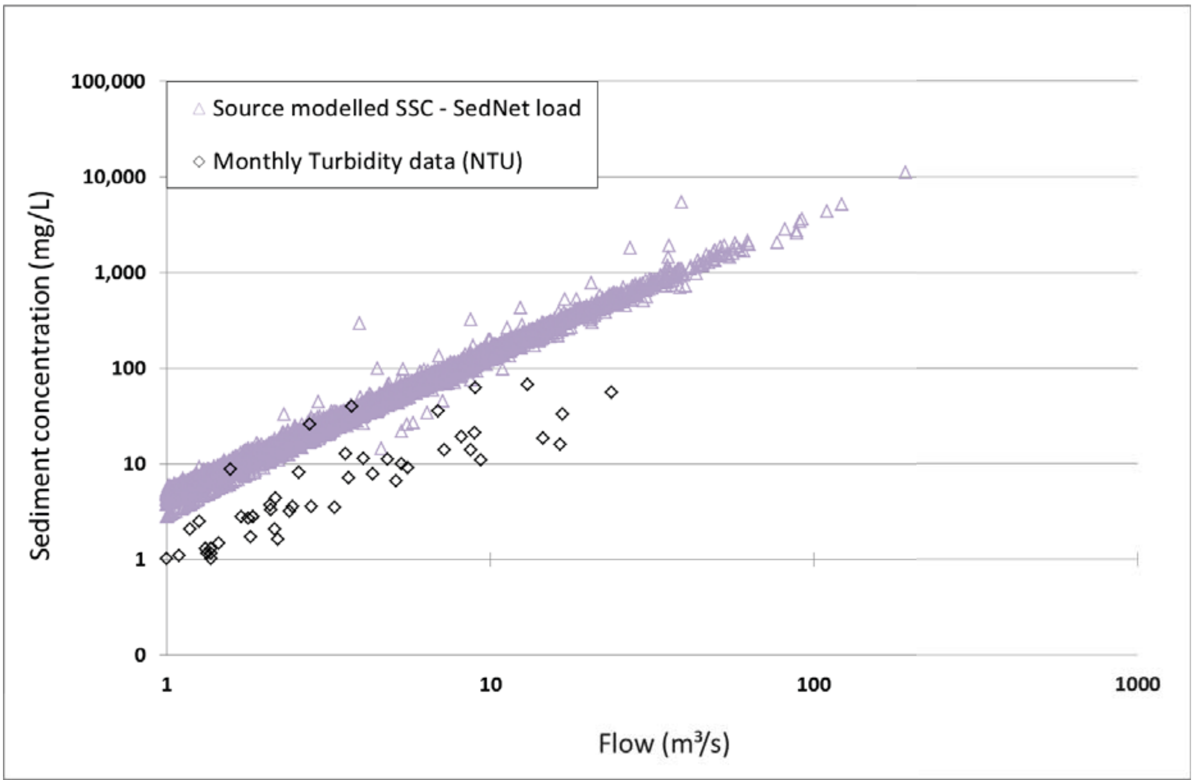


Figure 19 Interim modelled suspended sediment concentration at Kopuaranga at Stuart

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