Review and analysis of suspended sediment monitoring in the Tauranga Moana Catchment

Prepared for Bay of Plenty Regional Council

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Background and scope

In 2015, Bay of Plenty Regional Council began a project monitoring turbidity and suspended sediment at three priority stream locations within the Tauranga Moana/Harbour catchment. The overall project aim was to assess the impact of land management activities on suspended sediment load, while specific intentions of the data collection were to (i) complement existing monitoring of harbour sediment accumulation and stream quality data, (ii) help determine potential sediment impacts on instream ecological values and aesthetics, (iii) measure catchment erosion rates, and (iv) support calibration of future catchment models. Continuously-operating turbidity sensors were installed at discharge-monitoring stations on the Kopurererua, Tuapiro and Waimapu Streams, and one auto-sampler has been operating on the Kopurererua Stream to sample suspended sediment concentration (SSC) during runoff events. Monthly water quality results are available for all three sites.

This report:

- reviews the data collected and methods used to date at these three sites
- analyses the data to derive relationships between SSC and turbidity and discharge and assesses their fitness for the purpose of estimating sediment loads
- calculates event, annual and average annual sediment loads and their uncertainties, and partitions the sediment loads by season and between baseflow and storm runoff
- relates event sediment loads to event hydrological indices including measures of rainfall amount and intensity
- recommends changes to methodologies to improve robustness and fitness-for-purpose, and
- briefly reviews the value of the sediment monitoring to support potentially forthcoming national policy initiatives to manage sediment in waterways.

Main findings

The main findings and conclusions are:

- At Kopurererua Stream at SH29, a good turbidity record has been collected since mid-2016, and a fit-for-purpose calibration to auto-sampled SSC has been developed which enables sediment load determination to high precision. However, it is likely that these load estimates are significantly under-estimating the total sediment load into Tauranga Harbour because of non-uniform mixing of the suspended load over the cross-section. Thus, the focus of effort for this site should now be on sediment gaugings to relate the bank-side, auto-sampled SSC to the cross-section averaged SSC and to measure the size grading of the suspended load.
- At Waimapu Stream at McCarrols, moderate-quality sediment load results are obtained by using the monthly water quality dataset to develop an interim calibration of the turbidity record. However, the precision and accuracy of these results are limited by the low range of turbidity that has been calibrated to SSC, a relatively high

proportion of gaps in the edited turbidity record, and the sand component of the suspended load being underestimated because of mixing and sampling issues. The site also has probable issues with bank-side turbidity plumes caused by eroding upstream banks and wading cattle. Thus, the focus of effort for this site should be on (i) using an auto-sampler and sediment gaugings to calibrate the turbidity record to the cross-section average SSC, (ii) measuring the sand proportion or full size-grading of the sediment load, and (iii) resolving the on-site issues and reducing record gaps.

- At Tuapiro Stream at Woodland Road, moderate-quality sediment load estimates are also obtained by using the water quality dataset to develop an interim calibration of the Tuapiro turbidity record. Again, however, the main issues with the calibration and derived load estimates are that the calibration dataset is focussed on a very low turbidity range relative to that recorded, there is a significant proportion of gaps in the turbidity record, and there is no information on sediment mixing over the cross-section. Thus, the focus of effort for this site should be on using an auto-sampler and sediment gaugings to calibrate the turbidity record to the cross-section average SSC, and reducing gaps.

- The average sediment yields estimated from sediment rating curves for the three sites for the period 1998-2018 (36.4 ± 1.7 t/km^2/y at Kopurererua, 63.3 ± 12 t/km^2/y at Waimapu, and 43.6 ± 2.2 t/km^2/y at Tuapiro) are similar, but each of these results will be underestimating the true yields because the point-based sampling they are based on are not representative of the cross-section average load.

General recommendations

General recommendations on monitoring methodologies/strategies at all sites include:

- Continue using YSI-Exosonde turbidity sensors as SSC-proxy sensors at the BOPRC sites, taking care to avoid measuring unmixed sediment plumes from near-field sources, keeping a close watch on the quality of record using telemetry, and keeping up-to-date with data editing.

- Consider also using acoustic backscatter (ABS) as a proxy for SSC in at least the sand-rich Kopurererua and Waimapu Streams.

- Use the monitoring strategies and procedures detailed in the forthcoming NEMS for suspended sediment load.

- Analyse sediment samples collected from gaugings for particle size to inform on the sand and mud components of the load.

- Estimate the “unmeasured”, near-bed sand load at least in the sand-bedded Kopurererua and Waimapu sites using the “Modified Einstein” procedure (or variations) in association with the suspended sediment gaugings.

- Consider different analysis approaches for different sediment load objectives. Sediment ratings are suitable for estimating the long-term average load while the more precise high-frequency SSC-proxy monitoring is best for measuring event and annual loads.

- Maintain the turbidity monitoring to assist implementation of likely forthcoming, NPS-FM related, limits on turbidity and water clarity by defining the turbidity state and informing on sediment loads and their sources.

1 Introduction

1.1 Background

Bay of Plenty Regional Council (BOPRC) has a programme set up to routinely monitor the natural resources in its region. This Natural Environment Regional Monitoring Network (NERMN) includes (among many things) monthly water quality monitoring at the region's major rivers and harbours, and quarterly or annual monitoring of sediment accumulation in Tauranga Harbour.

BOPRC identified a lack of data about the amount of sediment entering Tauranga Harbour and in 2015 began a project to monitor turbidity and suspended sediment at priority stream locations within the catchment. The data collected from this project is intended to (i) complement the sediment accumulation information collected by BOPRC in the Tauranga Harbour and NERMN water quality data, (ii) help determine potential impacts on instream ecological values and aesthetics, (iii) measure catchment erosion rates, and (iv) support calibration of future catchment models.

Continuously-operating turbidity sensors were installed at discharge-monitoring stations on the Kopurererua, Tuapiro and Waimapu Streams, and one autosampler has been operating on the Kopurererua Stream to sample suspended sediment concentration (SSC) during events. Monthly water quality results (including turbidity and grab-sampled total suspended solids concentration, TSS[1]) are available for all three sites.

1.2 Objective, Scope, and Deliverables

The objective of the study reported here is to analyse and review the data collected to date from the three sites.

The study scope includes:

- For Kopurererua Stream:
  - reviewing the sediment rating curve (relationship between SSC and water discharge) and using it to estimate annual suspended sediment loads
  - investigating the relationship between SSC and turbidity, advising if it is accurate enough over the range of measured turbidity to use turbidity as a proxy to determine the annual sediment loads, or what other sampling is needed to improve the accuracy or at least be aware of what margin of error there will be from using a proxy
  - if the SSC-turbidity relationship is fit-for-purpose, calibrating the turbidity record to SSC and using it to calculate annual and event loads and relating these to rainfall (amount and intensity) and streamflow, including discussion and quantification of uncertainty
  - compartmentalising when sediment loads are generated between runoff events and baseflow and by seasons, and

[1] In the context of this report, SSC and TSS may be regarded as equivalent – see Section 2.1 for an explanation – and henceforth in this report SSC is generally used.

- comparing sediment load results to previous estimates and modelled values for relevant literature (including Elliot et al., 2009).

- For Tuapiro and Waimapu:
  - exploring options for estimating suspended sediment load based on available data, including examining relationships between SSC, turbidity (both continuous and discrete as appropriate) and water clarity data and advising if these relationships are accurate enough to determine the annual sediment loads, and
  - if a proxy is appropriate, advising what other sampling is needed to improve the accuracy of the relationship, and what margin of error there will be from using the recommended proxy.

- For all three sites:
  - providing formulas and methodologies so these can be implemented by BOPRC
  - comparing the turbidity and flow records to determine and discuss similarities/differences in the turbidity and catchment response to rainfall events
  - reviewing the methodologies used in the project and providing recommendations to improve robustness of any future monitoring, not excluding other ways of measuring and or inferring sediment load from measured parameters, and
  - evaluating the utility of the turbidity, SSC and water clarity data in relation to the proposed sediment attribute in the NPS-FM.

The work included a two-day visit to the BOPRC Tauranga office to review and discuss data collection methods and to inspect the Kopurererua and Waimapu sediment monitoring sites.

2 Kopurererua Stream

2.1 Monitoring station and data

Suspended sediment in Kopurererua Stream is monitored at the SH29 Bridge site. This includes a discharge record, continuously-recording turbidity, and an auto-sampler that is triggered to sample during runoff events. Also, monthly water quality grab-samples are collected for the NERMN and analysed for multiple constituents/characteristics (including clarity, turbidity, and SSC).

The discharge record (BOPRC site DO406909) began on 23/10/1980, but for the period before 1/1/1998 the record has poor continuity, with multiple and extended gaps.

A Hach Solitax turbidity sensor was installed in 2015, but provided data of mixed quality. It was replaced with a YSI ExoSonde[2] in early 2016, and this has provided a reliable turbidity record since 1/7/2016. The ExoSonde record since this date has been edited (using the AQUARIUS graphical data-editing toolbox) to remove spikes and suspect spans of data. Sensor biofouling does not appear to have been a significant issue, thanks to a wiper mechanism on the sensor. Gaps in the turbidity record between 1/7/2016 and 28/2/2019 total ~ 11 days (0.7% of record).

The auto-sampler, operated since 21/1/2016, has been operated on a flow-proportional basis (i.e., sampling interval inversely proportional to discharge) above a threshold stage, with sampling intervals within events typically varying from 1-3 hours. The auto-samples are analysed for SSC by BOPRC laboratory staff using a filtration approach that they align with the Total Suspended Solids (TSS) method (Procedure APHA 2540 D, APHA 1995). In fact, since they have been analysing all of the sample (rather than just an aliquot) the method aligns with the ASTM SSC-B method (Procedure D3977-37, ASTM 2013) – which is fortunate, since the formal TSS method using aliquots produces a biased, typically underestimated, SSC result with significant suspended sand loads (Gray et al. 2000).

To date, only one multi-vertical suspended sediment gauging using a D-49 depth-integrating sampler has been undertaken. This was done at the footbridge some 1 km upstream from the SH29 bridge. A slackline cableway at the SH29 bridge is now unusable because of concerns it may compromise the bridge's structural integrity.

The upstream catchment area is 59.75 km^2. On the day of the field inspection, the streambed material at SH29 Bridge was sand, and deposits of fine sand (dropped from the suspended load) were observed on the bank under the bridge and upstream. The banks immediately upstream were grassed, with a sediment drape on/under the grass (Figure 2-1), and showed frequent small slips – which will likely be causing some of the irregular turbidity "surges" detected by the turbidity sensor during event recessions.

The prevalence of sand in the streambed and in bank deposits indicates that sand comprises a significant (if not dominant) fraction of the suspended load. This warns that a turbidity sensor, which is more sensitive to the clay and fine-silt components of the suspended load, may not be sensing the sand load. It also warns of poor sand mixing across the stream cross-section, so the auto-samples, which are collected at a point beside the bank, may not be representative of the cross-section averaged SSC – which, if anything, is likely to be higher.

[2] Both sensors are certified to the ISO 7027 turbidity protocol and, when calibrated with Formazin standard solutions, their output is reported in Formazin Nephelometric Units (FNUs).

Figure 2-1: View upstream at Kopurererua at SH29 Bridge sediment monitoring site. Note sand deposits on bank (arrowed).

2.2 Sediment rating curve

2.2.1 Using auto-samples

At the Kopurererua site, 936 auto-samples were collected between 21/1/2016 and 29/4/2018. These samples had SSC ranging from 4 to 1807 mg/l and they covered a discharge range of 1263 to 22141 l/s. In comparison, since 1998 the mean discharge was 1945 l/s, the maximum discharge was 36150 l/s, and the mean annual flood was 17774 l/s. Thus, the samples cover a discharge range broader than the mean flow and mean annual flood – which is the typical range over which New Zealand rivers transport most of their suspended load (Hicks et al. 2004). Therefore, the coverage is suitable for estimating sediment loads using a "sediment rating curve", which is the relation between SSC and discharge.

The Kopurererua rating relationship is plotted in Figure 2-2. Note the broad data scatter and curvature of the data trend in log-log space. The curved pattern means that simple linear regression of the log-transformed data is not appropriate. Two appropriate methods are locally-weighted scatterplot smoothing (LOWESS) or band-averaging. LOWESS applies a regression fit to a moving window across the discharge range – the window width is controlled by a "stiffness factor" (F) that can be adjusted to optimise the overall quality of fit. Because the data are log-transformed, a moving log-bias correction (Duan 1981) is applied to the initial LOWESS curve. Band-averaging calculates the mean SSC in a moving window across the discharge range. This is calculated with untransformed data and so requires no log-bias correction, but the initial curve is typically "wiggly" (solid red line in Figure 2-2) so it may be approximated with a "step-function" comprising multiple linear segments (broken red line in Figure 2-2).

LOWESS and band-averaged rating curves were calculated for the Kopurererua dataset using in-house software. Step-functions approximating the band-averaged and LOWESS ratings are shown in Figure 2-3.

On Figure 2-2, the LOWESS curve (F = 0.5, SFE[3] = 1.81 – which approximates to an uncertainty of ± 63% on any individual estimate of SSC) aligns with the data-trend and band-averaged curve over most of the data range, but tends to underestimate at higher discharges – which are the most "potent" at transporting sediment. The band-average curve (calculated over 50 flow intervals, SFE = 1.86, equating to ± 66% error), with much the same overall error, was therefore preferred for load calculation.

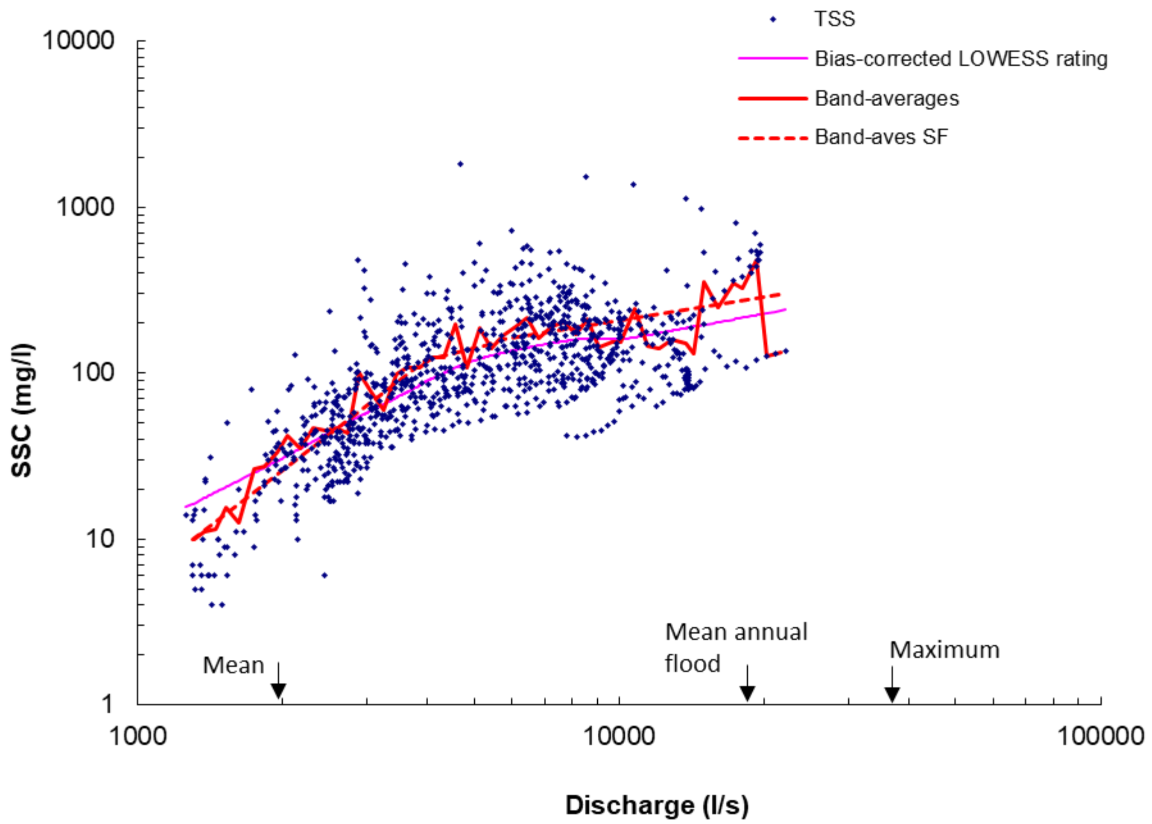

Figure 2-2: SSC-discharge rating at Kopurererua at SH29 from auto-samples. Lines show functions fitted using LOWESS (pink), band-averaging (solid red), and band-averaging smoothed with a step function (broken red).

[3] SFE is the standard factorial error. An SFE = 1.81 indicates that there is a 67% probability that the true SSC lies between the estimated value divided by 1.81 and the estimated value multiplied by 1.81. The SFE can be approximated as a ± % error using the formula: 100×average(1-1/SFE, SFE-1). Thus, in this example the estimated % error is ± 63%. While this might appear to be a disquietingly large error, it should be appreciated that this is really a measure of the scatter in the relationship between instantaneous SSC and discharge, and it relates to individual estimates at discrete points in time. When the sediment load is accumulated over time periods (e.g., over runoff events or years), the random components of this error tend to cancel out so that the net uncertainty on the time-averaged sediment load is smaller. This is detailed further in Section 2.3.1.

LOWESS
$Q < 4127$: $C = 0.0003Q^{1.52}$
$4127 < Q < 8014$: $C = 0.135Q^{0.786}$
$8014 < Q < 10410$: $C = 66.9Q^{0.0956}$
$Q > 10410$: $C = 1.183Q^{0.532}$

Band-averaging
$Q < 3969$: $C = 0.0000013Q^{2.23}$
$3969 < Q < 5359$: $C = 0.305Q^{0.720}$
$5359 < Q < 5689$: $C = 0.0053Q^{1.19}$
$Q > 5689$: $C = 2.93Q^{0.463}$

Figure 2-3: Step-functions approximating the LOWESS and band-averaging rating curves for Kopurererua at SH29. Q is discharge (l/s), C is SSC (mg/l).

No significant time-trend over the sampling period was observed in the rating curve residuals (R^2 = 0.015), which means that the rating relationship did not change over the sampling period. Note that short-term (event-scale) variation in the rating relationship does occur (as evident from the data scatter in Figure 2-2) but this is “averaged-out” when using the rating curve to calculate time-averaged sediment loads.

2.2.2 Using water quality samples

It is useful to compare the auto-sample based sediment rating relationship for Kopurererua with that shown by the water quality grab-samples (Figure 2-4). Key points to note are:

- there are 169 water quality samples available, collected between 15/9/1993 and 13/3/2018
- they cover an SSC range of 2-685 mg/l and a discharge range of 821-18210 l/s
- they plot in the same SSC-discharge space as the auto-samples but most were collected at discharges less than the mean, with few at high flows – thus the “business end” of the rating (in terms of the discharge range transporting most of the sediment load) is poorly sampled, and
- a linear regression model fitted to the log-transformed data aligns reasonably with the LOWESS and band-average ratings at discharges less than ~ 6000 l/s but it over-predicts at higher discharges and is highly sensitive to the one sample collected at 18210 l/s[4] .

This comparison stresses the importance of developing ratings from samples collected over as wide a range of the recorded discharge as possible. It also raises a warning flag around the use of water quality grab-samples to derive sediment ratings at the Waimapu and Tuapiro sites in lieu of any existing auto-samples from runoff events at those sites (see Sections 3.2 and 4.2, respectively). The errors in time-averaged loads estimated by extrapolating rating curves to discharges beyond the sampled range can be high but are not captured by the rating-fitting statistics. See Section 2.3.1 for results illustrating this.

[4] The water-quality sample based rating function (corrected for log-bias) is $SSC = 5.15 \times 10^{-5}Q^{1.74}$ (R^2 = 0.42). Omitting the datapoint at 18210 l/s produces the function $SSC = 3.74 \times 10^{-6}Q^{2.1}$ (R^2 =0.44)

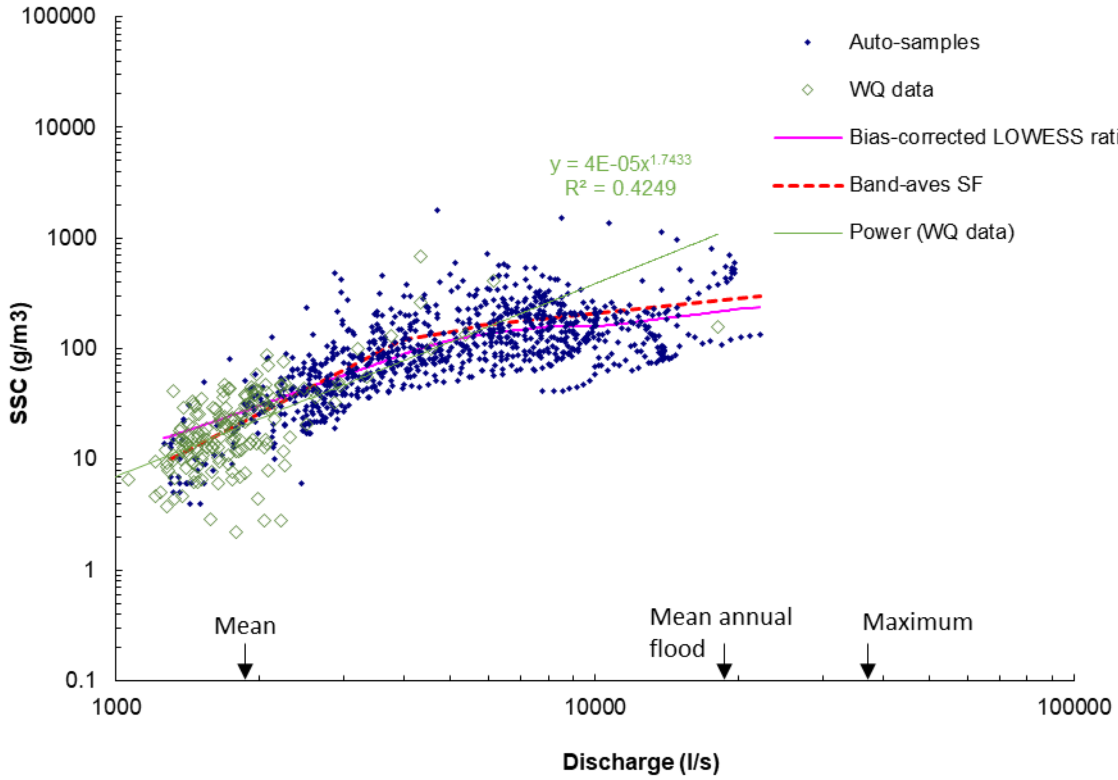

Figure 2-4: Kopurererua sediment rating using water quality samples. Water quality data plotted in green, overlaid on auto-sampled data and ratings based on auto-sampled data.

2.3 Annual and long-term average sediment loads from rating curve

The band-average-based sediment rating curve was combined with the reliable discharge record since 1998 to calculate annual loads and the mean annual load for the period 1/1/1998 to 31/12/2018[5].

2.3.1 Mean annual load

The mean annual Kopurererua load was 2175 ± 101 t/yr[6] (36.4 ± 1.7 t/km^2/y). The 4.6% error was estimated by:

- assuming the error in estimating the instantaneous SSC was systematic over the duration of runoff events and intervening baseflow periods
- assuming the error varied randomly between events
- summing the squared error (variance) of the loads from each event and intervening baseflow period, and
- setting the final error as the square-root of the summed variance.

[5] This 21 year period had 20.86 years of discharge record.
[6] For interest, the mean annual load calculated with the LOWESS rating was 2475 t/y, which aligns with the band-average-based result at a 5% significance level.

This approach was used to account for the short-term variation in rating curve position observed between events.

Applying the water-quality sample based rating produces a mean annual load estimate of 3989 t/y (1.8 times the result from the band average rating), while the rating re-calculated after dropping the highest-flow data point produces a mean annual load of 6929 t/y (3.2 times the band average rating result!). This shows that fitting rating curves to water quality datasets, acquired largely at baseflows, can induce large errors in estimates of mean annual sediment load.

2.3.2 Annual variability

The annual loads (Figure 2-5) ranged over a factor of 5 between 930 and 4653 t with a standard deviation of 983 t. This inter-annual variability creates a ± 10% uncertainty on the long-term averaged load[7], which is additional to the 4.6% standard error due to rating curve uncertainty. Both 2017 and 2018 had higher-than-average loads, by virtue of higher flows.

The average rating-based load over the period 1/7/2016 to 28/2/2019, which aligns with the turbidity record period, was 3532 ± 424 t/y. This is 1.6 times the longer-term (1998-2018) average load using the same auto-sample based rating. This signals that the 2016-2018 period had a higher-than normal load.

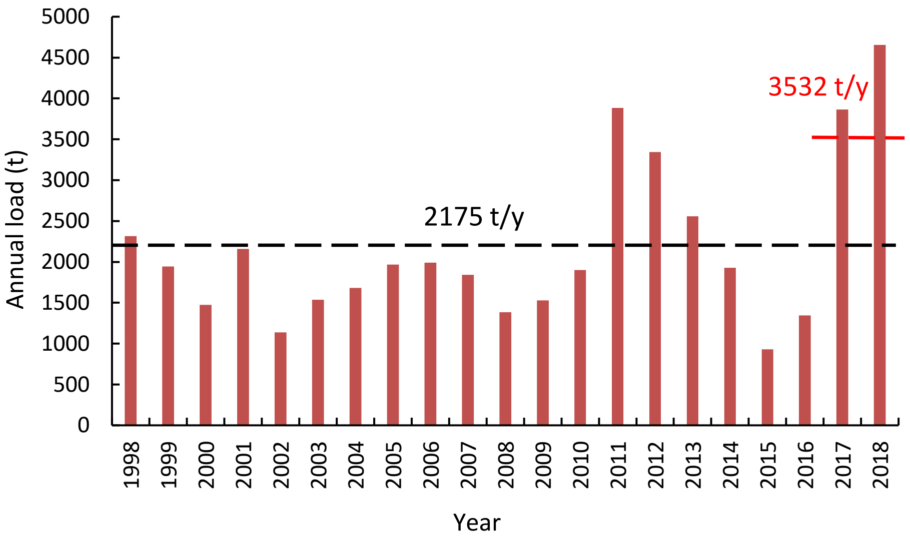

Figure 2-5: Annual suspended sediment load at Kopurererua from 1998-2018. Broken-black line shows long-term average load (2175 t/y); red line shows rating-calculated load averaged for period 1/7/2016-28/2/2019 (3532 t/y).

2.3.3 Seasonal distribution

The seasonal load distribution averaged over the 1998-2018 period (Figure 2-6) shows that most of the load is transported during Autumn and Winter (March – August), by virtue of the higher runoff then.

[7] The "long-term" average load is here estimated by sampling over the 21 year 1998-2018 period. The sampling error (SE) on the long term average load is SE = $SD/(n-1)^{0.5}$, where SD (=983) is the standard deviation of the annual loads and n (=21) is the number of years sampled.

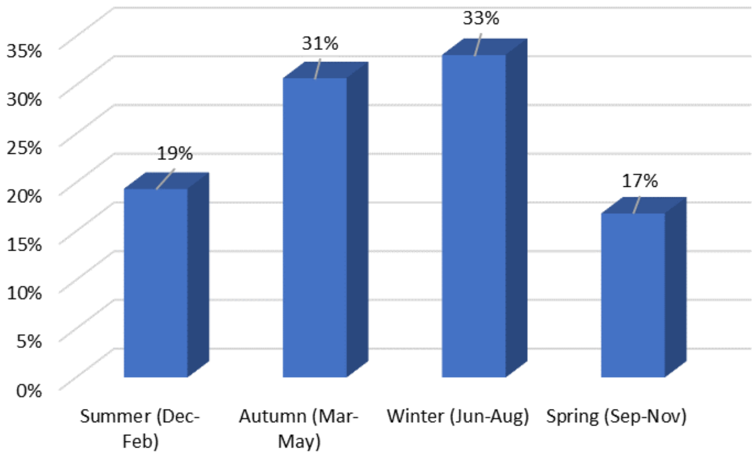

Figure 2-6: Seasonal proportions of long-term average sediment load, Kopurererua at SH29, 1998-2018.

2.4 SSC-turbidity relation

2.4.1 Deriving the calibration

The auto-samples collected since 1/7/2016 were used to calibrate the Kopurererua field turbidity (T_f) record to SSC. 714 auto-sampled SSCs were time-matched to the field turbidity from the YSI-Exosonde, covering a turbidity range of 5-740 FNU – which covers most of the field record range of 5 – 922 FNU. The calibration relationship (Figure 2-7A) was linear, passed through the origin, and had uniform data scatter over most of the turbidity range (except for turbidity values less than 50, where the scatter reduced proportionally), so a zero-intercept linear regression model was fitted, giving SSC(mg/l) = 1. 913 T_f (R^2 = 0.95, standard error = 29 mg/l). While the data were relatively sparse at turbidity values greater than 250, and the 10 points with higher values were all from the same event, the linear relation from the rest of the data bisected these higher values, so the overall relation is not biased by these few high data values.

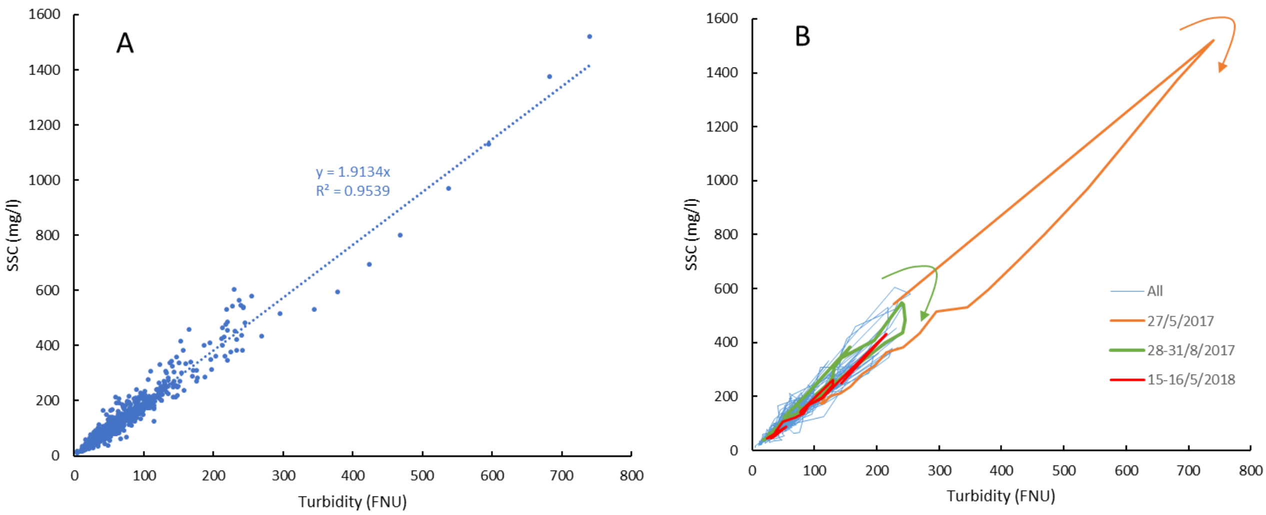

Figure 2-7: Relation between auto-sampled SSC and field turbidity at Kopurererua at SH29. A: Data-points and trendline; B: hysteresis loops, including selected events (arrows indicate clockwise hysteresis).

Moreover, when the sediment load calculated off the calibrated turbidity record (Section 2.5) is distributed across the range of measured turbidity, it is seen (Figure 2-8) that 95% of the load is carried over the well-sampled turbidity range less than 250 FNU[8].

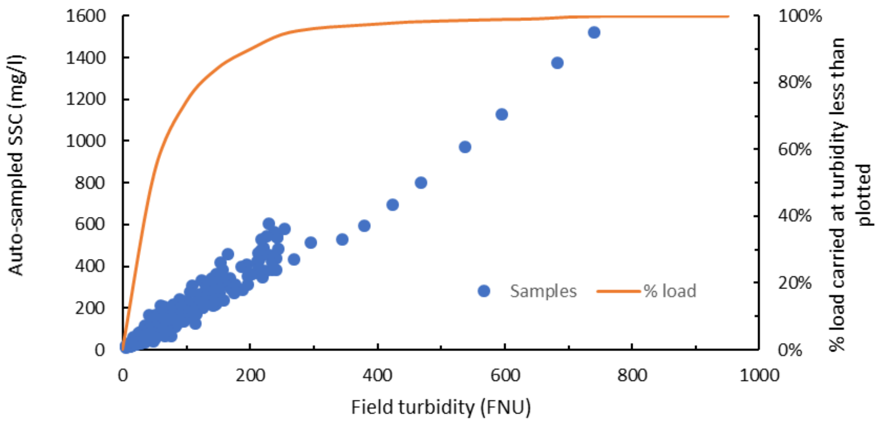

Figure 2-8: Percentage of sediment load carried in relation to turbidity, compared with auto-sampled calibration dataset. Orange curve shows % of the 2016-2019 sediment load transported while the turbidity is less than the plotted value. For example, 50% of the load transported with turbidity less than 50 FNU.

Further checks on the relationships found:

- no significant time trend was observed in the residuals (Figure 2-9, R^2 = 0.043), which indicates no drift in the relationship over time
- a multiple regression analysis relating SSC to turbidity and discharge provided no statistical advantage (R^2 =0.95), and
- relating SSC to the 15-minute (3 point) running-mean turbidity (rather than the instantaneous turbidity as above) provided negligible difference to the calibration relationship (SSC = $1.916T_f$; R^2 = 0.95).

Thus, the relation SSC = $1.913T_f$ provides a good, stable calibration and is suitable for converting the field turbidity record to an SSC record. This was done, and the band-average sediment rating (Section 2.2.1) was used to infill the SSC record to cover the ~ 11 days of gaps in the turbidity record.

2.4.2 Within-event variation in the SSC-turbidity relationship

The scatter in the SSC-turbidity data was not random but was associated with low-amplitude hysteresis loops in the SSC-turbidity relationship during runoff events (Figure 2-7B shows examples). These stem from within-event variations in the particle size grading of the suspended load. For a given SSC, turbidity is highly sensitive to sediment particle size, with, for example, suspended clay 1 micron in size returning a turbidity 100 times that from suspended sand 100 microns in size. Thus, clockwise hysteresis loops in the SSC-turbidity relation during a runoff event signal relatively coarser suspended load (i.e., relatively sand-rich) early on the event and finer sediment (i.e., more mud-rich)

[8] It is recommended that plots like Figure 2-8 are maintained on a running basis for all sites and used to help decide when sufficient calibration samples have been collected. This plot clearly shows that the turbidity range carrying the bulk of the sediment load has been well sampled.

later in the event (and vice-versa for anti-clockwise loops). In turn, this informs on the sources of the sediment carried at different stages of the event.

At Kopurererua at SH29, the hysteresis loops tend to be clockwise, notably for the "dirtier" events (e.g., 27/5/2017, 28-31/8/2017 on Figure 2-7B) – which suggests higher sand proportions earlier in the event (resuspended from the sandy bed-material as the discharge increases) but relatively more fine sediment sourced from up-catchment arriving later.

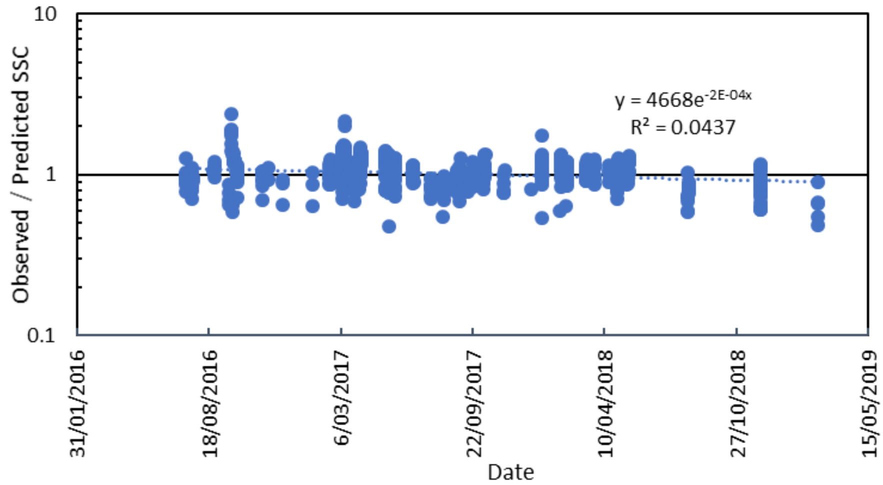

Figure 2-9: Residuals vs time plot for Kopurererua SSC-turbidity calibration relationship. The residuals are expressed as the ratio of observed SSC and predicted SSC. The near-zero R^2 on the trend-line signals no significant time trend.

2.5 Sediment load results from turbidity record

The turbidity-based SSC record was combined with the discharge record to calculate the sediment load over the period 1/7/2016 to 28/2/2019.

The within-event systematic variations in the SSC-turbidity relationship described above were used to set the time-scale over which error was accumulated in the calculation of sediment load. Thus, the error was regarded as systematic over individual events but the event-load errors were regarded as independent and so the accumulated error over multiple events and intervening baseflow periods was calculated using the root-sum-of-variance approach (as was done with the sediment rating function in Section 2.2).

2.5.1 Load over turbidity monitoring period

The mean annual load calculated from the turbidity record over the period 1/7/2016 to 28/2/2019 is 2928 ± 60 t/y. While this is 17% less than the load estimated by the band-average rating for the same period (3532 ± 424), considering the errors on both estimates they align at a 5% significance level. Accepting the turbidity-based result as more reliable (by virtue of its smaller error) suggests that the rating approach overestimates the time-averaged load by 20%. However, as discussed in Section 2.3.2, the variability in annual loads is considerably larger than the uncertainty in their measurement. Therefore, this relatively short turbidity-based measure of average load over less than 3 years is not a representative measure of the long-term average load. Note that the smaller uncertainty on the turbidity-based estimate shows that if the turbidity monitoring is continued it will provide a more precise measure of the long-term average load than will the rating curve approach.

2.5.2 Load distribution between baseflow and events

Storm runoff events were isolated from intervening baseflow periods by defining event start-times at the onset of quickflow and event end-times at the end of quickflow, where the quickflow was separated from delayed flow by an empirically-set hydrograph slope (Figure 2-10). The separation slope for Kopurererua at SH29 was set at 300 l/s/day, after inspection of the hydrograph and "turbidigraph" shapes over multiple events. Very small runoff events, with less than 1 mm of quickflow runoff, were regarded as baseflow. This separation indicated that 68% of the suspended load was transported during runoff events.

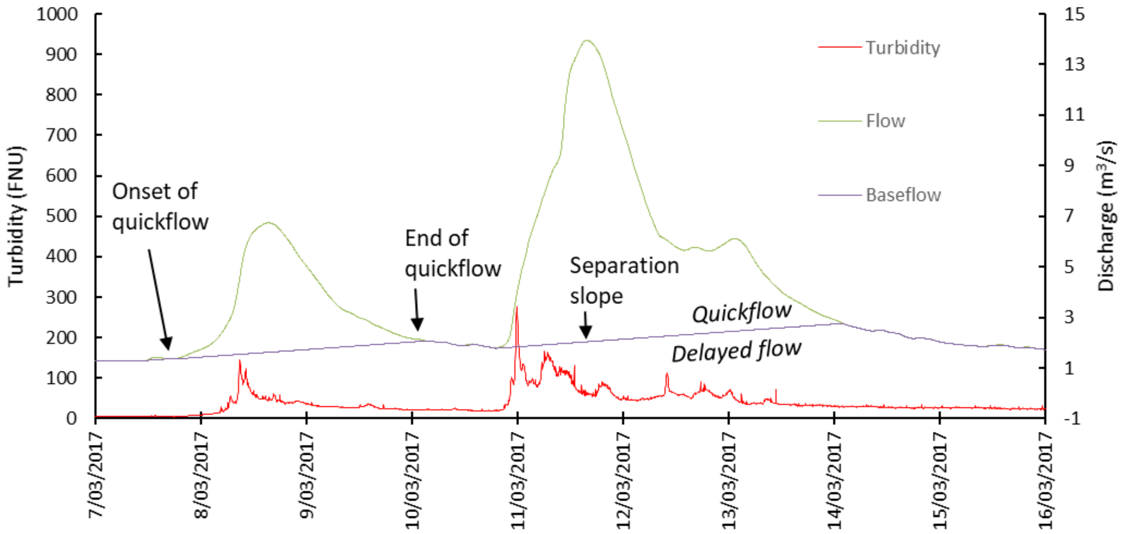

Figure 2-10: Example of how start and end of runoff events were defined. Start of event set at onset of quickflow; end of event set at end of quickflow. Separation slope set by inspection of hydrograph and turbidity record.

2.5.3 Event loads and relationships with runoff, rainfall, and season

Event sediment loads for all 48 events with more than 1 mm runoff[9] over the 1/7/2106 to 28/2/2019 period were compared with hydrological indices of the events, including peak discharge, total runoff, quickflow runoff, rainfall, rain energy, and rain erosivity.

After comparing the phasing of rainfall and runoff for multiple events, event rain start and end times were set at 7 hours before the corresponding quickflow start and end times. Rain energy (E, joules) was calculated, after Brown and Foster (1987), as:

$$E = \sum 0.29\ (1 - 0.72\ e^{-0.05I})\ I$$

where I is the hourly rain depth (mm) over the event.

Rain erosivity is usually calculated as the product of event rain energy × the maximum 30-minute intensity over the event (EI30); however, since the rainfall record provides only hourly values, this was approximated using the maximum 60-minute intensity (EI60).

[9] Event runoff is reported here as a depth (mm), equal to the volume of runoff over the event divided by the catchment area.

The detailed event results are listed in Appendix A. Table 2-1 shows that the event sediment loads correlated best with event peak discharge, although reasonably good correlations were observed with all the hydrological indices.

The best predictive function for event load (L_e, t), fitted using linear regression to log-transformed data (Figure 2-11) and corrected for log bias with Duan's (1983) estimator, is:

$$L_e = 6.27\ Q_{pk}^{\ 1.32}$$

where Q_{pk} (m^3/s) is the event peak discharge, R^2 = 0.85, and the SFE = 1.34 (equating to ± 30%).

This event-load rating is another means of estimating the long-term average load, allowing that only 68% of this is transported during runoff events.

Table 2-1: Correlation of event sediment load with event hydrological indices, Kopurererua at SH29. Correlation is Pearson's R. EI60 is rain erosivity.

Storm index	Correlation with event sediment load
Peak discharge	0.93
Quickflow runoff	0.91
Total runoff	0.87
Rain energy	0.82
EI60	0.79
Rainfall	0.77

Figure 2-11 distinguishes the events by season (summer is December - February; autumn is March – May; and so on). No seasonal differences in event load are apparent.

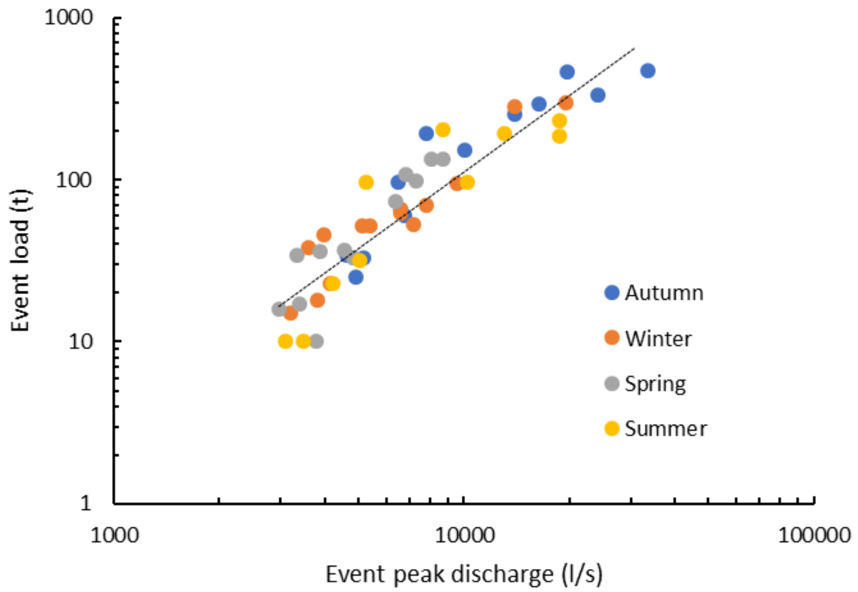

Figure 2-11: Event sediment load vs event peak discharge, Kopurererua at SH29. Events identified by season. Dotted line is regression line (R^2 = 0.85).

2.5.4 Event loads and SSC during March – June 2017

Over March - June 2017, elevated sediment concentrations in the Kopurererua River were traced to earthworks in a subdivision development at Kennedy Road (MacKay and Shaw 2017). Figure 2-12 highlights results from the turbidity monitoring of the eight runoff events that occurred over this period. This shows the sediment load for the event of 26-30 May 2017 lying well above the trend shown by events of the same peak discharge between 2016 and 2019, with the loads over 27-31 March and 4-8 April 2017 plotting along the upper margin of the general trend. Moreover, the events of 27-31 March and 26-30 May 2017 had peak SSCs well above those observed in other events, irrespective of event peak discharge. This illustrates how the turbidity-based monitoring may be used to identify abnormally high sediment inputs from the catchment.

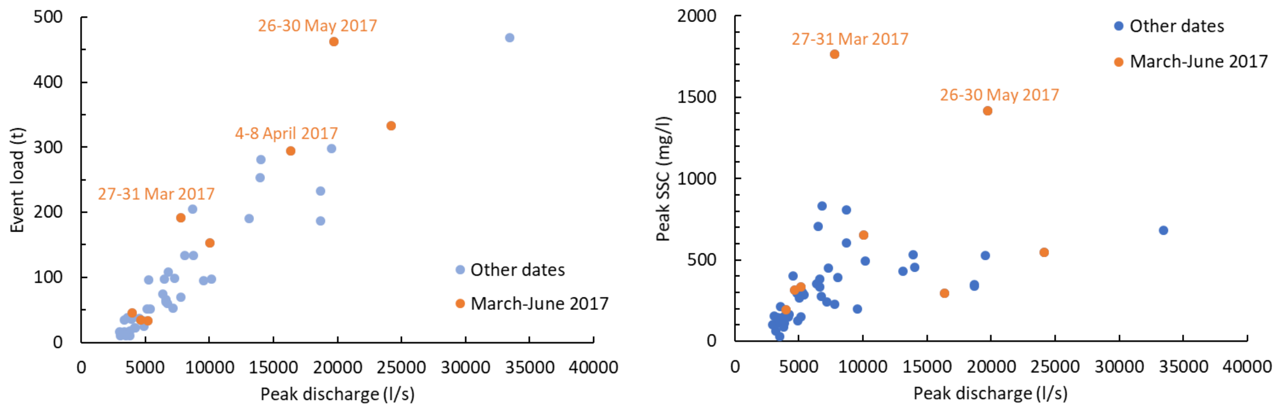

Figure 2-12: Kopurererua event sediment load and event peak SSC vs event peak discharge, highlighting events in period March-June 2017.

2.6 Cross-section averaged load

2.6.1 Sediment gaugings

The sediment rating curve and turbidity based sediment load results in Sections 2.3 and 2.5 assume that the bank-side auto-sampled SSC is representative of the discharge-weighted cross-section average SSC. However, in sand-bed streams like the Kopurererua this is rarely the case because the sand component of the suspended load can be significant but tends to be focussed nearer the bed and towards the middle of the cross-section where the flow is faster and more turbulent. Typically, the auto-sampled SSC is less than the cross-section average. Thus, a relationship needs to be established between the auto-sampled SSC and cross-section average SSC by undertaking sediment gaugings with a depth-integrating sampler at multiple verticals concurrently with auto-sampling.

To date, only one such gauging has been done at Kopurererua. For this, a D-49 sampler was used to collect samples at the mid-points of three sub-sections each conveying 1/3rd of the total discharge, employing the Equal Discharge Increment (EDI) approach. The sediment gauging was undertaken off the pedestrian bridge ~ 1 km upstream from the auto-sampler[10] under baseflow conditions from 1:45 to 2.00 pm on 27/2/2019, when the gauged discharge was 1.734 m^3/s and the turbidity record was steady at ~ 4.6 FNU. The gauged average SSC was 15.1 mg/l. Assuming the gauged mean velocity of

[10] This separation is not ideal, firstly because of the risk of undetected sediment sources between the gauging site and auto-sampler, and secondly because of the travel-time of the water – which complicates matching the auto-samples and gauged result if the SSC is changing rapidly.

0.52 m/s was uniform along the 1 km reach down to the autosampler, the water travel time would have been 32 minutes, thus the ideal matching sample time of the auto-sampler should have been 32 minutes after the mid-time of the sediment gauging – i.e., 2:22 pm. Auto-samples were collected at 11:38 am (16 mg/l) and 2:31 pm (10 mg/l). Interpolation of these two auto-sampled SSCs at 2:22 pm indicates an auto-sampled SSC of 10.3 mg/l. Thus, the ratio of cross-section average and auto-sampled SSC was 15.1/10.3 = 1.47. This ratio may well be even higher during runoff events.

While not proper sediment gaugings, on 9 occasions between 23/6/2016 and 11/3/2017, when the auto-sampled SSC ranged between 69 and 434 mg/l, BOPRC staff collected matching auto-samples and mid-stream surface-scooped samples for SSC analysis. The results (Figure 2-13) showed a trend for the mid-stream samples to be 18% larger than the auto-samples.

Both datasets, therefore, warn of significant under-representation of the cross-section SSC by the auto-samples and of the load estimates based on these (by at least 18%, possibly by up to 50%). More suspended sediment gaugings, using the methods detailed in the forthcoming suspended sediment NEMS (NEMS 2019), to better establish this sediment mixing factor over a range of discharges are imperative to increase the accuracy of the sediment load monitoring.

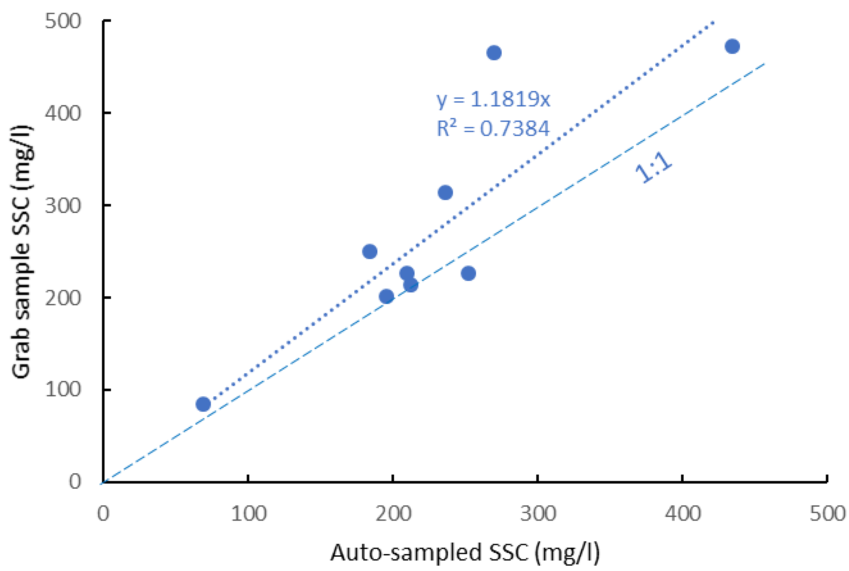

Figure 2-13: Mid-stream grab-sampled SSC vs bank-side auto-sampled SSC, Kopurererua at SH29. Dotted line shows regression trend of data; broken line is 1: 1 line.

2.6.2 Unmeasured load

Even suspended sediment gaugings do not sample the total sand load, part of which moves as bedload or in suspension in the "unmeasured" zone between the sampler intake nozzle and the streambed (when the sampler is just touching the bed). The "unmeasured load" can be estimated using the Modified Einstein Procedure (MEP, Colby and Hembree 1955)[11], which requires information on the concentration and size grading of the depth-integrated suspended load, the size grading of the streambed material, and channel hydraulic data (derived from a concurrent discharge gauging). A variation on the MEP is the "Series Expansion Modified Einstein Procedure" (SEMEP, Shah-Fairbank et al. 2011).

[11] The US Bureau of Reclamation provide the BOROMEP software to streamline the rather complicated Modified Einstein Procedure (Holmquist-Johnson and Raff, 2006).

2.7 Comparison with previous load estimates

Previous estimates of the mean annual suspended load of the Kopurererua at SH29 are summarised in Table 2-2.

Parshotam et al. (2009) estimated the long-term (50-year) average suspended load of the Kopurererua at SH29 as 5731 t/yr. This used a GLEAMS model validated against an SSC record generated from a rating curve developed from auto-samples collected between October 2006 and May 2008. They estimated a shorter-term average load of 4931 t/y directly off their sediment rating.

The national empirical sediment load predictor of Hicks et al. (2011) estimates an average load of 4925 t/y, while a recently updated version (Hicks et al. 2019) estimates 3450 t/y. Both estimates have a factorial uncertainty of about ×/÷ 1.9.

Note that the GLEAMS model and the Hicks et al. (2011) and Hicks et al. (2019) estimators predict the total, cross-section averaged load, which may account for their loads being significantly higher than the results derived in this report. This further emphasises the importance of undertaking full suspended sediment gaugings at the Kopurererua.

Table 2-2: Previous estimates of the Kopurererua annual average suspended load compared with the present estimates.

Source	Estimated mean annual load (t/y)
Parshotam et al. (2009) – GLEAMS model	5731
Parshotam et al. (2009) – rating based	4931
Hicks et al. (2011) – national empirical estimator	4925
Hicks et al. (2019) – updated national empirical estimator	3450
This study – 1998-2018 average based on rating curve	2176
This study – July 2016-Feb 2019 from turbidity	2928

2.8 Conclusions and recommendations for Kopurererua site

A good turbidity record has been collected at Kopurererua at SH29 since mid-2016, and a good, stable, fit-for-purpose calibration to auto-sampled SSC has been developed which enables sediment load determination to high precision. However, it is likely that these loads are being underestimated because of non-uniform mixing of the suspended load over the cross-section – which is expected given the sandy bed composition and confirmed by the higher concentrations observed in mid-stream scoop samples and in the one sediment gauging that has been done to date. Thus, the following recommendations are made:

- The highest priority should be to collect a set of multi-vertical, depth-integrated sediment gaugings over a range of discharge to establish a relation between bank-side auto-sampled SSC and cross-section average SSC.
- The sediment gaugings should be done using the procedures detailed in the forthcoming Suspended Sediment NEMS.
- The sediment gaugings should be done at the SH29 bridge if at all possible (using a rod-mounted sampler), rather than at the pedestrian bridge 1 km upstream, to avoid time-

lag issues when the SSC is changing rapidly. If the gauging must be done at the upstream site, then the water travel-time must be considered when matching the gauged SSC with that auto-sampled.

- The sediment gauging samples should also be analysed for particle size distribution, and this information used with appropriate hydraulic data and bed-material size gradings to calculate the unmeasured sand load using the Modified Einstein Procedure. This is important, given that a strong motivation for the Kopurererua monitoring is to measure the total sediment discharge into Tauranga Moana.
- Except for matching them with depth-integrated samples, the need for further auto-samples is low, given:
  - the large number of auto-samples collected already, which well-cover the turbidity range over which the bulk of the load is transported, and
  - the good, stable relationship between turbidity and auto-sampled SSC.

3 Waimapu Stream

3.1 Monitoring station and data

In Waimapu Stream, turbidity is monitored continuously at the McCarrols site but there is no auto-sampler at the site and no depth-integrated sampling has been done. McCarrols has a rated stage record (BOPRC site DO690531) which has run since 16/2/1991 but is only reasonably gap-free since 19/6/1997. A manually-operated slackline cableway is available on-site for gauging operations and could be used for sediment gaugings[12].

The turbidity sensor is a YSI Exosonde and was installed on 26/2/2016. An edited record was provided by BOPRC covering to period until 20/5/2019. Gaps spanned 16.4% of this edited record.

The upstream catchment area is 56.6 km^2, with most in pasture and lesser proportions in indigenous vegetation and exotic forest. The catchment is underlain by ignimbrite (the younger Mamaku and Waimakariri Ignimbrites on the eastern side, the older Waiteariki Ignimbrite on the western side).

The turbidity and stage sensors are located beside a pool that is controlled by an ignimbrite sill. The true left bank immediately upstream has abundant small slips/slumps (Figure 3-1). Most are associated with the eroding outer bank of the bend 70 m upstream, but the nearest slip is only 1 m from the turbidity sensor. On the day of my inspection, cattle were wading on the point bar on the opposite bank (Figure 3-1). Both the bank erosion and cattle will be causing transient pulses in turbidity that will not be representative of the stream's sediment load due to incomplete mixing (e.g., Terry et al. 2014). The pool by the sensor had thick deposits of pumiceous sandy grit (with a covering drape of brown organic material - Figure 3-2). This had accumulated over recent years following a large rainfall event and indicates a high sand component of the sediment load.

Monthly water quality sampling has been carried out approximately 2 km downstream at Pukemapu Road Bridge since July 2001. There are no significant tributaries entering between this site and McCarrols, thus the water quality samples may potentially be used to calibrate the turbidity record to SSC[13]. The channel bed at Pukemapu Road was also flush with gritty sand. This signals that surface or bankside grab-samples will almost certainly under-represent the cross-section averaged sediment concentration.

[12] The slackline requires a plate for mounting a gauging-reel before it can be used for sediment sampling.
[13] As with the Kopurererua, the Waimapu water quality samples have been analysed in the BOPRC laboratory using the TSS method but analysing the full sample, thus the TSS results equate to SSC results.

Figure 3-1: View upstream at Waimapu at McCarrols sediment monitoring site. Note stock wading in river and slipping banks on same side as turbidity sensor – both can “contaminate” the apparent turbidity from up-catchment.

Figure 3-2: View across-stream at Waimapu at McCarrols sediment monitoring site. Note pumice sand deposits on stream bed.

3.2 Relations between water quality SSC, turbidity, clarity and discharge

I examined the water quality dataset from Pukemapu Bridge (108 observations) for relations between SSC, turbidity, clarity and discharge[14]. Pearson correlation coefficients (R, Table 3-1) indicate the strength of the inter-relationships.

The weakest relationships (lowest R-values) are between visual clarity (as measured by black disk) and the other parameters, but this is of no consequence since clarity offers little value in regard to sediment load.

Table 3-1: Pearson correlation coefficients for turbidity, clarity, SSC, and discharge at Waimapu at Pukemapu Bridge. Red font gives R values for log-transformed data; black font gives R values for untransformed data.

	Discharge	SSC	Turbidity	Clarity
Discharge	1.00	0.66	0.63	-0.44
SSC	0.56	1.00	0.87	-0.54
Turbidity	0.56	0.91	1.00	-0.71
Clarity	-0.33	-0.35	-0.53	1.00

3.2.1 SSC – turbidity relationship

A reasonably good relationship is observed between SSC and turbidity (R =0.91), across a turbidity range of 0.72 to 50 NTU (Figure 3-3, blue points). The data-scatter was homoschedastic[15] when log-transformed (left plot, Figure 3-3), thus a power regression function was fitted. After correcting for log-bias with the Duan (1983) estimator, this function is:

$$SSC = 1.87\ T_{wq}^{1.0}$$

where T_{wq} is the lab-measured turbidity from the water quality samples, $R^2 = 0.75$, and the standard factorial error is ×/÷ 1.64 (which approximates to ± 50%).

Eleven water quality SSC results were able to be matched with the field-recorded turbidity (T_{field}) at McCarrols from January 2017. Figure 3-3 (orange points) shows these data plotting within the scatter of the water quality sampled turbidity. Also, Figure 3-4 shows a good linear relation ($R^2 = 0.92$, standard error ± 2.3 NTU) between the matched turbidity values from the water quality samples and the field record[16]:

$$T_{wq} = 1.32\ T_{field}$$

Combining these two relations, we derive:

$$SSC = 2.47\ T_{field}$$

This may be used as an interim calibration of the McCarrols field turbidity record to SSC, until such time as samples can be collected at McCarrols that span close to the full range of recorded turbidity

[14] The discharge data used were as provided by BOPRC. I have assumed these allow for the time-lag between the flow recorder at McCarrols and Pukemapu Bridge.
[15] That is, the data-scatter is uniform across the turbidity range when log-transformed values are used.
[16] Differences between field and laboratory turbidity instruments should be expected, due to different measurement protocols and even subtle variations between instrument brands observing the same protocol.

(0.1 to 345 FNU). It is noted that the turbidity range with matching SSC samples spans only 1/7th of the field turbidity range, so even though such SSC-turbidity relations tend to be linear, the extrapolation error could be substantial at the 100+ FNU range.

The extrapolation issue underpins the preference to use the two-step calibration rather than the direct power-relation between SSC and T_{field}. This is because the direct function is non-linear (exponent of 1.25) and covers a small field turbidity range (1.1-16.5 NTU), thus is more vulnerable to extrapolation errors when applied across the full range of recorded field turbidity than is the linear relation.

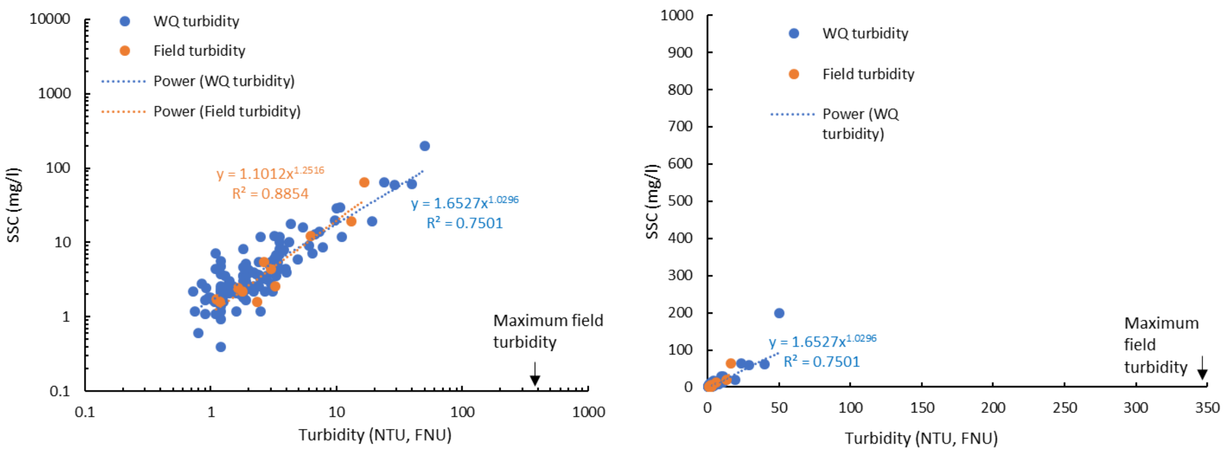

Figure 3-3: Relationships of water quality SSC with water quality turbidity at Pukemapu Bridge and with field turbidity at McCarrols. Orange points show water quality sampled SSC matched with field-recorded turbidity. Left plot on log scales; right plot on linear scales, which emphasise the wide gap between the highest sampled water quality turbidity (50 NTU) and the highest turbidity observed by the field sensor (345 FNU).

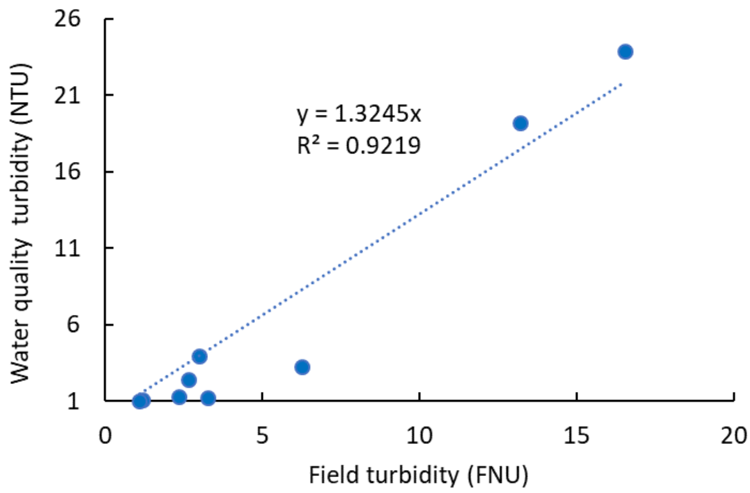

Figure 3-4: Water quality sample turbidity at Pukemapu Bridge vs field-recorded turbidity at McCarrols.

3.2.2 SSC - discharge relationship

Figure 3-5 shows the SSC-discharge sediment rating relationship for the Waimapu water quality data at Pukemapu Bridge. The best-fit power function is $SSC_{(mg/l)} = 0.00194Q_{(l/s)}^{1.01}$, which becomes $SSC = 0.00564Q^{1.01}$ when Duan's log-bias correction factor is applied. The quality of fit is only moderate ($R^2 = 0.44$), and the standard factorial error (×/÷ 3.31) is large. Moreover, as is typical with monthly water quality sampling, the majority of data points are at discharges less than the mean. Thus, the rating is poorly defined/fitted over the discharge range between the mean flow and the mean annual flood that is expected to be most-effective at transporting the suspended load (compare with auto-sampled Kopurererua sediment rating in Figure 2-2).

Therefore, while this rating may be used as an interim one for estimating the long-term average suspended load of the Waimapu, the results will carry a high uncertainty due to the large factorial error (×/÷ 3.31) in the model-fitting, the additional error from extrapolation, and because of the unknown relationship between the grab-sampled SSC and the cross-section averaged SSC.

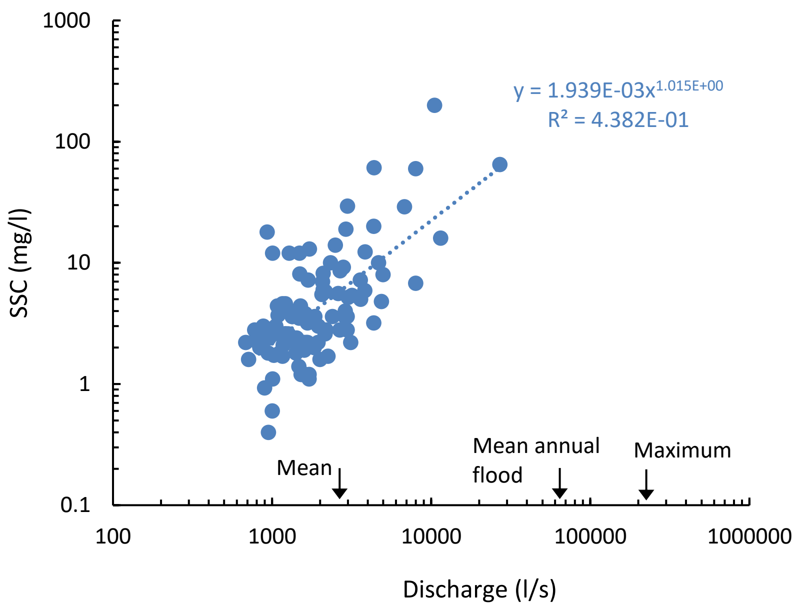

Figure 3-5: Sediment rating relationship from water quality data, Waimapu at Pukemapu Bridge. Discharge data from McCarrols recorder, 2 km upstream. Mean discharge is 2411 l/s, mean annual flood is 61,230 l/s, and maximum recorded discharge is 203,453 l/s. maximum sampled discharge is 27,000 l/s.

3.3 Long-term average and annual loads from water-quality data rating

Combining the above water quality sample derived sediment rating with the McCarrols discharge record for the period 1998-2018 gives a mean annual load of 3581 ± 680[17] t/y (63.3 ± 12 t/km^2/y). The annual loads ranged over a factor of 11, between 831 and 9289 t (Figure 3-6).

[17] This standard error, equal to 19% of the estimated load, is based only on the standard error of the rating-curve fit and does not account for error due to curve extrapolation or sample representativeness – so the true uncertainty will be substantially larger but is not able to be quantified from the information available.

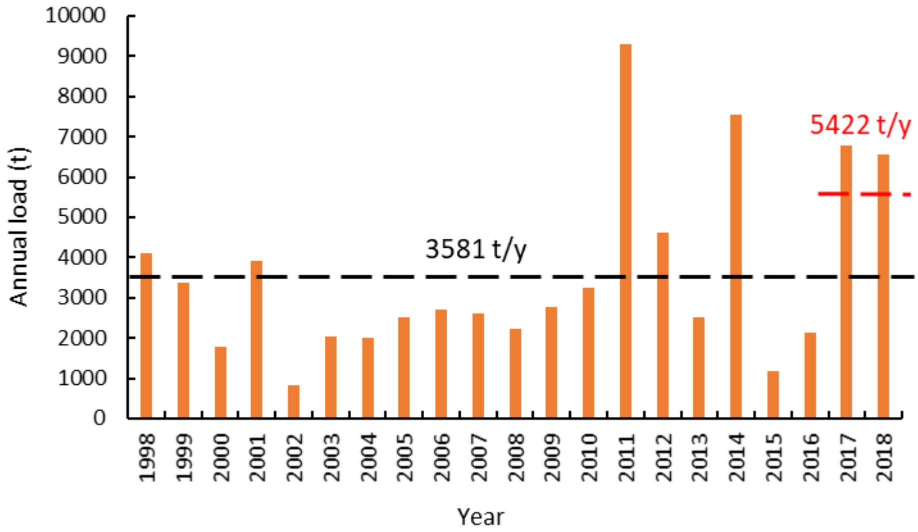

Figure 3-6: Annual Waimapu suspended loads, 1998-2018, estimated using sediment rating derived from water quality data. Black dashed line shows mean annual load over 1998-2018. Red dashed line shows mean annual load calculated with rating over period 1/7/2016 – 28/2/2019.

3.4 Sediment load results from turbidity record

The SSC = 2.47T_{field} calibration relation derived in Section 3.2.1 was applied to the Waimapu field turbidity record to generate an SSC record, with the water quality sample derived sediment rating used to "patch" gaps in this due to gaps in the turbidity record. This SSC record was then combined with the discharge record to calculate loads.

3.4.1 Load over turbidity monitoring period

The turbidity-based load averaged over the period 1/7/2016 to 28/2/2019 was 3737 ± 787[18] t/y. This equates to a specific load of 66 ± 14 t/km^2/y. In comparison, the turbidity-based Kopurererua load over the same period was 49 ± 1 t/km^2/y – thus the Waimapu specific load was slightly higher to within one standard error.

The rating-based Waimapu load over the same period was 5422 ± 2223 t/y (Figure 3-6). This is 45% larger than the turbidity-based result, but the two estimates align within their uncertainty limits. Accepting the turbidity-based result as more accurate, this suggests that the long-term average load estimated off the rating in Section 3.3 may be 45% too high. Adjusting for this the Waimapu long-term average load estimate reduces to 2470 t/y.

3.4.2 Load distribution between baseflow and events

Storm runoff events in the Waimapu were separated from baseflow periods using a quickflow separation slope of 200 l/s/day. This separation showed that 90% of the turbidity-based suspended load was transported during runoff events.

3.4.3 Event loads and relationships with runoff, rainfall, and season

The turbidity-based Waimapu event sediment loads were related to runoff and rainfall indices as explained in Section 2.5.3. The detailed event results are listed in Appendix A.

[18] This equates to a ± 21% standard error.

The event loads correlated best with event peak discharge (Table 3-2, Figure 3-7), with the log-bias-corrected relationship being:

$$L_e = 1.82{\times}10^{-6}\ Q_{pk}^{1.78}$$

where L_e is event load (t), Q_{pk} is the peak discharge (l/s), $R^2 = 0.92$, and SFE = 1.62 (equating to ± 50%).

Figure 3-7 generally shows no seasonal differences in the relationship between event load and peak discharge, except perhaps for lower event loads in summer months (9 of 10 summer events plot on or under the regression line).

Table 3-2: Correlation of event sediment load with event hydrological indices, Waimapu at McCarrols. Correlation is Pearson's R on untransformed values. EI60 is rain erosivity.

Storm index	Correlation with event sediment load
Peak discharge	0.89
Quickflow runoff	0.87
Total runoff	0.84
Rain energy	0.73
EI60	0.57
Rainfall	0.74

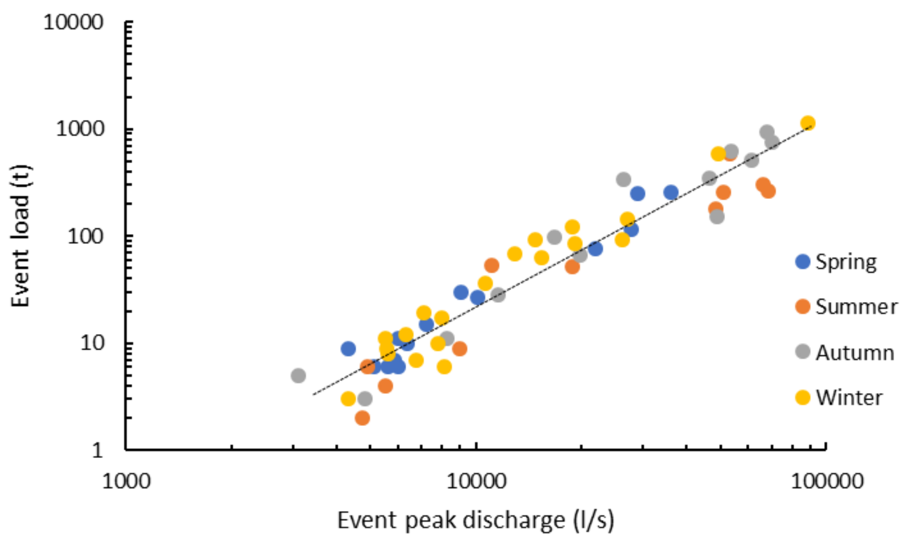

Figure 3-7: Event sediment load vs event peak discharge, Waimapu at McCarrols. Events identified by season. Dotted line is regression line (R^2 = 0.92).

3.5 Conclusions and recommendations for Waimapu site

From the above, I conclude reasonable sediment load results are obtained by using the water quality dataset to develop an interim calibration of the turbidity record. The main issues with the calibration are:

- it is focussed on a low turbidity range relative to that recorded
- it is based on a double-calibration between SSC and turbidity as measured in the water quality samples and between the time-lagged field turbidity and the matching water quality turbidity, and
- the associated uncertainties in the generated SSC record and the derived sediment loads are high (e.g., relative to those at the Kopurererua).

Additional uncertainty is added to the load estimates by:

- the higher proportion of gaps in the Waimapu record (16.4% compared with 0.7% at the Kopurererua)
- the issues with bank erosion and cattle at the site, which will be causing turbidity "surges" which (because they will not be fully mixed across the flow) will increase the apparent sediment load, and
- the sand component of the suspended load being underestimated because of mixing and sampling issues.

My recommendations are to:

- install an auto-sampler, with its intake beside the turbidity sensor, to collect turbidity-SSC calibration data over a wide range in turbidity (this site should take priority over the Kopurererua if auto-samplers are in limited supply)
- undertake a series of depth-integrated sediment gaugings (using the forthcoming NEMS procedures) to establish a relation between the bankside SSC at the sensor and the cross-section average SSC
- given the high sand content of the bed, with sediment gaugings undertake calculations of the "unmeasured load" (as described for Kopurererua), and
- consider installing a web-cam to record when cattle and eroding banks cause near-field turbidity plumes that corrupt the "background" turbidity record[19].

[19] By comparing high resolution photographic data of cattle in-stream activity with a downstream turbidity record, Terry et al. (2014) found that cattle presence coincided with signals in the turbidity record. They also found that structural damage to the channel banks by cattle activity was a contributor to SSC during non-cattle events.

4 Tuapiro Stream

4.1 Monitoring station and data

In Tuapiro Stream, which drains into the northwest corner of Tauranga Harbour, turbidity is monitored continuously at the Woodland Road site but there is no auto-sampler at the site and no depth-integrated sampling has been done. Woodland Road has a rated stage record (BOPRC site BR518499) since 23/11/2010. Before that, since 2/2/1984, discharge was recorded a short distance upstream at Farm Bridge, but the record contained many gaps up until March 1993. The Woodland Road record has relatively few gaps. For this study, I merged the two flow records, using the Farm bridge data since 1/1/1998 (to align with the long term flow records used for the Kopurererua and Waimapu analyses).

The Tuapiro turbidity sensor is an YSI Exosonde and was installed on 20/1/2016. An edited record was provided by BOPRC covering the period until 30/6/2018. Gaps spanned 14.4% of this edited record.

The upstream catchment area is 39.05 km^2, with most (notably the headwaters) covered in indigenous vegetation, with the rest in pasture and horticulture with minor exotic forest (Carter 2017).

I did not visit the Woodland Road site. Photographs in Carter (2017) show a cobble-bed[20] but do not inform on the stability of the bank upstream from the turbidity sensor.

Quasi-monthly water quality sampling has been carried out at Farm Bridge since November 2011, but only on a one-year-in-three rotational sampling regime. No significant tributaries enter between Farm Bridge and Woodland Road; thus the water quality samples may potentially be used to calibrate the turbidity record to SSC[21].

4.2 Relations between water quality SSC, turbidity, clarity and discharge

I examined the water quality dataset from Farm Bridge (58 observations) for relations between SSC, turbidity, clarity and discharge. Pearson correlation coefficients (R, Table) indicate the strength of the inter-relationships.

Table 4-1: Pearson correlation coefficients for turbidity, clarity, SSC, and discharge at Tuapiro at Farm Bridge. Red font gives R values for log-transformed data; black font gives R values for untransformed data.

	Discharge	SSC	Turbidity	Clarity
Discharge	1.00	0.29	0.38	-0.14
SSC	0.39	1.00	0.69	-0.42
Turbidity	0.26	0.93	1.00	-0.65
Clarity	0.18	0.21	0.46	1.00

[20] The cobble bed suggests that the Tuapiro's suspended load will have a lesser sand proportion compared with the Kopurererua and Waimapu, thus there may be less of a need there to estimate the "unmeasured" sand load – however, this should be confirmed from suspended sediment particle size analysis.

[21] As with the other two sites, the Tuapiro water quality samples have been analysed in the BOPRC laboratory using the TSS method but analysing the full sample, thus the TSS results equate to SSC results.

4.2.1 SSC – turbidity relationship

A moderate relationship is observed between SSC and turbidity across a turbidity range of 0.4 to 31 NTU (Figure 4-1, blue points). The untransformed data-scatter is homoscedastic, thus a linear regression function was fitted. This function is:

$$SSC = 1.39\ T_{wq}$$

where T_{wq} is the lab-measured turbidity from the water quality samples, $R^2 = 0.85$, and the standard error is ± 6.5 mg/l.

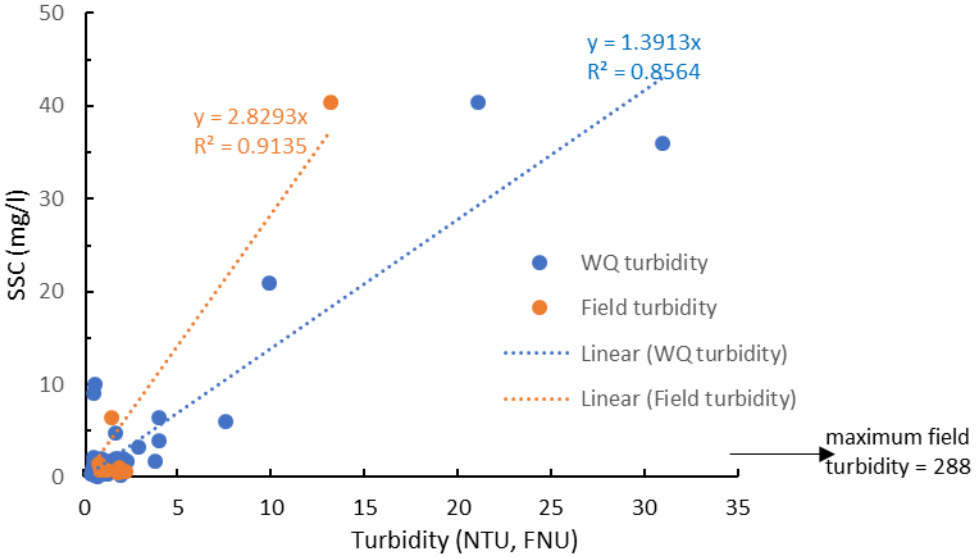

Figure 4-1: Relationships of water quality SSC with water quality turbidity at Farm Bridge and with field turbidity at Woodland Road. Orange points show water quality sampled SSC matched with field-recorded turbidity. Note that the field turbidity at Woodland Road ranges up to 288 FNU.

Twelve water quality SSC results were able to be matched with the field-recorded turbidity (T_{field}) at Woodland Road from March 2016. Figure 4-1 (orange points) shows these data mostly plotting within the scatter of the water quality sampled turbidity but the largest FNU value plots higher, indicating a steeper response to SSC:

$$SSC = 2.83\ T_{field}$$

where $R^2 = 0.91$ and the standard error is ± 3.8 mg/l, but the maximum T_{field} value is low at 13.2 FNU.

Figure 4-2 shows a good linear relation ($R^2 = 0.93$, standard error ±2.3 NTU) between the matched turbidity values from the water quality samples and the field record:

$$T_{wq} = 1.52\ T_{field}$$

Combining this with the SSC-T_{WQ} relation gives:

$$SSC = 2.11 T_{field}$$

which is similar to the relation obtained above directly from the field turbidity.

Because both direct and indirect relations for T_{field} have similar coefficients, are linear, and are based on a similar turbidity range, I recommend using the direct relation as an interim calibration of the Tuapiro field turbidity record to SSC. However, given the low range of calibrated turbidity compared with the observed range of the field record (i.e., 13 FNU compared with 288 FNU), there is an urgent need to collect calibration samples beside the sensor that span close to the full range of recorded turbidity.

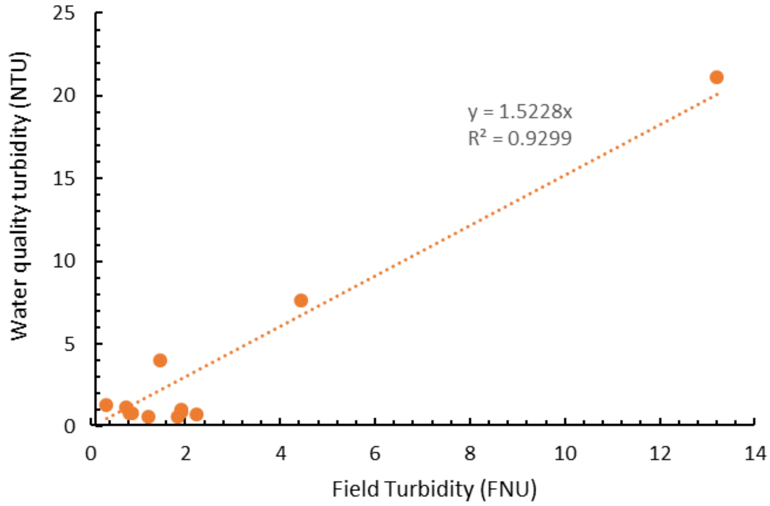

Figure 4-2: Water quality sample turbidity at Farm Bridge vs field-recorded turbidity at Woodland Road.

4.2.2 SSC - discharge relationship

Figure 4-3 shows the SSC-discharge sediment rating relationship for the Tuapiro water quality data. The relationship is poor (R^2 = 0.08); moreover, the majority of data points are at discharges less than the mean and all are well less than mean annual flood. Therefore, I consider it inadequate to estimate long term average loads.

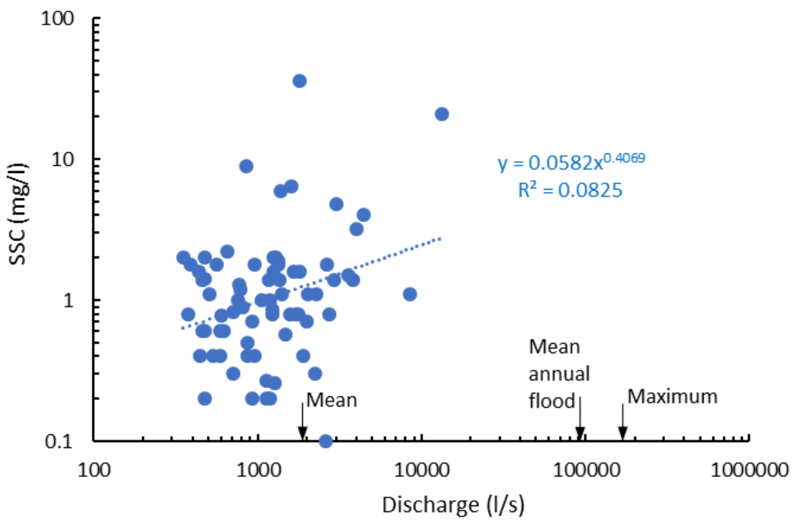

Figure 4-3: Sediment rating relationship from water quality data, Tuapiro at Farm Bridge. Mean discharge is 1908 l/s, mean annual flood is 91,845 l/s, and maximum recorded discharge is 159,120 l/s. Maximum sampled discharge is 13,279 l/s.

4.3 Sediment load results from turbidity record

The SSC = $2.83T_{field}$ calibration relation derived in Section 4.2.1 was applied to the Tuapiro field turbidity record to generate an SSC record. Without a sediment rating of adequate quality, gaps in the turbidity record were left unpatched. This SSC record was then combined with the discharge record to calculate loads.

4.3.1 Load over turbidity monitoring period

The turbidity-based load averaged over the period 20/1/2016 to 30/6/2018 (excluding the 14.5% of record that was gaps) was 1162 ± 58 t/y.

4.3.2 Load distribution between baseflow and events

Storm runoff events in the Tuapiro were separated from delayed flow and baseflow periods using a quickflow separation slope of 1000 l/s/day. This separation showed that 76% of the turbidity-based suspended load was transported during quickflow runoff events.

4.3.3 Event loads and relationships with runoff, rainfall, and season

Forty-eight events were identified with quickflow runoff exceeding 1 mm. The sediment loads for these events were related to runoff and rainfall indices as explained in Section 2.5.3. The detailed event results are listed in Appendix A.

The event loads correlated best (R=0.95) with event peak discharge (Table 4-2, Figure 4-4), with the log-bias-corrected relationship being:

$$L_e = 1.45\times10^{-5}\ Q_{pk}^{1.52}$$

where L_e is event load (t), Q_{pk} is the peak discharge (l/s), R^2 = 0.89, and SFE = 1.50 (equating to ± 42%).

Figure 4-4 generally shows no seasonal differences in the relationship between event load and peak discharge, except perhaps for higher event loads in spring months (all 6 spring events plot on or above the regression line).

Table 4-2: Correlation of event sediment load with event hydrological indices, Tuapiro at Woodland Road. Correlation is Pearson's R on untransformed values. EI60 is rain erosivity.

Storm index	Correlation with event sediment load
Peak discharge	0.95
Quickflow runoff	0.92
Total runoff	0.91
Rain energy	0.81
EI60	0.74
Rainfall	0.82

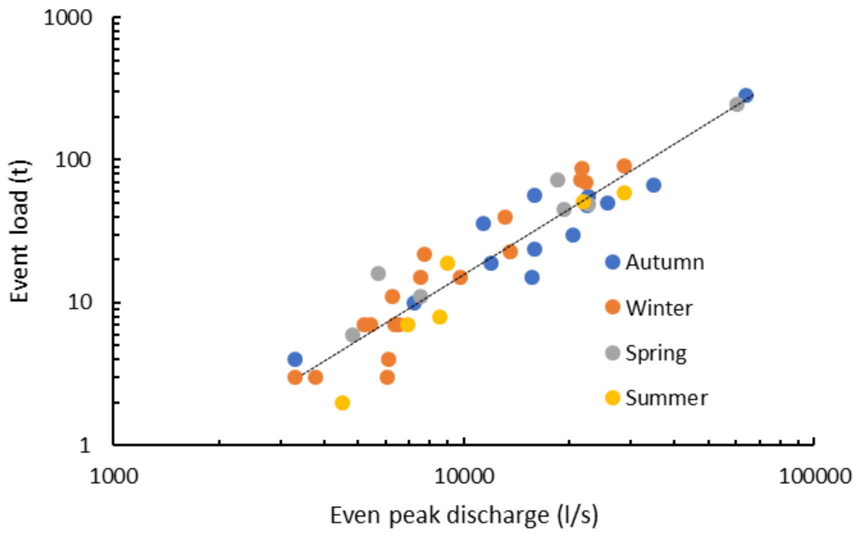

Figure 4-4: Event sediment load vs event peak discharge, Tuapiro at Woodland Road. Events identified by season. Dotted line is regression line (R^2 = 0.89).

4.4 Long-term average and annual loads from turbidity-based event rating

The event load rating against peak discharge was used with the discharge record to estimate the Tuapiro loads for the period 1998-2018, with a factor of 1.32 applied to adjust for load carried by delayed storm runoff and baseflows. The mean annual load so derived was 1701 ± 85 t/y (43.6 ± 2.2 t/km^2/y). The annual loads ranged over a factor of 5, between 630 and 3337 t (Figure 3-6).

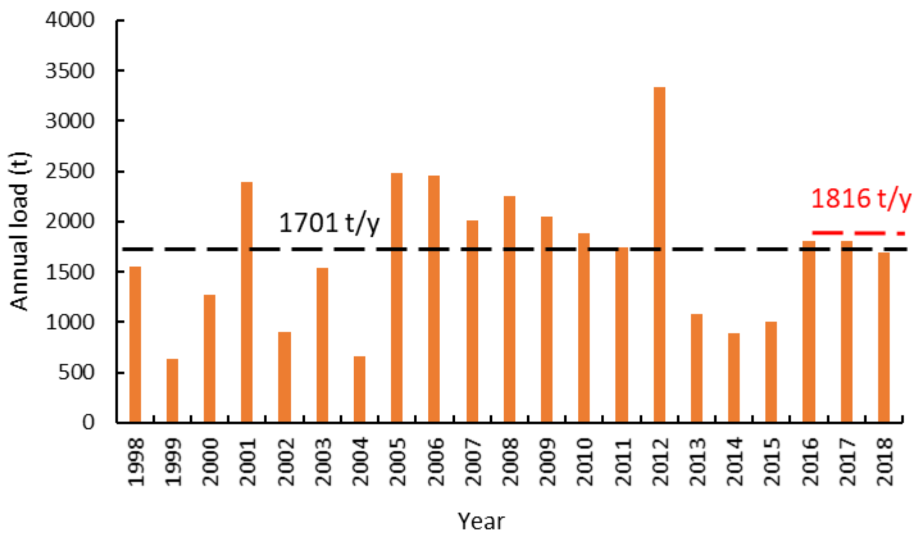

Figure 4-5: Annual Tuapiro suspended loads, 1998-2018, estimated using event sediment rating derived from turbidity data. Black dashed line shows mean annual load over 1998-2018. Red dashed line shows mean annual load calculated with event rating over period 1/7/2016 – 28/2/2019.

Applying the event load rating to the period 1/7/2016 – 28/2/2019 (to align with the turbidity record period analysed for the Kopurererua and Waimapu), and adjusting to include delayed flow loads, gives an average Tuapiro load for this period of 1816 ± 182 t/y (equating to 46.5 ± 4.7 t/km^2/y).

In comparison, the turbidity-based Kopurererua load over 1/7/2016 to 28/2/2019 was 49 ± 1 t/km^2/y – which is not significantly different.

4.5 Conclusions and recommendations for Tuapiro site

From the above, I conclude moderate-quality sediment load estimates are obtained by using the water quality dataset to develop an interim calibration of the Tuapiro turbidity record. The main issues with the calibration and derived load estimates are:

- the calibration dataset is focussed on a very low turbidity range relative to that recorded (calibrated to 13 FNU but record ranges up to 288 FNU), which means that the calibration has had to be extrapolated, resulting in potentially large but unquantified uncertainty in the derived sediment loads, and
- there is a significant proportion of gaps in the Tuapiro turbidity record (14.5% compared with 0.7% at the Kopurererua).

The instantaneous SSC-discharge relationship shown by the Tuapiro water quality data is too poor to warrant its use to estimate long-term loads, but the event load vs peak discharge rating developed from the relatively short turbidity record is adequate for this purpose.

My recommendations are to:

- stay “on top” of monitoring the turbidity sensor record and data editing, to minimise record gaps
- install an auto-sampler, with its intake beside the turbidity sensor, to collect turbidity-SSC calibration data over a wide range in turbidity (again, if auto-samplers are in limited supply this site should take priority over the Kopurererua since that is now well calibrated)
- undertake a series of depth-integrated sediment gaugings (using the forthcoming NEMS procedures) to establish a relation between the bankside SSC at the sensor and the cross-section average SSC, and
- a selection of the depth-integrated sediment samples should also be analysed for particle-size grading to establish the sand component, but the clean cobble bed at the site suggests that calculations of the “unmeasured load” should not be necessary.

5 Similarities/differences in the turbidity response to rainfall events

5.1 Phasing of sediment delivery during events

An interesting difference emerges when the phasing of the sediment load and average SSC is compared. Figure 5-1 shows that at the Kopurererua, rising stages transport the majority of the total event load during most events, and the average SSC on rising stages was greater than the average SSC on the subsequent falling stage for all but one event[22]. In contrast, at the Waimapu, falling stages transported the majority of the load of most events, while average SSC ratios did not particularly favour either rising or falling stages. The Tuapiro data pattern was in between the other two: with rising stages and falling stages sharing the dominance of the sediment load but with rising stages more often having higher average SSC.

A possible explanation for this varying behaviour is indicated by the event runoff ratios, since Figure 5-2 shows that Kopurererua events have the lowest runoff ratios (i.e., event quickflow runoff compared with event rainfall)[23]. Less (or at least delayed) runoff would lead to higher rising stage SSC at Kopurererua. The runoff ratio will most likely be reflecting catchment lithology.

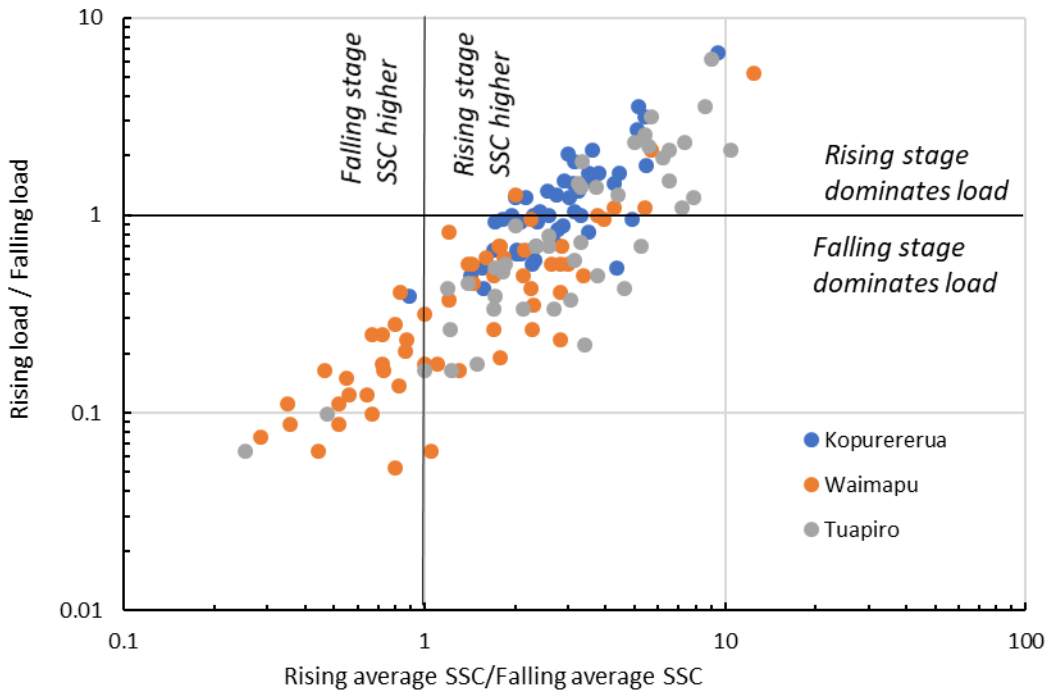

Figure 5-1: Sediment load and average SSC ratios for rising and falling stages of runoff events at Kopurererua, Waimapu, and Tuapiro turbidity sites. Events with Rising load / Falling load ratios > 1 have most of their sediment load transported before the discharge peak. Events with the ratio Rising average SSC / Falling average SSC> 1 have higher average SSCs being the discharge peak.

[22] This was for the relatively small event of 21-23/1/2017 – see Appendix A.
[23] The quickflow runoff ratios averaged over all events are 0.11, 0.25, and 0.23 for Kopurererua, Waimapu, and Tuapiro, respectively.

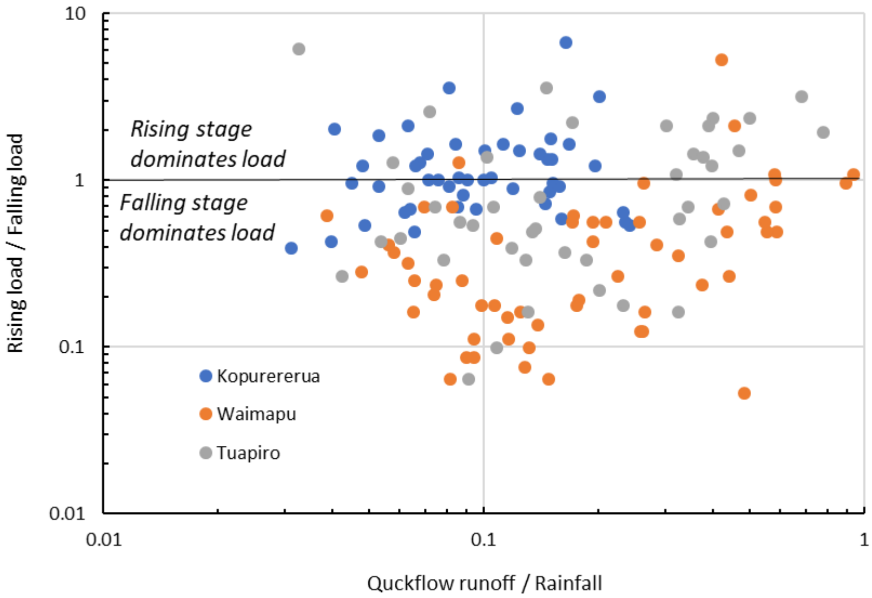

Figure 5-2: Sediment load ratio for rising and falling stages vs runoff ratio for events at Kopurererua, Waimapu, and Tuapiro turbidity sites. Runoff ratio is the ratio of event quickflow runoff to event rainfall.

5.2 Event sediment loads and rainfall

Figure 5-3 shows the relationship between event specific load and rainfall energy for the three sites. The sites plot in similar space, albeit with considerable scatter. This scatter likely reflects the rain gauges not representing the overall catchment rainfall and the effect of antecedent conditions (i.e., causing varying runoff and erosion responses to a given rainfall).

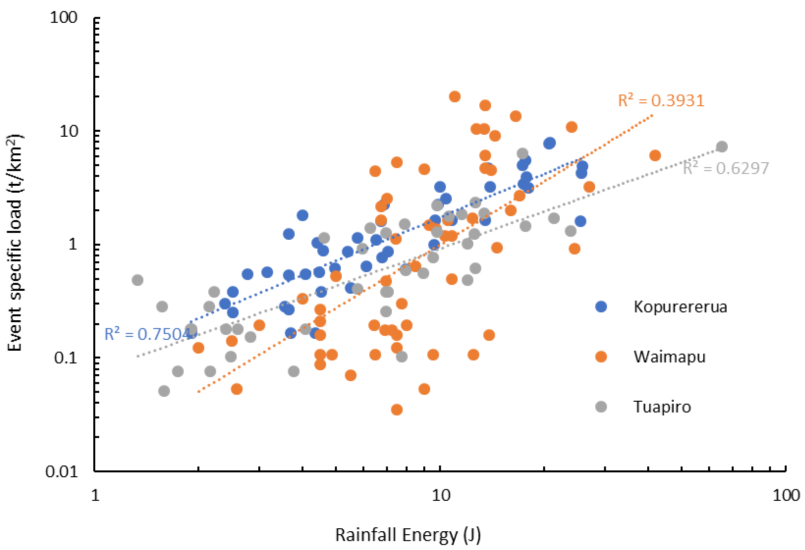

Figure 5-3: Specific sediment loads and rainfall energy for events at Kopurererua, Waimapu, and Tuapiro turbidity sites. Dotted lines show regression-fitted power functions.

6 General recommendations on monitoring methodologies

6.1 Turbidity data collection and editing

- YSI-Exosonde turbidity sensors have a good reputation for reliability and consistent behaviour amongst instruments[24], so they should continue to be used as SSC-proxy sensors at the BOPRC sites.
- Sensors should be installed where there is minimal risk that the turbidity of the water flowing past them is being affected by unmixed plumes from local upstream sediment sources (notably eroding banks, wading stock, and drains/tributary outlets).
- To minimise record gaps, the turbidity data quality should be checked at least weekly, ideally daily, via telemetry.
- The AQUARIUS hydrological software has an excellent set of graphical editing tools for "cleaning-up" turbidity records (e.g., removing electronic or debris-fouling "spikes", removing spans of data ruined by biofouling, or bridging turbidity pulses known to be caused by factors such as eroding nearby banks or wading stock). Such editing should be done regularly and kept reasonably up-to-date (i.e., time lag of months, not years).

6.2 Turbidity sensor calibration to SSC

- While use can be made of water quality samples to develop interim sensor calibrations with SSC (as done herein for the Waimapu and Tuapiro), water quality datasets are typically compiled at baseflows and so tend not to cover the full range of turbidity observed at the site, which leads to extrapolation errors over the observed range; moreover, the samples may not be collected close to the turbidity sensor and so may not be representative of the SSC being monitored.
- The recommended approach is to install an auto-sampler to collect samples during runoff events beside the turbidity sensor. This sampling should continue until most of the monitored turbidity range has been well sampled, or at least the turbidity range that carries the bulk of the suspended sediment load has been well sampled (e.g., Figure 2-8), and there is no sign after at least a year of temporal drift in the turbidity-SSC relation (e.g., Figure 2-9).
- An alternative is to directly relate the measured turbidity to the cross-section average SSC determined from sediment gauging; however, with this strategy it is often a challenge to acquire an adequate number and range of data in a timely way.
- Note that if the sensor fails and is replaced by another, it is good practice to recalibrate the new sensor with more auto-samples. This is because different sensors may respond differently to natural sediment mixtures, even when calibrated to Formazin and meeting the same measurement protocol (e.g., ISO 7027)[24].

[24] Recent checks at NIWA (Hughes et al. 2019) with a selection of ISO 7027 compliant turbidity sensors showed that the ExoSonde units were the only tested sensors that produced statistically indistinguishable outputs for natural sediment mixtures and could be considered truly 'interchangeable'.

6.3 Determining the cross-section average sediment load

- For all sediment monitoring sites calibrated with point-samples (e.g., from an auto-sampler), a series of sediment gaugings with depth-integrated samplers at multiple verticals (using NEMS procedures) should be done to establish a relationship between the auto-sampled SSC and the cross-section average SSC. Given the field evidence of a high sand load (e.g., sand drifts in pools, sandy bedforms, sand deposits on banks) in the Kopurererua and Waimapu, it is likely that the cross-section average load will be substantially higher than the load indicated by the point-calibrated turbidity record. The sand component of the depth-integrated samples should also be measured either by splitting the samples through a 63 micron sieve prior to filtering or else by doing a full-range particle-size grading[25].

- For the sand-rich streams like the Kopurererua and Waimapu, the "unmeasured", near-bed sand load should also be measured, particularly if a sediment monitoring objective is to measure the total sediment discharge into Tauranga Harbour.

- Consideration should also be given to using acoustic backscatter (ABS) as a proxy for SSC in the sand-rich rivers. Acoustic instruments like Sequoia's LISST-ABS are more responsive to sand grade sediment, whereas optical backscatter (OBS) turbidity sensors are most responsive to clay and fine silt (Figure 6-1).

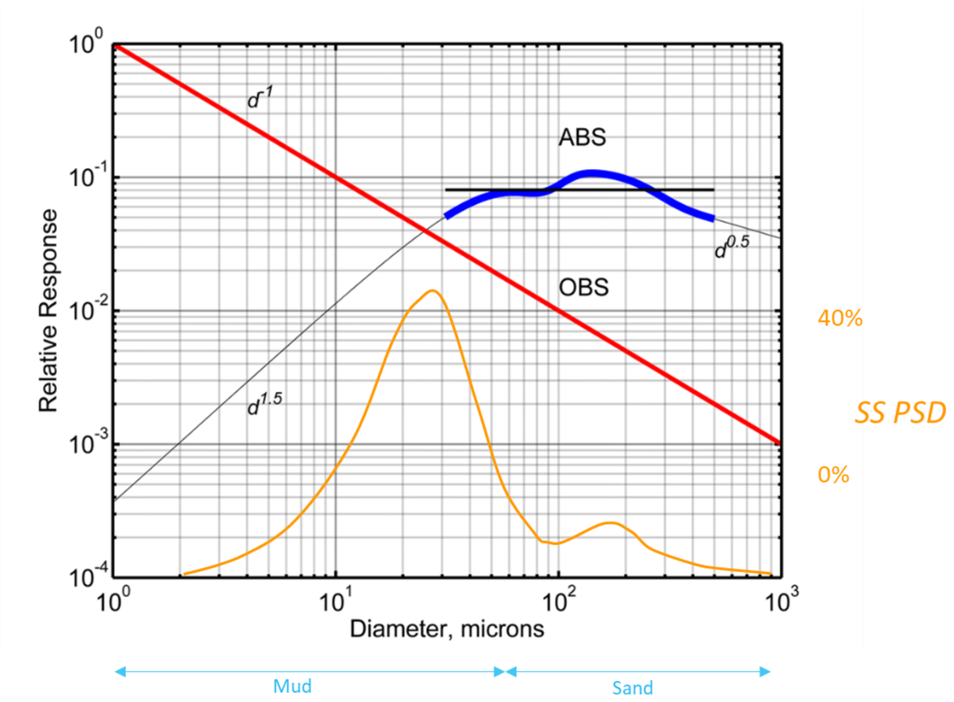

Figure 6-1: Relative response of optical backscatter (OBS) and acoustic backscatter (ABS) instruments for different sediment sizes. OBS sensor response is maximal for fine mud and declines inversely with grain diameter, while ABS response is approximately flat across the coarse-silt to sand range (30-500 microns). Orange curve shows a typical suspended sediment particle size distribution (SS PSD) for New Zealand rivers.

[25] As an indication, depth-integrated/multi-vertical samples from five central North Island rivers (Waihohonu, Waiotapu, Manganui, Punehu, Upper Whanganui) draining ash/ignimbrite terrain averaged 57% sand (the author, unpublished data).

6.4 Using different analysis approaches for different sediment load objectives

- If the monitoring objective is simply to estimate a long-term average suspended load, then a rating-curve based approach is expedient. Options include rating instantaneous SSC to discharge or rating event sediment load (as determined by turbidity monitoring) to event hydrological magnitude (peak discharge typically correlates best). Applying such ratings to a long-term discharge record enables inter-annual variability to be averaged out.
- If the objective is to determine sediment loads at higher temporal resolution (e.g., for discrete events or years), then high-frequency SSC-proxy monitoring or auto-sampling is best (since shorter-term load estimates from ratings typically carry high uncertainty).

7 Utility of monitoring to NPS-FM

Towards managing sediment under the National Policy Statement for Freshwater Management (NPS-FM), the Ministry for the Environment (MfE) are currently considering what limits might practically be applied to fine sediment-related attributes of streams and rivers, including median turbidity, median visual clarity, and average % streambed cover by fine sediment (i.e., finer than 2 mm). The thinking is that sediment loads will need to be reduced in waterways where these limits are exceeded.

Assuming that this MfE initiative progresses to an operational stage, BOPRC's current suspended sediment programme will assist in several ways:

- By precisely defining the temporal median clarity in the lower reaches of Kopurererua, Waimapu, and Tuapiro streams, for comparison against what thresholds MfE may decide upon. Based on the current turbidity records, these median values are 8.3, 1.9, and 1.2 FNU, respectively[26].
- If future sediment loads need reducing to achieve the sediment attribute limits, then the loads calculated from the turbidity monitoring will inform on how much they need to be reduced by and will thereafter demonstrate compliance.
- The high-frequency data on turbidity and loads will also inform on sediment source locations (e.g., by comparing the phasing of the sediment load and water runoff). This will be particularly valuable if combined with sediment tracing techniques that analyse the source of sediment in auto-samples collected through events. See Hughes et al. (2013) for advice on the complementary use of radionuclide sediment source tracing and sediment load monitoring in the Tauranga Moana catchments; also, see Hughes and Hoyle (2014) for results from using radionuclide tracing to investigate the importance of bank erosion as a source of the suspended load in the Kopurererua Catchment.

[26] The median values from the monthly but "gappy" water quality database, measured with laboratory instruments, are 5.9, 1.9. and 1.0 NTU for Kopurererua, Waimapu, and Tuapiro, respectively.

8 Conclusions

The main site-by-site conclusions are:

- At Kopurererua Stream at SH29, a good turbidity record has been collected since mid-2016, and a good, stable, fit-for-purpose calibration to auto-sampled SSC has been developed which enables sediment load determination to high precision. However, it is likely that these loads are significantly under-estimating the total sediment load into Tauranga Harbour because of non-uniform mixing of the suspended load over the cross-section.
- At Waimapu Stream at McCarrols, reasonable sediment load results are obtained by using the water quality dataset to develop an interim calibration of the turbidity record. However, the precision and accuracy of these are limited by the low range of turbidity that has been calibrated to SSC, a relatively high proportion of gaps in the edited turbidity record, and the sand component of the suspended load being underestimated because of mixing and sampling issues. The site also has probable issues with bank-side turbidity plumes caused by eroding upstream banks and wading cattle.
- At Tuapiro Stream at Woodland Road, moderate-quality sediment load estimates are obtained by using the water quality dataset to develop an interim calibration of the Tuapiro turbidity record. Again, however, the main issues with the calibration and derived load estimates are that the calibration dataset is focussed on a very low turbidity range relative to that recorded, there is a significant proportion of gaps in the turbidity record, and there is no information on sediment mixing over the cross-section.

The main recommendations on monitoring methodologies include:

- Continue using YSI-Exosonde turbidity sensors as SSC-proxy sensors at the BOPRC sites, taking care to avoid measuring unmixed sediment plumes from near-field sources, keeping a close watch on the quality of record using telemetry, and keeping up-to-date with data editing.
- Consider also using acoustic backscatter (ABS) as a proxy for SSC in the sand-rich Kopurererua and Waimapu Streams.
- Install auto-samplers to event-sample beside the Waimapu and Tuapiro turbidity sensors to calibrate these sensors to SSC over the full range of observed turbidity. These should take priority over the Kopurererua site, where the sensor is well calibrated to SSC.
- Establish a relationship between the auto-sampled point SSC beside the turbidity sensor and the cross-section average SSC at all sites by undertaking a series of sediment gaugings with depth-integrated samplers at multiple verticals (using NEMS procedures) during runoff events. Ideally, these samples should also be analysed for particle size grading, but if not a full size grading then at least the sand/mud proportions should be determined.

- Estimate the “unmeasured”, near-bed sand load at the Kopurererua and Waimapu sites using the “Modified Einstein” procedure in association with the suspended sediment gaugings. If not, then the total fine sediment delivered to Tauranga Harbour will likely be under-estimated.
- Consider different analysis approaches for different sediment load objectives. Sediment ratings are suitable for estimating the long-term average load while the more precise high-frequency SSC-proxy monitoring is best for measuring event and annual loads.
- Maintain the turbidity monitoring to assist implementation of likely forthcoming, NPS-FM related, limits on turbidity and water clarity by defining the turbidity state and informing on sediment loads and their sources.

9 Acknowledgments

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Appendix A Event results from Kopurererua, Waimapu, and Tuapiro turbidity data

Kopurererua events:

Start date & time	End date & time	Season	Peak discharge (l/s)	Quickflow runoff (mm)	Tot runoff (mm)	Event load (t)	Event load std error (t)	% load on rising stages	SSC at start (mg/l)	SSC at end (mg/l)	Peak SSC (mg/)	Average falling stage SSC (mg/l)	Average rising stage SSC (mg/l)	Time to flow peak (hr)	Time to SSC peak (hr)	Rainfall (mm)	Rain energy (J)	I60max (mm/h)	EI60
14/07/2016 0:20	16/07/2016 10:50	Winter	6605	6.61	9.91	66	9	51	12	51	382	174	55	16	13	50	6.54	10.5	68.6
23/07/2016 1:20	25/07/2016 12:40	Winter	5394	5.39	9.79	52	8	41	14	44	284	125	53	16	14	45	5.41	8.5	46.0
24/08/2016 12:20	27/08/2016 15:40	Winter	3586	3.59	9.54	38	5	49	9	38	211	62	34	41	40	56	6.10	4.5	27.5
17/09/2016 9:50	19/09/2016 9:20	Spring	3395	3.40	5.96	17	3	35	12	28	145	50	32	17	15	33	3.55	4.5	16.0
20/09/2016 15:25	23/09/2016 21:10	Spring	3345	3.35	10.93	34	5	33	16	44	113	50	35	29	36	45	4.46	4.0	17.8
24/09/2016 22:25	26/09/2016 17:25	Spring	2967	2.97	6.35	16	2	30	29	30	103	47	30	12	9	36	3.65	4.0	14.6
28/09/2016 22:15	1/10/2016 0:10	Spring	6363	6.36	10.19	74	9	59	22	51	355	156	50	22	20	34	3.65	6.5	23.7
7/11/2016 3:30	9/11/2016 1:00	Spring	4540	4.54	6.79	37	5	59	8	21	401	159	37	14	12	36	4.95	9.7	48.0
21/01/2017 23:55	23/01/2017 7:45	Summer	3083	3.08	3.49	10	2	28	10	21	157	31	35	14	16	37	4.36	5.5	24.0
16/02/2017 7:50	20/02/2017 20:50	Summer	5253	5.25	21.91	96	14	68	17	37	298	83	23	63	46	190	25.38	14.6	371.0
7/03/2017 11:05	10/03/2017 18:25	Autumn	6747	6.75	14.81	60	9	40	11	37	278	83	41	28	22	79	9.61	8.0	76.9
10/03/2017 19:10	14/03/2017 14:55	Autumn	13945	13.95	33.78	253	35	42	37	52	532	197	73	20	5	155	25.62	24.0	614.8
27/03/2017 0:10	31/03/2017 20:05	Autumn	7778	7.78	29.52	192	29	87	20	39	1764	132	14	79	7	104	13.93	13.5	188.0
4/04/2017 6:15	8/04/2017 18:40	Autumn	16339	16.34	41.91	294	43	37	22	65	294	170	73	29	19	178	25.82	14.4	372.3
12/04/2017 8:50	16/04/2017 17:55	Autumn	24167	24.17	39.13	333	37	55	36	50	547	194	64	41	35	124	17.67	16.5	291.3
29/04/2017 10:10	1/05/2017 8:10	Autumn	5175	5.18	7.44	33	4	56	16	24	334	91	33	22	19	32	4.06	10.8	43.9
11/05/2017 1:00	14/05/2017 18:05	Autumn	10040	10.04	20.20	153	16	60	10	31	655	178	51	44	36	78	10.42	12.4	128.7
17/05/2017 6:35	19/05/2017 0:20	Autumn	4643	4.64	7.12	34	5	62	18	55	315	109	31	20	11	23	3.16	10.8	34.2
26/05/2017 23:20	30/05/2017 13:45	Autumn	19735	19.74	27.34	462	37	49	11	42	1415	715	146	15	12	110	20.65	41.7	861.5
22/06/2017 4:50	25/06/2017 0:30	Winter	3970	3.97	11.02	46	6	48	12	26	194	62	36	38	43	62	6.79	6.7	45.7
1/07/2017 6:35	3/07/2017 23:10	Winter	6625	6.63	11.30	62	8	51	13	26	335	109	45	31	27	38	4.40	9.3	41.0

Start date & time	End date & time	Season	Peak discharge (l/s)	Quickflow runoff (mm)	Tot runoff (mm)	Event load (t)	Event load std error (t)	% load on rising stages	SSC at start (mg/l)	SSC at end (mg/l)	Peak SSC (mg/)	Average falling stage SSC (mg/l)	Average rising stage SSC (mg/l)	Time to flow peak (hr)	Time to SSC peak (hr)	Rainfall (mm)	Rain energy (J)	I60max (mm/h)	EI60
20/07/2017 11:05	23/07/2017 0:05	Winter	7182	7.18	12.06	53	7	47	11	23	242	113	39	19	16	41	4.59	6.7	30.9
27/07/2017 10:20	28/07/2017 18:20	Winter	3809	3.81	4.76	18	2	55	12	27	152	61	28	19	17	17	2.38	7.8	18.5
8/08/2017 22:15	11/08/2017 16:45	Winter	7787	7.79	14.87	69	10	57	12	24	226	107	33	25	16	47	5.77	10.3	59.6
27/08/2017 21:50	1/09/2017 18:05	Winter	19524	19.52	33.89	298	32	46	11	28	529	219	79	29	29	125	17.34	13.4	233.1
2/09/2017 3:05	4/09/2017 7:10	Spring	8732	8.73	15.79	134	14	64	24	38	606	285	52	15	10	51	6.90	12.4	85.6
21/09/2017 6:20	22/09/2017 23:45	Spring	4851	4.85	7.75	33	5	50	27	32	297	83	36	17	15	24	2.76	5.0	13.8
7/10/2017 22:05	10/10/2017 20:55	Spring	8054	8.05	20.28	134	20	73	13	29	392	153	30	34	22	83	9.87	9.0	88.7
27/10/2017 2:35	30/10/2017 12:00	Spring	3895	3.90	13.17	36	5	67	17	30	112	45	15	57	42	72	7.97	7.0	55.6
8/11/2017 5:55	9/11/2017 9:20	Spring	3800	3.80	4.41	10	1	48	16	17	87	42	20	12	10	14	1.90	9.5	18.2
4/01/2018 4:20	7/01/2018 18:30	Summer	10193	10.19	22.46	97	14	62	10	22	492	124	28	29	18	98	13.46	12.7	171.3
1/02/2018 16:00	7/02/2018 13:10	Summer	8701	8.70	40.42	205	83	35	14	40	807	240	55	17	9	93	17.44	27.0	471.0
9/02/2018 5:40	15/02/2018 23:15	Summer	18712	18.71	46.23	233	32	48	16	42	337	104	44	77	74	142	17.72	14.0	248.0
12/03/2018 9:05	14/03/2018 16:00	Autumn	4926	4.93	9.78	25	4	39	11	17	127	53	26	18	13	41	5.50	8.0	44.0
28/04/2018 4:45	2/05/2018 21:40	Autumn	33463	33.46	50.78	468	55	36	10	29	682	224	98	35	34	147	20.79	13.5	280.7
15/05/2018 9:45	18/05/2018 0:00	Autumn	6499	6.50	14.62	97	12	45	18	29	705	215	61	11	3	60	9.68	17.0	164.5
3/06/2018 2:50	7/06/2018 19:05	Winter	14007	14.01	40.04	281	35	76	24	36	453	152	28	59	22	110	13.80	11.0	151.8
13/07/2018 13:55	17/07/2018 23:20	Winter	9577	9.58	24.04	95	14	57	13	23	198	72	28	64	57	61	6.74	7.0	47.2
4/08/2018 11:35	6/08/2018 21:45	Winter	3206	3.21	9.24	15	2	55	14	21	64	24	12	38	50	26	2.51	4.0	10.0
13/08/2018 6:20	15/08/2018 15:05	Winter	4158	4.16	9.31	23	3	50	17	20	149	41	21	31	30	21	2.51	6.9	17.4
29/08/2018 4:30	1/09/2018 4:55	Winter	5128	5.13	14.67	52	8	78	12	23	151	67	13	50	10	59	7.05	7.4	52.3
12/11/2018 17:50	14/11/2018 9:30	Spring	6807	6.81	8.06	108	7	50	10	33	833	293	113	15	14	31	4.00	7.5	30.0
24/11/2018 5:45	27/11/2018 21:20	Spring	7300	7.30	19.81	98	12	60	17	23	448	96	33	45	44	79	10.80	16.0	172.9
1/12/2018 2:50	5/12/2018 23:20	Summer	13090	13.09	38.14	191	27	39	18	26	431	107	51	32	32	88	10.01	7.5	75.1
14/12/2018 21:00	16/12/2018 14:45	Summer	5029	5.03	8.38	32	5	50	15	17	264	106	32	11	8	28	3.65	7.5	27.3
19/12/2018 21:55	22/12/2018 3:45	Summer	4223	4.22	10.03	23	3	40	16	22	165	39	23	21	18	37	4.54	6.5	29.5
23/12/2018 21:05	28/12/2018 1:10	Summer	18693	18.69	37.77	187	24	62	22	29	347	122	32	37	33	129	18.05	13.5	243.7
22/02/2019 2:55	24/02/2019 3:10	Summer	3481	3.48	8.52	10	1	65	13	12	29	22	7	28	6	35	3.69	5.0	18.4

Waimapu at McCarrols events:

Start date & time	End date & time	Season	Peak discharge (l/s)	Quickflow runoff (mm)	Tot runoff (mm)	Event load (t)	Event load std error (t)	% load on rising stages	SSC at start (mg/l)	SSC at end (mg/l)	Peak SSC (mg/)	Average falling stage SSC (mg/l)	Average rising stage SSC (mg/l)	Time to flow peak (hr)	Time to SSC peak (hr)	Rainfall (mm)	Rain energy (J)	I60max (mm/h)	EI60
7/03/2017 17:35	17/03/2017 5:55	Autumn	53789	106.43	141.50	619	460	68	4	6	465	142	25	91	80	233	35.23	24.0	845.5
24/03/2017 3:05	24/03/2017 22:30	Autumn	4809	1.12	3.69	3	2	22	8	26	28	8	10	7	19	23.5	3.33	9.0	30.0
26/03/2017 5:10	3/04/2017 3:15	Autumn	26401	48.22	85.62	342	276	21	5	34	500	128	56	31	30	109.5	14.45	13.5	195.1
4/04/2017 6:10	10/04/2017 5:55	Autumn	61469	103.37	146.39	516	361	52	29	7	263	128	30	28	20	177.675	25.82	14.4	372.3
12/04/2017 9:00	18/04/2017 1:55	Autumn	70278	79.99	128.86	761	563	33	12	18	618	119	70	35	35	144.715	21.02	16.5	346.4
29/04/2017 14:30	1/05/2017 4:35	Autumn	11575	3.68	10.42	28	25	13	8	17	201	23	42	12	12	31.93	4.02	10.8	43.5
12/05/2017 1:10	16/05/2017 8:00	Autumn	16743	18.30	36.48	97	71	36	7	10	231	90	30	13	13	71.585	9.73	12.4	120.2
17/05/2017 7:00	19/05/2017 10:05	Autumn	19885	6.04	17.88	67	60	11	10	11	259	33	59	12	14	23.175	3.16	10.8	34.2
26/05/2017 22:55	1/06/2017 16:50	Autumn	46311	41.76	72.84	343	429	19	7	28	308	192	68	9	9	111.25	20.74	41.7	865.3
12/03/2018 13:20	14/03/2018 3:35	Autumn	8291	3.04	7.21	11	9	17	4	8	80	19	22	10	9	41	5.50	8.0	44.0
28/04/2018 13:35	5/05/2018 0:35	Autumn	67739	86.24	106.20	947	1063	33	7	19	452	226	106	22	22	146.5	20.79	13.5	280.7
12/05/2018 11:50	13/05/2018 22:10	Autumn	3119	1.07	5.72	5	6	38	12	15	20	16	10	14	14	27.5	2.98	4.5	13.4
15/05/2018 9:35	18/05/2018 22:35	Autumn	48657	17.10	30.49	154	177	29	12	19	323	179	63	6	6	60	9.68	17.0	164.5
17/09/2016 10:10	19/09/2016 16:30	Spring	7233	4.33	10.14	15	14	9	3	7	57	16	24	8	13	33	3.55	4.5	16.0
20/09/2016 18:05	3/10/2016 4:10	Spring	28870	63.43	132.69	252	178	45	4	9	559	23	19	209	209	126.5	12.92	6.5	84.0
6/10/2016 8:45	7/10/2016 13:15	Spring	5586	1.24	8.80	6	4	56	6	11	18	10	5	18	13	14.5	1.51	4.5	6.8
7/11/2016 3:25	8/11/2016 14:20	Spring	21982	7.03	10.86	77	58	30	3	11	389	198	88	5	4	36.375	4.95	9.7	48.0
15/11/2016 7:40	18/11/2016 3:15	Spring	5125	2.66	10.85	6	5	6	3	4	23	4	9	10	20	32.495	3.31	4.9	16.1
13/09/2017 21:50	14/09/2017 20:45	Spring	6346	1.75	6.30	10	9	8	9	18	107	14	27	4	19	18.612	2.35	7.2	17.0
21/09/2017 7:40	23/09/2017 3:10	Spring	9031	3.36	11.84	30	28	12	19	21	85	32	39	8	8	24.204	2.76	5.0	13.8
7/10/2017 21:00	14/10/2017 9:15	Spring	35930	47.78	80.64	260	265	36	15	13	238	105	37	27	27	87.325	10.29	9.0	92.4
28/10/2017 2:20	31/10/2017 9:00	Spring	10137	8.21	22.45	27	19	38	10	6	73	24	13	28	28	47.904	5.43	7.0	37.9
8/11/2017 2:20	9/11/2017 4:00	Spring	6009	1.58	4.67	6	5	10	4	24	45	7	20	9	9	13.635	1.90	9.5	18.2
2/09/2018 3:30	3/09/2018 13:30	Spring	5989	1.76	8.29	11	7	41	8	10	74	23	13	13	13	25.245	2.99	6.4	19.2
11/10/2018 17:20	13/10/2018 16:15	Spring	4337	3.21	7.16	9	8	14	4	12	77	26	20	6	6	49.005	6.68	13.9	92.6

Start date & time	End date & time	Season	Peak discharge (l/s)	Quickflow runoff (mm)	Tot runoff (mm)	Event load (t)	Event load std error (t)	% load on rising stages	SSC at start (mg/l)	SSC at end (mg/l)	Peak SSC (mg/)	Average falling stage SSC (mg/l)	Average rising stage SSC (mg/l)	Time to flow peak (hr)	Time to SSC peak (hr)	Rainfall (mm)	Rain energy (J)	I60max (mm/h)	EI60
12/11/2018 18:15	14/11/2018 5:00	Spring	5858	2.32	4.51	7	6	19	4	12	120	20	23	9	13	31	4.00	7.5	30.0
24/11/2018 6:05	28/11/2018 3:50	Spring	27842	15.26	23.46	114	83	36	5	5	442	79	55	40	40	79	10.80	16.0	172.9
23/12/2016 4:25	23/12/2016 22:10	Summer	4731	1.31	2.65	2	2	8	3	19	30	5	14	5	6	14.5	1.84	7.5	13.8
21/01/2017 23:40	23/01/2017 4:45	Summer	5531	2.31	4.14	4	3	24	2	11	31	12	12	9	9	36.5	4.36	5.5	24.0
16/02/2017 6:35	21/02/2017 5:30	Summer	11076	20.57	31.55	53	39	31	2	4	138	29	20	44	44	190.0435	25.38	14.6	371.0
18/12/2017 18:10	19/12/2017 14:05	Summer	18803	3.01	4.59	52	45	15	4	33	503	172	172	3	3	30.4515	6.24	24.5	153.2
3/01/2018 7:45	8/01/2018 14:00	Summer	53141	46.18	60.80	593	501	84	6	6	852	349	28	43	38	109.5345	14.57	12.7	185.4
1/02/2018 14:15	4/02/2018 18:10	Summer	48397	19.33	27.12	181	132	36	4	6	373	201	76	12	11	92.5	17.40	27.0	469.8
9/02/2018 6:00	18/02/2018 4:45	Summer	51146	82.38	122.59	254	181	41	6	6	227	63	22	71	70	141.5	17.72	14.0	248.0
1/12/2018 2:20	7/12/2018 22:00	Summer	66259	86.86	113.38	301	211	52	4	6	233	119	22	18	17	93	10.49	7.5	78.7
14/12/2018 21:00	16/12/2018 10:00	Summer	8965	3.42	8.79	9	7	14	4	7	43	11	15	6	9	27.5	3.65	7.5	27.3
19/12/2018 23:50	21/12/2018 12:20	Summer	4901	2.43	7.64	6	5	20	5	10	31	8	11	12	19	37	4.54	6.5	29.5
23/12/2018 20:55	30/12/2018 4:45	Summer	68560	78.05	107.01	267	187	50	5	6	215	83	22	30	31	134	18.54	13.5	250.3
8/07/2016 0:05	9/07/2016 7:20	Winter	6755	2.51	7.55	7	6	14	3	8	43	7	15	10	15	9.5	0.89	2.0	1.8
13/07/2016 22:55	17/07/2016 1:55	Winter	26255	11.11	22.11	92	74	21	2	5	266	99	58	10	10	49.5	6.54	10.5	68.6
22/07/2016 22:45	27/07/2016 12:20	Winter	10620	9.41	27.48	36	33	6	2	5	96	22	21	9	9	63.5	7.61	8.5	64.6
28/07/2016 10:35	30/07/2016 0:30	Winter	5586	1.73	9.88	8	8	7	3	7	38	4	14	10	17	13.5	1.30	2.5	3.2
24/08/2016 19:10	27/08/2016 2:05	Winter	5540	3.08	9.21	9	7	29	3	8	35	10	12	28	28	55	6.06	4.5	27.3
22/06/2017 0:10	27/06/2017 10:20	Winter	14773	29.93	52.46	93	88	5	5	5	158	24	30	13	17	62.1	6.84	6.7	46.0
1/07/2017 10:20	5/07/2017 1:55	Winter	19232	9.75	27.75	84	75	11	4	7	230	31	48	20	21	37.7775	4.40	9.3	41.0
20/07/2017 9:45	24/07/2017 6:05	Winter	18844	13.40	30.61	122	94	26	4	7	342	120	52	13	13	41.4	4.59	6.7	30.9
27/07/2017 17:25	28/07/2017 13:10	Winter	7972	1.60	5.41	17	15	10	5	28	140	26	50	4	4	17.0775	2.38	7.8	18.5
6/08/2017 20:00	7/08/2017 22:45	Winter	4323	1.27	5.04	3	3	20	4	14	17	6	9	11	19	14.476	1.43	2.6	3.7
8/08/2017 22:00	12/08/2017 17:35	Winter	12895	12.22	28.69	68	47	49	5	8	195	83	21	19	14	46.53	5.77	10.3	59.6
27/08/2017 16:25	6/09/2017 19:15	Winter	49205	79.55	133.53	592	438	33	4	10	495	180	53	29	29	183.018	24.98	13.4	335.7
1/06/2018 19:35	2/06/2018 16:00	Winter	8114	1.57	4.38	6	7	27	13	14	52	23	19	7	7	27	4.16	12.5	51.9
3/06/2018 0:15	10/06/2018 1:20	Winter	88861	98.27	132.75	1135	1204	49	14	27	596	174	77	55	55	110	13.80	11.0	151.8

Start date & time	End date & time	Season	Peak discharge (l/s)	Quickflow runoff (mm)	Tot runoff (mm)	Event load (t)	Event load std error (t)	% load on rising stages	SSC at start (mg/l)	SSC at end (mg/l)	Peak SSC (mg/)	Average falling stage SSC (mg/l)	Average rising stage SSC (mg/l)	Time to flow peak (hr)	Time to SSC peak (hr)	Rainfall (mm)	Rain energy (J)	I60max (mm/h)	EI60
12/06/2018 10:05	13/06/2018 8:00	Winter	6317	1.28	6.60	12	13	41	23	25	41	32	18	8	8	15.5	1.67	4.5	7.5
14/07/2018 13:35	19/07/2018 8:00	Winter	27135	22.65	41.16	144	156	40	12	21	179	80	37	33	33	55	6.20	7.0	43.4
4/08/2018 12:40	7/08/2018 5:35	Winter	7112	4.44	13.74	19	21	36	12	17	46	21	15	32	32	26	2.51	4.0	10.0
8/08/2018 10:30	10/08/2018 0:20	Winter	5497	1.92	8.43	11	14	15	16	19	35	22	20	7	6	11	1.09	3.0	3.3
13/08/2018 21:30	15/08/2018 9:35	Winter	7814	2.26	8.48	10	9	15	4	11	44	13	18	9	9	21.285	2.51	6.9	17.4
29/08/2018 4:25	1/09/2018 23:30	Winter	15401	10.64	23.69	63	53	16	5	8	245	70	39	11	10	59.895	7.09	7.4	52.6

Tuapiro at Woodland Road events:

Start date & time	End date & time	Season	Peak discharge (l/s)	Quickflow runoff (mm)	Tot runoff (mm)	Event load (t)	Event load std error (t)	% load on rising stages	SSC at start (mg/l)	SSC at end (mg/l)	Peak SSC (mg/)	Average falling stage SSC (mg/l)	Average rising stage SSC (mg/l)	Time to flow peak (hr)	Time to SSC peak (hr)	Rainfall (mm)	Rain energy (J)	I60max (mm/h)	EI60
16/03/2016 17:05	17/03/2016 13:45	Autumn	11920	3.47	5.31	19	5	15	3	9	231	114	76	2	3	15	1.34	1.0	1.3
17/03/2016 17:30	21/03/2016 15:20	Autumn	25677	33.02	60.92	50	15	41	5	2	325	63	12	13	13	96	9.81	2.8	27.3
23/03/2016 21:00	26/03/2016 20:15	Autumn	15973	30.80	59.89	24	9	37	2	3	35	19	6	15	12	94	12.61	9.4	118.2
17/04/2016 13:35	18/04/2016 20:50	Autumn	15680	7.33	11.17	15	4	34	1	4	87	42	23	10	10	54	6.96	8.9	61.8
29/05/2016 12:45	31/05/2016 0:40	Autumn	11360	7.29	13.30	36	10	18	3	4	425	194	57	2	2	36	5.97	18.3	109.5
7/03/2017 17:15	13/03/2017 17:40	Autumn	63992	137.49	183.41	283	68	59	3	5	356	52	16	77	77	386	65.37	26.3	1720.1
26/03/2017 23:40	28/03/2017 1:35	Autumn	15934	5.82	9.00	57	13	31	2	8	775	157	112	9	9	96	17.65	21.8	385.5
28/03/2017 23:40	31/03/2017 2:05	Autumn	20553	26.88	38.51	30	9	30	5	4	109	65	14	8	8	68	9.51	14.4	136.9
4/04/2017 6:35	7/04/2017 15:15	Autumn	34724	77.01	101.31	67	19	42	4	5	146	33	10	18	3	181	21.28	7.7	164.4
11/05/2017 9:20	14/05/2017 1:50	Autumn	22528	42.12	54.48	48	12	58	6	6	61	33	10	27	19	112	12.52	3.8	47.0
27/05/2017 2:50	29/05/2017 12:10	Autumn	22661	24.64	37.55	55	13	68	6	6	231	78	12	22	20	63	6.28	2.1	13.4
23/03/2018 15:30	24/03/2018 10:35	Autumn	7197	2.47	4.62	10	2	56	3	10	225	114	26	5	4	43	6.96	13.2	92.1
12/05/2018 12:50	13/05/2018 19:10	Autumn	3291	1.94	6.73	4	1	86	2	7	68	18	2	24	10	59	7.72	11.3	87.6
20/09/2016 18:40	24/09/2016 13:10	Spring	18553	46.86	69.02	73	18	55	3	5	236	94	12	15	8	118	13.40	5.7	76.2
24/09/2016 18:15	28/09/2016 13:10	Spring	60450	104.39	155.86	248	59	66	5	6	239	87	14	23	10	134	17.26	15.0	258.6
28/09/2016 22:55	1/10/2016 11:50	Spring	22668	30.23	73.69	49	14	70	6	6	82	25	5	32	19	60	6.95	6.7	46.7
7/10/2016 3:05	7/10/2016 19:30	Spring	7511	2.62	7.84	11	3	14	9	7	177	31	31	3	4	20	2.14	4.1	8.9
7/11/2016 3:55	7/11/2016 15:40	Spring	5710	1.36	2.26	16	4	21	3	42	441	180	148	3	4	32	5.76	20.7	119.0
2/09/2017 1:40	3/09/2017 20:55	Spring	19370	17.45	32.83	45	11	60	6	5	300	91	14	11	10	37	4.60	8.9	40.8
10/09/2017 9:45	11/09/2017 17:45	Spring	4818	1.77	9.59	6	2	47	4	7	33	16	8	15	14	28	2.82	3.4	9.7
5/02/2016 6:40	7/02/2016 22:10	Summer	8530	9.45	21.41	8	3	65	1	3	27	10	3	43	26				
18/02/2016 18:00	20/02/2016 21:50	Summer	28734	29.74	42.52	59	15	70	4	2	187	81	11	11	5	74	7.87	3.4	26.9
29/02/2016 9:30	2/03/2016 10:35	Summer	6923	5.10	13.74	7	3	25	1	4	91	27	10	8	8	27	2.40	0.6	1.4
16/02/2017 10:55	17/02/2017 23:55	Summer	8995	10.23	14.18	19	4	58	3	8	178	56	15	17	8	100	12.02	7.1	85.2
19/02/2017 1:35	19/02/2017 16:55	Summer	4501	1.32	4.53	2	1	35	6	7	20	12	7	6	6	14	1.59	4.7	7.5

Start date & time	End date & time	Season	Peak discharge (l/s)	Quickflow runoff (mm)	Tot runoff (mm)	Event load (t)	Event load std error (t)	% load on rising stages	SSC at start (mg/l)	SSC at end (mg/l)	Peak SSC (mg/)	Average falling stage SSC (mg/l)	Average rising stage SSC (mg/l)	Time to flow peak (hr)	Time to SSC peak (hr)	Rainfall (mm)	Rain energy (J)	I60max (mm/h)	EI60
4/01/2018 14:35	6/01/2018 13:15	Summer	21979	20.77	27.47	51	13	78	6	6	363	86	10	12	3	143	23.79	27.3	648.3
9/06/2016 16:20	11/06/2016 3:25	Winter	3773	3.50	9.00	3	1	41	2	4	22	13	5	10	4	33	3.76	6.1	23.0
22/06/2016 13:10	25/06/2016 5:55	Winter	21505	27.14	40.90	72	17	52	3	3	633	159	22	11	3	85	11.50	12.7	146.4
25/06/2016 10:45	26/06/2016 0:30	Winter	6046	1.01	5.87	3	1	30	3	5	33	12	10	5	5	19	2.16	5.6	12.1
27/06/2016 8:45	28/06/2016 11:15	Winter	6077	3.22	11.64	4	2	44	3	4	27	13	5	8	5	23	2.48	5.1	12.6
29/06/2016 6:35	1/07/2016 7:50	Winter	28690	23.99	43.58	91	22	68	2	3	489	178	17	11	8	79	12.66	16.8	212.9
24/07/2016 2:15	25/07/2016 7:50	Winter	5211	3.37	9.79	7	2	27	4	5	92	43	14	4	4	21	2.59	9.3	24.1
26/07/2016 3:55	26/07/2016 23:30	Winter	6363	1.95	7.09	7	2	28	3	5	78	31	18	4	6	17	1.90	5.2	9.8
30/07/2016 17:40	31/07/2016 5:50	Winter	6245	1.13	4.09	11	3	6	4	15	198	17	67	3	4	12	1.57	7.7	12.1
3/08/2016 17:05	4/08/2016 10:10	Winter	7543	1.79	6.15	15	4	9	3	8	249	26	55	4	6	17	2.22	8.3	18.4
24/08/2016 18:30	27/08/2016 9:15	Winter	13077	15.99	26.78	40	10	69	3	6	186	67	12	27	6	93	11.96	9.3	111.2
22/06/2017 6:55	25/06/2017 8:00	Winter	22373	59.36	75.04	69	18	76	3	5	382	34	6	29	3	87	10.62	7.9	83.6
1/07/2017 23:10	3/07/2017 6:40	Winter	13589	6.59	12.58	23	6	25	3	8	341	77	36	5	17	51	7.92	16.2	128.7
6/07/2017 16:55	7/07/2017 23:35	Winter	5438	2.63	10.01	7	2	72	5	7	59	27	5	17	2	36	4.08	5.9	24.1
9/07/2017 3:35	9/07/2017 18:30	Winter	6515	1.45	5.57	7	2	36	5	8	77	39	21	5	4	17	1.91	4.4	8.5
20/07/2017 9:50	22/07/2017 22:55	Winter	7716	10.08	23.87	22	6	33	5	7	116	60	16	12	12	75	8.92	7.4	65.9
9/08/2017 11:30	10/08/2017 9:50	Winter	3291	1.35	5.13	3	1	25	9	9	25	17	10	6	5	17	1.75	3.9	6.9
27/08/2017 18:00	30/08/2017 5:05	Winter	21848	24.58	36.93	87	25	14	6	6	399	64	52	17	26	76	9.79	12.3	120.4
30/08/2017 12:40	31/08/2017 16:05	Winter	9806	3.55	12.95	15	4	41	5	9	365	40	17	8	8	48	7.05	16.7	117.9