

Updated suspended sediment yield results for the Waikato region

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Executive Summary

Background

The presence of fine suspended sediment in water bodies can decrease water clarity, change river morphologies, deteriorate aquatic habitats, and affect domestic water supply. Suspended sediment is a widespread issue in New Zealand, affecting not only freshwater ecosystems but also estuarine and coastal systems, and arises from both land and within-channel erosion. Soil erosion can negatively impact soil production and reduce soil ecosystem services. The importance and deleterious effects of instream sediment have been widely recognised in both regional (e.g., The Waipā Catchment Plan) and national policy frameworks (e.g., The National Policy Statement for Freshwater Management) and in the setting of sediment related environmental targets. Understanding suspended sediment yields, and changes over time is an important component of regional state of the environment (SoE) monitoring.

Objectives

The objectives of this report are to:

- compare concurrently collected samples from the APHA 2540 D (total suspended solids, TSS) and ASTM 3977 97 (suspended sediment concentration, SSC) laboratory methods;
- compare suspended sediment concentration samples collected concurrently from automatic point samplers and manual depth integrated isokinetic samplers;
- derive average annual suspended sediment yield, average annual specific yield, and annual specific yield for each site, from the start of discharge monitoring until March 2022;
- investigate time trends in the relationship between suspended sediment concentration and SSC-Q discharge rating where sufficient data has been collected since the report by Hoyle (2014); and
- provide a set of recommendations for future monitoring of suspended sediment across the region that would improve and broaden the value of the monitoring network to service regional and national policy requirements relating to suspended sediment.

Methods

Waikato Regional Council (WRC) has monitored riverine suspended sediment at 26 sites, over periods ranging between 6 and 33 years. Yields are determined using the suspended sediment concentration – discharge (SSC-Q) rating approach, which is an accepted secondary method in the National Environmental Monitoring Standards (NEMS) for measurement of riverine suspended sediment. To develop the rating suspended sediment concentration data was collected concurrently with river discharge measurements. Suspended sediment concentration data was collected using manual depth integrated gauging at some sites, or a combination of automatic point sampling and manual depth integrated gauging at others. The NIWA suspended sediment data analysis toolbox SedRate version 2.23 (SedRate) was used to fit SSC-Q ratings and to calculate average annual suspended sediment yield using site-specific flow records. The SSC-Q ratings were exported from SedRate into R and applied to site-specific flow records for individual years to calculate annual suspended sediment yields. To compare suspended sediment yield between catchments, average annual yield was divided by catchment area to determine specific average annual yield.

To develop SSC-Q ratings over the history of the monitoring programme WRC have used a combination of the APHA 2540 D (TSS) and ASTM 3977 97 (SSC) methods to measure suspended sediment concentration in the laboratory. The TSS method is known to underestimate true suspended sediment concentration, especially when sand size material is greater than 25% of the sample. The suspended sediment NEMS recognises the error associated with the TSS method and only allows the use of SSC for suspended sediment concentration when calculating suspended sediment load. To quantify the impact of TSS on load estimates across the WRC monitoring network, samples were collected from nine sites and analysed for TSS and SSC to

compare the two methods. Across the nine sites, SSC was significantly higher than TSS at seven sites, with no difference measured at two sites. The gradient ($B \pm SB$) of the SSC versus TSS line ranged between 1.05 ± 0.02 and 2.06 ± 0.26 at the seven sites with higher SSC (Table A). However, further sampling is required at eight sites to confirm current results. For those sites where the TSS and SSC comparison was carried out average annual sediment yield is presented with and without a correction to historical TSS data in the main body of this report. Any correction to historical TSS data was applied prior to deriving the suspended sediment concentration – discharge rating curves.

To continue to develop the relationship between the two methods an SSC versus TSS comparison project has been established for ongoing monitoring of TSS and SSC for sites where sampling requirements were not met (e.g., insufficient sample numbers). This work highlights the importance of using the ASTM 3977 97 laboratory method for suspended sediment analysis, and that comparison studies should be undertaken to check for errors in previous suspended sediment yield estimates when APHA 2540 D was used.

Table A: Results from analysis of samples collected for TSS vs SSC. In the column *Sampling requirements met*, n = number of samples collected and Rep. = whether the samples cover the range of flows and total suspended sediment concentrations recorded at the site.

River	Site Name	No. of samples	Sampling requirement met		B†	SB‡	Significant difference *
			n	Rep.			
Kaniwhaniwha	Wright Road	15	No	No	1.05	0.02	Yes
Mangaokewa	Te Kuiti	22	No	No	1.10	0.02	Yes
Mangatutu	Walker Rd Br	35	Yes	No	1.11	0.03	Yes
Matahuru	Myjers	20	No	No	1.50	0.06	Yes
Moakurua	Warratah Farm Br	29	No	No	0.99	0.02	No
Opitonui	d/s Awaroa confl.	35	Yes	No	2.06	0.26	Yes
Waingaro	Ruakiwi Rd	38	Yes	Yes	1.00	0.01	No
Waitomo	Aranui Caves	40	Yes	No	1.19	0.02	Yes
Wharekawa	Adams Farms Br.	26	No	No	1.36	0.05	Yes

† Slope coefficient of the linear regression model fitted to the TSS vs SSC data.

‡ Standard error of the slope of the linear regression model.

* Significant difference at $\alpha = 0.05$. A detailed description of the statistical analysis for assessing significant differences between TSS and SSC is provided in section 2.4.2.

At all automatic point sampling sites, both manual depth-integrated gaugings (C_{mean}) and automatic point samplings (C_{point}) were undertaken simultaneously to ensure the point samples were representative of the cross-sectional suspended sediment concentration. For all sites, $C_{\text{mean}}:C_{\text{point}}$ ranged between 0.72 to 1.34, but most sites were close to one (Table B). Across all sites, the most recent $C_{\text{mean}}:C_{\text{point}}$ data was at least 3 years old, and at the Opitonui site, data had not been collected for 15 years due to challenges with collecting manual depth-integrated gaugings. At all sites the range of discharges sampled for the $C_{\text{mean}}:C_{\text{point}}$ comparison did not adequately represent the range of discharges sampled for the development of the SSC-Q rating. Due to this deficiency, a $C_{\text{mean}}:C_{\text{point}}$ correction was not applied to sediment concentration data collected by automatic sampler across the monitored sites.

Table B: Summary of comparison between concurrently collected manual depth integrated isokinetic (C_{mean}) and automatic point (C_{point}) sampling.

River	Site Name	No. of concurrent samples	Most recent sampling date	Average $C_{mean}:C_{point}$ ratio	$C_{mean}:C_{point}$ liner regression R^2
Kaniwhaniwha	Wright Rd	9	25/05/2018	0.90	0.89
Mangapu	SH3 Br U/S Mangaokewa	5	14/07/2006	1.04	0.91
Mangatutu	Walker Rd Br	6	28/09/2017	0.91	0.99
Matahuru	Myjers	6	23/08/2018	0.99	0.99
Moakurarua	Farm Br	12	22/05/2018	1.34	0.95
Opitonui	d/s Awaroa confl.	2	29/03/2007	0.72	0.97
Waingaro	Ruakiwi Rd	6	13/08/2019	0.87	0.98
Waipā	Otewa Rd	7	16/10/2015	1.12	0.96
Waitomo	Aranui Cave Br	7	16/05/2012	0.90	0.98
Wharekawa	Adams Farm Br	4	11/07/2018	1	0.99

Results and Discussion

Across the 26 monitoring sites, average annual suspended sediment yield (not accounting for the difference between TSS and SSC) ranged between 0.7 and 239.5 kt/y, with the highest yield recorded on the Waikato River at Rangiriri (Figure A). The Rangiriri site is located below the confluence of the Waikato and Waipā Rivers, and the average annual yield there is considerably higher than the 65.7 kt/y recorded upstream of the confluence at Hamilton Traffic Bridge. The difference (173.8 kt/y) represents the significant contribution of sediment from the Waipā River to the lower Waikato River and compares well with the 154.2 kt/y recorded on the Waipā at Whatawhata (Figure A). The two newest suspended sediment monitoring sites are in the Waipā catchment at Moakurarua at Farm Bridge and Kaniwhaniwha at Wright Road. The average annual suspended sediment yields at these sites were 29 kt/y and 8.4 kt/y, respectively (Figure A).

The Waihou River discharges into the Firth of Thames at Kopu near Thames and is the largest waterway in the Waihou-Piako management zone. The Waihou at Te Aroha site is upstream of the tidal zone and recorded an average annual suspended sediment yield of 61 kt/y. A major tributary of the Waihou, and not accounted for by the monitoring site at Te Aroha, is the Ohinemuri Stream, which had an average annual suspended sediment yield of 32.2 kt/y. The Piako River, measured at the Paeroa-Tahuna Road Bridge, also discharges into the Firth of Thames and had an average annual yield of 11.1 kt/y.

The Matahuru Stream is a tributary of Lake Waikare in the Lower Waikato management zone. Up until 2007, suspended sediment data was collected at the bottom of the catchment from the Waterimu Road site, however, the site was closed due to backflow from Lake Waikare during high flow events. In 2006, a new site (Matahuru at Myjers Farm) was established upstream of the Waiterimu site. This location recorded an average annual suspended sediment yield of 14.7 kt/y.

Across the suspended sediment monitoring network, the lowest average annual yield (0.7 kt/y) was measured on the Tapu River at Coroglen (Figure A). The Tapu River catchment covers a small area of the Coromandel Peninsula and is characterised by steep topography, covered almost entirely by indigenous vegetation.

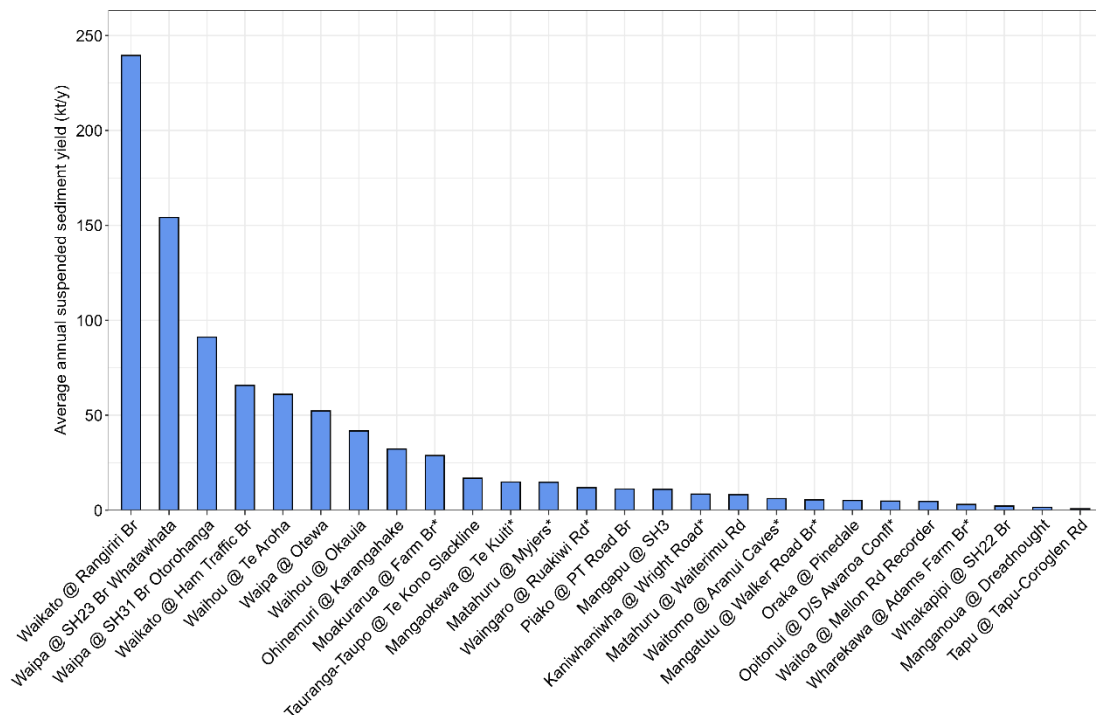


Figure A: Average annual suspended sediment yields (kt/y) from all riverine suspended sediment monitoring sites in the Waikato region. None of these results have been corrected for the difference between TSS and SSC. Sites with an asterisk were monitored using an automatic sampler.

To account for catchment area, average annual specific sediment yields ($\text{t}/\text{km}^2/\text{y}$) were calculated for all 26 sites and ranged between 7.9 and 176 $\text{t}/\text{km}^2/\text{y}$ (Figure B). The highest specific yield was recorded at the site in the Matahuru catchment at Myers, a tributary of Lake Waikare, which also had the highest mean suspended sediment concentration of $101 \text{ g}/\text{m}^3$. Sites at Waitomo at Aranui Caves, Upper Waipā at Otewa, Opitonui downstream of Awaroa Confluence and Moakurua at Farm Bridge had average annual specific yields between 140 and 170 $\text{t}/\text{km}^2/\text{y}$. The Opitonui site (downstream of Awaroa Confluence) is located on the Coromandel Peninsula, while the other sites located at Waitomo at Aranui Caves, Upper Waipā at Otewa and Moakurua at Farm Br. are in the Waipā catchment.

In response to the Waipā Catchment Plan, two new sites were established along streams in priority catchments (Kaniwhaniwha and Moakurua) to monitor changes in suspended sediment in response to soil conservation initiatives (e.g., riparian restoration and hill-country erosion schemes). The Moakurua at Farm Bridge site was added to the network in 2015, while the Kaniwhaniwha River at Wright Road site was established in 2016. The average annual specific yields of the Moakurua and Kaniwhaniwha catchments were $139.5 \text{ t}/\text{km}^2/\text{y}$ and $82.3 \text{ t}/\text{km}^2/\text{y}$, respectively. The sampling records for both sites are relatively short and hence the average annual yields for these sites may be biased by unusually wet or dry periods during the sampling timeframe.

The Ohinemuri at Karangahake and the Waingaro at Ruakiwi Road had average annual specific yields of 110.3 and $100.1 \text{ t}/\text{km}^2/\text{y}$, respectively. The Waingaro River is a tributary of Whaingaroa (Raglan) Harbour, and the Ohinemuri River feeds into the Waihou River. The remaining 18 sites had average annual specific sediment yields below $100 \text{ t}/\text{km}^2/\text{y}$, with specific yields ranging from $99.2 \text{ t}/\text{km}^2/\text{y}$ for Waipā at Otorohanga to $7.9 \text{ t}/\text{km}^2/\text{y}$ for Waikato at Hamilton Traffic Bridge (Figure B). The low specific yields on the Waikato mainstem sites are clearly influenced by sediment entrapment in Lake Taupo and the hydro-lakes. The variability in specific suspended sediment yield across the other catchments was not investigated but is likely due to differences in factors such as climate, lithology, land use, land cover and the presence or absence of erosion mitigations.

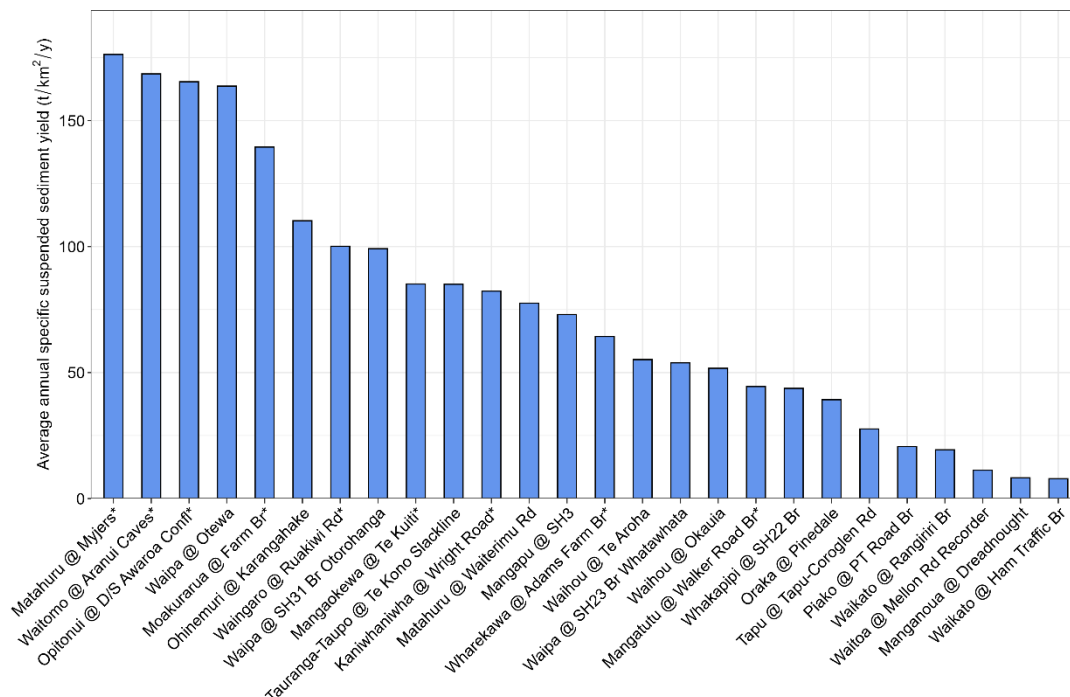


Figure B: Average annual specific suspended sediment yields (t/km²/y) from all riverine suspended sediment monitoring sites in the Waikato region. None of these results have been corrected for the difference between TSS and SSC. For those sites where TSS and SSC data was available, corrections were made and are presented alongside uncorrected results in Table 7. Those sites with an Asterisk were monitored using an automatic sampler.

The suspended sediment concentration-discharge rating method was applied to the flow records to determine annual suspended sediment yields for each site. The annual yields showed more than a tenfold variation for many sites. This large variation was brought about by weather patterns over time, and especially the occurrence of significant storm events during some years. For example, 14 of the 23 monitoring sites had highest annual suspended sediment yields in 2017 due to multiple high magnitude weather events that impacted the Waikato region in that year. Other years of high annual suspended sediment yield that were common among catchments included 1996, 1998, 2004 and 2008.

Time trends for the monitored catchments were assessed based on residuals from the relationship between suspended sediment concentration and water discharge (SSC-Q rating). A linear trend line was fitted, and a student's t-test applied to test the hypothesis that the slope on a linear relation between log (observed/predicted SSC) and time was significantly different from zero at the 5% significance level. To remove the effect of the change in laboratory methods from TSS to SSC, sites were adjusted for the effect of historic TSS analysis. Only 11 sites had sufficient data to undertake time trend analysis, and of those sites one displayed no trend, six an increasing trend and four a decreasing trend (Table C). However, these trends should be interpreted with caution due to changes in the primary sample collection method from depth integrated manual gauging to automatic point sampling, long periods with no sample collection, non-normally distributed concentration-discharge residuals and a change in laboratory methods from TSS to SSC. The magnitude of the significant trends typically averages 1- 4% per year (Table C). The exception is Moakurua at Farm Bridge, where the annual rate of increase of SSC at given discharge is almost 14%, however, this may be an artefact of the relatively short (5-year) monitoring period. To more accurately quantify long-term trends, a targeted study of each site would be necessary to evaluate the impact of catchment management and climate-driven factors, such as increased storm frequency and intensity, on long-term trends.

Table C: Output from concentration residuals time history analysis for river suspended sediment monitoring sites with updated data since 2014.

River	Site name	Time period	N ¹	Slope (B) [†]	Significant difference [‡]	Trend	Trend rate ^{***} (%/y)
Kaniwhaniwha*	Wright Rd	2015 - 2022	618	-1.38E-04	Yes	Decreasing	-3.6
Mangaokewa*	Te Kuiti	1190 - 2020	284	4.13E-05	Yes	Increasing	1.4
Mangatutu*	Walker Rd Br	2004 - 2020	2035	3.15E-05	Yes	Increasing	1.0
Matahuru*	Myjers	2007 - 2020	1283	-1.17E-04	Yes	Decreasing	-3.5
Moakurarua	Farm Br	2015 - 2020	457	3.95E-04	No	Increasing	12.6
Opitonui*	D/S Awaroa Confl.	1991 - 2019	1858	4.13E-05	Yes	Increasing	1.1
Oraka**	Pinedale	1986 - 2020	38	-7.53E-05	Yes	Decreasing	-1.7
Waingaro*	Ruakiwi Rd	2002 - 2019	1578	-7.10E-5	Yes	Increasing	2.4
Waipā*	Otewa	1990 - 2016	1286	-1.007E-4	Yes	Decreasing	-3.5
Waitomo*	Aranui Caves	1990 - 2020	2669	-8.99E-06	Yes	No trend	NA
Wharekawa*	Adams Farm Br	1991 - 2020	1055	7.50E-05	Yes	Increasing	2.0

¹ Number of samples

[†] Slope of the linear regression model fitted to the log (observed/predicted SSC) and time

[‡] A student's t-test was applied to test the hypothesis that the slope on a linear relation between log (observed/predicted SSC) and time was significantly different from zero at $\alpha = 0.05$

* Trend analysis undertaken using corrected data to account for differences between TSS and SSC

** The results for the Oraka site should be treated with caution due to the small sample size (n = 38)

*** Trend rate gives average yearly % increase in observed vs. predicted SSC over monitoring period

Recommendations

- Given the resourcing required to meet the requirements of the recently developed National Environmental Monitoring Standards (NEMS) for suspended sediment, it is recommended that WRC rationalise the network to align with available resources or increasing resources to meet the needs of the monitoring network.
- To better quantify the possible difference between suspended sediment concentrations determined using the APHA 2540 D (TSS) and ASTM 3977 97 (SSC) methods, further TSS–SSC comparative analyses are recommended and rating relationships updated accordingly. At most sites, existing SSC–TSS ratings do not span the full flow range, particularly at high flows.
- Conduct a comprehensive campaign to establish and apply the necessary $C_{\text{mean}}:C_{\text{point}}$ correction wherever autosamplers are installed and operational.
- Given that SedRate is no longer supported by NIWA (Earth Sciences NZ), consider developing an in-house tool that provides similar capability to SedRate.
- Undertake detailed event-based analysis for development of event yield ratings, both to improve the accuracy of calculated yields and allow for comparison with earlier studies which utilised this methodology (Hicks et al., 2011; Hoyle, 2014).
- It is recommended that WRC explore options for installing continuous turbidity or acoustic sensors as proxies for suspended sediment concentration. It is important that these sensors cover the range of turbidity at the site and are appropriately calibrated to suspended sediment concentration.
- Future reporting could include linear regression or other statistical approaches to assess the relationship between sediment yield and catchment characteristics such as land use, average rainfall and geology.

1 Introduction

1.1 Background and purpose

The presence of fine suspended sediment in a water body can decrease water clarity, change river morphologies, deteriorate aquatic habitats, and affect domestic water supply. Sediment may carry pollutants including heavy metals, polycyclic aromatic hydrocarbons, and phosphorus from the land to surface water (Brown and Peake, 2006; Parfitt et al., 2007). The issue of suspended sediment is widespread in New Zealand, affecting not only freshwater but also estuarine and coastal systems (Haddadchi and Hicks, 2019). Soil erosion, which contributes to suspended sediment, can impact on soil productivity and reduce soil ecosystem services (Steinhoff-Knopp et al., 2021).

Erosion and sediment are key issues addressed in the Waipā Catchment Plan, which outlines a 20-year framework to reduce erosion and sedimentation in priority areas within the Waipā Catchment (WRC, 2014). Within the wider Waikato River catchment, Healthy Rivers – Wai Ora (HR-WO) identifies sediment as one of four key contaminants and sets targets for improving visual clarity in rivers (WRC, 2016). Nationally, the National Policy Statement for Freshwater Management (NPS-FM) (MfE, 2023) includes two fine-sediment attributes: visual clarity (inversely related to suspended sediment concentration) and deposited fine sediment. These attributes are assessed through routine sampling at state of the environment (SoE) sites; however, because sampling is biased toward baseflow conditions, links to event-based and mean annual sediment yields are often uncertain. It is often assumed that improvements in NPS-FM sediment attributes will correspond directly to reductions in mean annual sediment yields arising from catchment management actions aimed at reducing soil loss (e.g., Dymond et al., 2017). Within the NPS-FM framework, the Waikato Regional Council event-based suspended sediment monitoring network provides a valuable strategic resource for helping set catchment-wide sediment yield reduction targets to achieve NPS-FM objectives, complementing the regular discrete SoE monitoring. Furthermore, effective land management strategies to reduce soil loss at a regional scale require a robust understanding of inter-annual variability of sediment yield (Hicks et al., 2021).

Up until 2020, Waikato Regional Council (WRC) monitored riverine suspended sediment at 26 sites across the region (Figure 1, Table 1). Some sites were part of the historical hydrological monitoring network, and their original purpose is unknown, while other sites were established in catchments identified as ‘high risk’ for soil erosion following catchment-scale investigations. Another set of sites was established for the purpose of monitoring the outcome of catchment management and soil conservation works (Hicks, 2017; Hill and Borman, 2016) (Table 2). Therefore, most sites were assembled into a network on an ad hoc basis with no conscious design to account for regional representativeness. However, in a review of the WRC suspended sediment monitoring network, Hicks (2017) found that the distribution of sites generally provided fair coverage, capturing most of the regional range of slope, rainfall, landcover and lithology.

In 2020, WRC ceased monitoring suspended sediment at all long-term sites due to resource constraints and the significant cost and effort required to ensure data collection met the requirements of the newly developed suspended sediment NEMS. Hence, the programme was rationalised and incorporated into the Catchment Environmental Monitoring (CEM) programme – designed to quantify the effectiveness of soil conservation efforts in priority catchments and to link on-land actions (e.g., soil conservation planting, riparian protection) to water quality outcomes. Currently, suspended sediment is monitored across four CEM catchments: Moakurarua, Kaniwhaniwha, Matahuru and Karapiro Catchments. It is anticipated that downsizing the suspended sediment monitoring network, yet with the same resourcing, will improve site management and the accuracy of yield estimates due to increased sampling

frequency and superior data quality. Furthermore, monitoring at existing sites could be restarted in the future if the need arises and resourcing allows.

Summaries of average annual sediment yields and time trends from the entire monitoring network have been reported previously in Stewart et al., (2001), Kotze et al., (2008), Hoyle et al., (2012) and Hoyle (2014). Other catchment specific studies have reported on sediment yields from the Waitomo, Waipā and Opitonui Rivers (McKercher and Hicks, 2003; Wild and Hicks, 2005; Hoyle, 2012). This report updates data presented in Hoyle (2014) and describes annual yields and average annual yields for each sediment monitoring site, including for two new sites installed since 2014. Trend analysis was also undertaken for sites where possible.

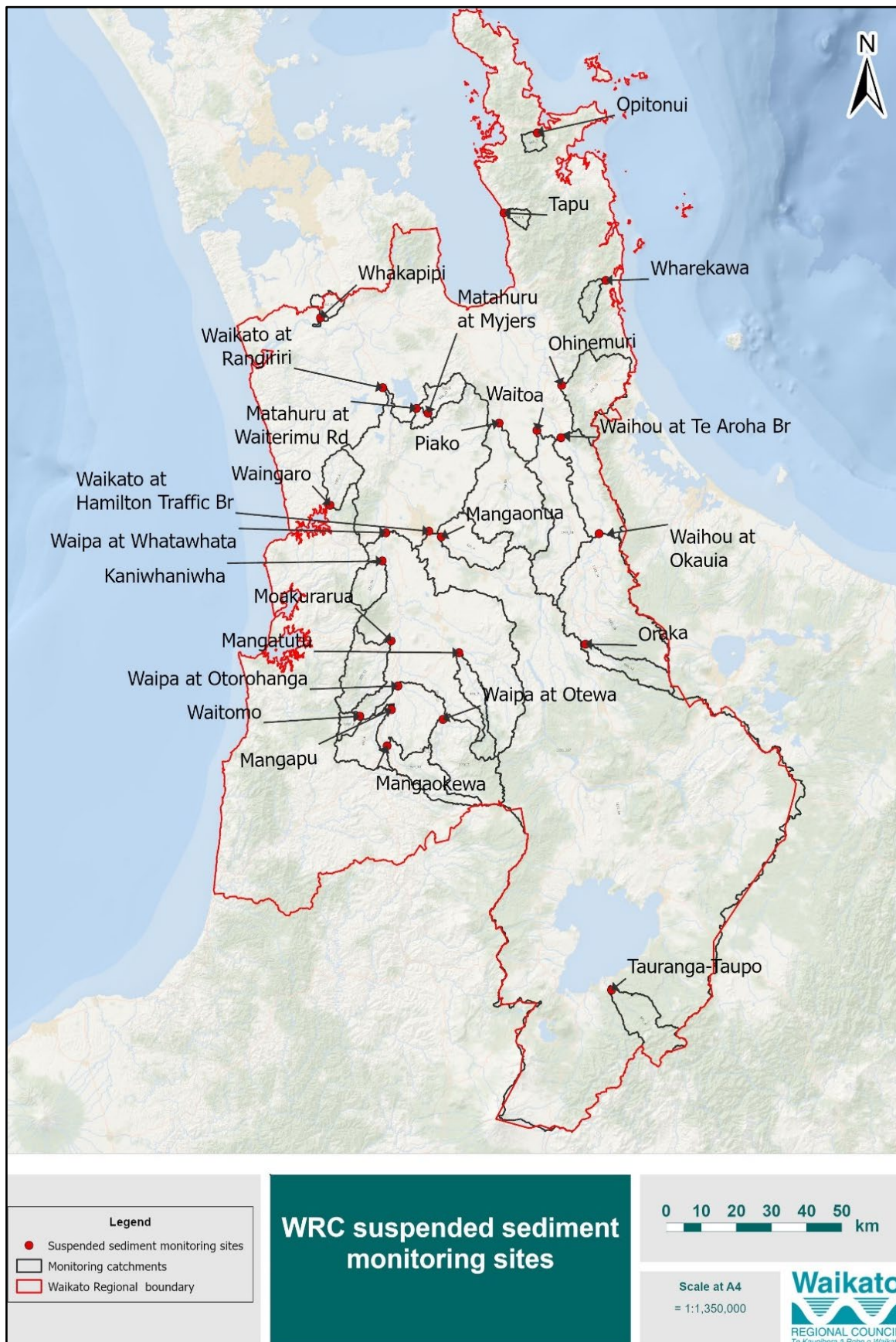


Figure 1: Suspended sediment monitoring sites in the Waikato region and their upstream catchments.

1.2 Objectives

The objectives of this report are to:

- compare concurrently collected samples from the APHA 2540 D (total suspended solids, TSS) and ASTM 3977 97 (suspended sediment concentration, SSC) laboratory methods;
- compare suspended sediment concentration samples collected concurrently from automatic point samplers and manual depth integrating isokinetic samplers;
- derive average annual suspended sediment yield, average annual specific yield, and annual specific yield for each site, from the start of discharge monitoring until March 2022;
- investigate time trends in the rating relationship between suspended sediment concentration and discharge where sufficient data has been collected since the report by Hoyle (2014); and
- provide a set of recommendations for future monitoring of suspended sediment across the region that would improve and broaden the value of the monitoring network to service regional and national policy requirements relating to suspended sediment.

1.3 Catchments

1.3.1 Monitoring sites

The location of the 26 suspended sediment monitoring sites in the Waikato region (monitored up to 2020) are shown in Figure 1. Samples were collected to develop a suspended sediment concentration – discharge (SSC-Q) rating for each site, using either manual depth integrated sampling only (undertaken at 14 sites) or a combination of automatic point sampling and manual depth integrated sampling (undertaken at 12 sites). For sites where depth integrated sampling was the primary method, the sample number was generally low and many of these sites have not been sampled over the past 10 years. At sites with automatic point samplers, sampling was more frequent and undertaken since 2017/2018 (Table 1). Sections 2.1 to 2.5 provide more detail on sample collection and laboratory analysis.

Since the last regional suspended sediment monitoring report (Hoyle, 2014), an additional two sites have been added to the network in 2015 and 2016, as part of the WRC CEM programme. These sites are:

- Moakurarua at Warratah Farm Br (553_12); and
- Kaniwhaniwha at Wright Rd (222_16).

The locations of all suspended sediment monitoring sites, along with the discharge and suspended sediment measurement period, catchment average rainfall and slope are presented in Table 1. Table 2 outlines the original purpose for each site where it is known.

Table 1: Summary information for each of the monitoring sites including site number, location, sampling method, sampling period, upstream catchment area (km²), mean rainfall (mm) and mean slope (degrees). Under sampling method, sites with A were a combination of manual depth integrated and automatic point sampling, and M is sampling by manual depth integrated sampling only.

Catchment and Site Name	Site No.	Flow recorder No.	NZTM Easting	NZTM Northing	Sampling method	Flow measurement period	Sediment sampling period	Catchment area (km ²)	Catchment mean annual rainfall (mm)	Catchment mean slope (degrees)
Kaniwhaniwha at Wright Rd	222_16	3143453	2698533	6368031	A	2015 - 2022	2016 – 2022	102.6	1914.2	12.34
Mangaokewa at Te Kuiti	414_13	1643462	2699840	6316096	A	1983 - 2022	1990 – 2020	173.8	1539.1	11.16
Mangapu at SH3 Br	443_4	1043444	2701061	6326277	A	2000 - 2022	2000 – 2012	150.4	1723.8	10.88
Mangatutu at Walker Rd Br	476_7	1943459	2720300	6342200	A	2004 – 2022	2004 – 2020	121.5	1483.4	12.01
Matahuru at Myjers	516_22	3043490	2711644	6409530	A	1984 - 2022	2007 – 2020	83.4	1238	11.59
Moakurua a Farm Br	553_12	3143452	2701054	6345599	A	2015 - 2022	2015 – 2020	206.1	1944.6	15.22
Ohinemuri at Karangahake	619_16	9213	2749644	6417389	M	1956 - 2022	1986 – 2015	291.8	1929.7	12.26
Opitonui at d/s Awaroa confl.	660_1	11310	2742873	6488366	A	1991 - 2022	1991 – 2019	28.8	1954.6	17.98
Oraka at Pinedale	669_13	1009213	2756300	6344600	M	1979 - 2022	1986 - 2019	130.2	1526.6	11.51
Piako at Paeroa Tahuna Rd Br	749_15	9140	2731800	6406800	M	1972 - 2022	1986 - 2019	538.9	1081.2	5.73
Tapu at Tapu-Coroglen	954_5	9701	2733364	6465803	M	1991 - 2022	1991 – 1999	26.5	1865.3	19.97
Tauranga-Taupō at Te Kono	971_4	1543413	2763600	6247300	M	1976 - 2022	1990 – 2010	197.8	1920.5	18.08
Waihou at Okauia	1122_18	9224	2760200	6375600	M	1982 - 2022	1986 - 2006	806.4	1464.3	8.25
Waihou at Te Aroha Br	1122_34	9205	2749400	6402600	M	1965 - 2022	1986 - 2006	1106.3	1485.9	8.45
Waikato at Hamilton Traffic Br	1131_64	43466	2711800	6376400	M	1975 - 2022	1991 - 2004	8333.6	1493.4	8.22
Waikato at Rangiriri	1131_117	43420	2698700	6416700	M	1965 - 2022	1991 - 2007	12372.0	1478.4	8.44
Waingaro at Ruakiwi Rd	1167_4	42601	2683700	6383700	A	2001 - 2022	2002 - 2019	118.5	1513.5	13.96
Waipā at Otewa	1191_7	43481	2715700	6323500	A	1985 - 2022	1990 - 2016	319.4	1585.9	13.11
Waipā at Otorohanga	1191_13	43468	2702900	6332900	M	1981 - 2022	1990 - 2019	918.7	1568.6	11.15
Waipā at Whatawhata	1191_11	43433	2699600	6376000	M	1972 - 2022	1990 - 2009	2863.1	1532.8	9.73
Waitoa at Mellon Rd	1249_18	9179	2742600	6404700	M	1986 - 2022	1986 - 2007	408.9	1146.6	3.36
Waitomo at Aranui Caves	1253_3	1943481	2692077	6324406	A	1986 - 2022	1990 - 2020	36.2	1978.5	15.21
Whakapipi at SH22-Tuakau	1282_8	1643457	2681052	6436497	M	1984 - 2022	1991 - 2000	49.1	1299.4	6.34
Wharekawa at Adams Farm Br	1312_1	12509	2762313	6446823	A	1991 - 2022	1991 - 2020	46.5	2029.2	15.45
Mangaonua at Dreadnought	421_4	1543497	2715375	6374751	M	1991 - 2022	1991 - 2004	182.5	1138.9	4.03
Matahuru at Waiterimu Rd	516_5	43489	2708300	6410900	A	1984 - 2022	2003 - 2006	105.3	1220.5	10.59

Table 2: Original purpose of each suspended sediment monitoring site and catchment.

Catchment and site name	Site purpose
Kaniwhaniwha at Wright Rd	Monitor the effects of soil conservation and river restoration works in the priority 1 catchment due to implementation of the Waipā Catchment Plan in 2014. The catchment is now part of the Catchment Environmental Monitoring (CEM) Programme.
Mangaokewa at Te Kuiti	Unknown, but likely part of the historical hydrological monitoring network. The site was upgraded from a manual depth integrated sampling site to an automatic point sampling site following a large slip in the headwaters in September 2017.
Mangapu at SH3 Br	Site selected due to being representative of karst geology of the west coast area and following a sub catchment riverine suspended sediment sampling campaign. Sampling was suspended in 2012 due to power supply issues. Difficult to undertake site calibrations due bridge associated with site being on a main highway.
Mangatutu at Walker Rd Br	Monitoring the outcome of soil conservation and river restoration works as part of the CEM Programme, this site is no longer part of that programme.
Matahuru at Myjers	Monitoring the outcome of soil conservation and river restoration works as part of the CEM Programme, the site is still part of this programme. Provided information about sediment inflows into Lake Waikare. Site was originally further downstream at Waiterimu Rd but moved due to issues with backflow from Lake Waikare.
Moakurua at Farm Br	Monitor the effects of soil conservation works in the priority 1 catchment due to implementation of the Waipā Catchment Plan in 2014. Now part of the CEM Programme.
Ohinemuri at Karangahake	Unknown, but likely part of the historical hydrological monitoring network.
Opitonui River at d/s Awaroa confl	The catchment has significant area of forestry and was installed as a paired site comparison to a site in the Maharikau catchment which was mostly native vegetation. Monitoring continued when the Maharikau site was disestablished. Prior to 1999 suspended sediment sampling was by manual depth integrated sampling only, an autosampler was installed in 1999. The slackline for sampling was often damaged making calibrations difficult. Automatic sampler intake was potentially influenced by local stream bank erosion.
Oraka at Pinedale	Unknown, but likely part of the historical hydrological monitoring network.
Piako at Paeroa Tahuna Rd Br	Unknown, but likely part of the historical hydrological monitoring network.
Tapu at Tapu-Coroglen	Unknown, but likely part of the historical hydrological monitoring network.
Tauranga-Taupō at Te Kono	Unknown, but likely part of the historical hydrological monitoring network.
Waihou at Okauia	Unknown, but likely part of the historical hydrological monitoring network.
Waihou at Te Aroha Br	Unknown, but likely part of the historical hydrological monitoring network.
Waikato at Hamilton Traffic Br	Unknown, but likely part of the historical hydrological monitoring network.
Waikato at Rangiriri	Unknown, but likely part of the historical hydrological monitoring network.
Waingaro at Ruakiwi Road	Selected following sub catchment sediment sampling campaign that identified catchment as a considerable sediment source to Whaingaroa Harbour. Turbidity was continuously monitored at the site between 2007 – 2018.
Waipā at Otewa	Identified because of a sub-catchment sediment sampling campaign as a considerable source of suspended sediment. Suspended sediment supply was influenced by a land slip in the Tunawaea catchment in 1991. Prior to 2000 suspended sediment sampling was by manual depth integrated sampling only, an autosampler was installed in 2000.
Waipā at Otorohanga	Unknown, but likely part of the historical hydrological monitoring network.
Waipā at Whatawhata	Unknown, but likely part of the historical hydrological monitoring network.
Waitoa at Mellon Rd	Unknown, but likely part of the historical hydrological monitoring network.
Waitomo at Aranui Caves	The site was set up to monitor the outcome of soil conservation works instigated by a local catchment care group due to concern about sediment deposition in the local cave network. Prior to 1997 suspended sediment sampling was by manual depth integrated sampling only, an autosampler was installed in 1997.
Whakapipi at SH22-Tuakau	Unknown, but likely part of the historical hydrological monitoring network
Wharekawa at Adams Farm Br	Monitoring the outcome of soil conservation and river restoration works as part of the CEM Programme, this site is no longer part of that programme. Prior to 2000 suspended sediment sampling was by manual depth integrated sampling only, an autosampler was installed in 2000.
Manganoua at Dreadnought	Unknown, but likely part of the historical hydrological monitoring network.
Matahuru at Waiterimu Rd	See comments on this site for Matahuru at Myjers.

1.3.2 Catchment characteristics

The Waikato is the fourth largest region in New Zealand, covering an area of about 25,000 km². Due to the large land area, there are a wide range of topographies and landscapes, resulting in varied environments across the monitored catchments. To provide an overview of key catchment characteristics, this section broadly describes Land Use Capability (LUC), surface geology, Soil Order, land cover, and rainfall in each catchment. The areas and boundaries of the catchments upstream of the monitoring sites (as shown in Figure 1) were determined using the River Environmental Classification version 2.5 (REC2) in ArcGIS Pro 3.2.3.

The catchment areas upstream of monitored sites range from 26.5 km² to 13,272 km². There are multiple monitoring sites along the Waipā, Waikato, and Waihou Rivers, with some monitoring catchments nested within others. The mean annual rainfall across catchments ranges from 1,139 mm to 2,029 mm (Table 1). Land Use Capability (LUC) is an assessment of the capability of land for productive use and is described with an index that ranges from one to eight. A higher number suggests decreasing versatility of use (Newsome et al., 2008) but also denotes generally steeper hill-country and greater risk for erosion. Within monitored catchments, there is a mix of LUC classes (Figure 2). However, over half of the catchments have more than 50% of their area in LUC class 6 or above. The catchments upstream of Tapu at Coroglen (954_5) and Tauranga-Taupō at Te Kono (971_4) have over 50% of their area as LUC classes 7 and 8.

Soil orders, as classified in the New Zealand Soil Classification (NZSC) (Hewitt, 2010), vary greatly across the monitored catchments (Figure 4), driven by differences in physiographic factors (e.g., geology, slope and land cover) along with differences in soil biology and climatic influences. Allophanic Soils are the most common soil order, often covering greater than 30% of the area of individual catchments.

Land cover was determined using the Land Cover Database version 5.0 (LCDB5), derived from satellite imagery collected in 2018. Exotic grassland (e.g., pasture) is the most common land cover across the region, covering between 30 and 80% of the area of monitored catchments (Figure 5). Exotic and indigenous forest are also common land covers across monitored catchments. For example, catchments upstream of Wharekawa at Adam Farm Bridge (1312_1), Opitonui at downstream of Awaroa Confluence (660_1) and Oraka at Pinedale (971_4) are covered by more than 40% exotic forest. The catchments upstream of Tapu at Coroglen (954_5) and Tauranga Taupō at Te Kono (971_4) have more than about 70% of the land area under indigenous forest. At Tauranga-Taupō at Te Kono (971_4), the combination of exotic and indigenous forest covered more than 90% of the monitored catchment.

Surface geology was determined using Qmap (GNS, 2023), and it varies considerably across the monitored catchments (Figure 6). Catchments in the Coromandel are dominated by andesite and rhyolite materials, while those in the northern and central Waikato have a mix of Pleistocene sediment and greywacke basement. The western monitored catchments are dominated by basaltic volcanics and tertiary siltstone, sandstone and other sedimentary rock. Ignimbrite and unconsolidated tephras prevail towards the south-east of the region and Lake Taupō.

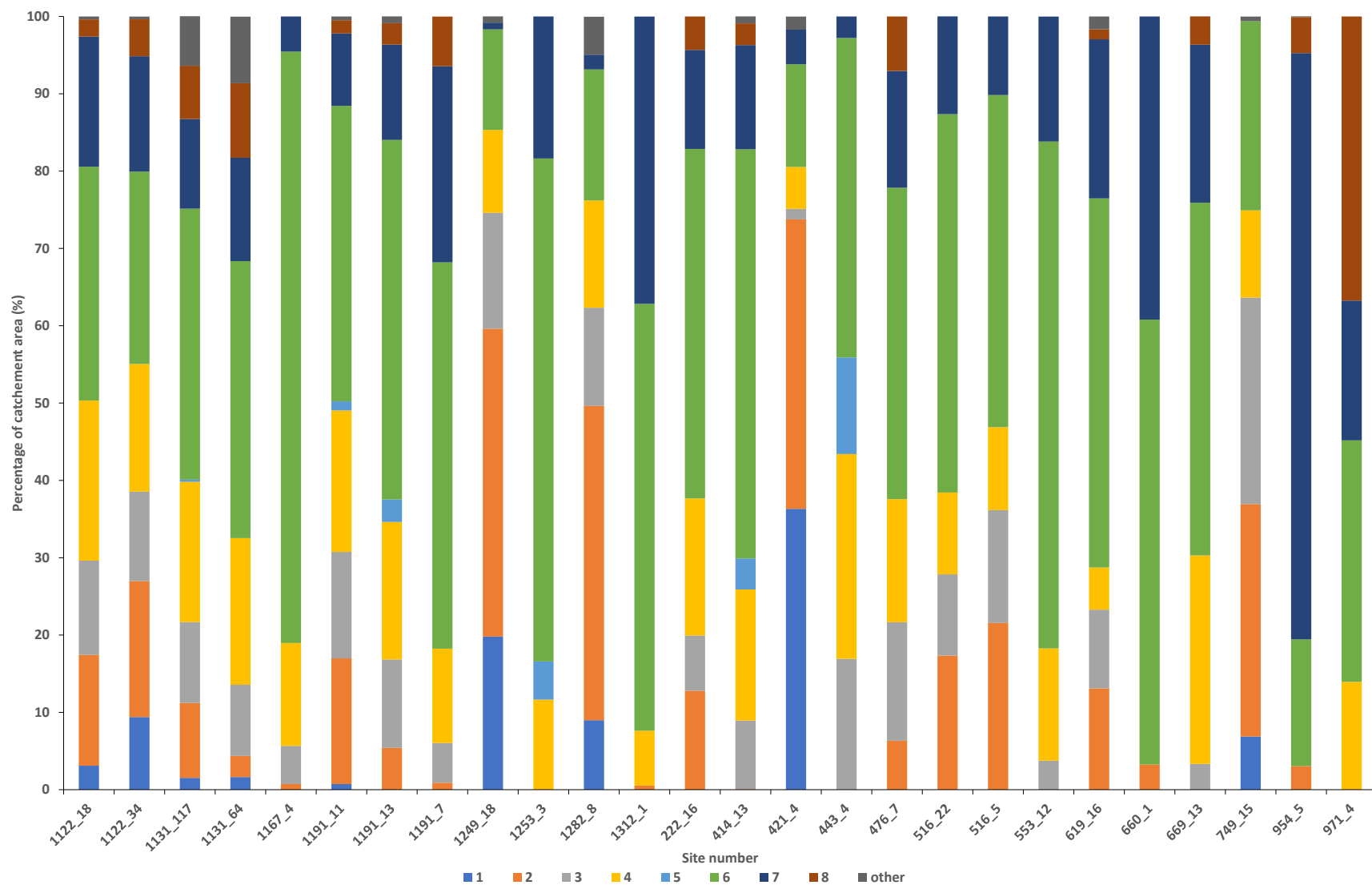


Figure 2: Land Use Capability (LUC) class code from Newsome et al., (2008). Site numbers can be matched with site name in Table 1.

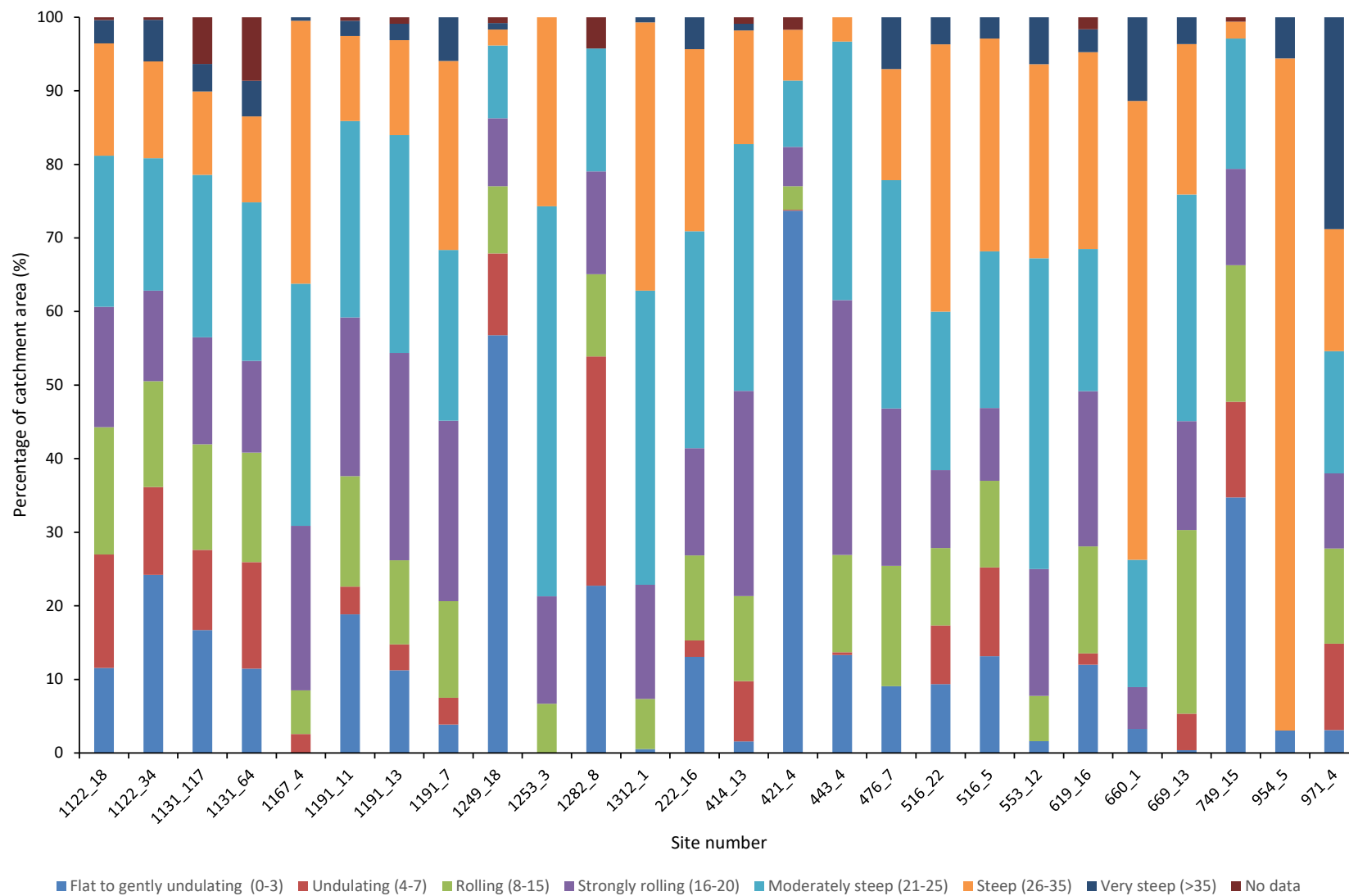


Figure 3: Catchment slope class (degrees) from the New Zealand Land Resource Inventory (NZLRI). Site numbers can be matched with site name in Table 1.

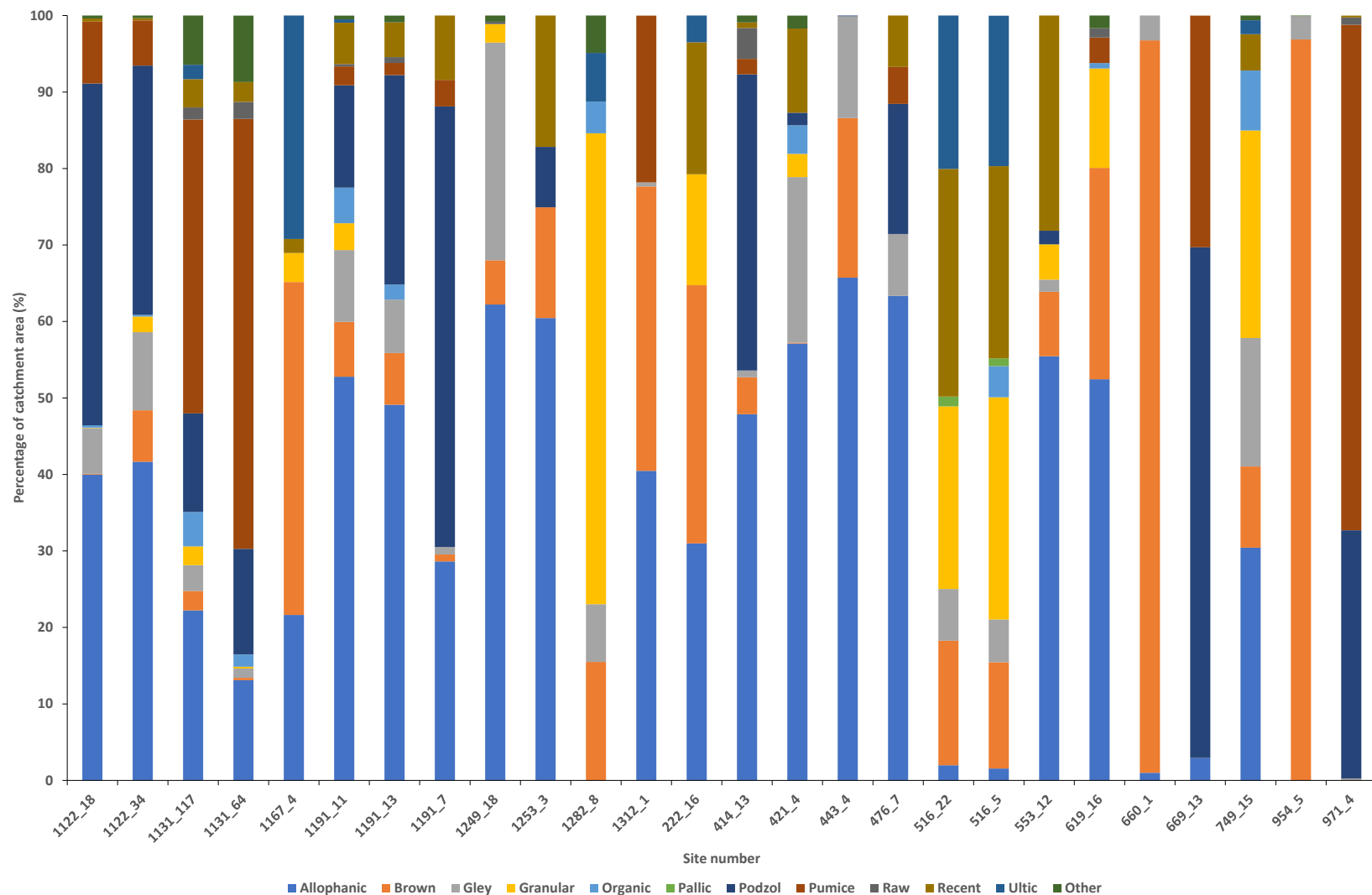


Figure 4: Soil order (NZSC) in each monitored catchment as mapped in the Fundamental Soils Layer of the NZ Land Resource Inventory. Site numbers can be matched with site name in Table 1.

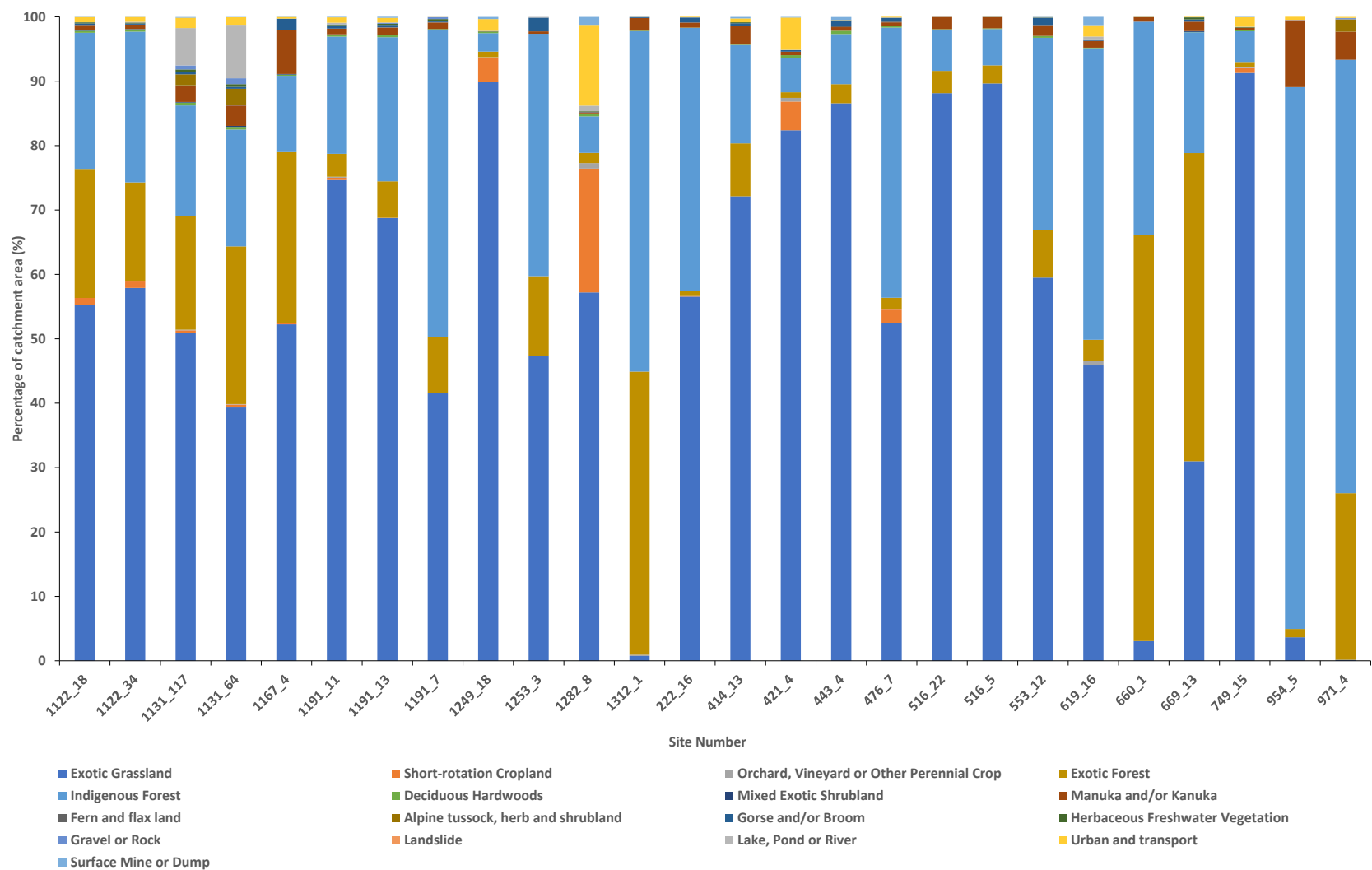


Figure 5: Land cover in each monitored catchment as adapted from Landcover database (LCDB) 5. Site numbers can be matched with site name in Table 1.

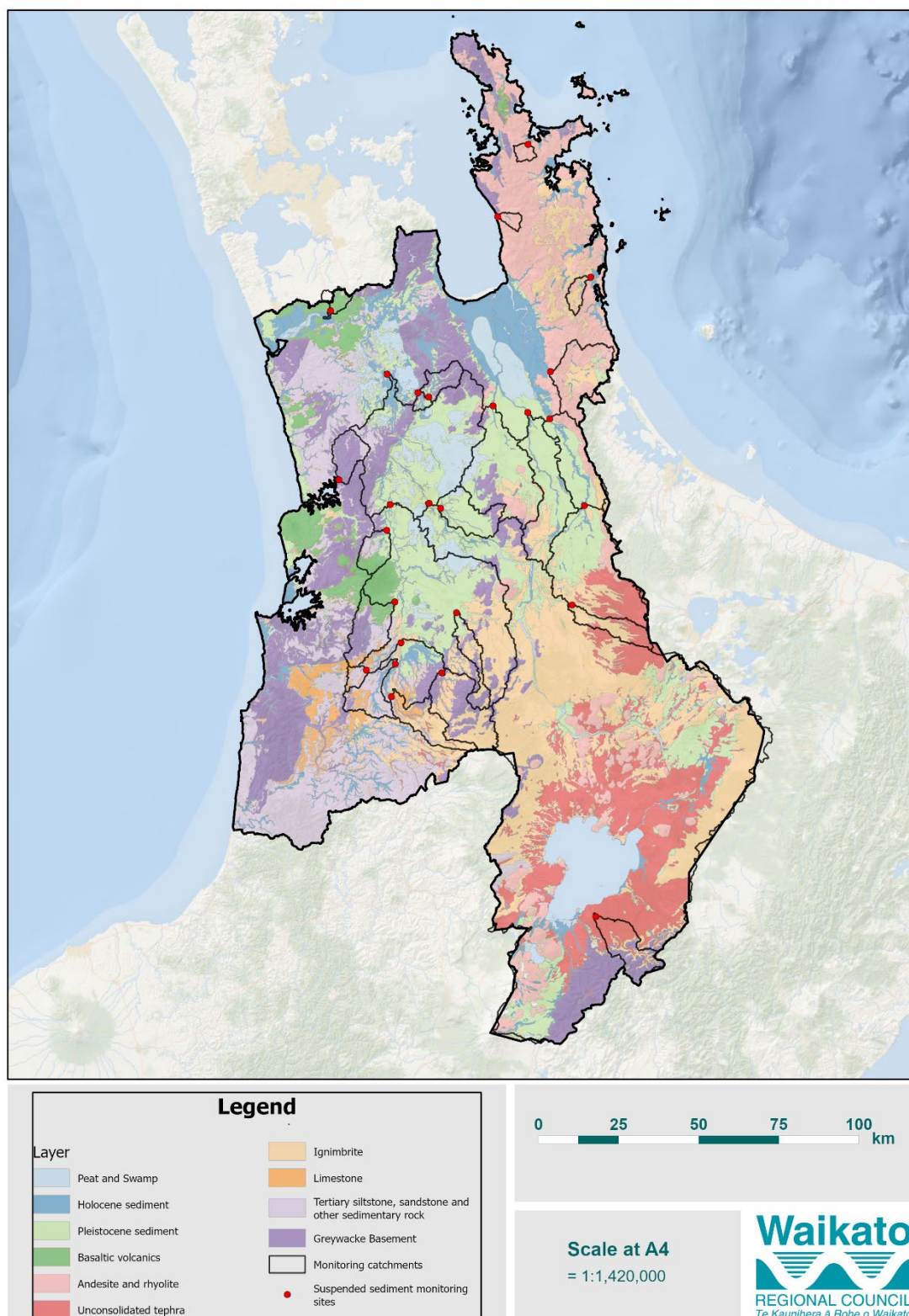


Figure 6: Simplified surface lithology map of the Waikato Region using data from QMAP 1:1M Geology.

2 Methodology

2.1 Overall approach

Waikato Regional Council (WRC) uses the suspended sediment concentration-discharge (SSC-Q) rating approach to determine suspended sediment yields at monitored sites. This involves a dataset of concurrently collected suspended sediment concentration samples (SSC) and water discharge (Q) to develop a relationship between the two. The rating is then combined with the discharge record to estimate time averaged suspended sediment load over annual and longer timescales (Hicks et al., 2020). The SS-Q approach is permitted under “other methods” in the National Environmental Monitoring Standard (NEMS) for suspended sediment. However, this approach can only achieve a quality code of up to QC 300, compared to QC 600 (maximum score) if using a primary method (Hicks et al., 2020).

2.2 Suspended sediment sample collection

SSC samples for developing SSC-Q ratings were collected by one of two approaches:

- 1) Manual depth integrated suspended sediment sampling only (**manual sites**) using isokinetic samplers.
- 2) A combination of manual depth integrated sediment sampling and automatic point sampling (**automatic sites**).

2.2.1 Manual depth integrated sampling

Manual depth integrated sampling was used to collect SSC samples to develop a suspended sediment rating at manual sites (Table 1, Sampling Method M) and to calibrate point samples collected by ISCO autosampler at the automatic sites.

The approach for manual sampling generally followed that set out by Hicks et al., (2020) and used either D49, DH48, DH59 or DH81 depth integrating isokinetic samplers. The type of sampler used was based on river size and velocity, although historically, this was applied in an ad-hoc manner. However, starting in 2019, general guidance for sampling (e.g., the sampler to be used and sampling targets) at each site was provided through a site-specific information card and an annual plan, as shown in Appendix 1. An important outcome of manual sampling was to cover the range of flows measured at each site. However, resource constraints in the programme’s later years restricted manual sampling, making it impossible to achieve the goal of covering an adequate range of flows. Table 3 compares an ideal manual sampling programme as outlined in Hicks (2017) and Hicks (2020) relative to the sampling undertaken by WRC.

When selecting the location of sampling verticals, WRC typically used the equal discharge increment (EDI) method. At most sites, either three or five verticals were used. Historically, sampling verticals were located between discharge subsections, however, this resulted in cross-section average SSC being under-estimated (Hicks, 2017). From 2018, this bias was avoided by locating the sampling verticals in the centroids of the discharge subsections, which is consistent with the approach of Hicks et al., (2020).

Table 3: Comparison between the annual sampling requirements set by the NEMS (Hicks, 2020), those recommended to WRC by Hicks (2017) and WRC's actual operational performances.

Site type	Primary objective	N*	Annual data collection targets		No. of sites meeting NEMS criteria**
			Suspended Sediment NEMS (Hicks et al., 2020)	WRC suspended sediment review (Hicks, 2017)	
Manual	Estimate mean annual suspended sediment load and trends using sediment rating curves	14	- 8 manual depth-integrated samples per year	- 8 manual depth integrated samplings - Samples distributed across rising and falling flow stages and seasons - Coverage of a wide range of flows	2
Automatic	Estimate mean annual suspended sediment load and trends using sediment or event-based rating curves	12	- 6 rainfall–runoff events sampled per year - $C_{\text{mean}}/C_{\text{point}}$ calibration: 5 manual samples between mean discharge and mean annual flood - At least 1 annual $C_{\text{mean}}/C_{\text{point}}$ campaign to check the accuracy of the relationship	- 6 rainfall–runoff events sampled per year - Average of ≥ 8 samples per event - $C_{\text{mean}}/C_{\text{point}}$ calibration samples collected within one event per year	6

*Number of sites in WRC monitoring network

** Criteria evaluated using the average number of samples collected per year over the entire monitoring period

2.2.2 Automatic point sampling

To increase the frequency of sampling, particularly during large runoff events, key sites had Teledyne 3700 ISCO autosamplers installed (Table 1, Sampling Method A). The ISCO autosamplers collected 24 single samples during runoff events and were programmed to trigger and collect a sample when a predefined river level was reached. Subsequent samples were collected at set time intervals (e.g., 30 mins) or discharge-volume increments (e.g., 40,000 litres). At most sites, samples were collected at set time intervals while at newer sites such as the Kaniwhaniwha and Moakurarua, sampling was by discharge-volume increment. The change to sampling by discharge-volume was to ensure that the rising limb of the flood hydrograph, and the discharge peak of the runoff event was sampled adequately. Auto sampling stopped once all 24 bottles were filled. Typically, autosampler bottles would not be changed within an event if the autosampler filled part-way through the event.

The purpose of automatic point sampling was to make it easier to collect samples during rainfall-runoff events and represent the range of flows occurring at the monitoring site. Initially sampling was ad-hoc, with an attempt to capture as many events as resources allowed. However, in 2019 general guidance for sampling at each site was set out by a site-specific annual plan (example provided in Appendix 1). While the site-specific annual plan followed the guidance outlined in Hicks (2017) and Hicks et al., (2020), actual sampling seldom met the criteria (Table 3).

Since autosamplers collect samples from a single point in the stream cross-section, samples may not accurately represent the discharge-weighted cross-section average SSC. Therefore, it is necessary to calibrate the auto-sampled SSC results to the cross-section average values. This can be achieved by developing relationships between the auto-sampled SSC and the concurrently and manually derived SSC. The method for collecting these manually derived and concurrent SSC samples is detailed in section 2.2.1.

2.2.3 Data availability

Up to 31 March 2022, suspended sediment data was collected at 14 manual sites and 12 automatic sites (Table 1). Since 1986, a total of 15,924 suspended sediment samples were collected, with between 12 and 2,690 samples collected at each site (Table 6).

Of the 26 monitoring sites, only 14 sites had additional suspended sediment data collected since the analysis of Hoyle (2014) (Table 1, Sediment sampling period). Most sites without new data were manual sites, and while these sites were still 'active' until 31 December 2020, limited resourcing meant that they were seldom sampled.

2.3 River discharge

River discharge measurements were collected concurrently with manual depth integrated and automatic point SSC samples to develop an SSC-Q rating. Continuous river discharge records were then combined with the SSC-Q rating to calculate annual and average annual suspended sediment yields. The flow measurement period column in Table 1 identifies the length of the flow record for each site, and therefore the period that annual and average annual yields were calculated for.

Discharge and suspended sediment measurements were carried out within 500 m of each other. There were no significant inflows or outflows between any discharge monitoring station and suspended sediment measurement site.

For manual depth integrated sampling, discharge measurements were made using either the velocity-area stationary meter method or the velocity-area acoustic doppler current profiler (ADCP) moving boat method. Where automatic point sampling was used, discharge was typically derived from 5-minute river stage height measurements and based on a stage height-discharge relationship. River stage height measurements were collected using either a water bubbler system, radar water level sensor or water level encoder.

2.4 Suspended sediment laboratory analysis

2.4.1 History of methods

Prior to 1997 suspended sediment samples were analysed by WRC for SSC using the ASTM 3977 97 method and involved analysing the full sample that was collected in the field. However, if visual inspection indicated that samples had very high suspended sediment concentrations, they were sub-sampled to speed up the filtering process (Ian Buchanan, personal communication), thereby following the APHA 2540 D method (APHA, 1995) for total suspended solids (TSS). Between 1997 and 2018, all suspended sediment samples returned from the field were analysed for TSS using the APHA 2540 D method by a commercial laboratory.

The APHA 2540 D method uses a sub-sampling procedure where the aliquot to be filtered is extracted from the original sample. The sample is normally shaken prior to withdrawing the aliquot to ensure that a representative sub-sample is extracted. This method was developed for use on wastewater samples (Ward & York, 2000) but has been used as a measure of suspended sediment in stream samples because of the convenience of subsampling¹ and the relatively low cost compared to other methods. However, investigations (e.g., Gray et al., 2000) have shown that extracting a truly representative sub-sample is difficult (Ward & York, 2000) and potentially leads to an underestimate of the true SSC, especially when the sand content is > 25% (Gray et al., 2000). Data collected from a range of stream and rivers across New Zealand suggests that the particle size distribution of sediment is strongly influenced by catchment lithology. For example, sediment samples collected from catchments dominated by weak volcanoclastic

¹ This method is compatible with undertaking multiple analysis from a single field sample and the smaller sample size means there is less chance of the filter paper becoming clogged with sediment.

material are likely to contain a high proportion of sand (Hicks et al., 2004). Unfortunately, there is no reliable riverine suspended sediment particle size data for the Waikato region. In addition to catchment lithology, particle size distribution is also impacted by flow conditions, with higher sand content likely to occur at high flow. This can lead to an underestimation of suspended sediment concentration when using the subsampling approach of the APHA 2540 D method (Gray et al., 2000; Hicks et al., 2024).

An alternative to the APHA 2540 D method is the ASTM 3977 97 method, which analyses the full field sample² and so is not vulnerable to bias (Gray et al., 2000). This approach is used by the United States Geological Survey (USGS) (Hicks, 2017) and is specified in both the turbidity and suspended sediment National Environmental Monitoring Standards (Hicks et al., 2017; Hicks et al., 2020).

A review of the Waikato region suspended sediment network by Hicks (2017) suggested that the council should transition from the APHA 2540 D method to the ASTM 3977 97 method, citing the issues outlined above. The ASTM 3977 97 method is recommended by the NEMS and often provides a more accurate and consistent measurement of suspended sediment concentration required for catchment load and yield calculations. Determining catchment suspended sediment loads and yields is an important objective of the WRC suspended sediment monitoring network. Therefore, since 2018 WRC has transitioned away from the APHA 2540 D method to the ASTM 3977 97 method.

2.4.2 APHA 2540 D (TSS) vs ASTM 3977 97 (SSC)

To quantify the possible difference between SSC determined using the APHA 2540 D (TSS) and ASTM 3977 97 (SSC) methods, WRC undertook a comparative study at 9 of the 12 automatic sites, following the approach detailed in Wyatt (2018). Three automatic sites were not investigated, either because long-term monitoring had ceased (Mangapu at SH3 Br and Matahuru at Waiterimu Rd) or because of health and safety concerns (Waipā at Otewa).

Between 15 and 40 samples were collected from runoff events at each site. Samples were submitted to the NIWA water quality laboratory and analysed using the APHA 2540 D and ASTM 3977 97 methods to measure TSS and SSC. An overview of the laboratory process is presented in Appendix 2 and individual site data are listed in Appendix 3 and 4. The aim of the comparative study was to collect at least 30 samples from each site that represented the full range of flows and suspended sediment concentrations. However, at most sites those sampling requirements were not met and further sampling is required (Table 4).

To test if there was a significant difference between TSS and SSC results, a linear regression model was fitted to the data and a two-sided t-test applied to determine whether the intercept of the regression line was significantly different to 0. In cases where the intercept was significantly different to 0 (i.e., $P < 0.05$), then the linear regression model was selected to correct TSS results to SSC equivalent results. If $P > 0.05$, then the regression line was forced through 0 (zero-intercept line) and a two-sided t test applied to test if the gradient of the line was significantly different to 1 (i.e., $P < 0.05$). If the gradient of the line was significantly different to 1, then the zero-intercept model was selected to correct the TSS results, otherwise no correction was applied. Figure 7 provides a schematic outlining the process to select an appropriate method (if any) for correcting APHA 2540 D (TSS) samples. The t-test results are included in Table 4. If correction of TSS data was required, corrections were applied to the raw data prior to input into SedRate.

² The ASTM 3977 97 method offers a selection of sub procedures (from filtering to evaporation) depending on the mass and typical particle size of sediment in the sample (Hicks, 2017).

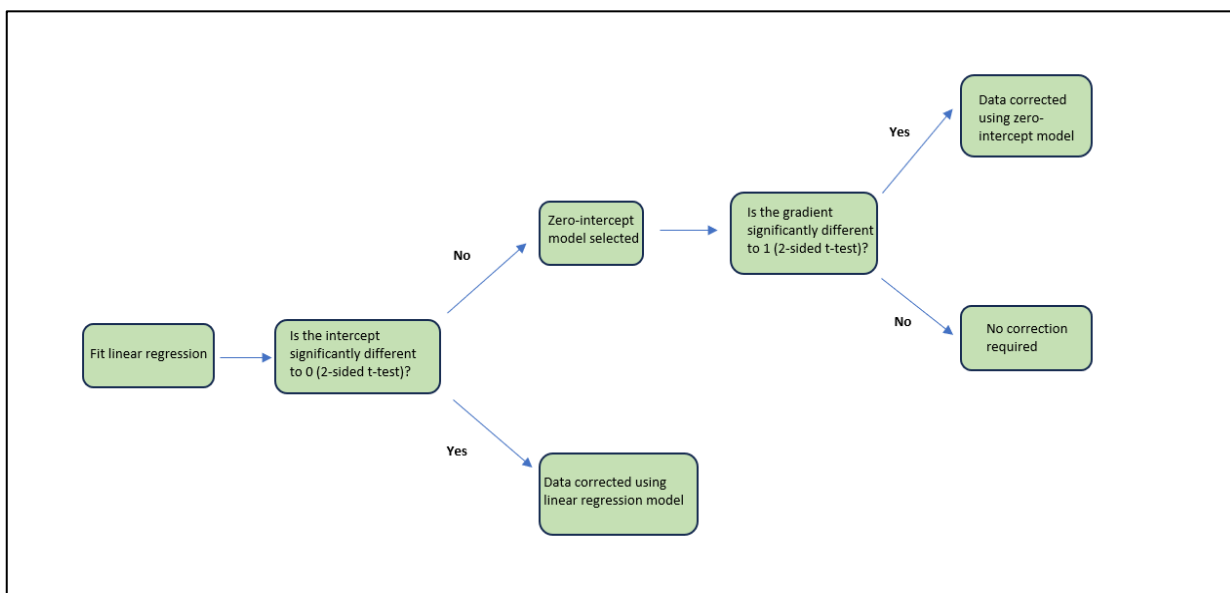


Figure 7: Process followed to select an appropriate method (if required) to correct APHA 2540 D (TSS) analysis results.

Table 4: Results from analysis of samples collected for TSS vs SSC. In the column *Sampling requirements met*: n = number of samples collected and Rep. = whether the samples cover the range of total suspended sediment load recorded at the site. The P value for the intercept is based on a two-sided t-test to determine whether the intercept was significantly different to 0. If the intercept was significantly different to 0, a zero-intercept regression model was fitted and a two-sided t-test was applied to determine whether the slope was significantly different to 1.

Catchment and Site Name	Site Number	Maximum historical measurement		No. of samples	Range of flows sampled (m ³ /s)		Range of TSS concentrations sampled (g/m ³)		Sampling requirement met		P value (intercept)	Regression model	P value (zero-intercept model)	Slope or regression equation
		Flow (m ³ /s)	TSS (g/m ³)		min	max	min	max	n†	Rep.*				
Kaniwhaniwha at Wright Rd	222_16	40.9	570	15	6.7	15.0	44	318	No	No	0.69	Zero-intercept	0.017	1.05
Mangaokewa at Te Kuiti	414_13	92.7	800	22	7.1	22.8	30	365	No	No	0.79	Zero-intercept	<0.01	1.08
Mangatutu at Walker Rd Br	476_7	35.4	2100	35	4.4	20.3	20	215	Yes	No	0.03	With- intercept	NA	y = 0.98x + 14.49
Matahuru at Myjers	516_22	34.8	2200	20	1.9	8.3	115	889	No	No	0.09	Zero-intercept	<0.01	1.50
Moakurarua at Warratah Farm Br	553_12	79.8	2500	29	9.3	31.0	31	499	No	No	0.53	Zero-intercept	0.334	NA
Opitonui at d/s Awaroa confl.	660_1	286.3	5900	35	4.9	97.3	24	1100	Yes	No	0.12	Zero-intercept	<0.01	2.05
Waingaro at Ruakiwi Road	1167_4	77.8	2400	38	1.3	69.0	23	1550	Yes	Yes	0.25	Zero-intercept	0.173	NA
Waitomo at Aranui Caves	1253_3	52.7	2520	40	2.1	10.3	24	784	Yes	No	0.41	Zero-intercept	<0.01	1.19
Wharekawa at Adams Farm Br	1312_1	222	10000	26	10.1	134.9	8	336	No	No	0.23	Zero-intercept	<0.01	1.36

* Assessment based on comparing the range of instantaneous loads determined using the TSS/SSC samples and the long-term gauging dataset. Raw data for this assessment can be found in Appendix 3 and 4.

† Assessment based on the number of samples, with at least 30 samples needed for the requirements to be met.

An example of a TSS vs. SSC plot is provided in Figure 8 for Waitomo at Aranui Caves, where the intercept of the linear regression model was not significantly different to 0, and therefore a zero-intercept model selected. The gradient of the zero-intercept model was significantly different to 1 at $\alpha = 0.05$ and hence TSS values were multiplied by 1.2 to account for the difference between TSS and SSC. Plots displaying TSS vs SSC data for each of the nine sites are displayed in Appendix 3.

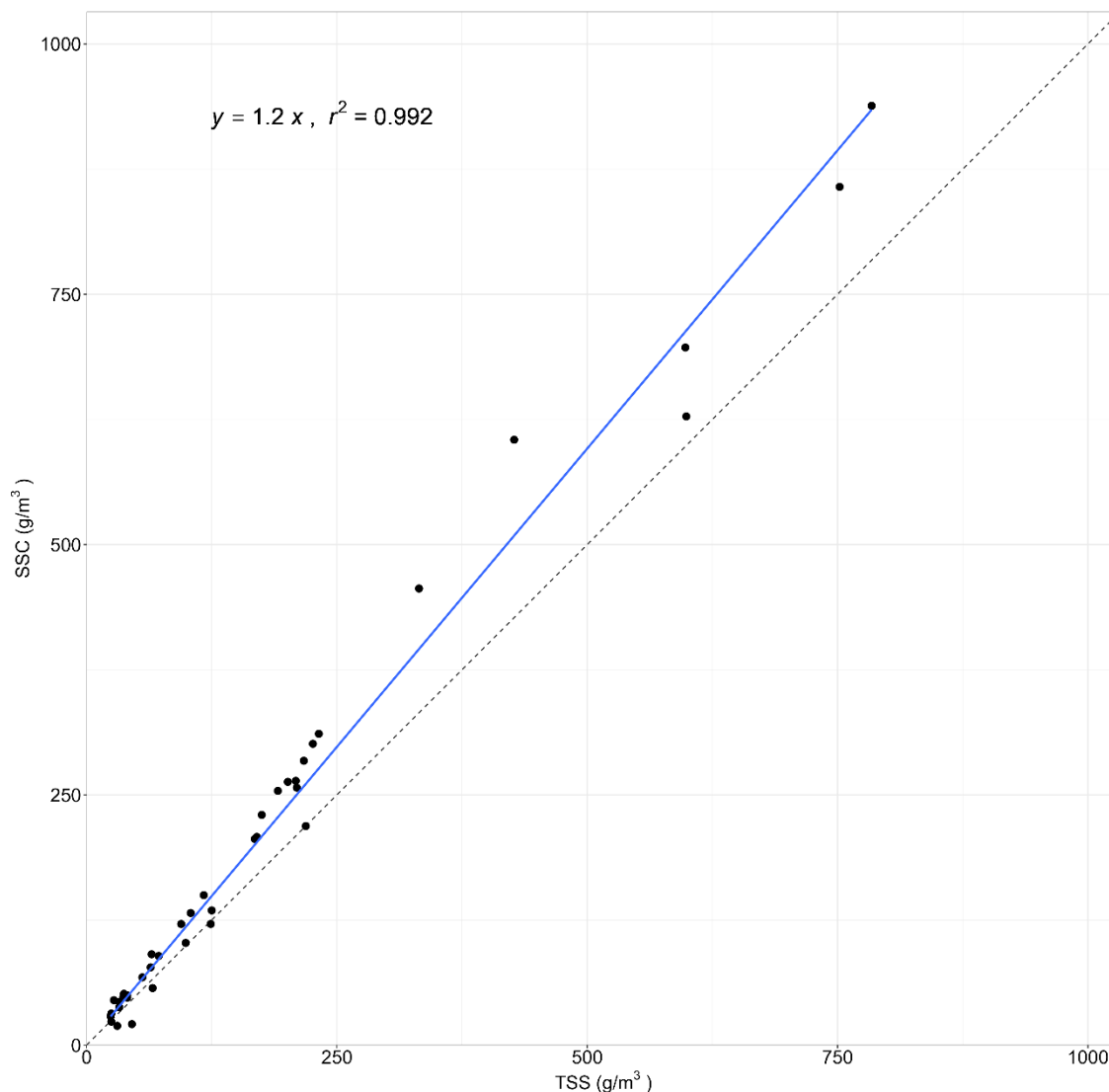


Figure 8: Example of TSS vs SSC plot from Waitomo at Aranui Caves (1253_3).

2.5 Point to cross section sample comparison

As discussed in Section 2.2, manual isokinetic depth integrating sampling provides a measure of the mean SSC over the river cross section (C_{mean}) whereas automatic samplers only collect samples at a single point in the river channel (C_{point}). To ensure that point samples represent the cross-section, Hicks et al., (2020) recommend collecting concurrent manual depth integrated and automatic samples from each automatic site across a range of flows and comparing them.

Following the installation of automatic samplers, WRC undertook ad-hoc calibration measurements at each site. Figure 7 provides an example of data collected from Waitomo at Aranui Caves. Data for other sites are presented in Appendix 5.

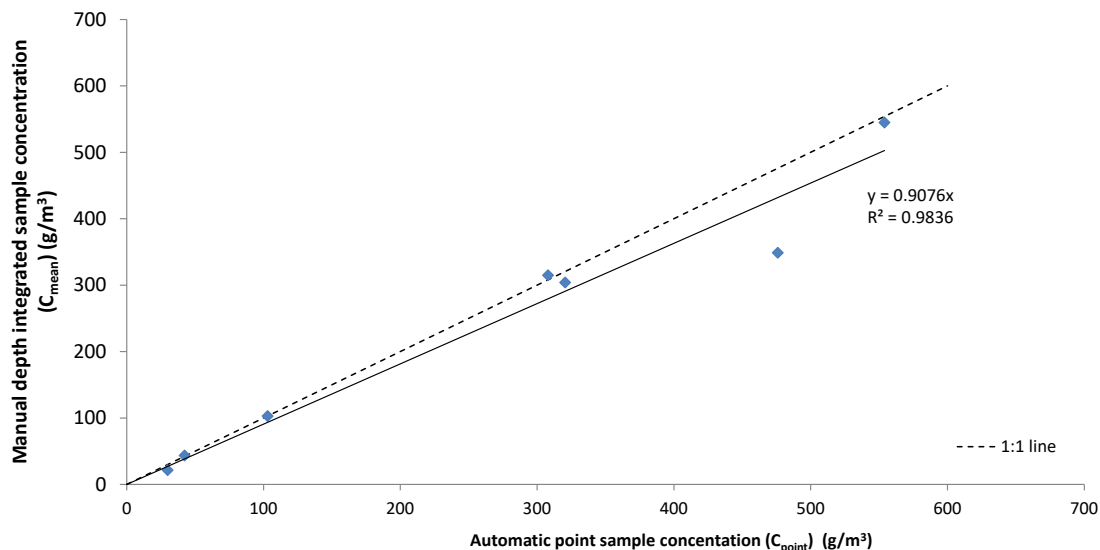


Figure 9: Manual depth integrated sample concentration (C_{mean}) compared to automatic sample concentration (C_{point}) for Waitomo at Aranui Caves.

The average ratio of $C_{mean}:C_{point}$ ranges between 0.72 and 1.34, with most sites showing a $C_{mean}:C_{point}$ ratio close to 1 (Table 5). Generally, point vs cross-section sampling did not capture the entire ranges of SSC observed during routine sediment sampling. Additionally, at most sites the ratio and variability of $C_{mean}:C_{point}$ varied with discharge (refer to Figure 10 for an example). Due to the limited range of $C_{mean}:C_{point}$ data, a correction was not applied to sediment concentration data collected from automatic sites. Therefore, in this report results for automatic sites are based on uncalibrated C_{point} data. However, the $C_{mean}:C_{point}$ results to hand at least inform on the potential bias in the yields derived from the unadjusted C_{point} data.

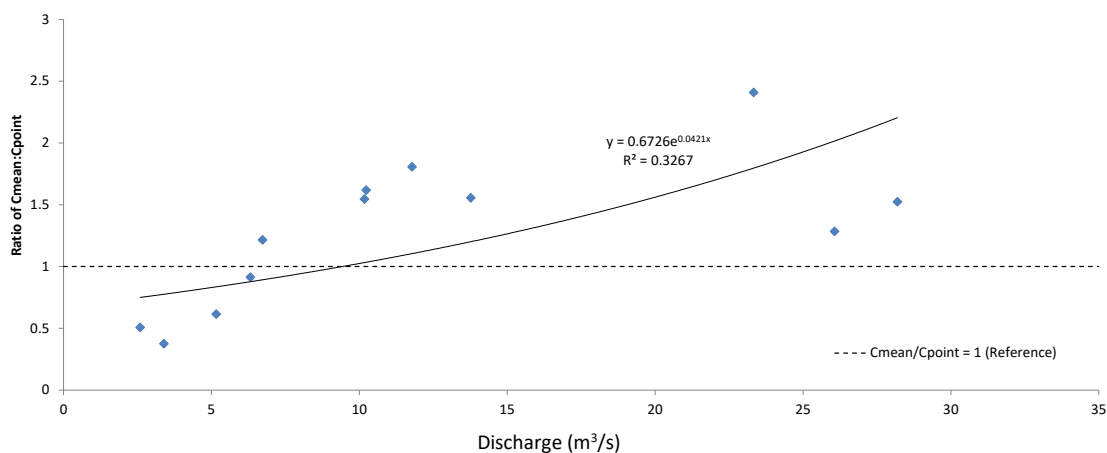


Figure 10: Ratio of $C_{mean}:C_{point}$ compared to discharge for Moakurarua at Farm Br.

Table 5: Summary of comparison between SSC concurrently measured by manual depth integrated isokinetic sampling (C_{mean}) and automatic point (C_{point}) sampling.

Site	No. of concurrent samples	Most recent sampling date	Range of flows sampled (m^3/s)		Range of concentrations sampled (g/m^3)		Average $C_{\text{mean}}:C_{\text{point}}$ ratio	$C_{\text{mean}}/C_{\text{point}}$ linear regression		Comments
			min	max	min	max		y	R^2	
Kaniwhaniwha at Wright Rd	9	25/05/2018	0.7	20.6	9	136	0.90	0.8322x	0.89	Most recent sampling 4 years old. Full range of concentrations not sampled.
Mangapu at SH3 Br U/S Mangaokewa	5	14/07/2006	3.0	34.2	17	205	1.04	0.7588x	0.91	Site has been closed since 2012. Therefore, the most recent samples are very old. Full range of concentrations not sampled.
Mangatutu at Walker Rd Br	6	28/09/2017	4.7	23.7	14	50	0.91	0.9007x	0.99	Most recent sampling 5 years old. Full range of concentrations not sampled.
Matahuru at Myjers	6	23/08/2018	3.2	17.4	73	1373	0.99	0.9818x	0.99	Most recent sampling 4 years old. Full range of concentrations not sampled.
Moakurua at Farm Br	12	22/05/2018	2.6	28.2	7	368	1.34	1.4341x	0.95	Most recent sampling 4 years old. Full range of concentrations not sampled.
Opitonui at d/s Awaroa confl.	2	29/03/2007	18.3	21.6	60	63	0.72	0.6769x	0.97	Very few samples, and over 15 years old. No slack line so unable to take manual samples at high flows.
Waingaro at Ruakiwi Rd	6	13/08/2019	3.4	32.3	21	340	0.87	0.8227x	0.98	Most recent sampling 3 years old. Full range of concentrations not sampled.
Waipā at Otewa Rd	7	16/10/2015	44.9	204.3	9	1210	1.09	1.0647x	0.96	Most recent sampling 7 years old. Full range of concentrations not sampled.
Waitomo at Aranui Cave Br	7	16/05/2012	2.9	35.5	22	545	0.90	0.907x	0.98	Most recent sampling 10 years old. Full range of concentrations not sampled.
Wharekawa at Adams Farm Br	4	11/07/2018	1.0	46.0	9	96	1	1.6088x	0.99	Most recent sampling 4 years old. Full range of concentrations not sampled.
Matahuru at Waiterimu Rd	2	29/09/2003	8.8	18.1	58	449	1.02	1.0766x	0.99	Site has been closed since 2007. Therefore, the most recent samples are very old. Full range of concentrations not sampled.

2.6 Suspended sediment calculations

2.6.1 Suspended sediment rating fit and yield calculation

As described in section 2.1, WRC uses the suspended sediment concentration-discharge (SSC-Q) rating approach to determine suspended sediment yield at monitored sites. To fit sediment ratings, WRC utilised the NIWA suspended sediment data analysis toolbox SedRate version 2.23 (SedRate). SedRate enables a sediment rating to be established for each site by applying one of four automated methods (ordinary least squares regression, minimum variance unbiased estimator, load weighted regression, or LOWESS) or alternatively by visually fitting a segmented line. If necessary, Quasi-maximum likelihood (QMLE) or smearing bias correction can be applied to the rating curve to correct for logarithm induced bias. To fit the sediment rating, the following steps were completed:

- Identification and investigation of outliers in the SSC-Q data.
- Assessment of maximum gauged discharge relative to mean annual flood discharge and the discharge above which 50% of the sediment yield occurs.
- Determining if there is a rising and falling stage separation in the SSC-Q data.
- Assessing whether the data was linear or curved in log-log space.
- Assessing the sensitivity of yields and RMSE or SE for each method.
- If a LOWESS method was selected, the stiffness factor was assessed.
- Visually assessing the fit of the rating through the SSC-Q data, overall and at high and low suspended sediment concentrations, and checking the sensitivity of the yield to manually-fitted rating adjustments at high and low flow ranges.
- Assessing whether the residuals from the fitted rating were normally distributed.
- Sensitivity checks were undertaken and compared to a manual fit at high and low flow. If a LOWESS method was selected, the stiffness factor was assessed.
- Checking if the predicted maximum suspended sediment concentrations were sensible.
- Based on the criteria above, the most appropriate yield method was selected and bias correction applied if necessary.

As well as SSC and concurrent river flow, SedRate requires flow distribution tables to calculate average annual yields over the duration of the monitoring period. The flow distribution tables were based on the long-term flow record at each site and were generated using NIWA's GenDIST software. Concurrent suspended sediment and flow data, as well as flow distribution tables were stored in a Microsoft Access Database. The SedRate software is designed to link to the Microsoft Access Database to extract all data necessary to undertake the analysis outlined above.

Figure 11 presents an example of a SedRate output from Waitomo at Aranui Caves, and Table 6 summarises the key SedRate outputs for each site, including the selected yield method. Detailed SedRate outputs and SSC-Q ratings for all 26 sites are presented in Appendix 6. It is important to note that the maximum flow for SSC samples at Whakapipi at SH22 Br. and Tapu at Tapu-Coroglen Road were below the mean annual flood flow. Furthermore, the percent of the sediment yield that occurred within the gauged range of flow (% in gauged) was less than 75% at Manganoua at Dreadnought, Matahuru at Waiterimu Road, Tapu at Tapu-Coroglen Road, Waitomo at Aranui Caves, Whakapipi at SH22 Bridge, Matahuru at Myers, and Ohinemuri at Karangahake (Table 6). At these sites a considerable proportion of the rating curve was extrapolated, mostly at high flow, and therefore the results should be treated with caution.

To compare suspended sediment yield between catchments, average annual yield was divided by catchment area (as shown in Table 1) to determine specific average annual yield. For calculation of annual suspended sediment yields at each site, the sediment ratings were

exported from SedRate into R (R Core Team, 2022) and applied to flow records on a year-by-year basis.

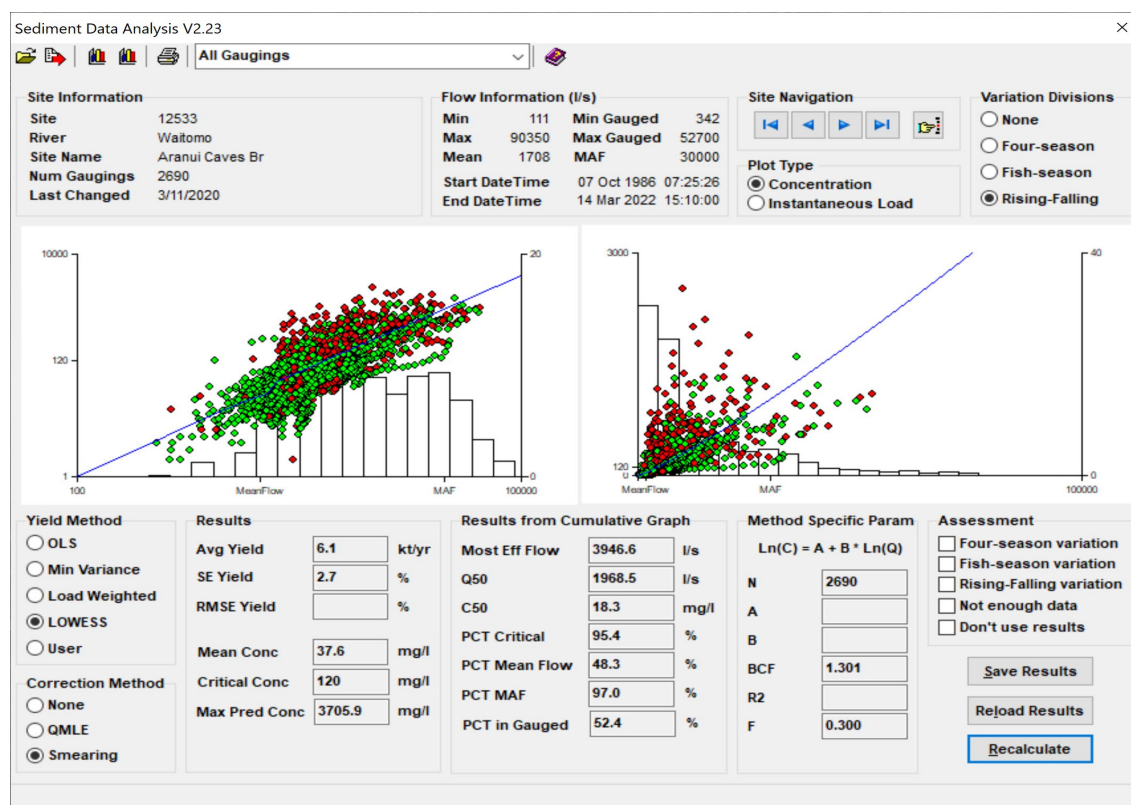


Figure 11: Example of SedRate output for Waitomo at Aranui Caves. The rating fitting method selected was LOWESS, with a stiffness factor (F) of 0.3 and using the Smearing bias correction factor. Red points were collected on rising stages, green points on falling stages. The average annual yield was 6.1 kt/y.

Table 6: Key SedRate information (excluding yield) for each site including selected rating-fitting method.

Site	River	Site name	Site type	No. of gaugings	Flow measurement period	Sediment sampling period	Residual normality	% yield in gauged range	Min. gauged flow (l/s)	Max. gauged flow (l/s)	Mean annual flood (l/s)	Q50 (l/s)	Max. predicted conc. (g/m³)	Rating-fitting method (including bias correction and stiffness factor (F))
4214	Manganoua	Dreadnought	M	73	1991 – 2022	1991 – 2004	No	97.6	761	36522	27200	3742	157	LOWESS + Smearing (F = 0.5)
4434	Mangapu	SH3	A	1379	2000 – 2022	2000 – 2012	Yes	94.5	1369	55266	41100	15969	140	Manual Fit (no bias correction)
4767	Mangatutu	Walker Road Br	A	2035	2004 – 2022	2004 – 2020	Yes	99.0	1425	35363	29100	11687	323	Min Var
5165	Matahuru	Waiterimu Rd	A	435	1984 – 2022	2003 – 2007	No	79.5	363	28859	65466	7255	846	LOWESS + Smearing (F= 0.3)
6601	Opitonui	D/S Awaroa Confl	A	1858	1991 – 2022	1991 – 2019	Yes	99.6	159	286319	130400	57155	3567	Min Var
9545	Tapu	Tapu-Coroglen Rd	M	27	1991 – 2022	1991 – 1999	No	69.3	209	27067	59700	16911	615	Min Var
9714	Tauranga-Taupō	Te Kono Slackline	M	80	1976 – 2022	1990 – 2010	No	76.7	3055	149539	152800	81818	3442	LOWESS + QMLE (F = 0.8)
11674	Waingaro	Ruakiwi Rd	A	1584	2001 – 2022	2002 – 2019	Yes	92.6	433	77819	63200	26549	2342	Min Var
11917	Waipā	Otewa	A	1289	1985 – 2022	1990 – 2016	No	95.7	2435	254178	158600	62252	3588	Manual Fit (no bias correction)
12533	Waitomo	Aranui Caves	A	2668	1986 – 2022	1990 – 2020	Yes	96.8	342	52700	30000	1969	3706	LOWESS + Smearing (F = 0.3)
12828	Whakapipi	SH22 Br	M	59	1984 – 2022	1991 – 2000	No	34.4	120	11963	34300	20673	2645	LOWESS + Smearing (F= 0.3)
13121	Wharekawa	Adams Farm Br	A	1055	1991 – 2022	1991 – 2020	No	98.8	321	222118	143400	65885	562	LOWESS + QMLE (F=0.5)
22216	Kaniwhaniwha	Wright Road	A	618	2015 – 2022	2016 – 2020	No	99.9	721	40947	28500	11544	416	Manual Fit (no bias correction)
41413	Mangaokewa	Te Kuiti	A	284	1983 – 2022	1990 – 2020	No	98.1	797	92682	57600	16615	956	LOWESS + No Bias Correction (F=0.3)
51622	Matahuru	Myjers	A	1283	2006 – 2022	2006 – 2020	No	95.1	842	43261	30624	13221	1831	LOWESS + QMLE (F=0.3)
55312	Moakurarua	Farm Br	A	457	2015 – 2022	2015 – 2020	No	95.6	2233	79770	63800	25593	1429	Min Variance
61916	Ohinemuri	Karangahake	M	64	1956 – 2022	1986 – 2015	No	47.2	1228	246486	447300	267540	2549	LOWESS + QMLE (F = 0.8)
66913	Oraka	Pinedale	M	38	1979 – 2022	1986 – 2019	No	85.2	1950	13808	15200	4041	10441	LOWESS Smearing (F = 0.3)
74915	Piako	PT Road Br	M	163	1972 – 2022	1986 – 2019	No	91.8	627	90548	83900	30264	211	LOWESS + Smearing (F = 0.3)
112218	Waihou	Okauia	M	101	1982 – 2022	1986 – 2006	No	92.0	17945	157578	130000	40004	2035	LOWESS + Smearing (F = 0.3)
112234	Waihou	Te Aroha	M	44	1965 – 2022	1986 – 2006	No	99.3	19094	374134	185800	45493	323	LOWESS + QMLE (F = 0.3)
113164	Waikato	Ham Traffic Br	M	58	1975 – 2022	1991 – 2004	No	94.8	168130	697766	505600	295691	30	LOWESS + QMLE (F = 0.8)
119111	Waipā	Whatawhata	M	82	1972 – 2022	1990 – 2009	No	99.8	12002	811922	444900	201501	197	LOWESS + Smearing (F = 0.3)
119113	Waipā	SH31 Br Otorohanga	M	13	1981 – 2022	1990 – 2019	No	97.3	3255	416166	224800	111867	2169	LOWESS + QMLE (F = 0.5)
124918	Waitoa	Mellon Rd Recorder	M	188	1986 – 2022	1986 – 2007	No	98.0	688	75324	38200	12023	119	LOWESS + Smearing (F = 0.5)
1131117	Waikato	Rangiriri Br	M	67	1965 – 2022	1991 – 2007	No	97.9	194707	1382334	866500	442246	103	LOWESS + QMLE (F=0.8)

2.6.2 Concentration residuals time history analysis

The fluctuations in annual suspended sediment yields are primarily due to changes in the amount and intensity of rainfall over time. However, several other factors such as land use and land use management may also drive changes in suspended sediment yields over time. Separating climatic factors from other long-term land use and land management effects is difficult but can be achieved using a range of statistical approaches. Our approach was to remove the influence of rainfall variability by exploring for a time trend in the residuals in the SSC-Q rating.

For this, a linear trend line was fitted to the natural log residuals, i.e., $\ln(C_{\text{observed}}/C_{\text{predicted}}) = A + Bt$ (where A and B are the regression intercept and slope and t is time in days since 1/1/1900), and a two-sided t-test was applied to test if B was significantly different to 0. In some cases, the time-trend analysis was reduced to a specified time span to test for the influence of factors such as change from TSS to SSC laboratory methods.

The annual percentage rate of change in $C_{\text{observed}}/C_{\text{predicted}}$ associated with a significant time-trend was calculated by differentiating the regression equation, giving $d(C_{\text{observed}}/C_{\text{predicted}})/dt = 365 \cdot 100 \cdot B \cdot e^A \cdot e^{Bt}$, where 365 converts time units from days to years and 100 converts to a percentage. Since this rate-of-change is time dependent, it was evaluated for the mid-date of the monitoring period.

Of the 26 sites across the WRC network, only 11 sites had new suspended sediment concentration data since the last report in 2014 (Hoyle, 2014). Hence, time-trend analysis was only applied to these 11 sites, with results displayed in Table 8. For sites where TSS vs SSC corrections were implemented, time-trend analysis was applied to the corrected data.

Figure 12 presents an example of an output of the concentration residuals time history analysis for Mangatutu at Walker Rd Bridge. In this example, the slope ($B = 5.718\text{E-}5$) is positive, and the t test statistic exceeds the critical value at $\alpha = 0.05$. Therefore, the null hypothesis $H_0: B = 0$ is rejected and we conclude that the slope of the line is significantly different to 0. Using this information, we can conclude there is evidence of a positive trend and that the sediment concentration at a given discharge has increased over the monitoring period. With the trendline intercept $A = -2.599$ and mid-date (t) = 2012 = 40909, the indicated annual average rate of concentration increase at given Q is 1.6%/y.

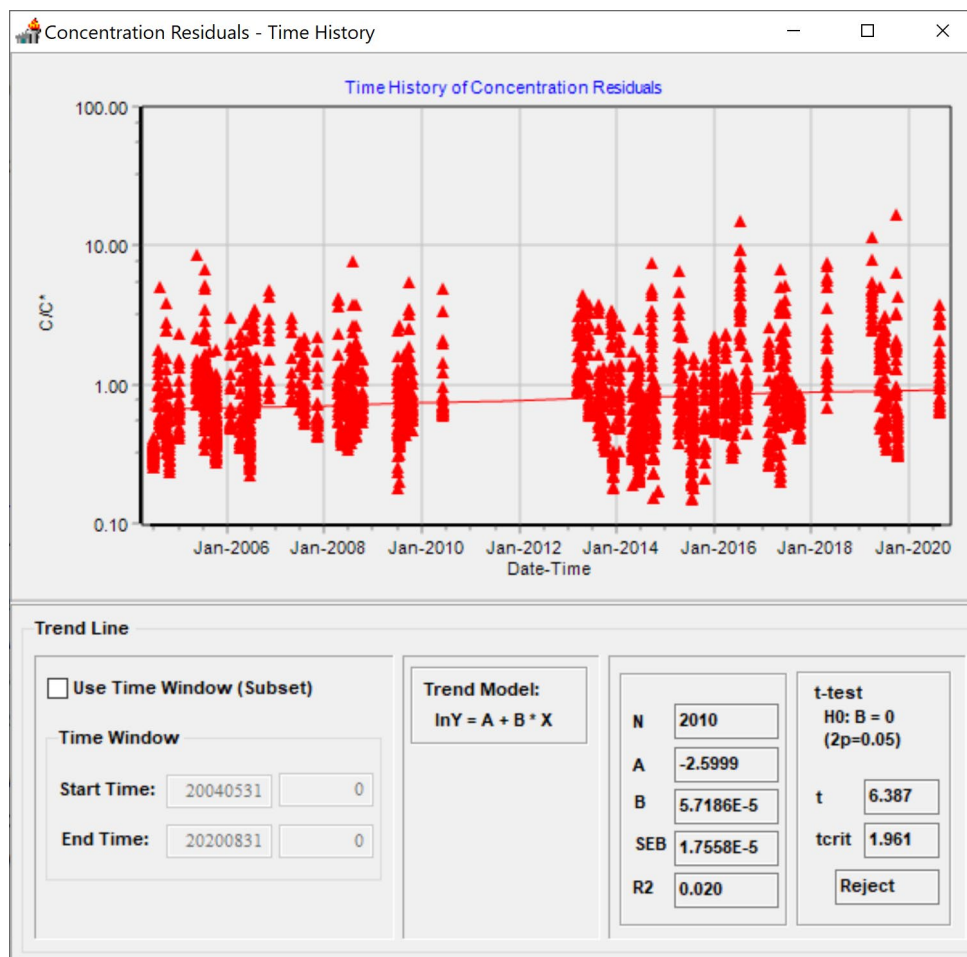


Figure 12: Example of output of time trend analysis from SedRate for Mangatutu at Walker Rd Br.

3 Results and discussion

This section presents and discusses results from each sediment monitoring site, covering a general overview of key catchment characteristics (surface geology, slope, dominant soil types, and land cover) and results on suspended sediment yield, specific suspended sediment yield, annual specific suspended sediment yield, and, where sufficient data was available, SSC trend analysis. Finally, this section describes suspended sediment delivery in a regional context, and the results are discussed to understand the relative contributions of sediment from individual sites to the overall regional sediment load.

Table 7 presents average annual yield (kt/y), average annual specific yield (t/km²/y), and average concentration (g/m³) for each monitoring site, both before and after being corrected for the difference between TSS and SSC. Results and statistics from trend analysis are displayed in Table 8, with associated graphs for individual sites presented in the proceeding subsections.

Table 7: Average annual yield (including error), average concentration and average annual specific yield for each monitoring site, both before and after being corrected for the difference between TSS and SSC (where a correction was possible). Moakurarua and Waingaro were the only sites where the difference between TSS and SSC was not statistically significant.

Site	River	Site name	Site type	Uncorrected			Corrected for TSS vs SSC						
				Average annual yield (kt/y)	SE (%)	RMSE (%)	Mean conc. (g/m ³)	Average annual specific yield (t/km ² /y)	Average annual yield (kt/y)	SE (%)	RMSE (%)	Mean conc. (g/m ³)	Average annual specific yield (t/km ² /y)
4214	Manganoua	Dreadnought	M	1.5	9.8	-	11.9	8.2	-	-	-	-	-
4434	Mangapu	SH3	A	11.0	3.6	-	30.1	73.0	-	-	-	-	-
4767	Mangatutu	Walker Road Br	A	5.4	-	1.6	20.3	44.5	6.8	-	1.3	31.9	56.0
5165	Matahuru	Waiterimu Rd	A	8.2	5.6	-	41.6	77.5	-	-	-	-	-
6601	Opitonui	D/S Awaroa Confl	A	4.8	-	3.2	13.7	165.5	9.1	-	3.0	27.3	317
9545	Tapu	Tapu-Coroglen Rd	M	0.7	-	21.5	5.4	27.6	-	-	-	-	-
9714	Tauranga-Taupō	Te Kono Slackline	M	16.8	18.7	-	11.3	85.1	-	-	-	-	-
11674	Waingaro	Ruakiwi Rd	A	11.9	-	2.1	27.4	100.1	11.9	-	2.1	27.4	100.1
11917	Waipā	Otewa	A	52.3	3.2	-	35.5	163.7	-	-	-	-	-
12533	Waitomo	Aranui Caves	A	6.1	2.7	-	37.3	168.6	8.4	2.7	-	51.5	232
12828	Whakapipi	SH22 Br	M	2.1	37.4	-	11.5	43.7	-	-	-	-	-
13121	Wharekawa	Adams Farm Br	A	3.0	4	-	6.7	64.3	4.0	4	-	9.1	85.2
22216	Kaniwhaniwha	Wright Road	A	8.4	4.4	-	31.1	82.3	8.4	4.4	-	31.1	82.3
41413	Mangaokewa	Te Kuiti	A	14.8	9.1	-	27.5	85.2	15.2	9	-	36.2	87.6
51622	Matahuru	Myjers	A	14.7	3.7	-	100.9	176.3	21.5	3.8	-	155.1	257.8
55312	Moakurarua	Farm Br	A	28.8	-	3.2	48.9	139.5	28.8	-	3.2	48.9	139.5
61916	Ohinemuri	Karangahake	M	32.2	25.9	-	10.8	110.3	-	-	-	-	-
66913	Oraka	Pinedale	M	5.1	22.1	-	37.4	39.2	-	-	-	-	-
74915	Piako	PT Road Br	M	11.1	8.3	-	22.1	20.6	-	-	-	-	-
112218	Waihou	Okauia	M	41.7	10.4	-	33.3	51.7	-	-	-	-	-
112234	Waihou	Te Aroha	M	61.0	11.1	-	43.9	55.2	-	-	-	-	-
113164	Waikato	Ham Traffic Br	M	65.7	11	-	7.5	7.9	-	-	-	-	-
119111	Waipā	SH23 Br Whatawhata	M	154.2	7.8	-	31.7	53.9	-	-	-	-	-
119113	Waipā	SH31 Br Otorohanga	M	91.1	12.8	-	35.4	99.2	-	-	-	-	-
124918	Waitoa	Mellon Rd Recorder	M	4.6	6.9	-	17.4	11.2	-	-	-	-	-
1131117	Waikato	Rangiriri Br	M	239.5	9.2	-	18.5	19.4	-	-	-	-	-

Table 8: Output from concentration residuals time history analysis for river suspended sediment monitoring sites with updated data since 2014.

Site	River	Site name	Monitoring period	Number of samples	Slope (B) [†]	SE slope (B) [‡]	Intercept	T statistic	P value*	R ²	Trend	Annual % change ³
22216	Kaniwhaniwha ¹	Wright Road	2015 - 2022	618	-1.38E-04	5.39E-05	5.66	-2.55	1.09E-02	0.01	Decreasing	-3.6
41413	Mangaokewa ¹	Te Kuiti	1990 - 2020	284	4.13E-05	1.15E-05	-1.70	3.58	4.02E-04	0.04	Increasing	1.4
4767	Mangatutu ¹	Walker Road Br	2004 - 2020	2035	3.15E-05	6.93E-06	-1.45	4.54	5.86E-06	0.01	Increasing	1.0
51622	Matahuru ¹	Myjers	2007 - 2020	1283	-1.17E-04	-1.04E-05	4.67	-11.25	4.60E-28	0.09	Decreasing	-3.5
55312	Moakurua ¹	Farm Br	2015 - 2020	457	3.95E-04	6.29E-05	-17.16	6.29	7.68E-10	0.08	Increasing	12.6
6601	Opitonui ¹	D/S Awaroa Confl	1991 - 2019	1858	4.13E-05	7.22E-06	-1.89	5.50	4.41E-08	0.02	Increasing	1.1
66913	Oraka ²	Pinedale	1986 - 2020	38	-7.53E-05	-2.48E-05	2.37	-3.03	4.47E-03	0.20	Decreasing	-1.7
11674	Waingaro ¹	Ruakiwi Rd	2002 - 2019	1578	7.26E-05	6.99E-06	-3.06	10.38	1.6E-24	0.06	Increasing	2.4
11917	Waipā	Otewa	1990 - 2016	1286	-1.01E-04	9.52E-06	3.75	-10.64	2.06E-25	0.08	Decreasing	-3.5
12533	Waitomo ¹	Aranui Caves	1990 - 2020	2669	-8.99E-06	4.93E-06	0.06	-1.82	6.82E-02	0.01	No trend	No trend
13121	Wharekawa ¹	Adams Farm Br	1991 - 2020	1055	7.50E-05	8.09E-06	-3.21	9.28	9.55E-20	0.08	Increasing	2.0

[†] Slope of the linear regression model fitted to the log (observed/predicted SSC) and time

[‡] Standard error of the slope coefficient

* A student's t-test was applied to test the hypothesis that the slope on a linear relation between log (observed/predicted SSC) and time was significantly different from zero at $\alpha = 0.05$.

¹ Trend analysis undertaken using corrected data to account for differences between TSS and SSC

² The results for the Oraka site should be treated with caution due to the small sample size (n = 38)

³ Trend magnitude estimated for mid-date of monitoring period.

3.1.1 Kaniwhaniwha Stream

The Kaniwhaniwha catchment monitored at Wright Rd (222_16) is 103 km² with a mean rainfall of 1914 mm/y (Table 1). More than 60% of the catchment is classified as LUC class 6 or above (Figure 2) and is strongly rolling or steeper (Figure 3). Surface lithology is dominated by Basaltic volcanic material (38%), Pleistocene sediment (25%), and Tertiary sedimentary rocks (23%) (Figure 5). Predominant soil orders are Brown Soils (34%) and Allophanic Soils (31%), with some Granular Soils (15%) and Recent Soils (17%) (Figure 3). The land cover over the monitoring period was dominated by exotic grassland (i.e., pasture) (57%), and indigenous forests (41%) (Figure 4). The Wright Rd site, established in 2015, was commissioned to facilitate ongoing monitoring in the Waipā Catchment. More specifically the Kaniwhaniwha catchment has been identified as a priority one catchment for soil conservation in the Waipā Catchment Plan (WRC, 2014). Between 2016 and 2020, 618 samples were collected at the site, mostly during rainfall-runoff events by ISCO autosampler (Table 6).

The average annual suspended sediment yield for the period 2015 - 2022 was 8.4 kt/y, with an average annual specific yield of 82.3 t/km²/y and a mean concentration of 31.1 g/m³ (Table 7). These results should be interpreted with caution due to the relatively short sampling duration and potential bias introduced by unusually wet or dry years during this period. There was a significant difference between TSS and SSC ($p < 0.05$). However, since the regression slope was 1.05 (Table 4), and most of the collected data was already SSC, applying the correction did not alter the average annual specific yield (Table 7). During the monitoring period, annual specific yields ranged between 35 and 159 t/km² (Figure 13). Results from a one-off suspended sediment snapshot exercise (Wyatt, 2017) suggested that sediment generation is elevated in the western hills, which are characterised by sandstone, siltstone, and mudstone lithologies (Norris et al., In Prep). In 2022, a catchment scale riparian survey of pastoral land found that 65% of surveyed bank length was effectively fenced. Additionally, 15% of surveyed bank length was either actively eroding (2%) or recently eroded (13%) (Norris, 2022).

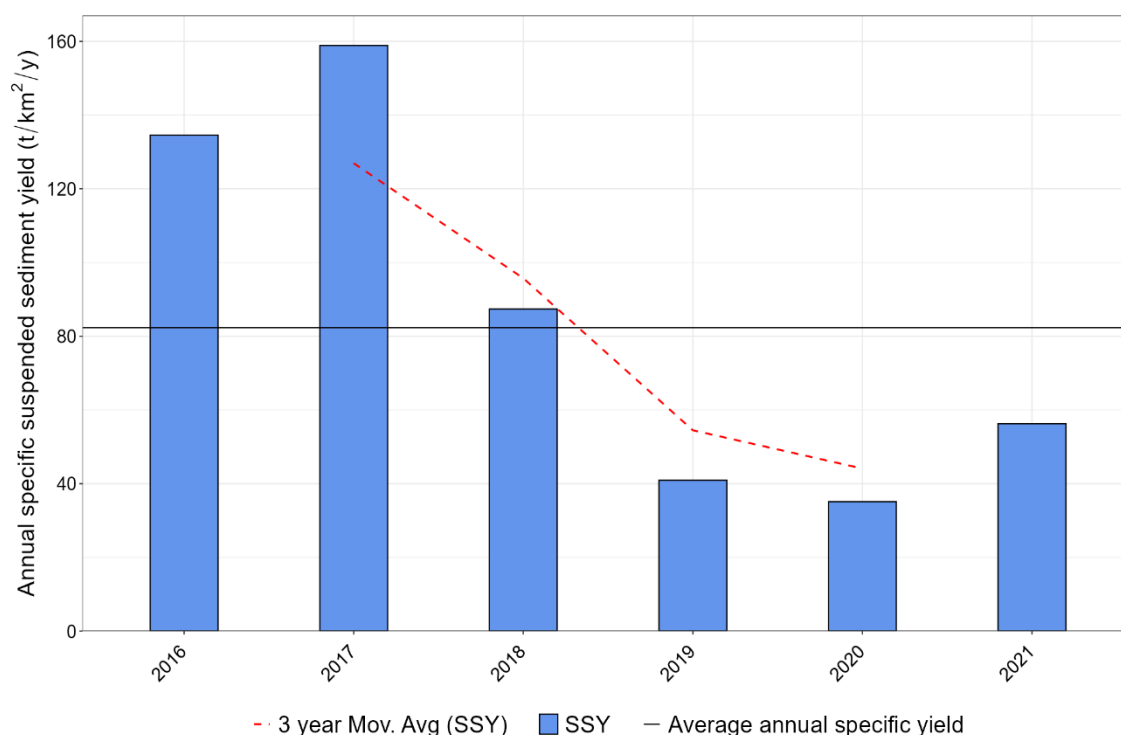


Figure 13: Annual specific suspended sediment yield for Kaniwhaniwha at Wright Rd. The red line is a three-year moving average, and the black line represents average annual specific yield for the entire monitoring period.

After adjusting for the difference between TSS and SSC, there was a statistically significant ($P < 0.05$) negative trend in concentration residuals between 2016 and 2020 (Figure 14), suggesting a decrease in suspended concentration relative to discharge. However, these results should be interpreted with caution given the short duration of sampling and the non-normality of the residuals. The Kaniwhaniwha catchment is part of the redesigned Catchment Environmental Monitoring (CEM) programme, and it is anticipated that more detailed suspended sediment and catchment data will be collected in the future and will allow for more comprehensive time-trend analysis to be undertaken.

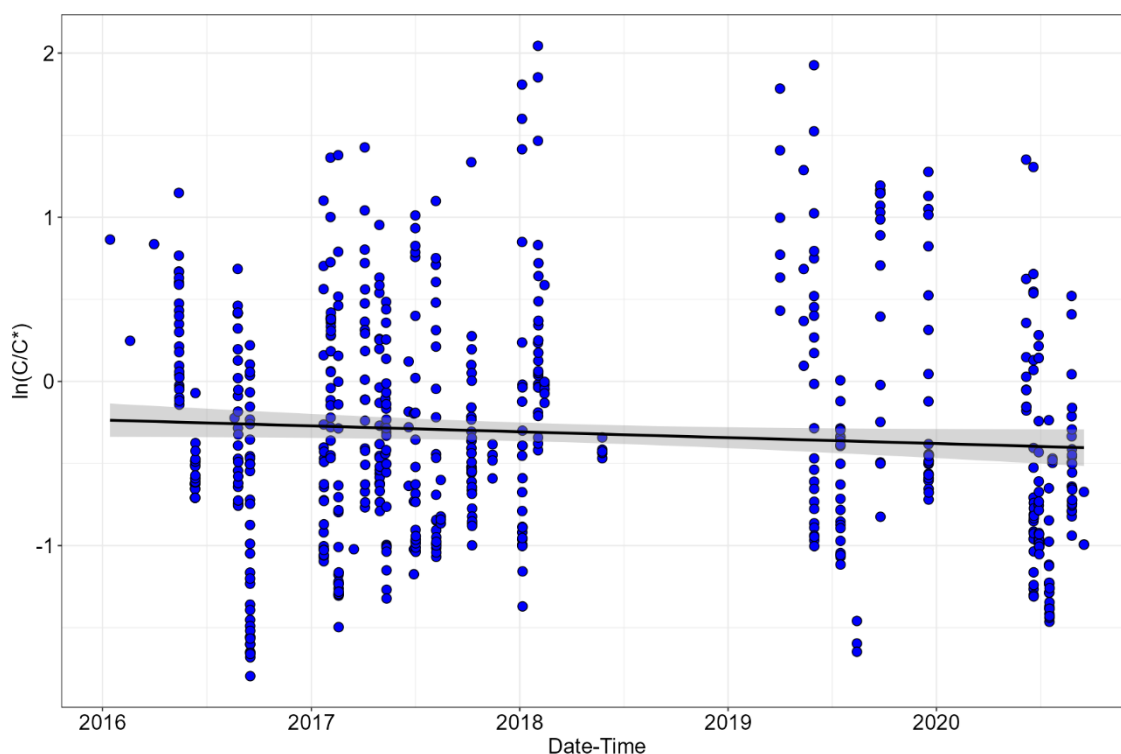


Figure 14: Suspended sediment rating residual (C/C^*) versus time for Kaniwhaniwha at Wright Rd. The black line is a linear regression, with 95% confidence intervals represented by the shaded area. The trend is significant ($P < 0.05$).

Kaniwhaniwha at Wright Rd is a routine water quality monitoring site, and data on the LAWA website (www.lawa.org.nz) showed that between 2011 and 2021 (10-year trend), both clarity and turbidity were “likely degrading” but that between 2016 and 2021 (5-year trend) turbidity was “very likely improving” (clarity was not assessed). The short-term clarity and turbidity trend in the LAWA data is consistent with the suspended sediment monitoring network time trend (Figure 14).

3.1.2 Mangaokewa Stream

The Mangaokewa catchment monitored at Te Kuiti (414_13) is 174 km² (Table 1) and has a mean rainfall of 1540 mm/y (Table 1). About 68% of the catchment is mapped as LUC class 6 or above (Figure 2) and 78% of the catchment is strongly rolling or steeper (Figure 3). Surface lithology is dominated by Ignimbrite (61%) and Limestone (18%) (Figure 5). Allophanic Soils (48%) and Podzol Soils (39%) are the dominant soil orders (Figure 3). Land cover is mostly high producing exotic grasslands (72%), with some indigenous (15%) and exotic (8%) forest (Figure 4).

The Te Kuiti monitoring site has operated since 1990, with 284 suspended sediment samples collected up until 2020. However, most samples were collected over two time periods, the first of which was between 1990 and 2000, when only manual depth integrated samples were collected. The second period was between 2017 and 2020, when an autosampler was installed

at the site following a large landslide on farmland in the headwaters adjacent to Mangaokewa Rd in September 2017 (Figure 15).



Figure 15: Aerial photograph of landslide in the headwaters of the Mangaokewa stream in September 2017 (Photo; Stuff, 2017).

The average annual suspended sediment yield at this site for the period 1983 – 2022 was 14.8 kt/y, with an average concentration of 27.5 g/m³. The average annual specific suspended sediment yield was 85.2 t/km²/y (Table 7). After correction for the difference between TSS and SSC the average annual specific suspended sediment yield was 87.6 t/km²/y (Table 7). Annual specific yields ranged between 15 and 203 t/km², with the highest yield recorded in 1998 (Figure 16). For most other years, yields were below 100 t/km².

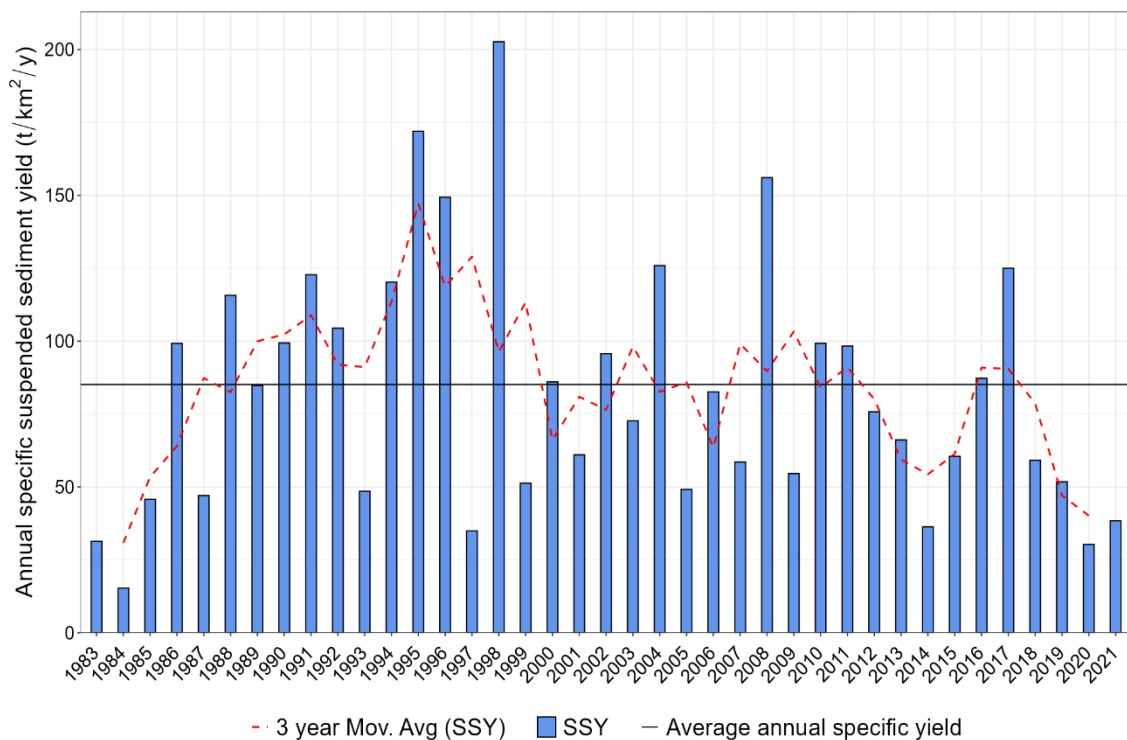


Figure 16: Annual specific suspended sediment yield for Mangaokewa at Te Kuiti. The red line is a three-year moving average, and the black line represents average annual specific yield for the entire monitoring period.

After adjusting for the difference between TSS and SSC, there was a statistically significant ($P < 0.05$) positive trend in concentration residuals between 2016 and 2020 (Figure 17), suggesting an increase in suspended concentration relative to discharge.

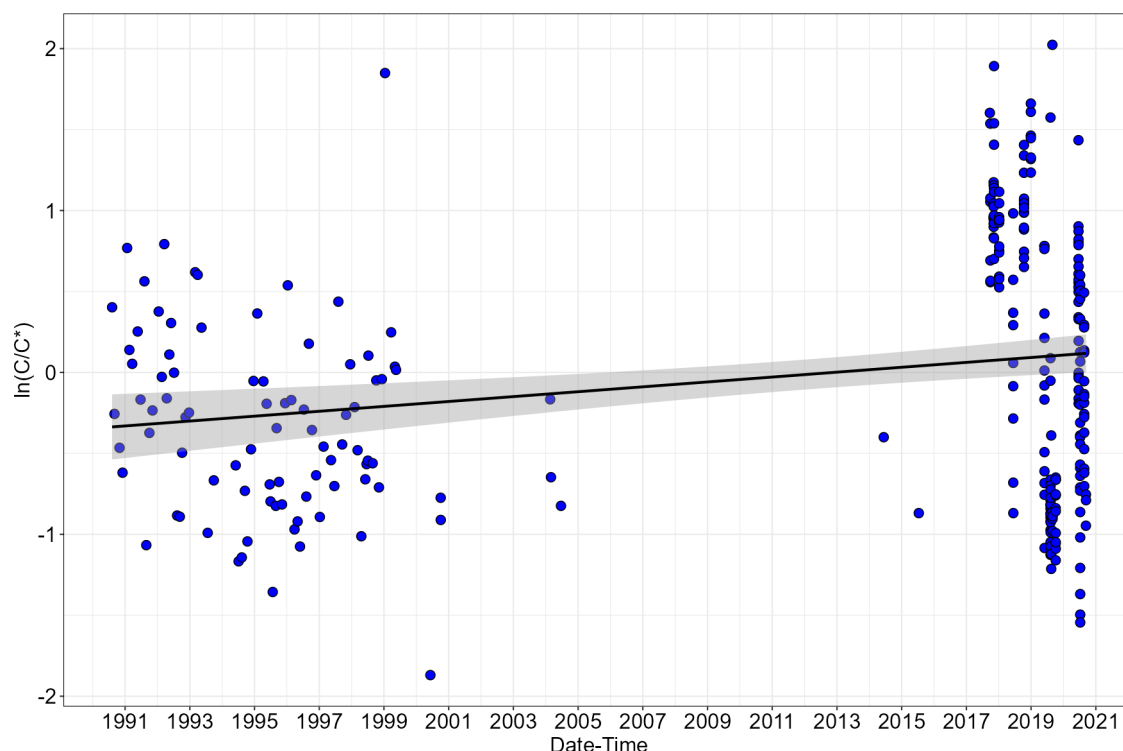


Figure 17: Suspended sediment rating residual (C/C^*) versus time for Mangaokewa at Te Kuiti. The trend is significant ($P < 0.05$).

Separate time trend analyses were applied to data collected from 1990 – 2015 and 2017 – 2020 (Figure 18). From 1990 – 2015, there was a statistically significant negative trend in $\ln(C/C^*)$ over time, suggesting a decrease in suspended sediment concentration relative to discharge. Although the average concentration residual during the 2017 – 2020 period was significantly higher than for the 1990 – 2015 period, the concentration residuals showed a statistically significant decrease over the 2017 to 2020 period (Figure 17). While these results should be interpreted with caution due to the differing sampling methods used across periods and the gaps between samplings, it remains likely that the large increases in suspended sediment load in 2017 were a result of the Mangaokewa slip (Figure 15), with the subsequent decreases caused by reduced sediment supply at the slip site and transfer of sediment downstream of the monitoring site. Such large erosion events can have a significant impact on sediment delivery within a catchment, leading to increased suspended sediment concentrations relative to flow for a period after the event.

Since the annual yields shown in Figure 16 are derived from a single rating based on data collected from 1983 to 2022, these rating changes over time mean that the estimated annual yields in Figure 16 are likely overstated prior to 2017 and understated in the years following 2017.

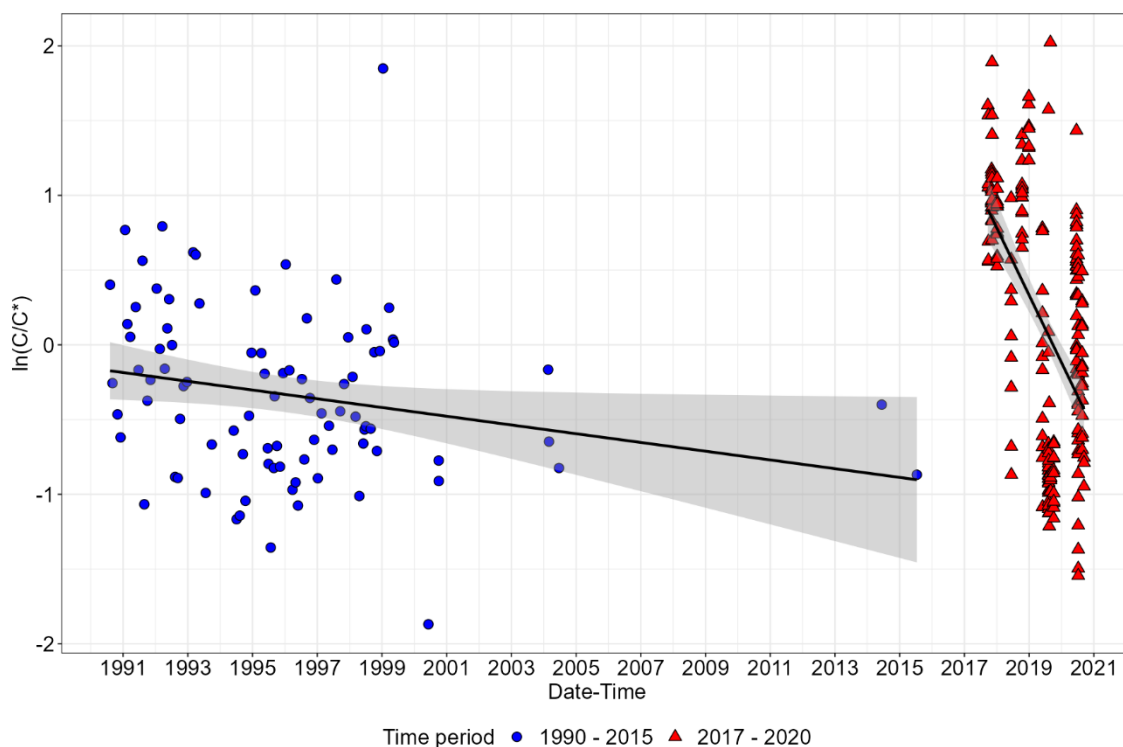


Figure 18: Suspended sediment rating residual (C/C^*) versus time for Mangaokewa at Te Kuiti. Trend analysis was undertaken over two separate periods: 1990 – 2015 and 2017 – 2020. The trend was significant for both periods ($P < 0.05$).

3.1.3 Mangapu Stream

The Mangapu catchment monitored at SH3 Bridge (443_4) has an area of 150 km² (Table 1), with LUC class 3 (17%), class 4 (26%), and class 6 (41%) being the most common (Figure 2). Lithology is dominated by siltstones and sandstones, interspersed with Holocene sediment (Figure 6). Limestone is common, particularly in the upper south-western area of the catchment. As a proportion of the catchment area, 66% is covered by Allophanic Soils, with the remaining area covered by Brown Soils and Gley Soils (Figure 4). Exotic grassland (pasture) occupies most of the catchment area, constituting 86% of the cover (Figure 4).

Between 2000 and 2012, 1,379 samples had been collected at the site, mostly by autosampler (Table 6). Average annual suspended sediment yield was 11 kt/y and average annual specific yield was 73.1 t/km²/y. Average suspended sediment concentration was 30 g/m³ (Table 7). The highest annual specific yield was in 2008 and was 123 t/km², but values were typically below 75 t/km² (Figure 19). The SSC-Q rating was fitted manually because of the high variability in suspended sediment concentration between mean flow and mean annual flood (Appendix 6). Because suspended sediment hasn't been sampled since 2012, no time trend analysis was undertaken.

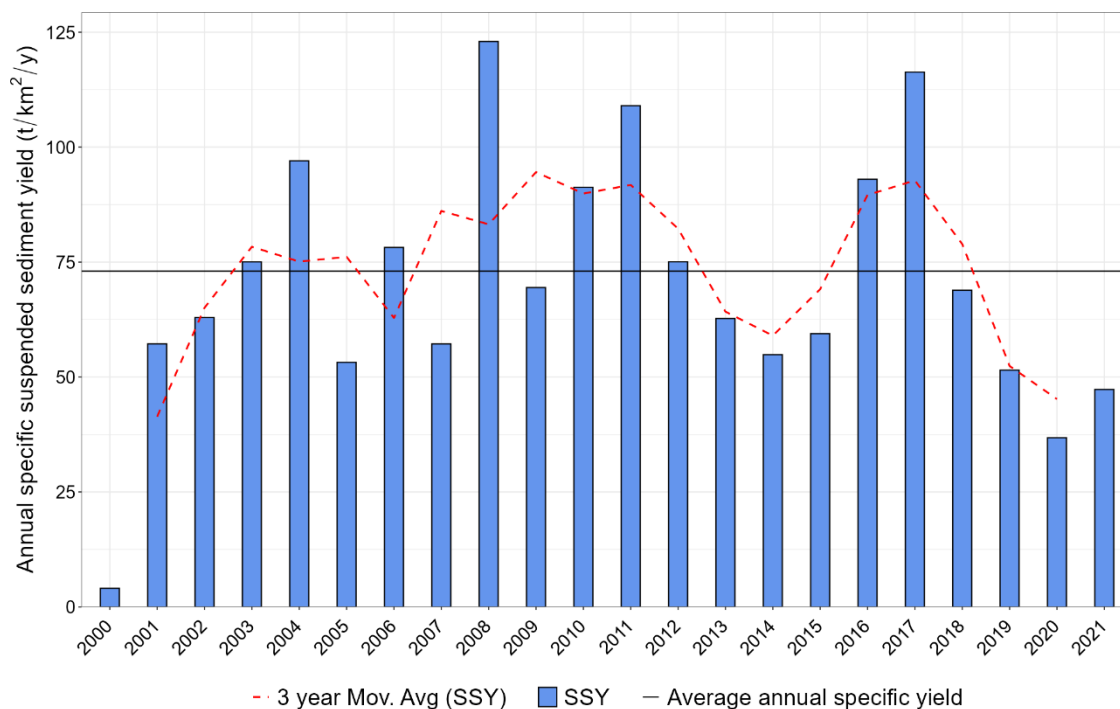


Figure 19: Annual specific suspended sediment yield for Mangapu at SH3 bridge. The red line is a three-year moving average.

3.1.4 Mangatutu Stream

The Mangatutu catchment is monitored at Walker Rd Bridge (476_7) and has an area of 122 km^2 and mean annual rainfall of 1,484 mm (Table 1). Approximately 62% of the catchment is LUC class 6 or above, and 37% is LUC class 3 or below (Figure 2). Pleistocene alluvial deposits dominate the lower catchment, while greywacke and ignimbrites are common across the mid to upper reaches of the catchment (Figure 6). Allophanic Soils are the dominant soil order, covering 63% of the catchment area (Figure 4). Most of the catchment is either exotic grassland (52%) or indigenous forest (42%) (Figure 5).

Between 2004 and 2020, a total of 2,035 samples were collected during runoff events, mostly by autosampler (Table 6). Average annual suspended sediment yield between 2004 and 2022 was 5.4 kt/y , with a specific yield of 44.5 $\text{t/km}^2/\text{y}$ and a mean sediment concentration of 20.3 g/m^3 (Table 7). When corrected for the difference between TSS and SSC, the average annual specific yield was 56 $\text{t/km}^2/\text{y}$ (Table 7). Between 2004 and 2021, the annual specific suspended sediment yield ranged between 25 and 80 t/km^2 , with the highest values occurring in 2008 and 2017 (Figure 20).

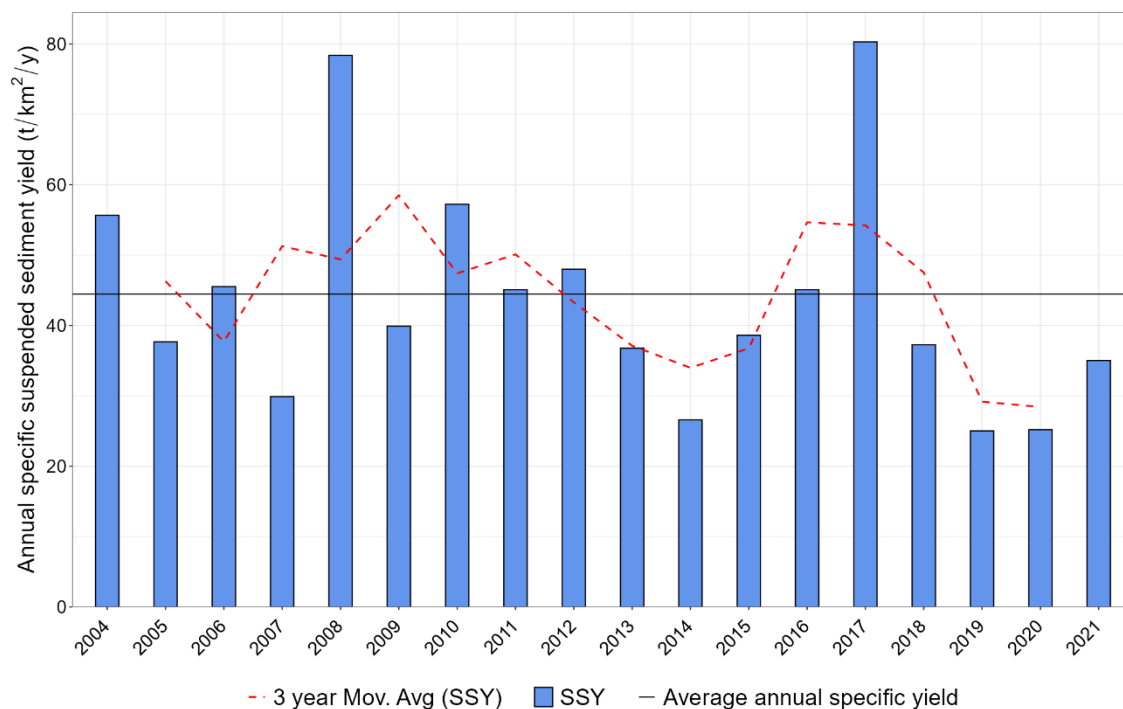


Figure 20: Annual specific suspended sediment yield for Mangatutu at Walker Rd Br. The red line is a three-year moving average.

After adjusting for the difference between TSS and SSC, there was a statistically significant ($P < 0.05$) positive trend in concentration residuals between 2004 and 2020 (Figure 21), suggesting an increase in suspended concentration relative to discharge. This is consistent with the findings of Hoyle (2014) who observed an increasing trend between 2004 and 2013.

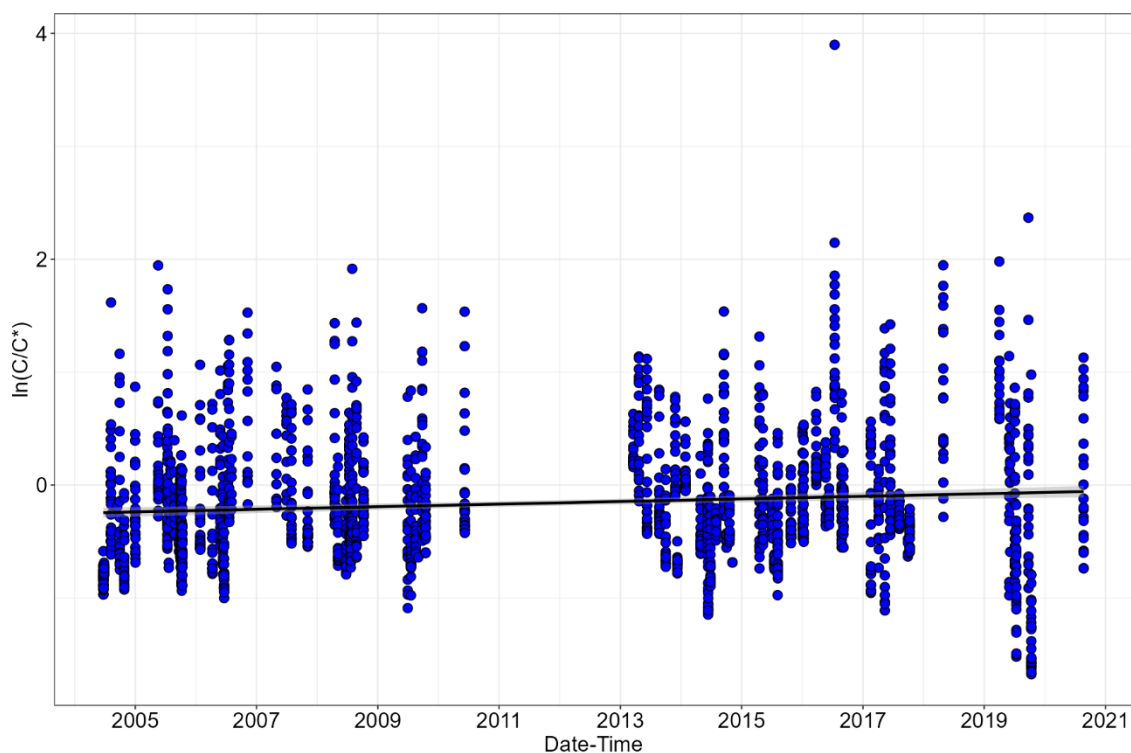


Figure 21: Suspended sediment rating residual (C/C^*) versus time for Mangatutu at Walker Rd Br. The trend is significant ($P < 0.05$).

Separate time trend analyses were applied to data collected from 2004 – 2011 and from 2013 – 2020 (Figure 22). Analysis revealed a statistically significant positive trend from 2004 – 2011, consistent with the finding of Hoyle (2014); however, no trend was detected from 2013 – 2020.

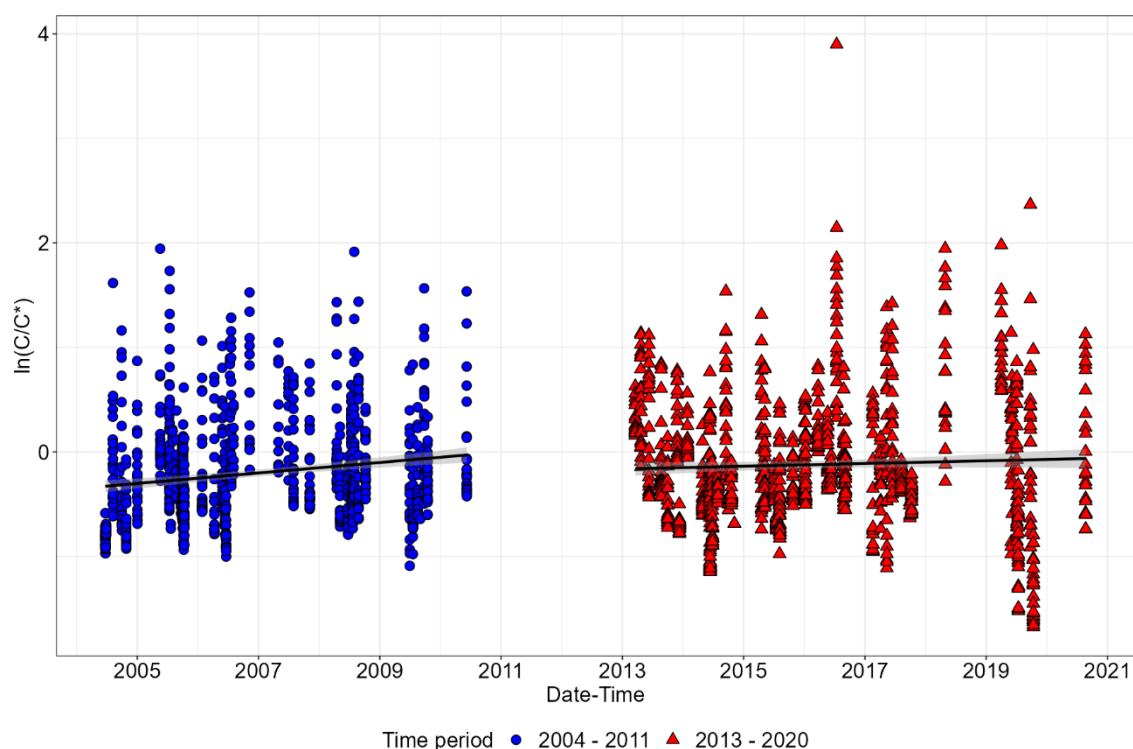


Figure 22: Suspended sediment rating residual (C/C^*) versus time for Mangatutu at Walker Rd Br. Trend analysis was undertaken over two separate periods: 2004 – 2011 and 2013 – 2020. A significant positive trend was observed from 2004 – 2013 but no trend was detected for the 2013 – 2020 period.

The Mangatutu site on Walker Road is a routine water quality monitoring site, and analysis of data available on the LAWA website (www.lawa.org.nz) showed that clarity and turbidity have been trending as “very likely improving” or “likely improving” over the 15-, 10-, and 5-year periods up to 2021.

Between 2002 and 2019, WRC contributed to the implementation of 61 ha of soil conservation measures across the Mangatutu catchment. Most soil conservation measures focussed on retirement of erosion prone land into indigenous forest and riparian restoration efforts. Over the same period (2002 – 2019), 25 km of fencing was established (Norris et al., In Prep). Prior to 2014, the Mangatutu catchment was part of the Catchment Environmental Monitoring (CEM) programme, and riparian surveys were completed in the lower catchment between 2004 and 2012. During this period, the proportion of surveyed bank length effectively fenced increased from 45% to 82% and the proportion of bank length with active erosion decreased from 15% to 0% (Littler, 2014). However, these riparian surveys were not representative of the whole catchment since surveys focused on waterways in the lower catchment. Therefore, it is likely that the proportion of effectively fenced bank length was an overestimate of the true catchment-wide proportion.

3.1.5 Matahuru Stream

The Matahuru catchment monitored at the Myjers’ property (516_22) has an area of 83 km² and an average rainfall of 1238 mm/y (Table 1). As a proportion of the catchment area, 61% is classified as LUC class 6 or above, and the remaining 39% is LUC class 2 to 4 (Figure 2). The surface geology is characterised by the predominance of Manaia Hill Group sandstones interbedded with siltstone. These formations overlie pumiceous fluvial deposits as described by Singleton (2016). Beneath these layers, mudstones and volcanoclastic deposits are present (Figure 5). The dominant soil orders are Recent, Granular, Brown, and Ultic Soils, which cover

similar proportions of the catchment area. (Figure 4). Most of the catchment is covered by exotic grassland (pasture – 88%), with the remainder being covered by indigenous or exotic forest (Figure 5). A catchment-scale desktop soil stability survey in 2005 found that 65% of the catchment was classified as “unstable” and that 84% of this unstable land required vegetative soil conservation measures (Hicks, 2005).

Between 2007 and 2020, 1,283 samples were collected at the Myjers’ site, mostly during rainfall-runoff events. From 2006 to 2022, average annual suspended sediment yield was 14.7 kt/y, with an average annual specific yield of 176.3 t/km²/y and a mean sediment concentration of 101 g/m³ (Table 7). Not accounting for the difference between TSS and SSC, the Myjers’ site had the highest specific yield of all suspended sediment monitoring sites across the WRC network. After adjusting for the difference between TSS and SSC, the average annual suspended sediment yield increased from 176.3 t/km²/y to 257.8 t/km²/y. The annual suspended sediment yields from 2006 to 2021 are displayed in Figure 23. Due to the commencement of monitoring at the Myjers’ site partway through 2006, the yield estimates for this year should be interpreted with caution. Over the 14-year monitoring period from 2007 to 2021, the annual suspended sediment specific yield varied between 61 and 418 t/km², with the highest values recorded in 2017 and 2018.

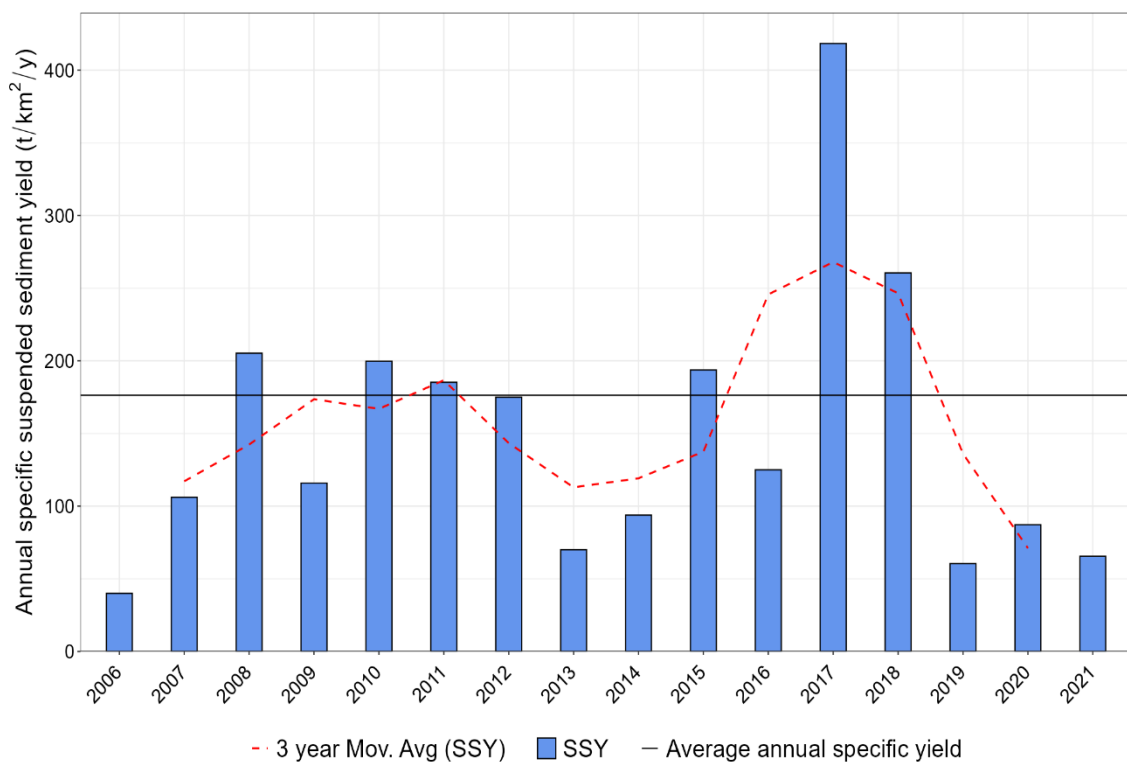


Figure 23: Annual specific suspended sediment yield for Matahuru at Myjers’. The red line is a three-year moving average.

After accounting for the difference between TSS and SSC, there was a statistically significant ($P < 0.05$) negative trend in concentration residuals between 2007 and 2020 (Figure 24), suggesting a decrease in suspended concentration relative to discharge. In a previous suspended sediment monitoring report, Hoyle (2012) found a statistically significant increase in the suspended sediment concentration relative to discharge between 2006 and 2010 at the Myjers’ site. However, between 2006 and 2013, Hoyle (2014) reported no statistically significant trend.

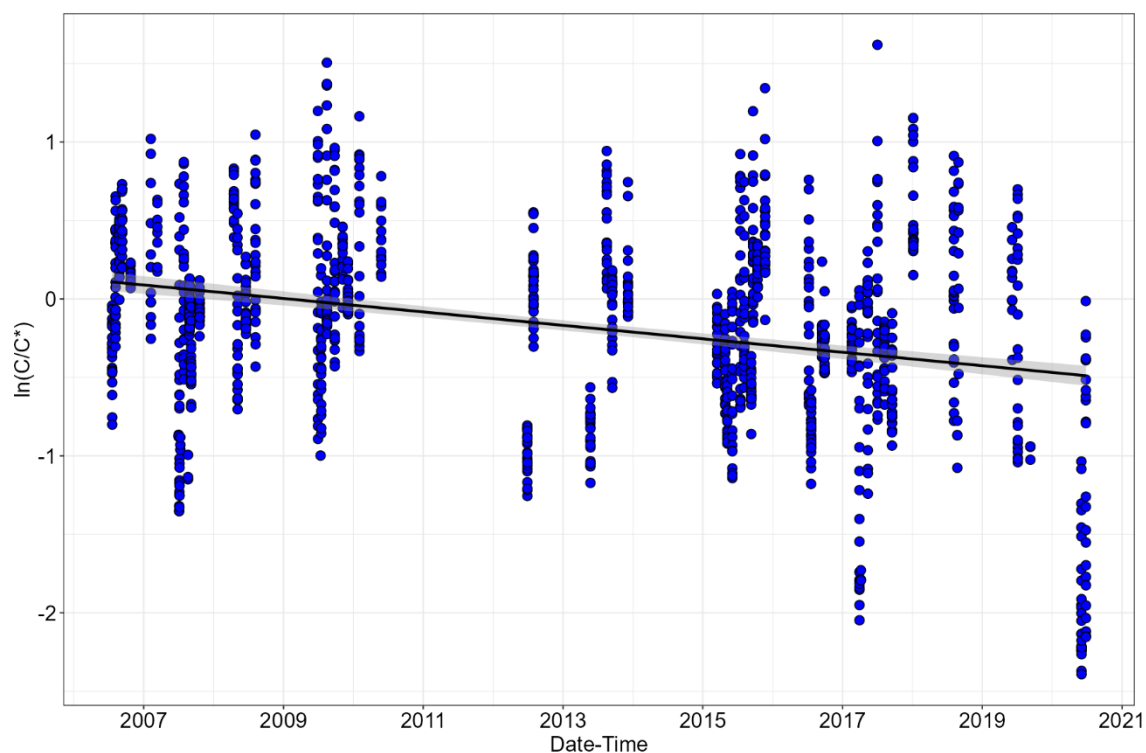


Figure 24: Suspended sediment rating residual (C/C^*) versus time for Matahuru at Myers' for samples collected from 2007 to 2020. The trend is significant ($P < 0.05$).

Downstream of the suspended sediment monitoring site at Myers', routine water quality sampling is undertaken at Waiterimu Road. According to LAWA, trends in turbidity until 2021 are indeterminate over 15 years, but "likely" and "very likely" improving over 10 and 5 years respectively. This is consistent with the suspended sediment monitoring network time trend (Figure 24). While further analysis is required to understand the drivers behind these improvements, it is noted that extensive soil conservation work has been undertaken across the catchment. For example, between 2002 and 2019, soil conservation efforts such as riparian and indigenous retirement were implemented across 495 hectares of the catchment (5% of the catchment area), and fencing was installed along 48 kilometres of bank length (Norris et al., 2022). A lower catchment riparian survey in the summer of 2013/2014 showed that there is near complete stock exclusion along the main stem of the Matahuru and that the proportion of effectively fenced bank length has improved since surveys started in 2003/2004 (Littler, 2014). However, a more comprehensive catchment-wide riparian survey in 2021 reported that only 52% of surveyed riparian margins were effectively fenced and that first order streams had the lowest proportion of bank length fenced (15% of surveyed bank length). Additionally, about 8% of the surveyed bank length had active erosion and 5% had recent erosion (Norris et al., 2021). The monitoring of suspended sediment, along with a suite of other measures, will continue in the Matahuru catchment as part of the ongoing Catchment Environmental Monitoring programme.

3.1.6 Moakurarua Stream

The Moakurarua catchment monitored at Warratah Farm Bridge (553_12) has an area of 206 km² and an average rainfall of 1945 mm (Table 1). As a proportion of the catchment area, 66% is LUC class 6, 16% is class 7 and 18% is class 2 – 4. (Figure 2). In terms of surface lithology, the northern segment of the catchment is dominated by basalts and basaltic andesite lavas of the Pirongia Volcanic Formation (Figure 6). The eastern and southern parts are composed of Tertiary siltstones, sandstones and other sedimentary rock layers, while the western areas of the catchment are predominantly formed in greywacke. Predominant soil orders include Allophanic (55%) and Recent (28%) soils (Figure 4). About 60% of the catchment is high producing exotic grassland (pasture), with the remainder of the catchment being covered by exotic forest (30%), indigenous forest (7%) and other land uses such as urban areas (3%) (Figure 5).

The Warratah Farm Bridge site has operated since 2015, with 457 samples collected from 2015 – 2020, mostly during runoff events by ISCO autosampler (Table 1). Over the monitoring period, the average annual suspended sediment yield was 29 kt/y and the average annual specific yield was 140.7 t/km²/y, with a mean concentration of 48.9 g/m³. There was no difference between TSS and SSC, and therefore no corrections were applied prior to calculation of yields. Annual specific yields are displayed in Figure 25 and ranged from 65 – 285 t/km², with the highest value occurring in 2017.

In 2016, a one-off high-flow suspended sediment snapshot was undertaken to quantify the relative contributions of sub-catchment sediment supply to the catchment total. A total of 12 sites were sampled across the Moakurua catchment, with each site representing a contributing sub-catchment. Sampling revealed that during the high flow event, sub-catchment suspended sediment concentrations ranged from 29 – 540 g/m³. These values were considerably higher than those recorded at the same sites during a one-off low-flow snapshot in the same year. During the low-flow snapshot, suspended sediment concentration ranged from <3 – 12 g/m³ (Wyatt, 2017).

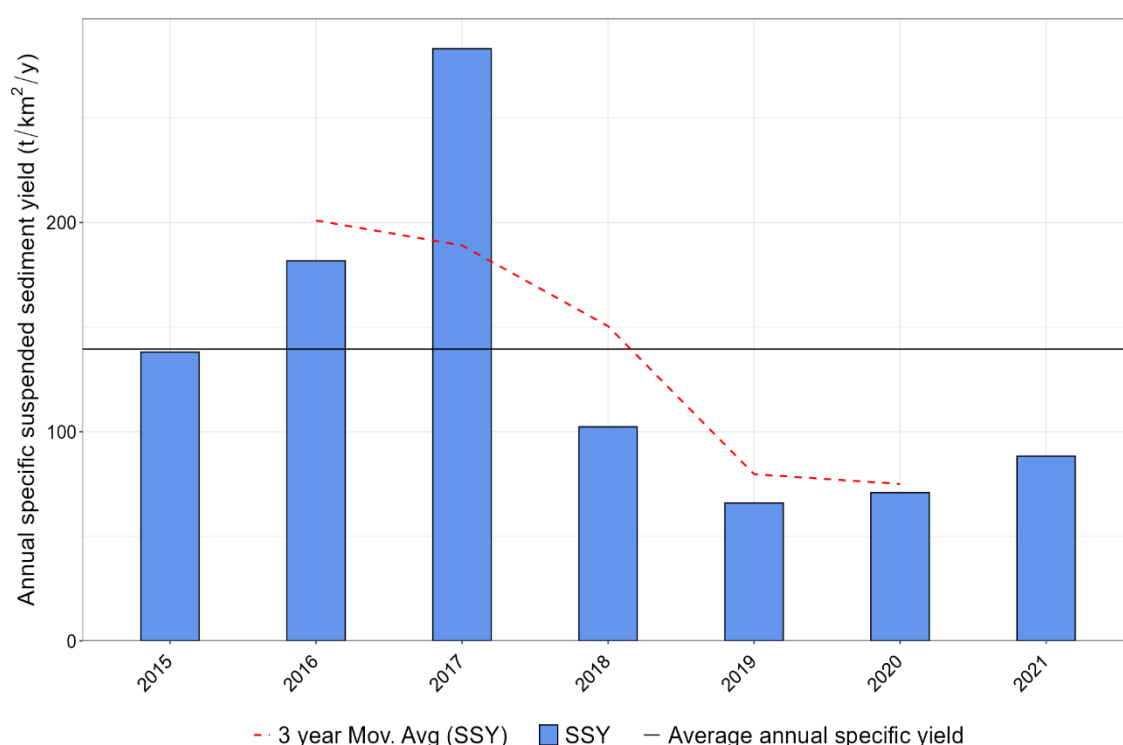


Figure 25: Annual specific suspended sediment yield for Moakurua at Warratah Farm Br. The red line is a three-year moving average.

Time trend analysis indicated a statistically significant ($P < 0.05$) positive trend in concentration residuals from 2015 to 2020 (Figure 26), suggesting an increase in suspended concentration relative to discharge. Notably, there was a considerable gap in sample collection between mid-2018 and mid-2019, relative to the overall length of the sampling period. However, there was also a statistically significant ($P < 0.05$) positive time trend over the period from 2015 to mid-2018. The sampling period for the Moakurua site is relatively short. A longer dataset, spanning 10 years or more, with frequent sampling of runoff events that represent the expected range of discharges at the site, would provide greater confidence in the time trend analysis. The monitoring of suspended sediment, along with a suite of other measures, will continue in the Moakurua catchment as part of the ongoing Catchment Environmental Monitoring programme.

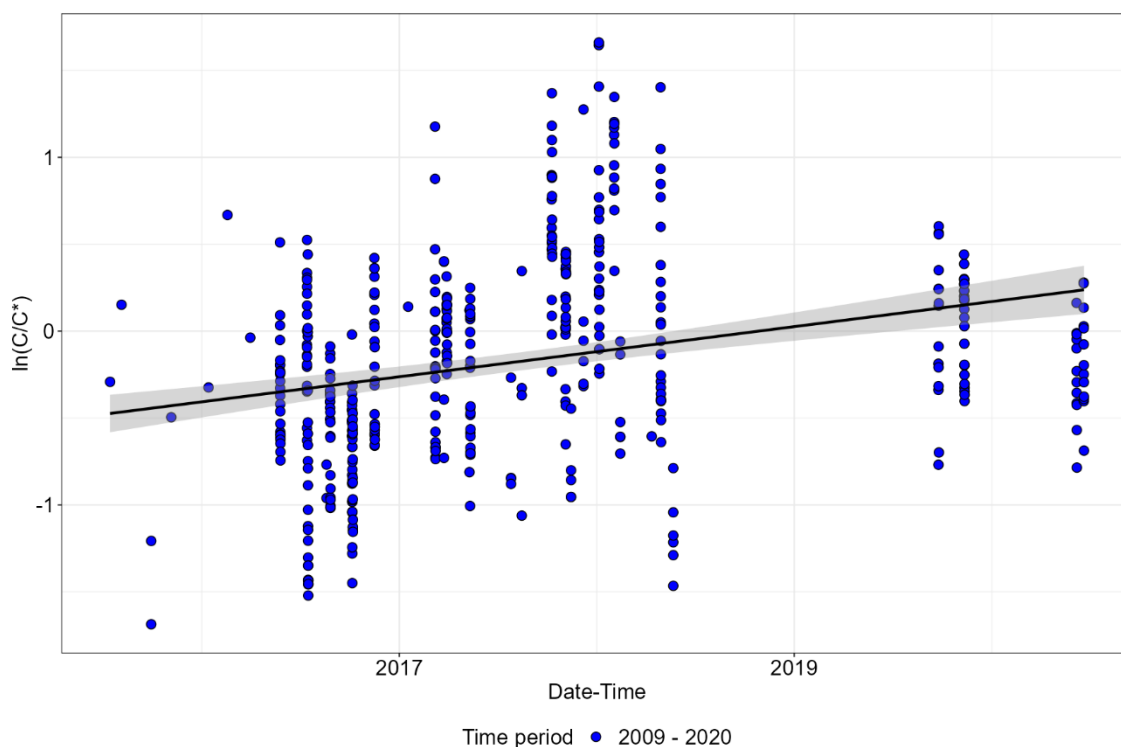


Figure 26: Suspended sediment rating residual (C/C^*) versus time for Moakurua at Warratah Farm Br. The trend is significant ($P < 0.05$).

3.1.7 Ohinemuri Stream

The Ohinemuri catchment monitored at Karangahake (619_16) has an area of 292 km² and a mean annual rainfall of 1930 mm (Table 1). Approximately 70% of the catchment is LUC class 5 (48%) and 6 (21%), with the remaining catchment (29%) being LUC class 2 – 4 (Figure 2). The surface geology is primarily Coromandel Group andesites and dacites, interspersed with ignimbrite and Pleistocene sediment deposits (Figure 6). Dominant soil types include Allophanic Soils (56% of the catchment area) and Brown Soils (28%) (Figure 4). Land cover is dominated by exotic grassland (pasture) (46%) and indigenous forest (45%) (Figure 5).

Over the monitoring period from 1986 to 2007, the Ohinemuri at Karangahake site had 66 manual depth integrated samples, most of which were collected between 1986 and 1999 (64 samples), with only two samples collected in 2007 and 2015 (Table 6). After applying the sediment-discharge rating to the full flow record, the average annual suspended sediment yield for the period 1956 to 2022 was 32.2 kt/y, with a specific yield of 110 t/km²/y (Table 7). Between 1987 and 2022, the annual specific sediment yield ranged from 103 to 5676 t/km², with the highest yielding year (1981) being approximately 56 times greater than the lowest (1991) (Figure 27). Due to the low number of samples collected since the previous report in 2014 (Hoyle, 2014), time trend analysis was not undertaken.

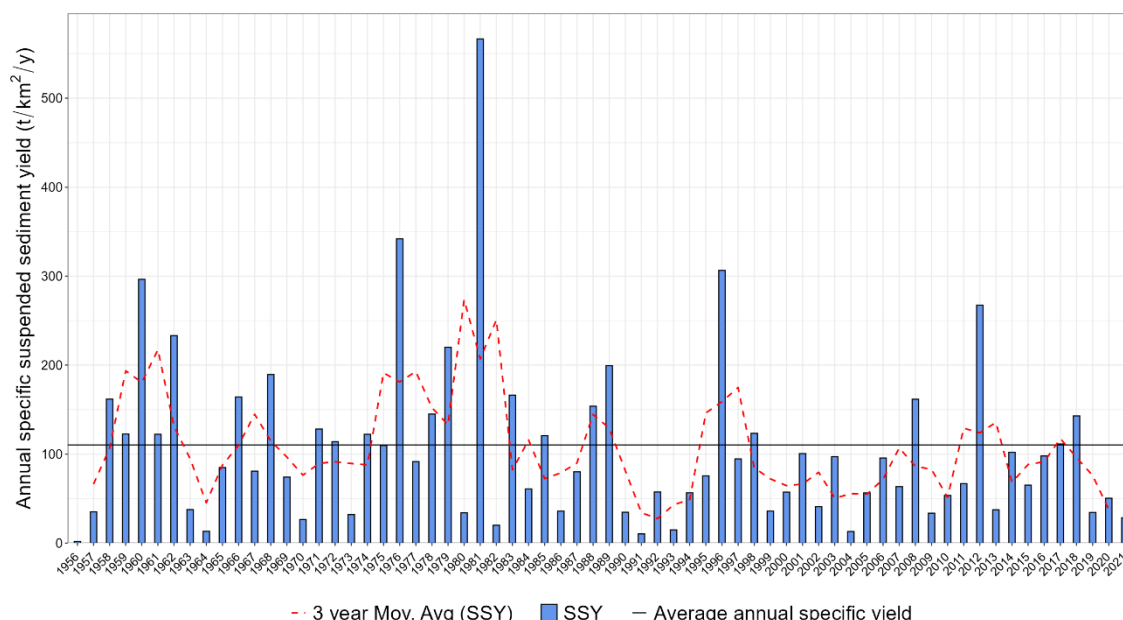


Figure 27: Annual specific suspended sediment yield for Ohinemuri at Karangahake. The red line is a three-year moving average.

3.1.8 Opitonui Stream

The Opitonui catchment monitored downstream of the Awaroa confluence (660_1) has an area of 29 km² and a mean annual rainfall of 1955 mm (Table 1). About 87% of the catchment is classified as 'steep' (LUC class 6 and 7) (Figures 2 and 3). The surface geology in the Opitonui catchment comprises andesite and dacite flows or intrusions, with unconsolidated Holocene fluvial deposits along streams (Figure 6). The soils across the catchment are predominantly Brown Soils (96%) (Figure 4), and land cover is almost entirely exotic forest (63%) and native forest (33%) (Figure 5).

A total of 1,858 suspended sediment samples were collected at the Opitonui sampling site between 1991 and 2019. Samples collected prior to 1999 were obtained via manual depth-integrated gauging, while those collected since then have predominantly been automatic point samples. Due to the instability of stream banks at the sampling site, and damage to the slackline, high flow manual depth integrated sampling was not possible. Between 1991 and 2022, the average annual suspended sediment yield was 4.8 kt/y and the specific yield was 165.5 t/km²/y (Table 7). At this site, the difference between TSS and SSC was a factor of 2. Consequently, after adjustment, the average annual specific yield was 317 t/km²/y (Table 7), considerably higher than the non-corrected estimate of 165.5 t/km²/y.

Between 1991 and 2022, the annual specific suspended sediment yield ranged from 10 to 532 t/km², with the highest yielding year (2011) being approximately 53 times greater than the lowest (2015) (Figure 28).

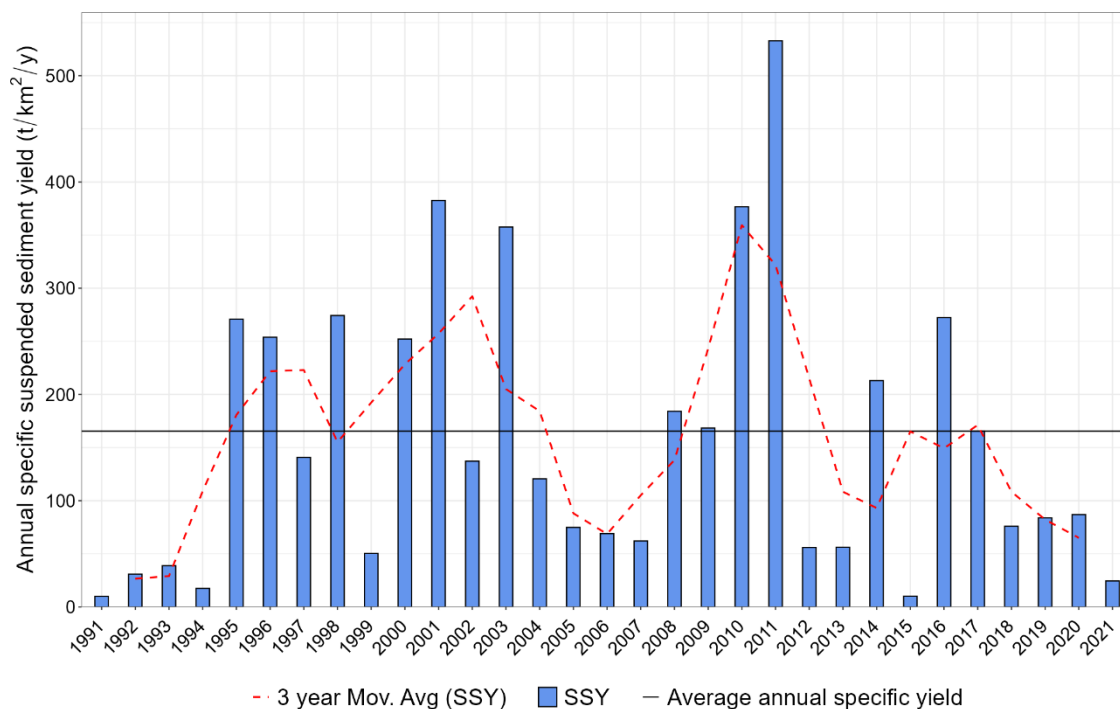


Figure 28: Annual specific suspended sediment yield for Opitonui at Downstream of Awaroa Confluence. The red line is a three-year moving average.

Time trend analysis was undertaken for both corrected (using the TSS-SSC regression) and uncorrected data to assess change over time. In both instances, there was a statistically significant ($P < 0.05$) positive trend in concentration residuals between 1991 and 2019 (Figure 29), suggesting an increase in suspended concentration relative to discharge. However, the magnitude of change over time was slightly different for the two datasets, with the slope of the line being 0.000062 for uncorrected data and 0.000041 for the corrected data. In a previous report, Hoyle (2014) found no time trend for the period 1991 to 2013. When we adjusted our time trend analysis to the same period as Hoyle (2014), no trend was detected suggesting that increases in suspended sediment have occurred in the years since 2013. However, further analysis is required to verify this finding including analysis of individual storm events to better understand sediment dynamics over shorter time periods. Previously, concerns have been raised that suspended sediment from the Opitonui Stream has negatively impacted the water quality and muddied the bed of the Whangapoua Estuary (Wild & Hicks, 2005). Therefore, the potential trend identified in this study warrants further investigation, with an emphasis on establishing connections to possible land use management practices within the catchment, such as forestry harvesting.

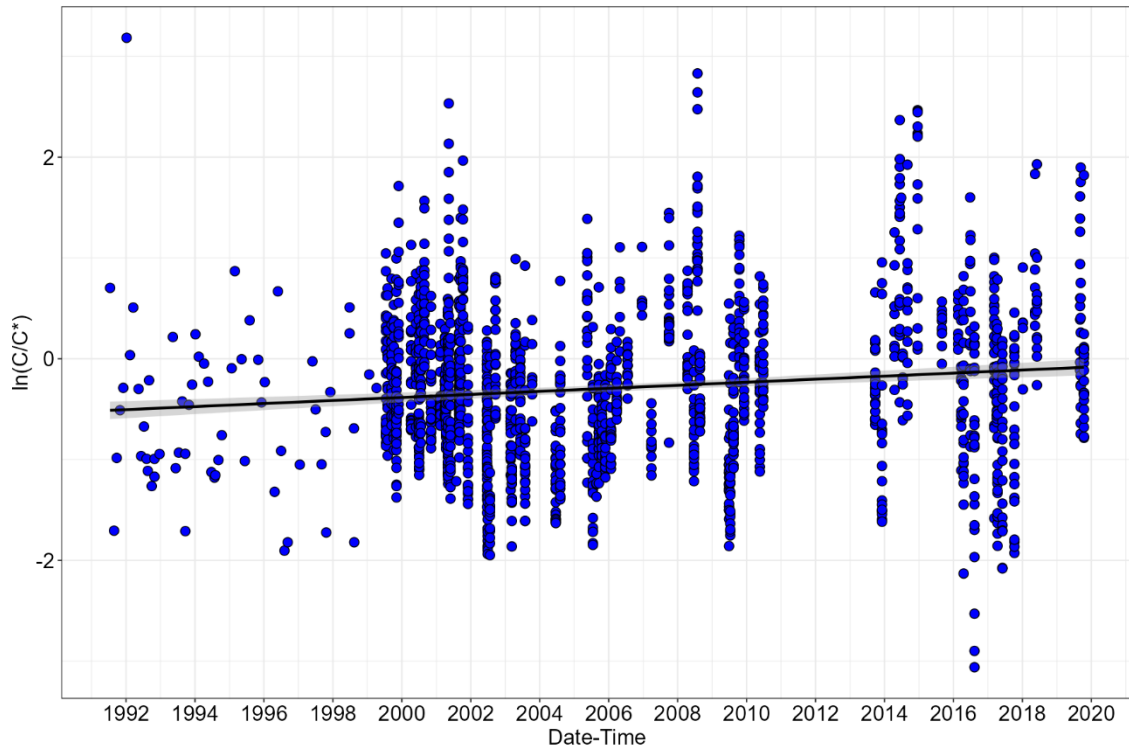


Figure 29: Suspended sediment rating residual (C/C^*) versus time for Opitonui at Downstream of Awaroa Confluence. The trend is significant ($P < 0.05$).

3.1.9 Oraka Stream

The Oraka catchment monitored at Pinedale (669_13) has an area of 130 km² and mean annual rainfall of 1527 mm (Table 1). As a proportion of the catchment area, 27% is classified as LUC class 3, with 70% of the catchment being LUC class 6 or above (Figure 2). In terms of geology, proximity of the catchment to the Taupō Volcanic Zone means that unconsolidated tephra and ignimbrites are most common across the catchment (Figure 5). Podzol Soils cover 67% of the catchment area, with the remaining area being covered mostly by Pumice Soils 30% (Figure 4).

Suspended sediment sampling commenced at the site in 1986, with all 37 samples collected manually by depth integrated gauging. Most samples were collected between 1986 and 1991, with a single sample being collected in 2003, and a further four samples between 2015 and 2019. Between 1979 and 2022, the average annual suspended sediment yield was 5.1 kt/y and specific yield was 39.2 t/km²/y. The mean concentration was 38 g/m³ (Table 7). Between 1980 and 2021, annual specific sediment yield ranged between 7 and 120 t/km² (Figure 30). The highest yield occurred in 1996, with high yields also recorded in 1980, 1988 and 2017.

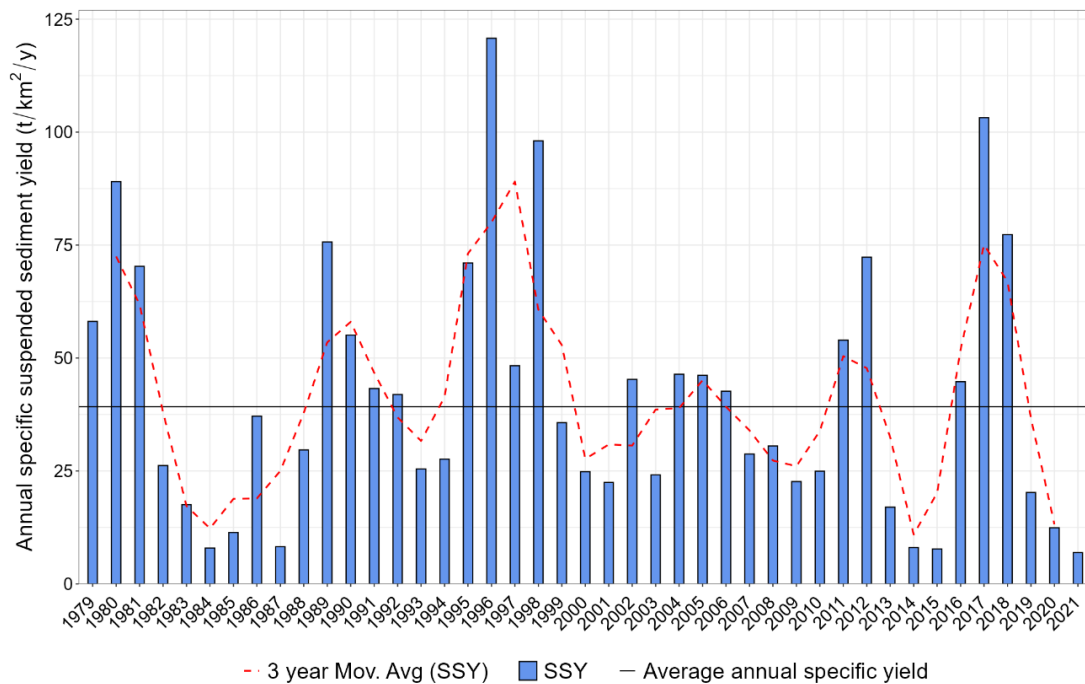


Figure 30: Annual specific suspended sediment yield for Oraka at Pinedale. The red line is a three-year moving average.

The time trend analysis output is displayed in Figure 31. Overall, from 1986 – 2019, there was a statistically significant ($P < 0.05$) negative trend in concentration residuals suggesting a decrease in suspended concentration over time. However, the limited number of samples since 1991 means that trend data should be treated with caution. Since 1991, only six samples were collected, with only two of those being collected during runoff events when flows were greater than the mean flow. Furthermore, the suspended sediment concentration of these two samples was lower than most historical data for similar flows (Figure 32). Therefore, more data is needed to confirm the apparent decreasing trend in suspended sediment concentration, and furthermore, the site requires more sampling during medium to large runoff events to improve the SSC-Q rating.

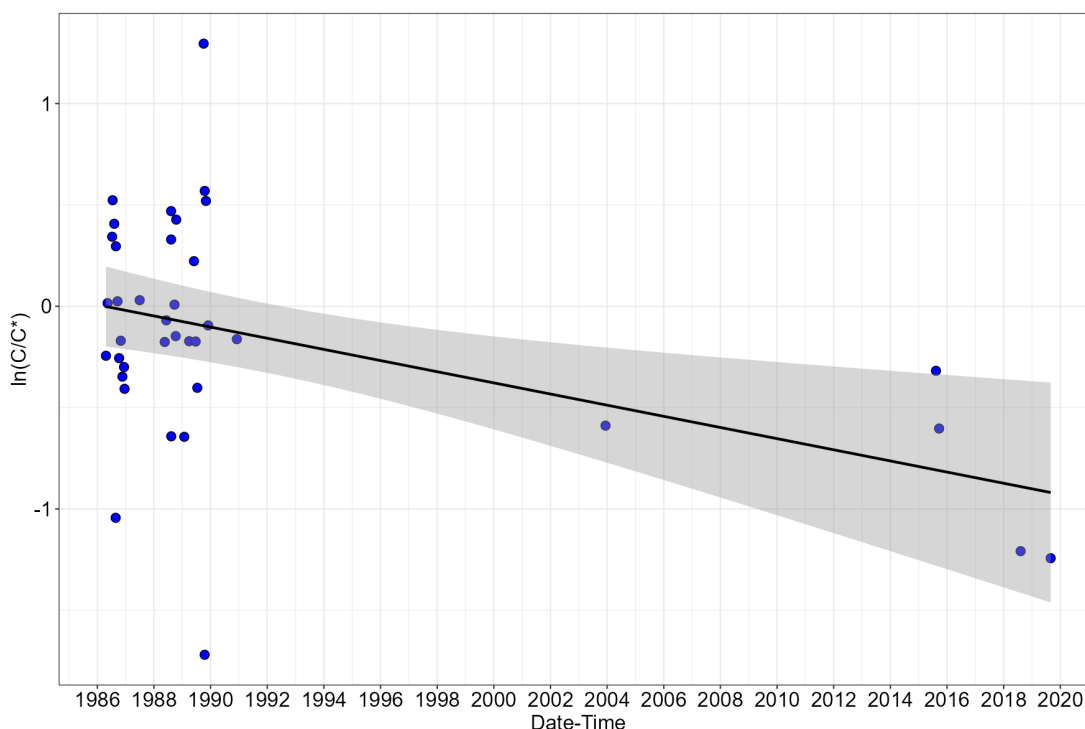


Figure 31: Suspended sediment rating residual (C/C^*) versus time for Oraka at Pinedale. The trend is significant ($P < 0.05$).

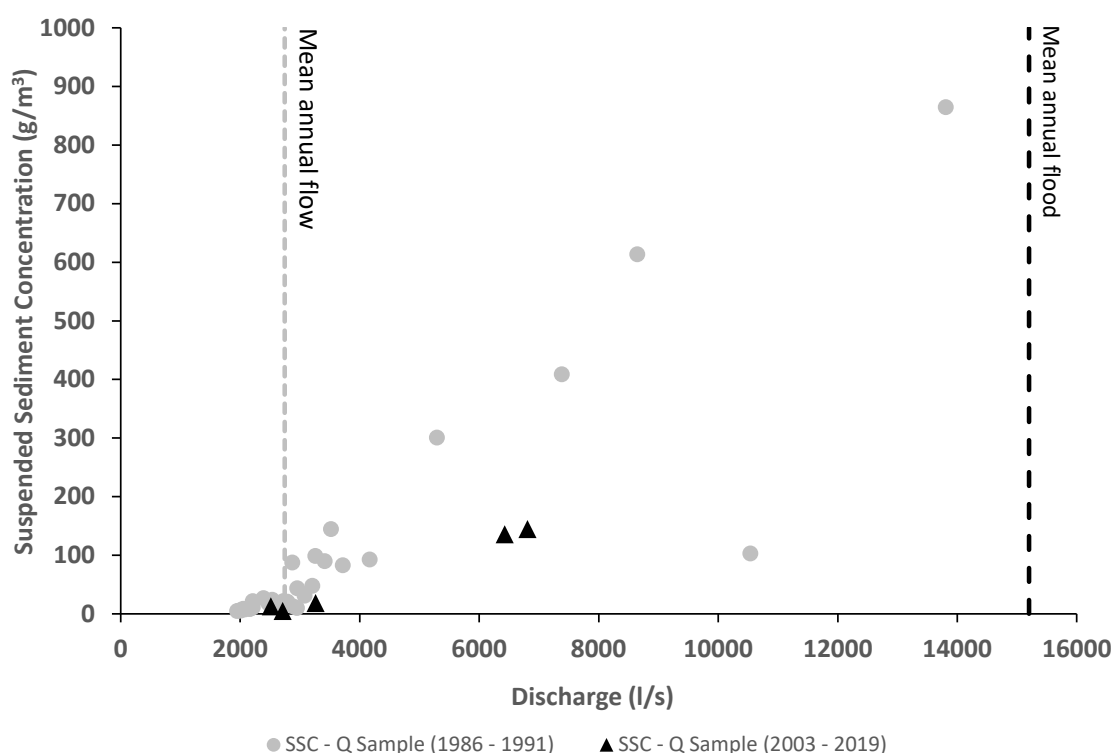


Figure 32: SSC – Q plot showing samples collected at Oraka at Pinedale between 1986 and 1991 and between 2003 and 2019. Mean annual flow and mean annual flood are shown in the graph.

3.1.10 Piako Stream

The Piako catchment monitored at Paeroa-Tahuna Rd Bridge (749_15) has an area of 539 km² and a mean annual rainfall of 1081 mm (Table 1). About 75% of the catchment is LUC class 4 or lower, with the remaining 25% being LUC class 6 (Figure 2). The geology across the catchment is a mixture of Pleistocene fluvial deposits, basaltic andesites, ignimbrites, and greywacke (Figure 6). Over 90% of the land cover is high producing pasture (Figure 5), and soils are characterised as mostly Allophanic, Granular and Gley Soils, with small areas of Brown and Organic Soils (Figure 4).

Suspended sediment sampling commenced at the site in 1986, with 162 of the 163 samples collected between 1986 and 2004 (Table 6). A single sample was collected in 2019. All sampling was undertaken by manual depth integrated sampling, and the sediment rating was applied to the long-term flow record from 1972 – 2021. Over this period, the average annual suspended sediment yield was 11.1 kt/y and the specific yield was 20.6 t/km²/y. The mean concentration was 22.1 g/m³ (Table 7). Over the duration of the flow record, the annual specific sediment yield ranged from 4.0 t/km² in 1982 to 56.8 t/km² in 2017 (Figure 33).

Time trend analysis was not undertaken for the Piako catchment because of the lack of suspended sediment data since 2003.

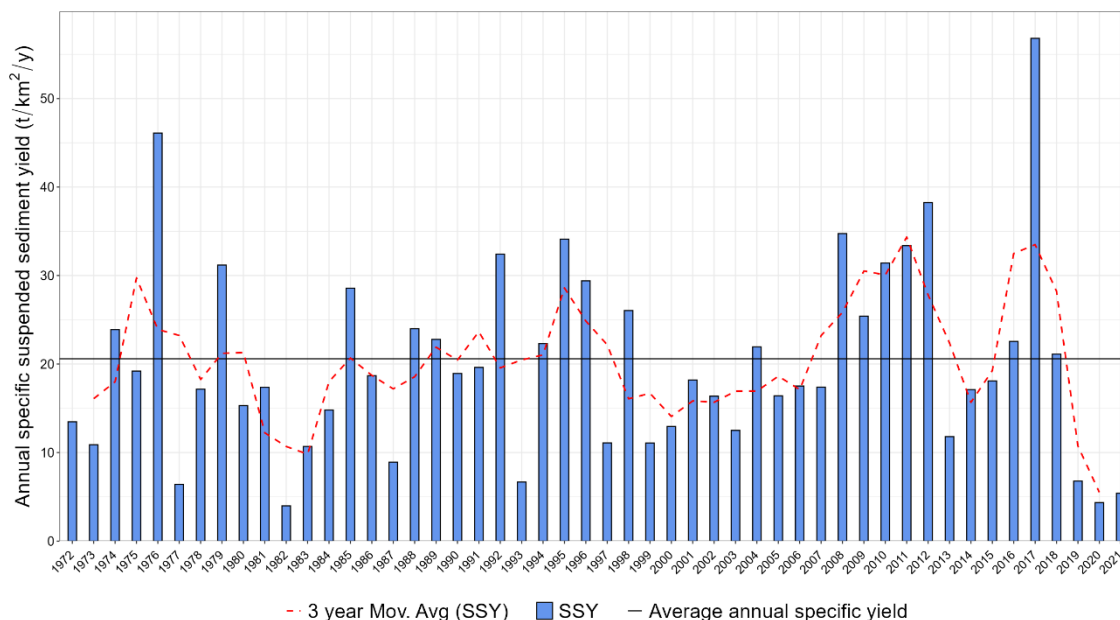


Figure 33: Annual specific suspended sediment yield for Piako at Paeroa-Tahuna Road. The red line is a three-year moving average.

3.1.11 Tapu River

The Tapu catchment monitored at Tapu-Coroglen (954_5) covers 27 km² and has a mean annual rainfall of 1,865 mm (Table 1). About 76% of the catchment is LUC class 7, with the remainder being mostly LUC class 6 and 8 (Figure 2). The geology across the catchment is predominantly basalt, andesite and dacite (Figure 6). Brown Soils are the predominant soil type, covering about 97% of the catchment area (Figure 4). Land cover is dominated by indigenous vegetation (Manuka/Kanuka shrubland or forest), covering about 95% of the catchment area (Figure 5).

The monitoring site at Tapu-Coroglen operated since 1991, with 28 samples collected between 1991 and 1999, all of which were collected with manual depth integrated sampling (Table 6). Over the sampling period, only 69% of the sediment yield occurred within the gauged range of discharge, and the maximum sampled discharge was less than 50% of mean annual flood (Table 6). Therefore, a high proportion of the load fell within the extrapolated range of the sediment–flow rating, introducing uncertainty into the total load estimates. Between 1991 and 2022, the average annual suspended sediment yield was 0.7 kt/y, with a specific yield of 27.6 t/km²/y (Table 7). Annual specific sediment yield ranged between 6.2 and 65.7 t/km² (Figure 34).

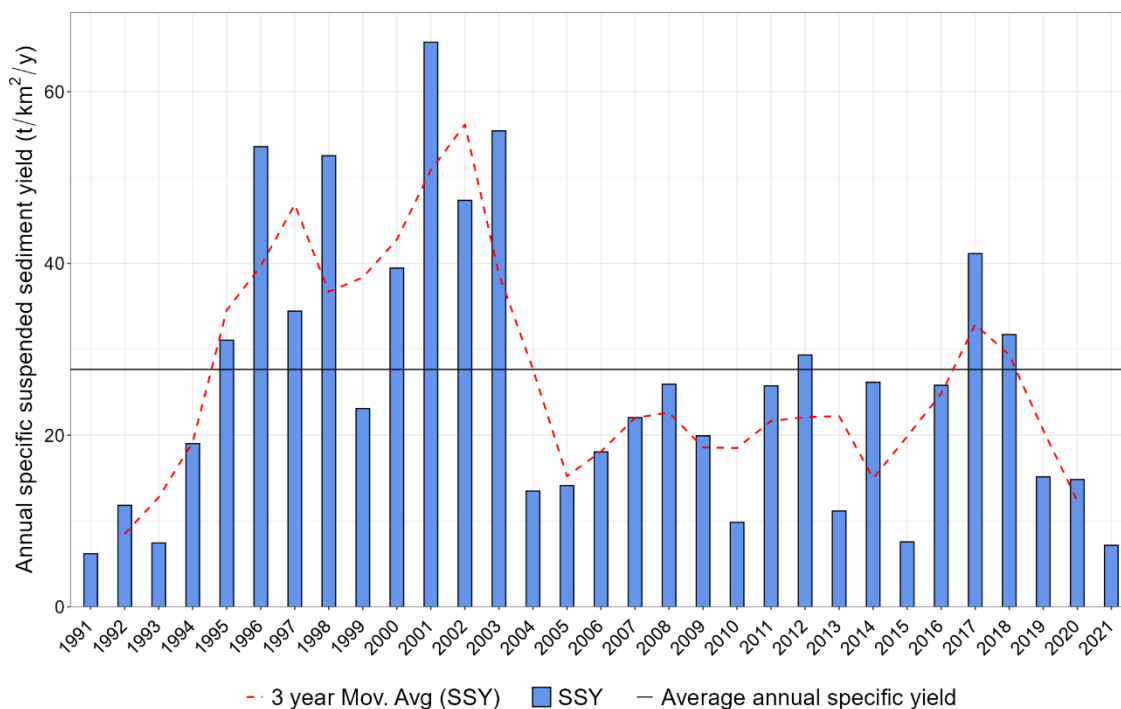


Figure 34: Annual specific suspended sediment yield for Tapu at Tapu-Coroglen Road. The red line is a three-year moving average.

Time trend analysis was not undertaken for the Tapu-Coroglen site due to lack of monitoring data since 1999.

3.1.12 Tauranga-Taupō River

The Tauranga-Taupō catchment monitored at Te Kono (971_4) is 198 km² and has a mean annual rainfall of 19,21 mm/y (Table 1). About 86% of the catchment is LUC classes 6, 7 and 8 (Figure 2). In terms of geology, the lower part of the catchment is composed of ignimbrite and unconsolidated tephra, while the upper half is dominated by sandstone and siltstone overlaying greywacke (Figure 6). Soils in the catchment are mostly Pumice (66%) or Podzols (32%) (Figure 4). Landcover is dominated by indigenous (67%) and exotic (26%) forests (Figure 5).

Between 1990 and 2010, 80 manual depth integrated samples were collected at the Tauranga-Taupō site, with no further sampling since 2010. Although 77% of the sediment yield occurred within the gauged range of discharge, no samples were collected above mean annual flood (Table 6). Between 1976 and 2022, mean annual suspended sediment yield was 16.8 kt/y and specific yield was 85.1 t/km²/y. Mean concentration was 11.3 g/m³. From 1987 to 2022, annual specific suspended sediment yield ranged from 10.5 to 359 t/km². The highest suspended sediment yield occurred in 1998 and is almost double the value of the second highest yield in 2015 (Figure 35).

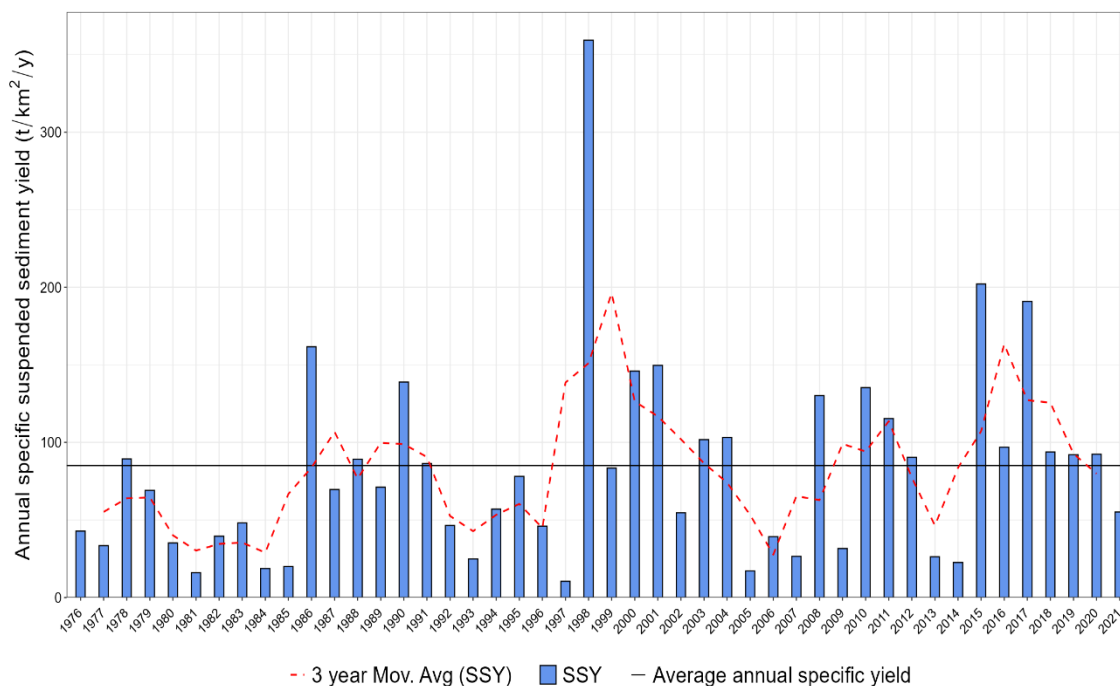


Figure 35: Annual specific suspended sediment yield for Tauranga-Taupō at Te Kono. The red line is a three-year moving average.

Since suspended sediment hasn't been regularly sampled since 1999, no time trend analysis was undertaken.

3.1.13 Waihou River

There are two monitoring sites on the Waihou River, located at Okauia (1122_18) and Te Aroha Bridge (1122_34). The Okauia site (1122_18) is furthest upstream, with a catchment area of 806 km² and a mean annual rainfall of 1,464 mm (Table 1). About 30% of the catchment is LUC class 6, while LUC classes 2, 3, 4 and 7 covering between 10 and 20% of the catchment area. Surface geology in the lower Okauia catchment comprises Pleistocene fluvial deposits with minor ignimbrites, while the upper catchment is dominated by ignimbrites and unconsolidated tephra. (Figure 6). Allophanic and Podzol Soils cover 40% and 45% of the catchment area, respectively (Figure 4). About 58% of the catchment is covered by exotic grassland with the remainder being covered by exotic and indigenous forest (Figure 5).

The site at Okauia has been active since 1986, with 101 manual depth integrated suspended sediment samples collected between 1986 and 2006 (Table 6). While only one sample was collected at flows below the mean annual flood value, 92% of the sediment yield occurred within the gauged range of discharge. Between 1982 and 2022, the average annual suspended sediment yield was 41.7 kt/y and the specific yield was 51.7 t/km²/y. The mean concentration was 33.3 g/m³ (Table 7).

Between 1987 and 2022, the annual specific yield ranged from 17.1 to 182.3 t/km². The highest yield occurred in 2017 (Figure 36).

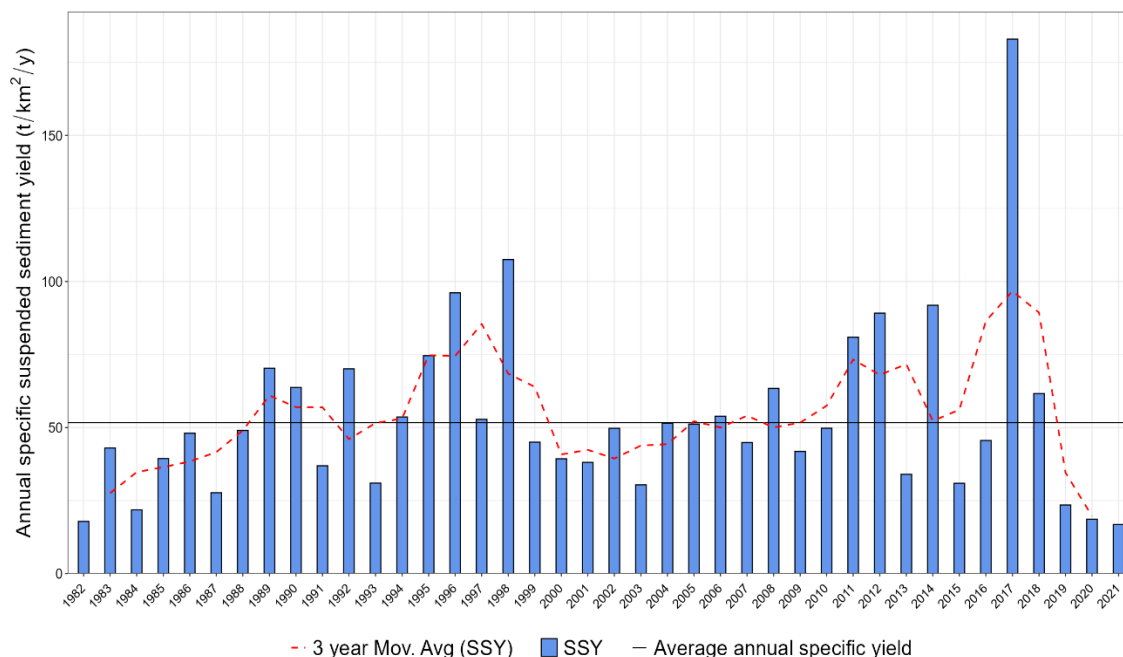


Figure 36: Annual specific suspended sediment yield for Waihou at Okauia. The red line is a three-year moving average.

The total catchment area above the Te Aroha Bridge site is 1,106 km² and the mean rainfall is 1,486 mm (Table 1). About one quarter of the catchment is LUC class 1 and 2, with 45% of the catchment classified as LUC class 6 or above (Figure 2). The flatter western parts of the catchment are composed of Pleistocene to Holocene fluvial deposits, while the eastern parts are composed of Coromandel group andesites and dacites, Waiteariki Formation dacitic ignimbrites, and minor earthflow deposits (Figure 6). Allophanic and Podzol Soils cover about 42% and 33% of the catchment, respectively (Figure 4). In terms of land cover, about 58% of the catchment is exotic grassland (pasture) and 15% exotic forest and 23% indigenous forest (Figure 5).

In total, 42 manual depth integrated samples were collected at the Waihou at Te Aroha between 1986 and 2006 (Table 6), with most samples being collected between 1986 and 1992. Single samples were collected in 2005 and 2006. Even though the number of samples is relatively low compared with other sites, 99% of the sediment yield occurred within the gauged range of discharge. Between 1965 and 2022, the average annual suspended sediment yield at Te Aroha was 61 kt/y and the specific yield was 55.2 t/km²/y. The mean concentration was 43.9 g/m³ (Table 7). It is important to note that no samples were collected between 1965 and 1985. Hence, the annual yields for this period were estimated using a rating developed from data collected after 1985.

Between 1987 and 2019, the annual specific suspended sediment yield ranged from 29.1 t/km² (2020) to 98.4 t/km² (1979) (Figure 37).

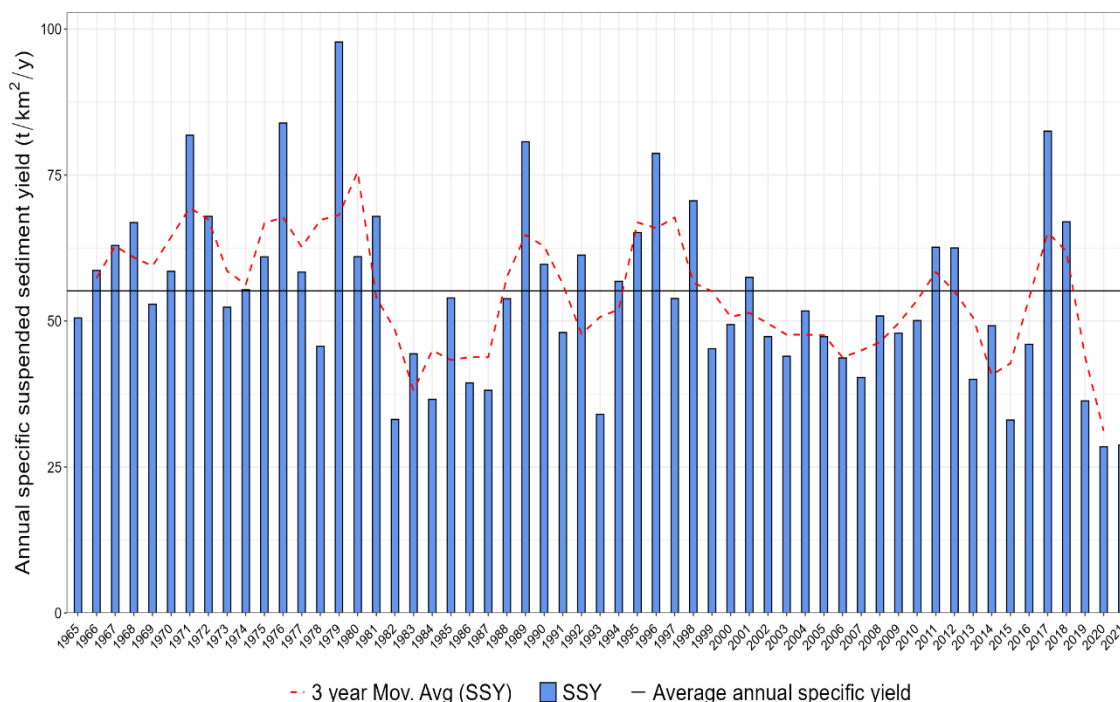


Figure 37: Annual specific suspended sediment yield for Waihou at Te Aroha. The red line is a three-year moving average.

Time trend analysis was not undertaken for either Waihou at Okuia or Waihou at Te Aroha because no new SSC-Q data had been collected since the last suspended sediment monitoring report (Hoyle, 2014).

3.1.14 Waikato River

There are two monitoring sites on the Waikato River, these being at Hamilton Traffic Bridge (1131_64) and Rangiriri (1131_117). Both sites are below the Waikato River hydroelectric dams, and therefore sediment entrapment in the dams will affect the sediment load passing these sites (Hicks et al., 2001).

The Waikato River catchment monitored at Hamilton Traffic Bridge (1131_64) has an area of 8,334 km² (Table 1). About 4% of the catchment area is LUC class 1 and 2, 9% is LUC class 4, and the remaining 49% is LUC class 6 or above (Figure 2). The surface geology varies greatly across the catchment, with the lower reaches covered by Quaternary fluvial sediments. The Taupō Volcanic Zone is primarily a rhyolitic terrane, with areas of pumice, ignimbrites and lacustrine deposits also present. South of Lake Taupō, rhyolites are replaced by andesites with lahar flows and volcanoclastics. The dominant soils in the catchment area are influenced by the volcanic parent material, with Pumice Soils covering just over half of the region. Other prevalent soil types include Podzols and Allophanic Soils, each accounting for 13% of the catchment area (Figure 4). Dominant land cover types across the catchment include exotic grassland (pasture – 40%), exotic forest (24%) and indigenous forest (18%) (Figure 5).

Between 1991 and 2004, 58 manual depth integrated samples were collected at the Hamilton Traffic Bridge site. Despite the relatively low number of samples, 95% of sediment yields occurred within the gauged range of discharge (Table 6). Between 1975 and 2022, the average annual suspended sediment yield was 65.7 kt/y, and the specific yield was 7.9 t/km²/y. Mean suspended sediment concentration was 7.5 g/m³ (Table 7). The catchment upstream of Hamilton Traffic Bridge includes the Lake Taupō Catchment, from which minimal sediment is discharged. Furthermore, entrapment of sediment in the hydro lakes along the main stem of the Waikato River has also contributed to the low specific sediment yields and concentrations observed at Hamilton Traffic Bridge.

Between 1987 and 2022, annual specific suspended sediment yields ranged from 4.2 t/km² in 1984 to 13.7 t/km² in 1996 (Figure 38).

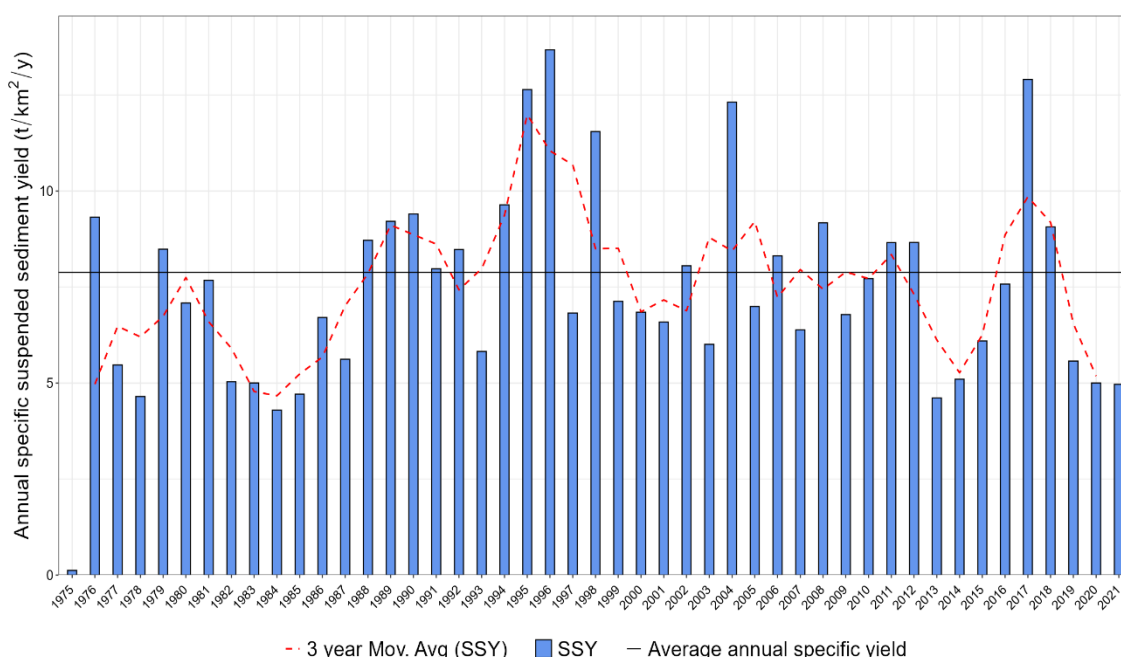


Figure 38: Annual specific suspended sediment yield for Waikato at Hamilton Traffic Br. The red line is a three-year moving average.

The Rangiriri monitoring site is downstream of the confluence of the Waipā and Waikato Rivers and has a catchment area of 12,372 km² (Table 1). About 11% of its catchment is covered by LUC class 1 and 2, with LUC classes 3 and 4 covering 29% of the catchment. The remaining 54% of the catchment area is covered by LUC class 6 or above (Figure 2). Pumice Soils dominate the upper catchment and cover about 38% of the catchment. Other dominant soil types include Allophanic and Podzol Soils that cover 22% and 13% of the catchment, respectively. All other soil orders cover less than 5% of the catchment area (Figure 4). As a proportion of the upstream catchment area, exotic grassland (pasture) is the most dominant (51%), followed by exotic (18%) and indigenous forest (17%) (Figure 5).

Between 1991 and 2007, 67 manual depth integrated samples were collected at the Rangiriri site. Overall, 98% of the sediment yield occurred within the gauged range of discharge (Table 6). Between 1965 and 2022, the mean annual suspended sediment yield was 239.5 kt/y, and the specific yield was 19.4 t/km²/y. The low specific yield reflects the inclusion of the Lake Taupō catchment and the hydro lake sediment entrapment. Notably, the difference in mean annual suspended sediment yield between Rangiriri and Hamilton Traffic Bridge (173.8 kt/yr) aligns closely with the yield recorded in the Waipā River at Whatawhata (154.8 kt/yr). This indicates that most of the sediment load at Rangiriri is sourced from the Waipā River. The mean sediment concentration at the Rangiriri site was 18.5 g/m³ (Table 7). Between 1987 and 2022, the annual specific suspended sediment yield ranged from 10.4 to 33.7 t/km² (Figure 39).

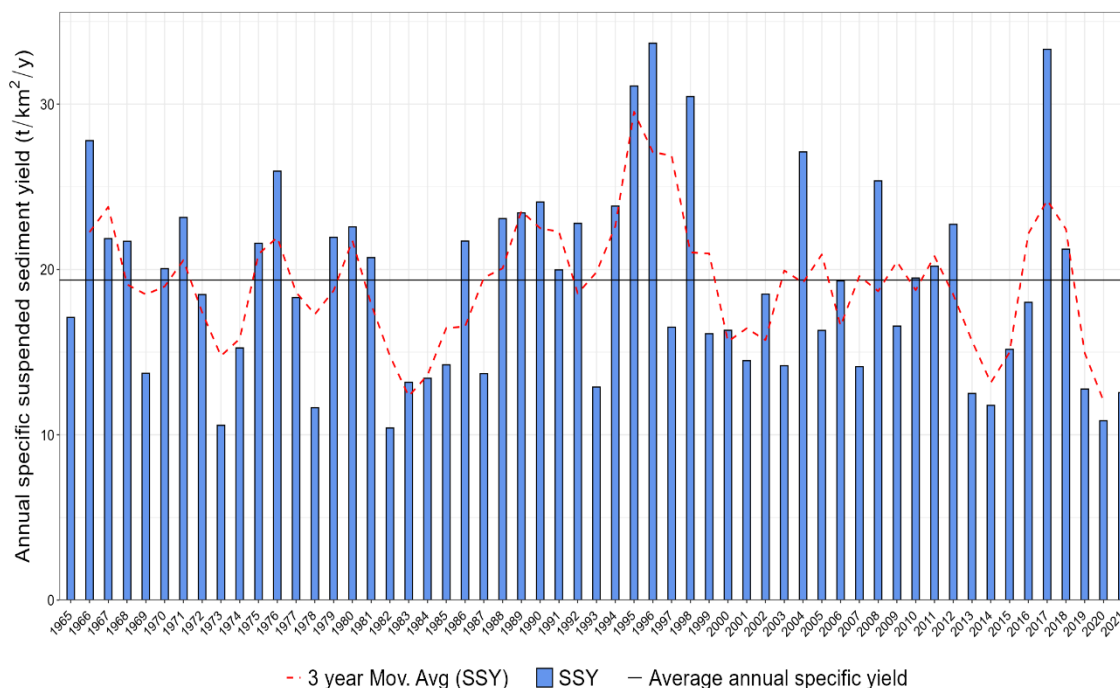


Figure 39: Annual specific suspended sediment yield for Waikato at Rangiriri. The red line is a three-year moving average.

Time trend analysis was not completed for either Waikato at Hamilton Traffic Bridge or Waikato at Rangiriri because no new SSC-Q data had been added since the last suspended sediment monitoring report (Hoyle, 2014).

3.1.15 Waingaro River

The Waingaro catchment monitored at Ruakiwi Rd (1167_4) is the only suspended sediment monitoring site in the West Coast Management Zone. The upstream catchment has an area of 119 km² and a mean annual rainfall of 1544 mm (Table 1). About 76% of the catchment area is LUC class 6, with the remaining 18% being LUC class 3 and 4 (Figure 2). The dominant surface lithologies across the catchment are Tertiary siltstones and sandstones with a greywacke basement covering most of the catchment (Figure 6). In terms of soil type, 43% of the catchment is covered by Brown Soils, 29% Ultic and 22% Allophanic. (Figure 4). About half of the catchment (52%) is covered with high producing exotic grassland, with much of the remainder being under exotic (27%) and indigenous (12%) forest (Figure 5).

Between 2002 and 2019, 1,601 suspended sediment samples were collected, mostly by autosampler. Overall, 93% of the sediment yield occurred within the gauged range of discharge (Table 6). Between 2001 and 2022, the average annual suspended sediment yield was 12 kt/y and the specific yield was 101.3 t/km²/y. The mean concentration was 27.4 g/m³ (Table 7).

The Ruakiwi Rd site is the only site where sampling requirements were met for the TSS-SSC comparison (Table 7). Visually, the TSS vs. SSC datapoints followed the 1:1 line closely and further statistical testing revealed no difference between SSC and TSS values. Therefore, no adjustment of TSS data was required.

From 2001 to 2022, the annual specific yield ranged from 18 to 273 t/km². The highest yield occurred in 2017 (Figure 40).

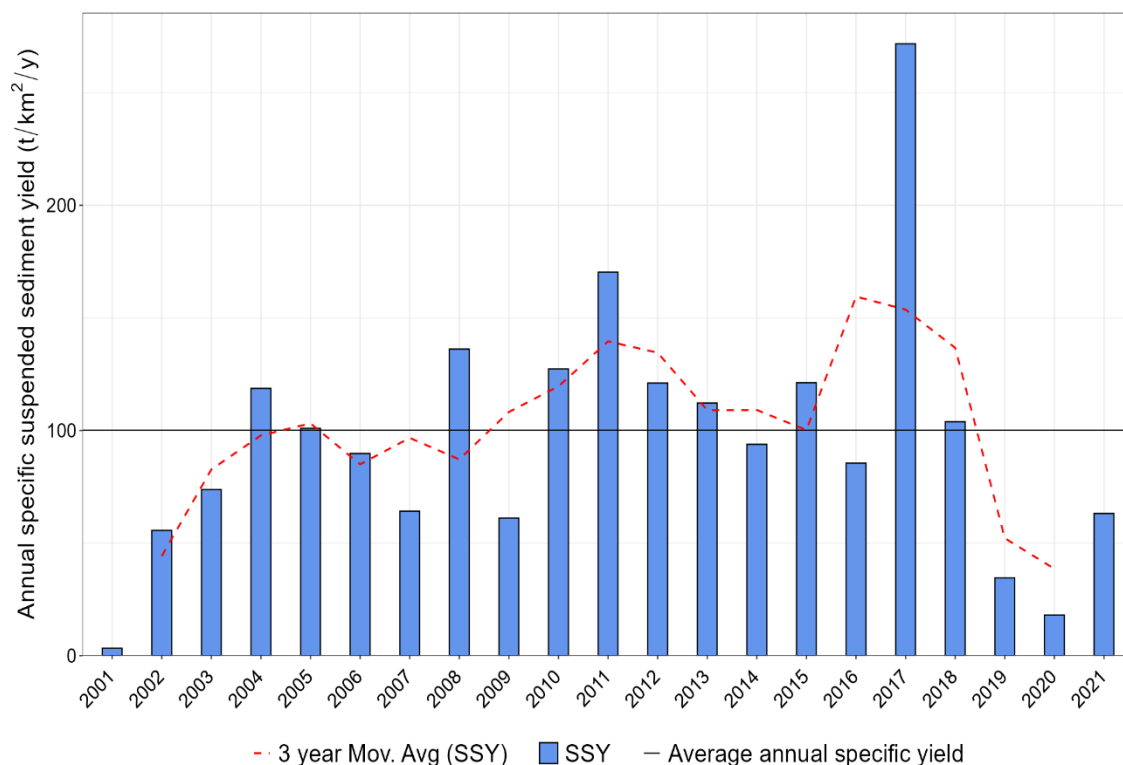


Figure 40: Annual specific suspended sediment yield for Waingaro at Ruakiwi. The red line is a three-year moving average.

Time trend analysis revealed a significant ($P < 0.05$) positive trend in concentration residuals between 2002 and 2019 (Figure 41), suggesting an increase in suspended sediment concentration relative to discharge. There was a large spread of data for the most recently sampled runoff event in late September 2019 (Figure 42), suggesting possible blockage of the intake tube over part of the event. However, even after removing potentially erroneous values the positive trend and statistical significance of the concentration residuals remained unchanged albeit with a slightly decreased slope from 7.1×10^{-5} to 6.8×10^{-5} .

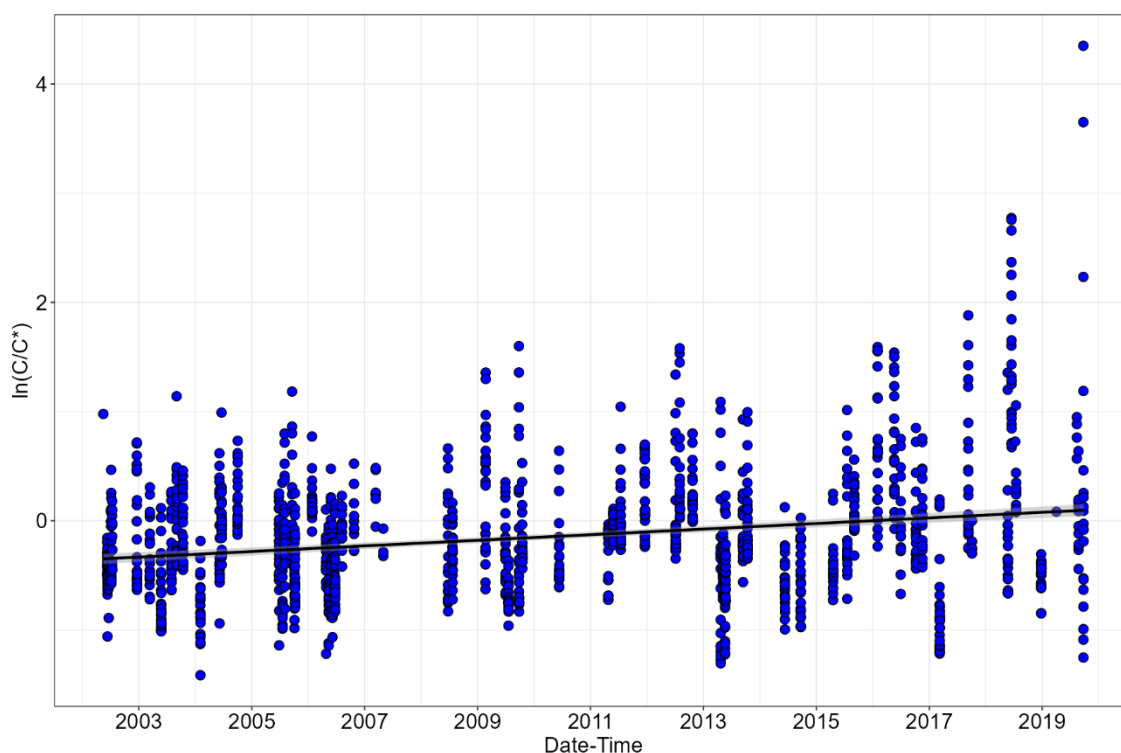


Figure 41: Suspended sediment rating residual (C/C^*) versus time for Waingaro at Ruakiwi Rd. The trend is significant ($P < 0.05$).

Hoyle (2014) found a significant increase in suspended sediment concentration over the 2002 to 2013 period but advised caution with respect to the interpretation of the observed trend because the residuals for that period were not normally distributed. In the current analysis, however, the residuals were normally distributed (Table 6), so there is no reason to doubt the trend. In contrast, monthly SoE monitoring suggests an improvement in visual clarity and turbidity over time. The LAWA website (www.lawa.org.nz) which uses monthly SoE data, reported that the visual clarity and turbidity attributes have been “very likely improving” or “likely improving” over the previous 15, 10 and 5 year monitoring periods.

3.1.16 Waipā River

There are three monitoring sites on the Waipā River, located at Otewa (1191_7), SH31 Br. Otorohanga (1191_13) and SH23 Br. Whatawhata (1191_11).

The uppermost site on the Waipā is at Otewa (1191_7), which has an upstream area of 319 km² and a mean annual rainfall of 1,586 mm (Table 1). Across this catchment, 82% of the area is LUC class 6 or above. (Figure 2). Surface geology is dominated by ignimbrites, sandstones and siltstones (Figure 6). Podzols are the dominant soil type, covering 59% of the catchment, followed by Allophanic Soils, which cover about 30% of the catchment (Figure 4). Even though a high proportion of the upstream catchment is LUC class 6 and above, 42% of the area is covered by exotic grassland. The remaining area is a mix of indigenous forest (48%) and other land cover types such as exotic forest (Figure 5).

Suspended sediment sampling commenced at the Otewa site in 1990, and up until 2000, all samples were collected via manual depth integrated sampling. From 2000 to 2016, most samples were collected using an autosampler. Overall, from 1992 – 2016, a total of 1,272 samples were collected, with most samples collected via autosampler (Table 6). Due to ongoing mechanical issues associated with the autosampler and health and safety concerns, WRC stopped monitoring suspended sediment at the Otewa site in 2016. This meant that no TSS vs. SSC comparison samples were collected and a correction was not applied to the raw data. Between 1985 and 2022, the average annual suspended sediment yield was 52.3 kt/y, with a specific yield of 163.7 t/km²/y and a mean concentration of 35.5 g/m³ (Table 7).

Between 1987 and 2022, the annual suspended sediment yield ranged from 35 to 489 t/km² (Figure 42). The highest annual yield occurred in 2008 and was 14 times that lowest yield recorded in 2020, highlighting the temporal variability in suspended sediment yield over time.

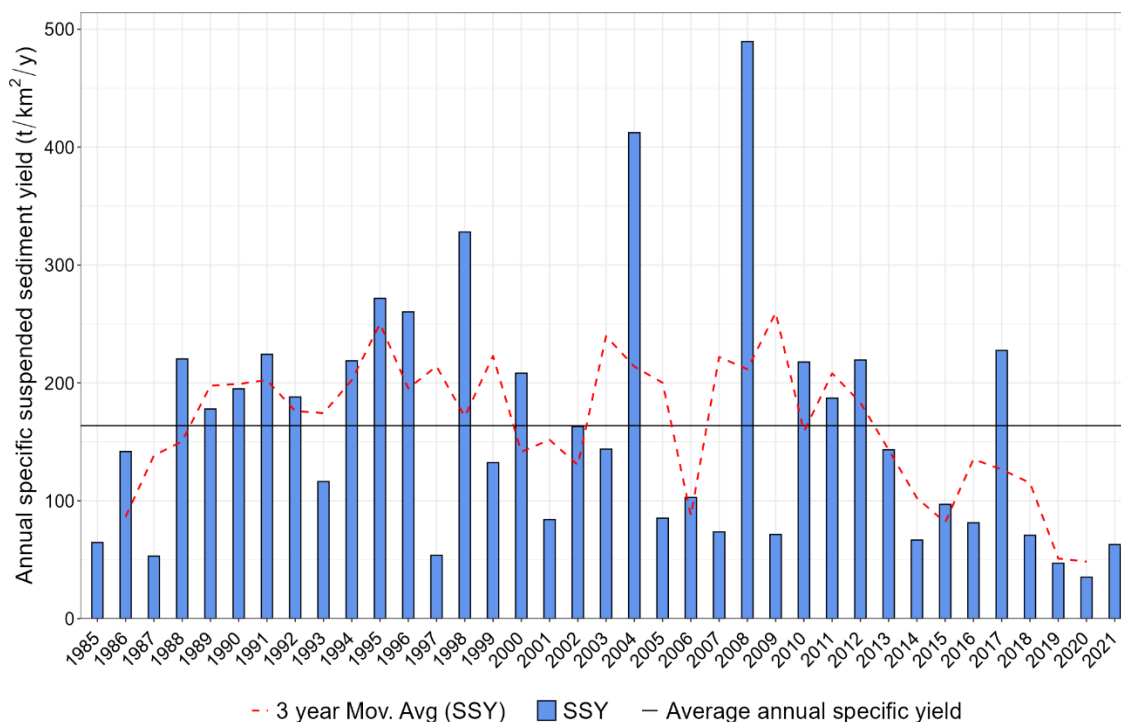


Figure 42: Annual specific suspended sediment yield for Waipā at Otewa. The red line is a three-year moving average.

Time trend analysis revealed a statistically significant ($P < 0.05$) negative trend in concentration residuals between 1992 and 2016 (Figure 43), suggesting a decrease in suspended concentration relative to discharge at the Otewa site during the sampling period. The negative trend remained statistically significant when samples collected via manual depth-integrated sampling between 1992 and 2000 were removed from the analysis. This left only samples collected via autosampler, and the analysis was then conducted for the period from 2000 to 2016. The trend of decreasing concentration over time is consistent with and continues the trend observed by Hoyle (2014).

Hoyle (2012) undertook a detailed trend analysis of suspended sediment yields at the Otewa site to assess changes over time from 1992 – 2011. The study focused on quantifying the outcomes of catchment and bank remedial works carried out in the catchment following a major landslide in the Tunawaea catchment (part of the Waipā catchment) in 1991. She found an increases in suspended sediment concentration prior to 2000, followed by a decrease from 2000 until at least the end of 2010. This analysis suggested that mitigation works had, at least in part, contributed to a decrease in sediment loads over time. However, Hoyle (2012) noted that later sampling disproportionately captured rising flow stages, potentially overestimating yields and underestimating reductions in suspended sediment over time. A key recommendation, duly implemented, was that WRC revisit their sampling schedule to ensure that both falling and rising stages of hydrographs were adequately sampled. It remains plausible, however, that the downward trend observed in Figure 43 is influenced by the rising-stage sampling focus noted by Hoyle and the trend may be stronger than the data indicates.

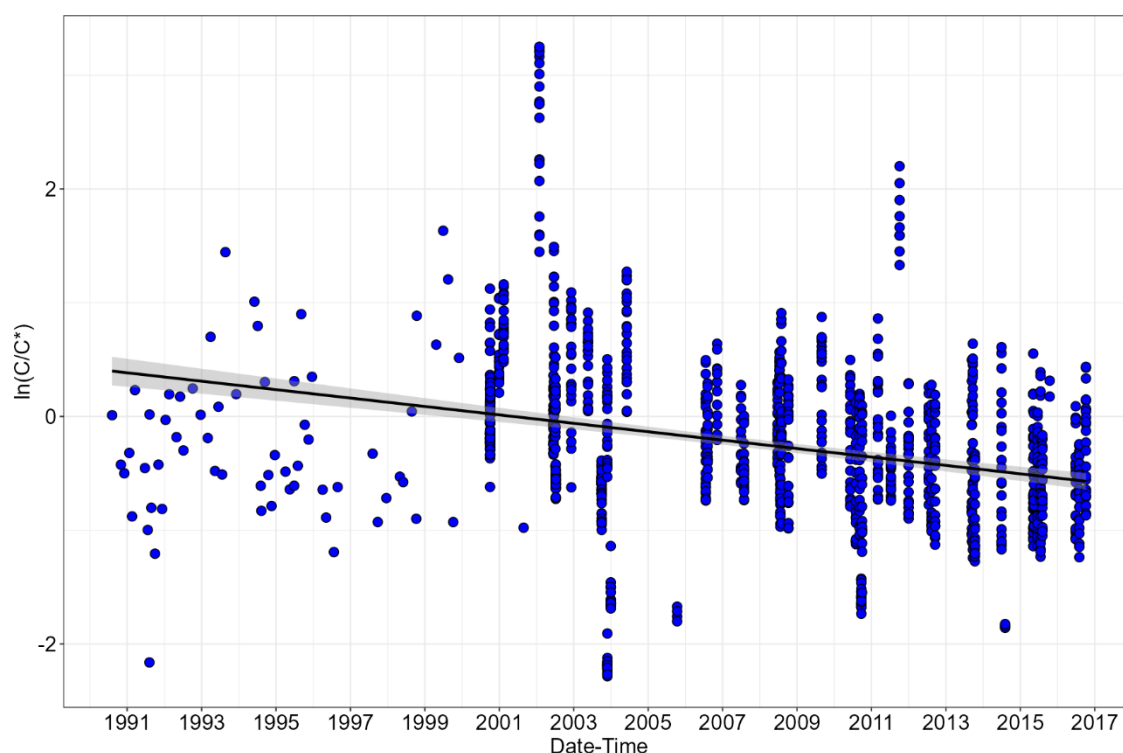


Figure 43: Suspended sediment rating residual (C/C^*) versus time for Waipā at Otewa. The trend is significant ($P < 0.05$).

A second monitoring site on the Waipā River is located downstream of the Otewa site at the bridge along SH31 at Otorohanga (1191_13). The upstream catchment area is 919 km² in area (Table 1), with about half the catchment classed as ‘moderately steep’ to ‘very steep’ (Figure 3). Approximately 62% of the catchment area falls under LUC class 6 or higher. The remaining area is covered by LUC class 2 (5%), LUC class 3 (11%) and LUC class 4 (18%). This suggests a higher proportion of versatile, less steep land compared to the catchment above the Otewa site (Figure 2). In terms of geology, the area upstream of the Otorohanga site is dominated by Quaternary fluvial sediments, with small areas of Taumatamairi Formation mudstones, Manaia Hill Group siliciclastics, and isolated sections of Pakaumanu Group ignimbrites (Figure 6). About half the catchment area (49%) is covered by Allophanic soils, with 27% covered by Podzols and the remaining made up of a mix of Brown, Gley and Recent soils (Figure 4). The majority of the catchment is managed under pasture (69%), with the remainder of the area covered in Indigenous (22%) and exotic (6%) forest (Figure 5).

Suspended sediment sampling at Waipā at SH31 Bridge Otorohanga (1191_13) commenced in 1990, with most samples collected between 1990 and 1991. A total of 12 manual depth integrated samples were collected at the site, with the most recent samples collected in 2019. Despite the low number of samples (12 in total), 97% of the sediment yield occurred within the gauged range of discharge, although there was only one sample collected at a discharge greater than the mean annual flood (Table 6). For the period 1981 – 2022, the average annual suspended sediment yield was 84.1 kt/y, with a specific yield of 91.5 t/km²/y.

Between 1987 and 2022, the annual specific suspended sediment yield for the Otorohanga site ranged from 12 to 249 t/km² (Figure 44), with the highest annual specific suspended sediment yield (1998) being 21 times greater than the lowest (2020), indicating considerable variability between years.

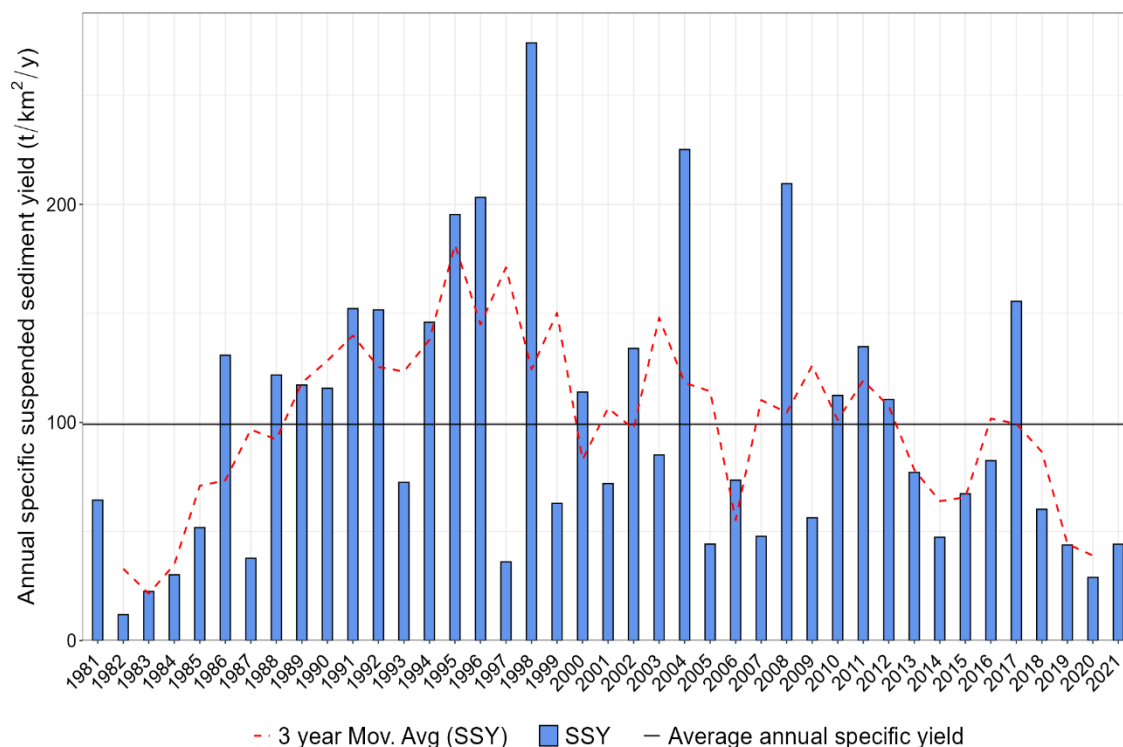


Figure 44: Annual specific suspended sediment yield for Waipā at SH31 Br. Otorohanga. The red line is a three-year moving average.

The monitoring site at Whatawhata (1191_11) is the furthest downstream monitoring site on the Waipā River. Its upstream catchment area is 2,863 km², with a mean annual rainfall of 1,533 mm (Figure 1). Above Whatawhata, the catchment has a higher proportion of flat land compared to the catchments upstream of the Otorohanga and Otewa sites, with about half of the catchment being less than LUC class 4 and the other half being LUC class 6 and above (Figure 2). The surface geology between Whatawhata and Otorohanga is predominantly fluvial and swamp deposits, with basaltic lithologies of the Pirongia Volcanic Formation to the west (Figure 6). About half the catchment is covered by Allophanic soils (52%), with Podzols, Gley, Brown, Recent and Organic soils each covering between 13% and 5% of the catchment area (Figure 4). Three quarters of the catchment (75%) is covered in pasture with 18% and 4% under indigenous and exotic forest, respectively (Figure 5).

A total of 84 manual depth integrated suspended sediment samples were collected between 1990 and 2009 at the Whatawhata site. The discharge range at the site was well sampled, with 98% of the suspended sediment yield transported within the gauged range of discharge (Table 6). Between 1972 and 2022, the average annual suspended sediment yield was 154.2 kt/y, with a specific yield of 53.9 t/km²/y and mean concentration of 31.7 g/m³ (Table 7). Between 1987 and 2022, the annual specific yield ranged between 13 and 99 t/km² (Figure 45).

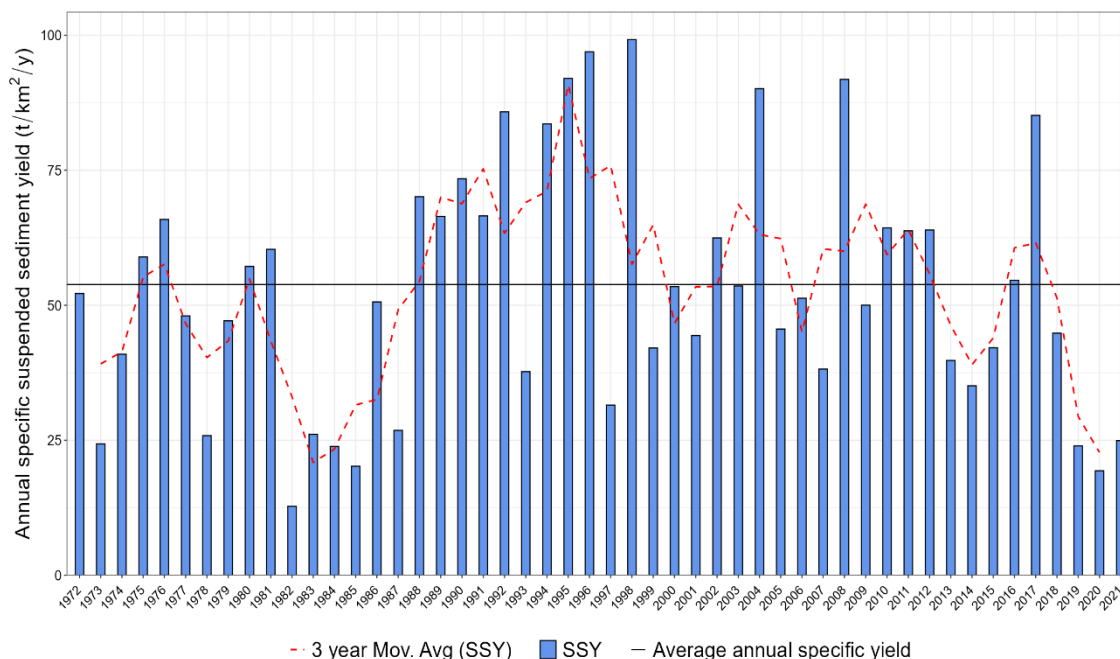


Figure 45: Annual specific suspended sediment yield for Waipā at Whatawhata. The red line is a three-year moving average.

Trend analysis was not undertaken for the Waipā at SH31 Bridge Otorohanga and Waipā at Whatawhata, either due to an insufficient number of samples or because no additional samples were collected since the previous suspended sediment monitoring report (Hoyle, 2014).

3.1.17 Waitoa River

The Waitoa catchment monitored at Mellon Road (1249_18) has an area of 408 km² and a mean annual rainfall of 1,147 mm (Table 1). Much of the catchment is flat to rolling, with about 85% classified as LUC class 1 to 4 (Figures 2 and 3). Surface lithology is dominated by Pleistocene sediment in the lower to middle reaches of the catchment, while ignimbrites are most common in the upper reaches. Allophanic Soils cover 62% of the catchment, with the remainder of the area covered by poorly drained Gley Soils (28%) (Figure 4). A high proportion of the catchment is covered by exotic grassland (90%), with small areas of cropland (4%) and indigenous forest (3%) (Figure 5).

A total of 187 manual depth integrated samples were collected between 1986 and 2007 (Table 6). Between 1986 and 2022, the average annual suspended sediment yield was 4.6 kt/y, with a specific yield of 11.2 t/km²/y and a mean concentration of 17.1 g/m³ (Table 7). Over the same period, annual specific suspended sediment yield ranged between 2 and 33 t/km² (Figure 46).

Trend analysis was not undertaken for Waitoa at Mellon Road because no new SSC-Q data had been collected since the previous suspended sediment monitoring report (Hoyle, 2014).

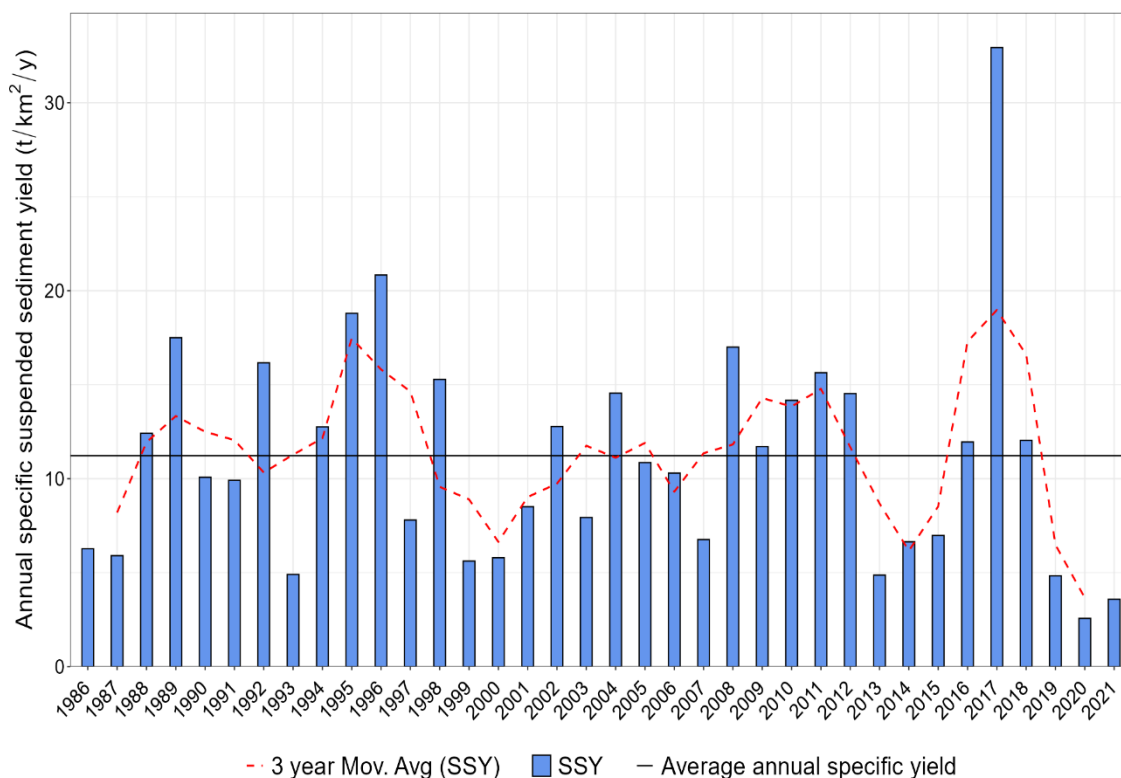


Figure 46: Annual specific suspended sediment yield for Waitoa at Mellon Rd. The red line is a three-year moving average.

3.1.18 Waitomo Stream

The Waitomo catchment monitored at Aranui Caves (1253_3) has an area of 36.2 km² and a mean annual rainfall of 1979 mm/y (Table 1). Most of the catchment is steep, with 73% being LUC classes 6 and 7, and 23% being LUC class 4 and 5 (Figure 2). The surface geology on the eastern half of the catchment is dominated by poorly consolidated fissile mudstones, ignimbrites, and other volcanoclastics of the Mahoenui Group (Singleton, 2017; Figure 5). The western part of the catchment is dominated by Te Kuiti Group skeletal limestones and calcareous sandstones. Allophanic Soils cover approximately 60% of the catchment, while poorly drained Gley Soils are found in 14%, Recent Soils in 18%, and Podzol Soils in 8% of the catchment (Figure 4). Exotic grassland covers about half (48%) the catchment area, with the remainder of the catchment being under indigenous (38%) and exotic forest (12%) (Figure 5).

A total of 2,690 suspended sediment samples were collected between 1990 and 2020 (Table 6). The sampling method varied over time, with manual depth integrated samples collected in two phases from 1990 to 1997 and from 2000 to 2008 and auto samples collected from 1997 to 2000 and from 2008 to 2020. Minimal sampling occurred between 2000 and 2008, with only five samples collected during this period. Between 1986 and 2022, the average annual suspended sediment yield was 6.1 kt/y, with a specific yield of 168.5 t/km²/y and a mean concentration of 37.6 g/m³. Analysis of TSS and SSC samples revealed that there was a significant difference between TSS and SSC (Table 6). Once the data was adjusted for this difference, the average annual specific yield increased to 223 t/km²/y (Table 7). Given the large number of samples collected from the Aranui Caves site, high flows were well represented in the dataset, with 97% of collected sediment samples being within the gauged range of flow (Table 6). Between 1986 and 2021, annual specific suspended sediment yield ranged between 56 and 415 t/km², with the highest specific yield measured in 1998 and higher than average annual specific yields measured in 1996, 2008, 2011 and 2017 (Figure 47).

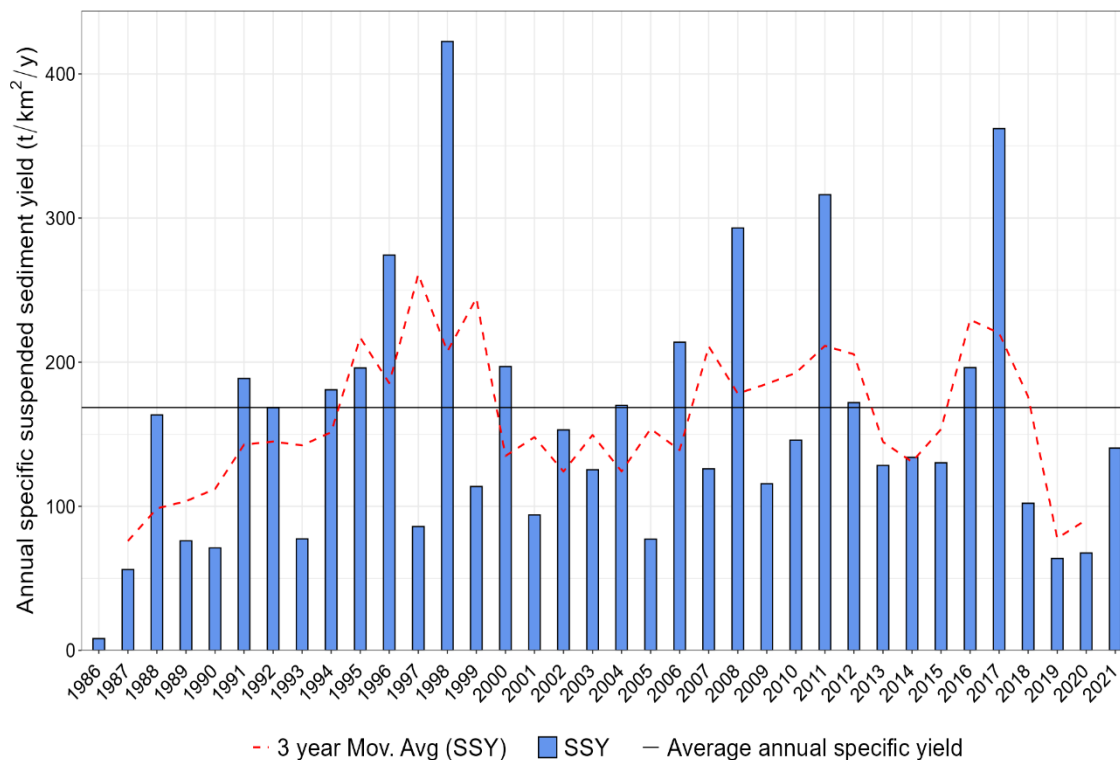


Figure 47: Annual specific suspended sediment yield for Waitomo at Aranui Caves. The red line is a three-year moving average.

Trend analysis was undertaken using both the uncorrected and TSS-corrected data by applying TSS-SSC regression method outlined in section 2.4.2. In both cases, there was no detectable trend in the concentration residuals between 1990 and 2020 (Figure 48), suggesting no change in suspended concentration relative to discharge. Given the gap in the long-term dataset between 2000 and 2008, trend analysis was repeated for the 1990 – 2008 and 2009 – 2020 periods. The latter period showed no significant trend, but a statistically significant increase was observed for the 1990 – 2008 period, implying that there was an increase in suspended sediment relative to discharge over that 18-year period.

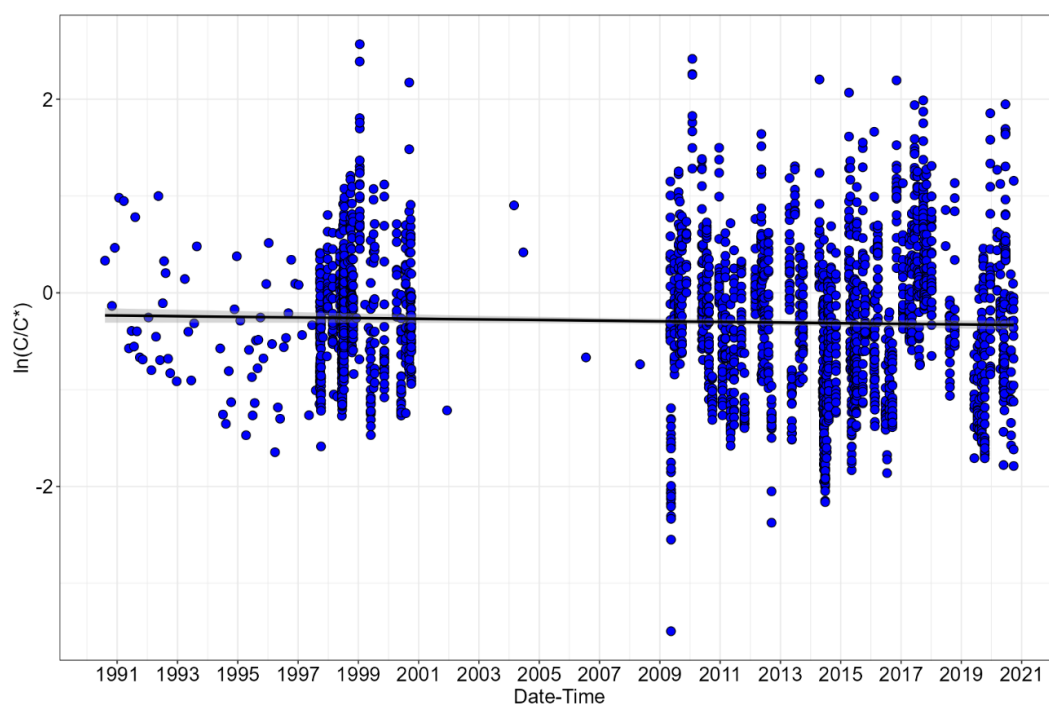


Figure 48: Suspended sediment rating residual (C/C^*) versus time for Waitomo at Aranui Cave. There is no significant trend.

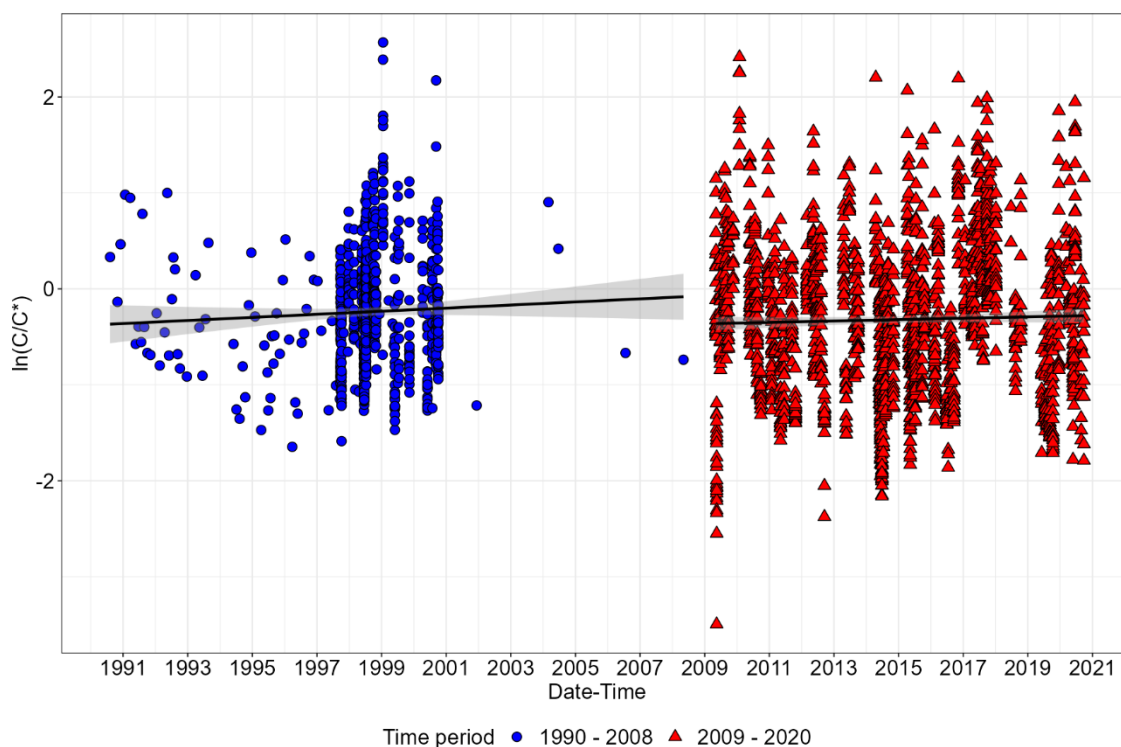


Figure 49: Suspended sediment rating residual (C/C^*) versus time for Waitomo at Aranui Caves for the period 1990 to 2008 and 2009 to 2020. The trend is statistically significant for the 1990 to 2008 period but is not significant for the 2009 to 2020 period.

In a comprehensive trend analysis of suspended sediment yield in the Waitomo catchment, Hoyle (2012) determined that trends changed depending on the period assessed. For example, Hoyle (2012) found that for Waitomo at Aranui Caves suspended sediment concentration decreased from 1990 to 1996, increased from 1997 to 1998, showed no change from 1999 until 2006 and increased from 2006 until 2010. A subsequent decrease in suspended sediment concentration was measured from 2010 to 2012. Hoyle (2012) concluded that the decline in suspended sediment from 1990 – 1996 could be the result of catchment works implemented by the Waitomo Landcare group. A large flood occurred during in 1997 and may explain the increase in suspended sediment between 1997 and 1998. Later changes are likely a result of other drivers that cannot be determined without further investigation (e.g., land use, climatic events etc.). A similar comprehensive analysis from the existing dataset including a catchment investigation would be useful but is outside the scope of this study.

3.1.19 Whakapipi Stream

The Whakapipi catchment is monitored at SH22 Tuakau (1282_8) and has an upstream area of 49 km² and a mean annual rainfall of 1,299 mm/y. (Table 1). Compared to other monitoring catchments (Figure 1), the Whakapipi catchment features a significant amount of flat to rolling land (Figure 3). LUC classes 1 and 2 account for 50% of the area, while LUC classes 3 and 4 comprise 27%. Steeper land, classified as LUC class 6, covers 17% of the catchment (Figure 2). The surface geology is dominated by basalt lavas (Figure 5). Soils are mostly well weathered Granular Soils, covering 62% of the catchment. Brown Soils cover 16% of the catchment area, and Gley, Ultic and Organic Soils cover between 4 and 8% (Figure 4). Over half of the catchment (57%) is exotic grassland, with cropping and urban land making up 19% and 13% of the catchment area, respectively (Figure 5).

A total of 59 manual depth integrated suspended sediment samples were collected over the monitoring period between 1991 and 2000 (Table 6). Between 1984 and 2022, the average annual suspended sediment yield was 2.1 kt/y, with a specific yield of 42.8 t/km²/y and a mean

concentration of 11.5 g/m³ (Table 7). However, the maximum gauged flow to establish the SSC-Q rating was below the mean annual flood value and only 34% of the derived sediment yield occurred within the range of discharges sampled for sediment and contributing to the SSC-Q rating dataset. Therefore, a high proportion of the derived yield relied on extrapolation of the SSC-Q rating, adding unknown uncertainty to the yield estimates.

Between 1984 and 2022, annual specific suspended sediment yield ranged between 4 and 166 t/km² (Figure 50), with the lowest yield measured in 1993 and the highest yield measured in 2018.

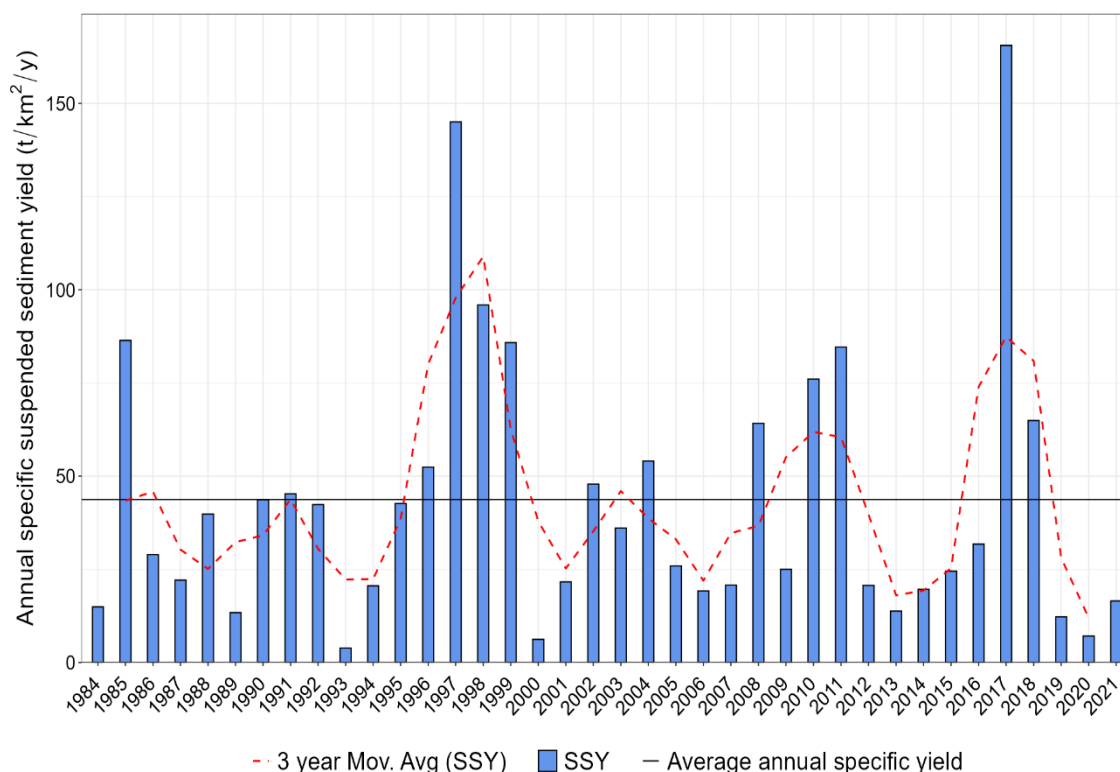


Figure 50: Annual specific suspended sediment yield for Whakapipi at SH22 Tuakau. The red line is a three-year rolling mean.

Trend analysis was not undertaken for Whakapipi at SH22 Tuakau because of the low percentage of samples within the gauged range of flow and because no new SSC-Q data had been collected since the previous suspended sediment monitoring report (Hoyle, 2014).

3.1.20 Wharekawa Stream

The Wharekawa catchment is monitored at Adams Farm Bridge (1312_1) and has an upstream catchment area of 47 km². The mean annual rainfall is 2,029 mm (Table 1). Most of the land is steep with 92% mapped as LUC classes 6 (55%) and 7 (37%) (Figure 2 and 3). Only 7% of the catchment is mapped as LUC class 4, and less than 1% as class 2 (Figure 3). The surface geology is composed of ignimbrites and rhyolites (Figure 5). Soils in the catchment (Figure 4) are dominated by Allophanic and Brown Soils, which cover 40% and 37% of the catchment area, respectively. Pumice Soils cover 22% of the catchment. Most of the catchment is covered by exotic (44%) and indigenous (53%) forest, with just over 1% being under pasture (Figure 5).

Between 1991 and 2020, a total of 1,023 suspended sediment samples were collected (Table 6). Samples were collected via manual depth integrated sampling between 1991 and 1999 and an autosampler was used to collect samples after 1999. A range of runoff events were sampled over the monitoring period, with 99% of the derived suspended sediment yield being transported by flows within the sampled range of flow (Table 6). Between 1991 and 2022, the average annual suspended sediment yield was 2.1 kt/y, with a specific yield of 42.8 t/km²/y and

a mean concentration of 5.9 g/m^3 (Table 7). Analysis of TSS and SSC data revealed a statistically significant difference in concentrations between samples and a correction factor of 1.36 was applied to TSS samples. Once the correction factor had been applied, the adjusted average annual specific suspended sediment yield increased from to $79.5 \text{ t/km}^2/\text{y}$ (Table 7).

Between 1991 and 2022, annual specific suspended sediment yield ranged between 4 and 143 t/km^2 (Figure 51).

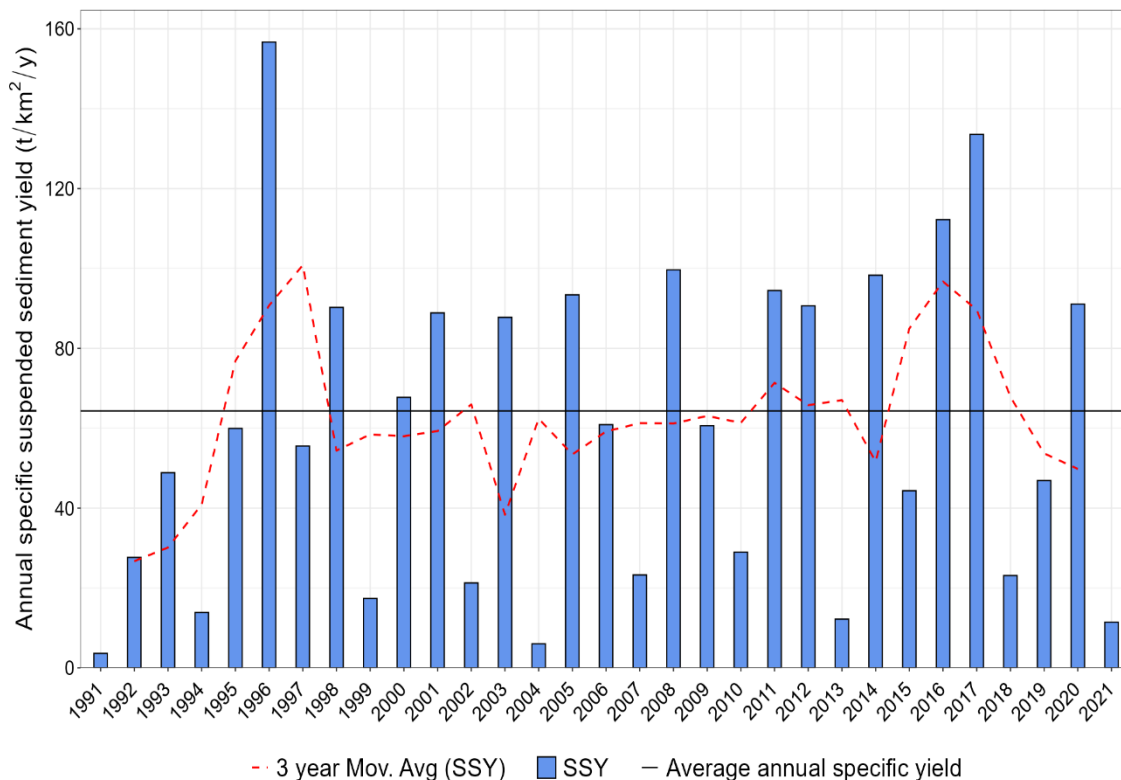


Figure 51: Annual specific suspended sediment yield for Wharekawa at Adams Farm Br. The red line is a three-year rolling mean.

For both corrected and uncorrected data, trend analysis revealed a statistically significant ($P < 0.05$) positive trend in concentration residuals between 1991 and 2020 (Figure 52), suggesting an overall increase in suspended concentration relative to discharge. The slope of the line reduced from 0.000082 to 0.000071 when the difference between TSS and SSC was accounted for. Given the large gap in the dataset between 2003 and 2009, trend analysis was rerun for the 1991 – 2003 and 2009 – 2020 periods. Both periods showed statistically significant decreasing trends in concentration residuals, suggesting a decrease in suspended sediment concentration during both periods, but the “jump” in residuals over the 2003-2009 gap in sampling suggests an event occurred some time over that period to cause a substantial increase in sediment supply that subsequently decreased (Figure 53).

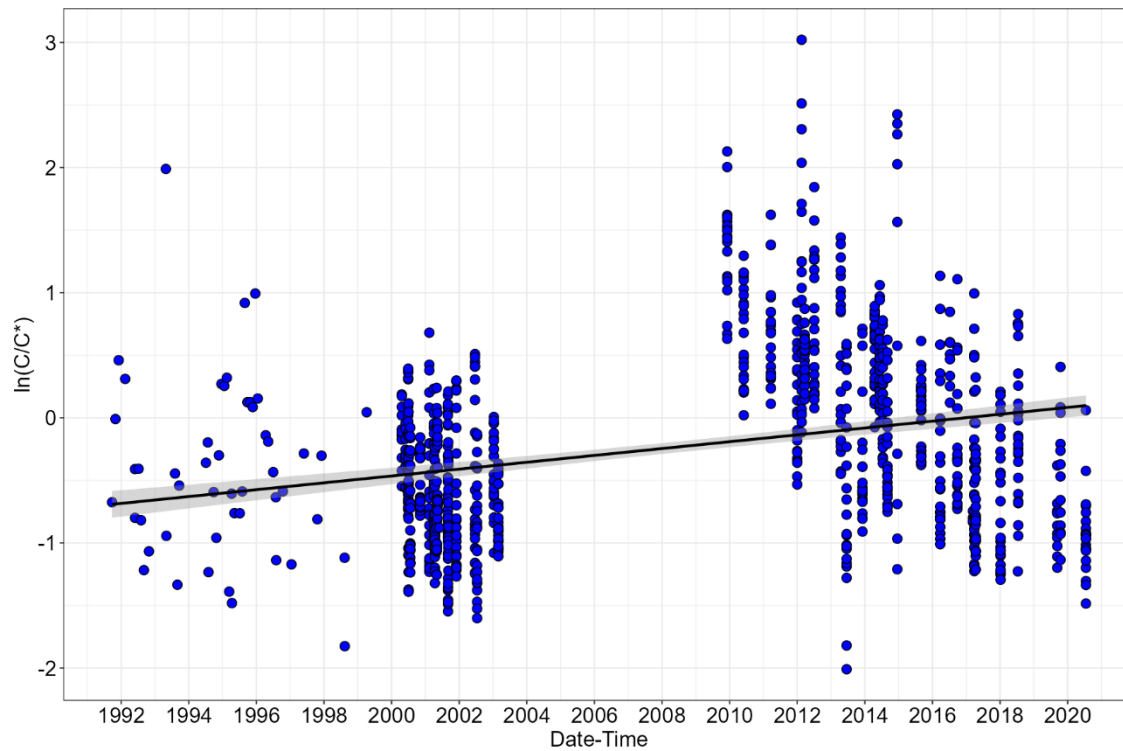


Figure 52: Suspended sediment rating residual (C/C^*) versus time for Wharekawa at Adams Farm Br. The trend is significant ($P < 0.05$).

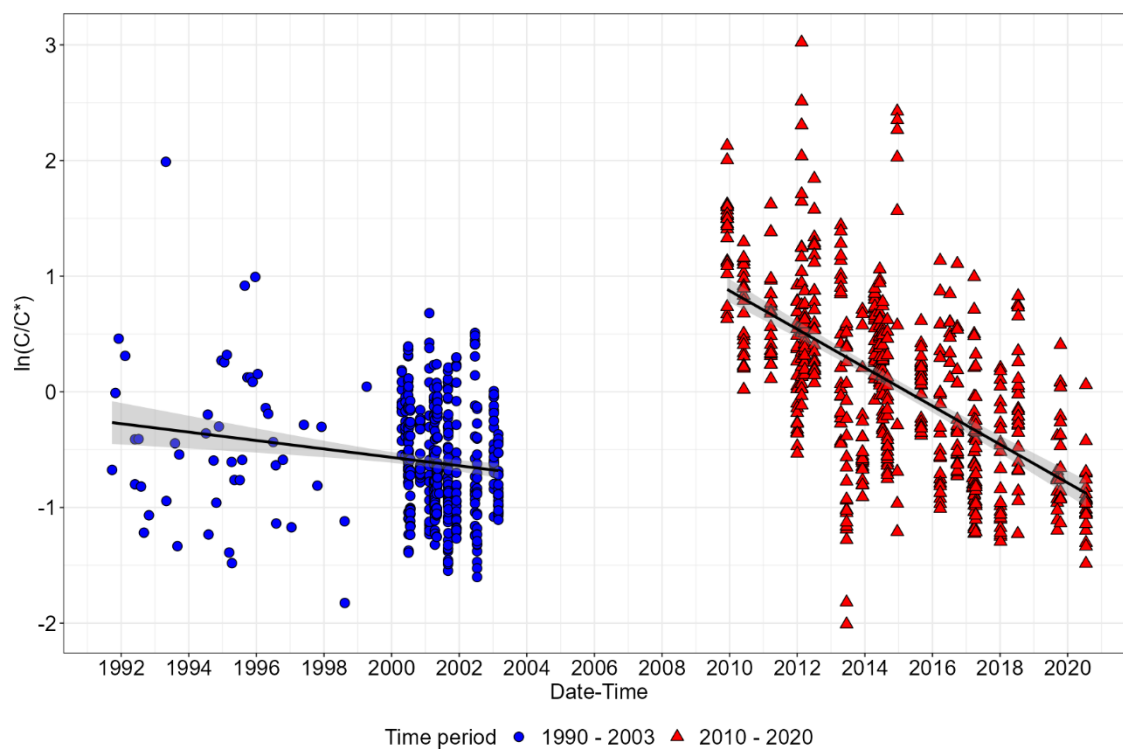


Figure 53: Suspended sediment rating residual (C/C^*) versus time for Wharekawa at Adams Farm Br between 1990 and 2003 and between 2009 and 2020. The trend is significant for both time periods ($P < 0.05$).

3.2 Regional-scale observations and summary

To assess the average annual suspended sediment yield across the WRC monitoring network, the suspended sediment concentration and discharge rating was applied to the full flow record for each site. Across the 26 monitored catchment, average annual yields ranged between 0.7 and 239.5 kt/y, with the highest yield recorded on the Waikato River at Rangiriri. The site at Rangiriri is below the confluence of the Waikato and Waipā Rivers and has a considerably higher average annual yield than that measured upstream of the confluence at Hamilton Traffic bridge (65.7 kt/y) due to the significant contribution of sediment from the Waipā River where the yield at Whatawhata was 154.2 kt/y.

The main factor influencing the spread in yield across monitoring sites is catchment area. This effect is removed in the specific sediment yield results (Table 7, Figure 54), which ranged between 7.9 and 176 t/km²/y. The highest specific yield was recorded at Matahuru at Myjers', a tributary of Lake Waikare, which also had the highest mean suspended sediment concentration of 101 g/m³. Waitomo at Aranui Caves, Waipā at Otewa, Opitonui downstream of the Awaroa Confluence and Moakurarua at Farm Bridge had average annual specific yields between 140 and 170 t/km²/y. The Opitonui site is on the Coromandel Peninsula, while the other three sites are part of the Waipā catchment. Due to the large catchment area and the Waikato at Hamilton Traffic Bridge site recorded the lowest average annual specific sediment yield by virtue of the sediment-trapping effects of the upstream hydro lakes and Lake Taupo (Figure 55).

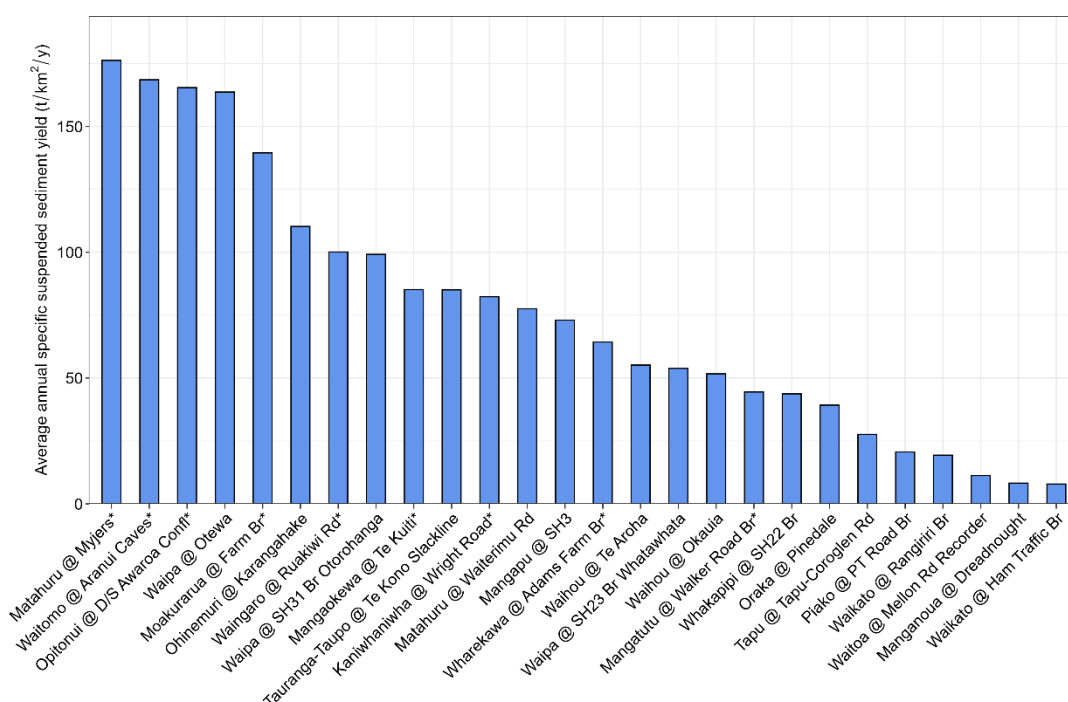


Figure 54: Average annual specific suspended sediment yields (t/km²/y.) from all riverine suspended sediment monitoring sites in the Waikato region. None of these results have been correction for the difference between TSS and SSC.

Annual yields showed more than a tenfold variation for many sites. This large variation was brought about by inter-annual variability in weather patterns and events, especially the occurrence of significant storm events in certain years. For example, 14 of the 23 monitoring sites had their highest annual suspended sediment yields in 2017 due to multiple high magnitude weather events that impacted the Waikato region. The first event, ex-tropical Cyclone Debbie, occurred in March 2017 and originated from the east coast of Australia (Craig, 2017). Despite the storm being short-lived locally, it brought along a low-pressure system with heavy rainfall that resulted in elevated river levels across many catchments but still below the

annual flood levels. The resultant flood events triggered a Tier 2 regional flood response based on the Regional Flood Response Management Plan (Munro and McKenzie, 2015). Before catchments in the Waikato region had time to recover, another low-pressure system crossed the Tasman Sea onto New Zealand, which was quickly followed by the Ex-tropical Cyclone Cook (Craig et al., 2017). The region's rainfall records were up by 450% on the March average and 317% on the April average, while all catchments experienced rainfalls >100% of their respective averages. Other years of high annual suspended sediment yield that were common among catchments included 1996, 1998, 2004 and 2008. These also would have been associated with significant regional or local scale weather events. For example, between 9-20 July 1998 a period of high rainfall occurred in the Waikato region, resulting in significant flooding and soil mass movement (Munro, 1998).

There were nine catchments (not including Kaniwhaniwha at Write Rd and Moakurarua at Farm Br) with updated suspended sediment concentration data since the 2014 study (Hoyle, 2014). For each of these catchments, the residuals of SSQ-Q taking relationship were plotted against time to test for a trend (section 3). Eight of the nine catchments with new SSC data show a trend in SSC-Q residuals over time. Of these, Matahuru at Myjers', Oraka at Pinedale and Waipā at Otewa saw decreasing trends, with Mangalorean at Te Kuiti, Opitonui D/S Awaroa Conflu., Waingaro at Ruakiwi Rd and Wharekawa at Adams Farm Br all showing an increasing trend over time.

Trend analysis results for Kaniwhaniwha at Wright Road and Moakurarua at Farm Br should be treated with caution due to the short duration of the sediment record. Both sites will be monitored over the long term under the CEM programme, and hence more comprehensive trend analysis will be undertaken during future analysis and reporting. At Mangaokewa (Te Kuiti), suspended sediment saw an average annual increase of 1.4% from 1990 – 2020, largely attributable to a major slip event in the upper catchment in 2017. A statistically significant decrease was observed in the residuals between 2017 and 2020, reflecting a reduction in sediment supply and in-channel storage. Mangatutu (Walker Road Bridge) and Opitonui (downstream of Awaroa confluence) showed comparable increases of approximately 1% per year. The drivers of these trends remain uncertain, and further quantitative analysis is required to relate sediment dynamics to catchment condition, land management, and climatic influences. Excluding the Moakurarua at Farm Br, Waingaro at Ruakiwi Rd and Wharekawa at Adam Farm Br saw the highest annual average increases in suspended sediment of 2 – 2.5% per year. The underlying causes are unclear; however, the Wharekawa data suggest elevated sediment loads prior to 2010, followed by a declining trend thereafter. This pattern is consistent with an episodic increase in sediment supply followed by gradual depletion of source material and reduction in in-channel storage over time, similar to that observed at the Mangaokewa site.

Not including the Kaniwhaniwha Catchment (due to the short duration of the sediment record), Waipā at Otewa and Matahuru at Myjers' saw the largest reduction in sediment loads over time, with an average annual decrease of 3.5%. These trends likely reflect multiple interacting drivers, including improved farm management practices, implementation of soil conservation measures (e.g., pole planting on highly erodible slopes), riparian restoration, and climatic variability. A detailed catchment-scale study of the Matahuru Catchment is currently underway as part of the CEM programme to explore the linkages between changing catchment characteristics and sediment load trends.

4 Conclusions and recommendations

4.1 Conclusions

- Across the monitoring network, average annual sediment yields ranged from 0.7 to 239.5 t/y. The highest yield was recorded at Rangiriri in the lower Waikato River catchment, reflecting the river's large catchment area and substantial sediment inputs from the Waipā River. The Waipā River recorded the second-highest annual yield (154.2 t/y) at Whatawhata. The lowest yield (0.7 t/y) was measured at the Tapu River at Coroglen, attributable to its small catchment and predominant indigenous vegetation cover
- When accounting for catchment area, average annual specific yields ranged from 7.9 to 176 t/km²/y, with most catchments having yields in the range of 40 to 100 t/km²/y.
- Comparative manual and auto sampling shows the ratio of $C_{\text{mean}}:C_{\text{point}}$ ranging between 0.72 and 1.34. However, no corrections have been applied to yield determinations because the $C_{\text{mean}}:C_{\text{point}}$ ratio has not yet been sampled across the full range of flows at any site.
- Comparative analyses of total suspended solids (TSS) and suspended sediment concentration (SSC) from nine autosampler sites showed SSC values to be 1.05 - 2.06 times higher than corresponding TSS values. This confirms that TSS underestimates true suspended sediment concentrations and supports the decision to replace the TSS laboratory method with the SSC method. Where comparative data were available, sediment yields from autosampler sites were calculated both with and without a TSS–SSC correction.
- Previous yield estimates for several study catchments (Hoyle et al., 2011; Hoyle, 2014) show acceptable agreement with those reported here, noting that some catchments in the present study benefited from longer monitoring periods.
- Ten of the eleven catchments with new SSC data show a trend in SSC-Q residuals over time. Decreasing trends were observed at Mangatutu at Walker Road, Opitonui at Awaroa confluence, and Wharekawa at Adams Farm Bridge, whereas increasing trends were identified at Waitomo at Aranui, Waingaro at Ruakiwi, Wharekawa at Adams Farm Bridge, and Mangatutu at Walker Road. These trends are broadly consistent with those reported by Hoyle et al. (2014), with most catchments retaining the same trend direction despite changes in statistical significance. The exception is Matahuru at Myjers', which shifted from an increasing trend in the earlier study to a decreasing trend in the 2022 analysis. Observed trends in SSC–Q residuals may reflect land-use change but can also be influenced by variability in sediment supply associated with large storm events.

4.2 Recommendations

- Given the resourcing required to meet the requirements of the recently developed National Environmental Monitoring Standards (NEMS) for suspended sediment, it is recommended that WRC rationalise the network to align with available resources or increasing resources to meet the needs of the monitoring network.
- To better quantify the possible difference between suspended sediment concentrations determined using the APHA 2540 D (TSS) and ASTM 3977 97 (SSC) methods, further TSS–SSC comparative analyses are recommended and rating relationships updated accordingly. At most sites, existing SSC–TSS ratings do not span the full flow range, particularly at high flows.
- Conduct a comprehensive campaign to establish and apply the necessary $C_{\text{mean}}:C_{\text{point}}$ correction wherever autosamplers are installed and operational.

- Given that SedRate is no longer supported by NIWA (Earth Sciences NZ), consider developing an in-house tool that provides similar capability to SedRate while providing improved functionality and compatibility with WRC databases and systems. Such a tool would allow for more regular updates of sediment ratings, yield estimates and trend analyses. Preliminary development of an R based script is underway.
- Undertake detailed event-based analysis for development of event yield ratings, both to improve the accuracy of calculated yields and allow for comparison with earlier studies which utilised this methodology (Hicks et al., 2011; Hoyle, 2014).
- To enhance the temporal resolution of monitoring and improve the accuracy of event-based yield estimates in priority catchments, it is recommended that WRC explore options for installing continuous turbidity or acoustic sensors as proxies for suspended sediment concentration. It is important that these sensors cover the range of turbidity at the site and are appropriately calibrated to suspended sediment concentration.
- Future reporting could include linear regression or other statistical approaches to assess the relationship between sediment yield and catchment characteristics such as land use, average rainfall and lithology. Such analyses should also be undertaken in relation to sediment trends to understand drivers behind these changes.

5 References

- American Public Health Association (APHA), 1995. *Standard methods for the examination of water and wastewater*. 19th ed. Washington, DC: American Public Health Association.
- American Society for Testing and Materials (ASTM), 2000. Standard test methods for determining sediment concentration in water samples. ASTM D3977–97. *Water (III)*, 11.02, pp.395–400.
- Brown, J.N. and Peake, B.M., 2006. Sources of heavy metals and polycyclic aromatic hydrocarbons in urban stormwater runoff. *Science of the Total Environment*, 359(1-3), pp.145-155.
- Christie, A.B., Simpson, M.P., Brathwaite, R.L., Mauk, J.L. and Simmons, S.F., 2007. Epithermal Au-Ag and related deposits of the Hauraki goldfield, Coromandel volcanic zone, New Zealand. *Economic Geology*, 102(5), pp.785-816.
- Craig, H., 2017. *Regional flood summary: rainfall event 7 to 12 March 2017*. Waikato Regional Council Technical Report 2017/21. Hamilton: Waikato Regional Council.
- Craig, H., Koh, S.S., Williams, J., Lovatt, D. and Stewart, D., 2017. *Regional flood summary: Ex-Tropical Cyclone Debbie (4–6 April), Tasman Low (11–13 April), and Ex-Tropical Cyclone Cook (13–14 April)*. Waikato Regional Council Technical Report 2017/20. Hamilton: Waikato Regional Council.
- Dymond, J.R., Herzig, A., Basher, L., Betts, H.D., Marden, M., Phillips, C.J., Ausseil, A.G.E., Palmer, D.J., Clark, M. and Roygard, J., 2016. Development of a New Zealand SedNet model for assessment of catchment-wide soil-conservation works. *Geomorphology*, 257, pp.85-93.
- Dymond, J.R., Davies-Colley, R.J., Hughes, A.O. and Matthaei, C.D., 2017. Predicting improved optical water quality in rivers resulting from soil conservation actions on land. *Science of the Total Environment*, 603, pp.584-592.
- Gray, J.R., Glysson, G.D., Turcios, L.M. and Schwarz, G.E., 2000. *Comparability of suspended-sediment concentration and total suspended solids data*. USGS Water-Resources Investigations Report 00-4191. <https://water.usgs.gov/osw/pubs/WRIR00-4191.pdf>
- Haddadchi, A. and Hicks, D.M., 2016. *Models for estimating sediment yields in the Waikato-Auckland-Northland regions: a comparison*. Technical Report 2016/036. Auckland: Auckland Council.
- Hall, J., 2017. *Catchment riparian characteristics survey of Kaniwhaniwha Catchment*. Waikato Regional Council Internal Series 2021/04. Hamilton: Waikato Regional Council.
- Hewitt, A.E., 2010. *New Zealand Soil Classification*. 3rd ed. Lincoln: Manaaki Whenua Press.
- Hicks, D., 2005. *Soil conservation survey of the Matahuru Catchment*. Environment Waikato Technical Report 2005/39. Hamilton: Waikato Regional Council.
- Hicks, D.M., Webby, M.G., Duncan, M.J. and Harding, S., 2001. *Waikato River sediment budget and processes*. National Institute of Water & Atmospheric Research Ltd (NIWA) client report no. CHC01/24 prepared for Mighty River Power.

- Hicks, D.M., Quinn, J. and Trustrum, N., 2004. Stream sediment load and organic matter. In: Harding, J.S., Mosley, M.P., Pearson, C.P. and Sorrell, B.K., eds. *Freshwaters of New Zealand*. Christchurch: New Zealand Hydrological Society and New Zealand Limnological Society.
- Hicks, D.M., 2017. *Review of suspended sediment monitoring in the Waikato Region*. NIWA client report no. 2017170CH prepared for Waikato Regional Council. Doc ID 10611722.
- Hicks, D.M., Watson, B. and Micheala, R., 2017. *National Environmental Monitoring Standard (NEMS): turbidity v1.2*. National Environmental Monitoring Standards. NEMS Steering Group.
- Hicks, D.M., Doyle, M., Watson, J., Holwerda, N., Lynch, B., Wyatt, J., Jones, H. and Hill, R., 2020. *National Environmental Monitoring Standard (NEMS): measurement of fluvial suspended sediment load and its composition v1.0.0*. National Environmental Monitoring Standards. NEMS Steering Group.
- Hicks, D.M., Holwerda, N. and Grant, C.M., 2021. *Rural catchment sediment yields from the Auckland Region: state of the environment reporting*. Technical Report 2021/12. Auckland: Auckland Council.
- Hill, R. and Borman, D., 2016. *Waikato regional prioritisation project: Phase 2 overview*. Waikato Regional Council Technical Report 2016/01. Hamilton: Waikato Regional Council.
- Hoyle, J., 2012. *Suspended sediment time trends in the Waipā River and Waitomo Stream*. Waikato Regional Council Technical Report 2012/33. Hamilton: Waikato Regional Council.
- Hoyle, J., Hicks, M. and Roulston, H., 2012. *Sampled suspended sediment yields from the Waikato region*. Waikato Regional Council Technical Report 2012/01. Hamilton: Waikato Regional Council.
- Hoyle, J., 2014. *Waikato suspended sediment indicators: state and trend*. Waikato Regional Council Technical Report 2014/43. Hamilton: Waikato Regional Council.
- Kimberley, M., 2019. *Riparian characteristics of pastoral waterways in the Waitomo Catchment in 2019*. Unpublished Environmental Statistics Ltd report. Doc ID 15372436.
- Kotze, C., Sally, G. and Hill, R., 2008. *Suspended sediment monitoring report 2007*. Environment Waikato Technical Report 2008/30. Hamilton: Waikato Regional Council.
- Littler, C., 2014. *Catchment environmental monitoring report 2013/14*. Waikato Regional Council Technical Report 2014/67. Hamilton: Waikato Regional Council.
- McKercher, A.I. and Hicks, M., 2003. *Suspended sediment in Waitomo Stream*. NIWA Client Report CHC2003-014 prepared for Environment Waikato. Christchurch: National Institute of Water & Atmospheric Research Ltd.
- Ministry for the Environment (MfE), 2023. *National Policy Statement for Freshwater Management 2020*. As amended February 2023. Wellington: Ministry for the Environment.
- Munro, A.J., 1998. The Waikato regional flood event of 9–20 July 1998. *Australasian Journal of Disaster and Trauma Studies*, 2.

- Munro, A. and McKenzie, A., 2015. *Regional flood response management plan*. Waikato Regional Council Internal Series 2016/22. Hamilton: Waikato Regional Council.
- Newsome, P.F.J., Wilde, R.H. and Willoughby, E.J., 2008. *Land Resource Information Systems spatial data layers: data dictionary*. Palmerston North: Landcare Research New Zealand Limited.
- Norris, M. and Norris, T., 2021. *Catchment riparian characteristics survey of Matahuru Catchment (2021)*. Waikato Regional Council Internal Series 2021/05. Hamilton: Waikato Regional Council.
- Norris, M., Kotze, C., Wyatt, J., Hamer, M. and Norris, T., 2022. *Review of the Catchment Environmental Monitoring Programme*. In press. Waikato Regional Council Technical Report 2022/40. Hamilton: Waikato Regional Council.
- Norris, M., Borman, D. and Hill, R., 2021. *Waikato prioritisation framework and its use for soil conservation: development and methods*. Waikato Regional Council Technical Report 2021/06. Hamilton: Waikato Regional Council.
- Parfitt, R., Dymond, J., Ausseil, A-A., Clothier, B., Deurer, M., Gillingham, A., Gray, R., Houlbrooke, D., Mackay, A. and McDowell, R., 2007. *Best practice for phosphorus losses from agricultural land*. Landcare Research contract report LC0708/012 prepared for Horizons Regional Council.
- R Core Team, 2022. *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. <https://www.R-project.org/>.
- Singleton, P., 2016. *The Moakurarua Sub-Catchment*. Natural Knowledge Ltd report prepared for Waikato Regional Council.
- Singleton, P., 2017. *The Waitomo Sub-Catchment*. Natural Knowledge Ltd report prepared for Waikato Regional Council.
- Singleton, P., 2018. *The Matahuru Sub-Catchment*. Natural Knowledge Ltd report prepared for Waikato Regional Council. Doc ID 14108621.
- Singleton, P., 2019. *The Mangaokewa and Waipā at Mangaokewa Road Sub-Catchment*. Natural Knowledge Ltd report prepared for Waikato Regional Council.
- Singleton, P., 2020. *Waipā River at Whatawhata Bridge Sub-Catchment*. Natural Knowledge Ltd report prepared for Waikato Regional Council.
- Smith, H., Herzig, A., Dymond, J. and Basher, L., 2019. *Application of a revised SedNetNZ model to the Oreti and Aparima catchment, Southland*. Manaaki Whenua–Landcare Research contract report LC3507 prepared for Our Land and Water National Science Challenge.
- Steinhoff-Knopp, B., Kuhn, T.K. and Burkhard, B., 2021. The impact of soil erosion on soil-related ecosystem services: Development and testing a scenario-based assessment approach. *Environmental Monitoring and Assessment*, 193(Suppl 1), p.274.
- Stewart, D., Hill, R. and Jones, R., 2001. *River sediment monitoring in the Waikato region: final*. Environment Waikato Internal Series 2001/08. Hamilton: Waikato Regional Council.
- Ward, J.R. and Yorke, T.H., 2000. *Collection and use of total suspended solids data*. Office of Water Quality Technical Memorandum No. 2001.03 and Office of Surface Water Technical Memorandum No. 2001.03. Reston, VA: USGS Water Resources.

- Wild, M. and Hicks, M., 2005. *Opitonui Stream suspended sediment analysis*. Environment Waikato Technical Report 2005/45. Hamilton: Waikato Regional Council.
- Waikato Regional Council (WRC), 2014. *Waipā catchment management plan*. Waikato Regional Council Technical Report 2014/33. Hamilton: Waikato Regional Council.
- Waikato Regional Council (WRC), 2016. *Proposed Waikato Regional Plan Change 1: Waikato and Waipā River Catchments*. Hamilton: Waikato Regional Council.
- Wyatt, J., 2017. 2016 *Moakurarua and Kaniwhaniwha sediment snapshot*. Unpublished Waikato Regional Council filenote. Doc ID 9979703. Hamilton: Waikato Regional Council.
- Wyatt, J., 2018. *Total suspended solids (TSS) vs suspended sediment concentration (SSC) comparison protocol*. Unpublished Waikato Regional Council filenote. Doc ID 10889988. Hamilton: Waikato Regional Council.

Appendix 1: Site Information Card Example

Mangatutu at Walker Road 476_7

- **Catchment / Zone:** Waipā
- **Sampling Method:** Automatic sampler / manual gaugings
- **Gauged widths:** 5.2 m – 14.1 m
- **Min flow:** 0.475 cumecs
- **Max flow:** 37.26 cumecs
- **Infrastructure:** Bridge – TMP required for D49.
- **Purpose:** Part of CEM programme.
- **Charge code:** AM1420 001.1.21
- **Max recorded level:** 4.668 m
- **Max gauged level:** 4.315 m (max velocity 1.511 m/s)
- **Max velocity gauged:** 1.511m/s (level 4.315 m)

Use the table below to select sampler according to stream depth and velocity:

Level (m)	Velocity (m/s)	Sediment Sampler
0.5 – 1.6	0 – 2.7	DH48
1.0 – 4.7	0 – 1.52	DH59
1.0 – 5.0	0 – 3.7	D49*

*Put a comment in Wiski if max depth is over 4.66m.

- Use the nomographs on associated general sediment sampling sheet, flow and depth information from current gauging to help determine sampler nozzles to use and sampling speed.
- Remember to take: Crane for D49 and rope for DH59 and gloves. Spare ISCO sample bottles for calibrations.



2019 Annual Plan:
Mangatutu at Walker Rd 476_7

- **Current ISCO settings:**
 - Trigger level: 1.5 m
 - Trigger reset: 1.49 m
 - Sampling Interval: 60 minutes
- **Sampling Strategy:**

- 4 automatic sampler calibrations per year over a range of flows and seasons
- 6+ events sampled with the auto sampler over a range of flows and seasons
- One manual sediment gauging in low flow conditions
- Use graphs and tables below to guide selection of flows and timing for samples.

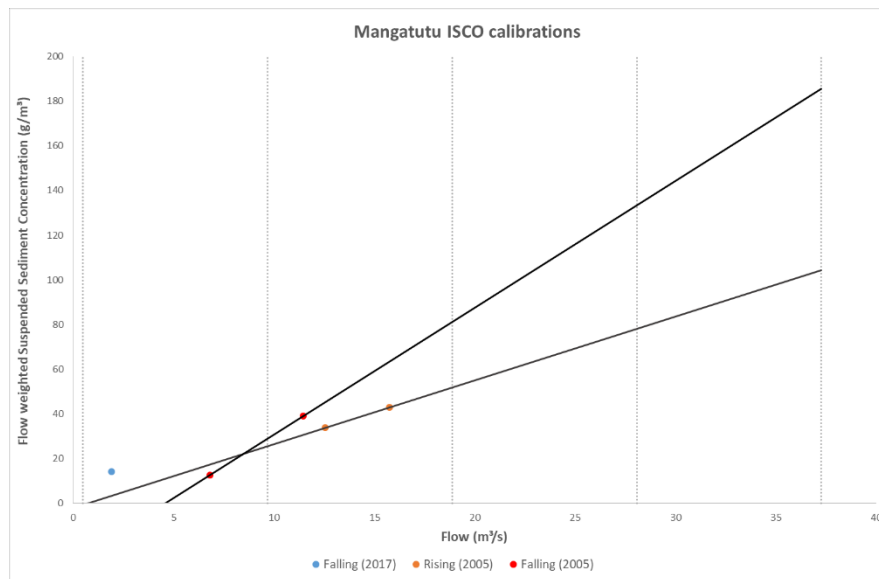


Figure: Flow vs flow weighted suspended sediment concentration. Vertical lines indicate targeted flow.

Low Flow Manual Gauging		
Target flow:	<0.77 m³/s	✓

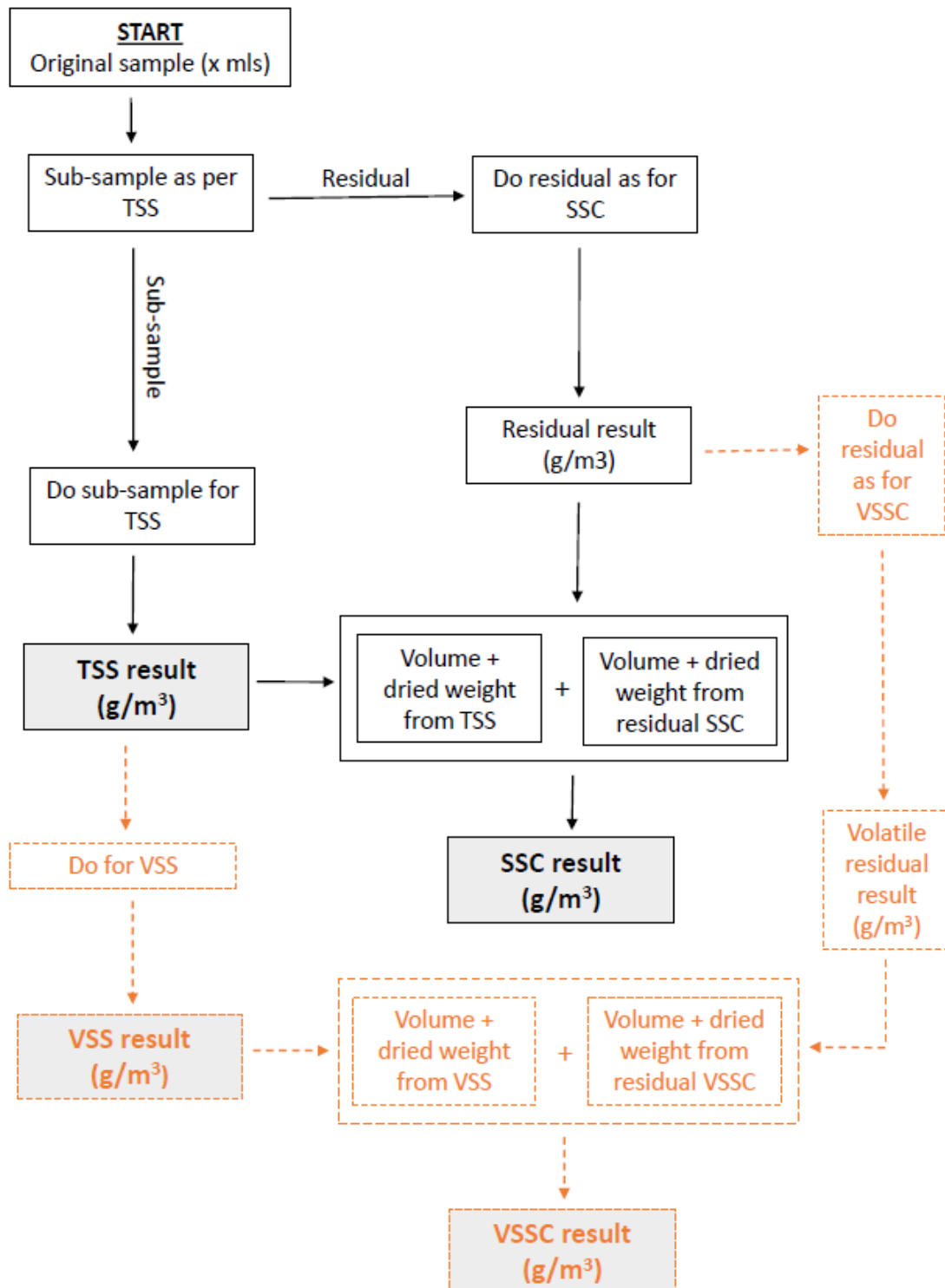
Completed Calibration Flows:		
Season	Rising Flow	Falling Flow
Spring		6.69
Winter	10.68	

Target Calibration Flow Bands:		
Flow (cumeecs)	Rising (✓)	Falling (✓)
0.475-9.671		✓✓
9.671-18.867	✓✓	✓
18.867-28.063		
28.063-37.259		

ISCO Events Sampled:		
Flow (cumeecs)	Level (m)	Events sampled (✓) (Peak)
<10	<2.0	✓
>15	>3.1	
>20	>4.1	✓✓
>25	>5.0	
>30	>5.7	✓
>40	>6.5	

Appendix 2: TSS vs SSC analysis

Overview of single bottle TSS vs SSC analysis approach.



Appendix 3: TSS vs SSC graphs

Graphs of TSS vs SSC with a linear regression fitted.

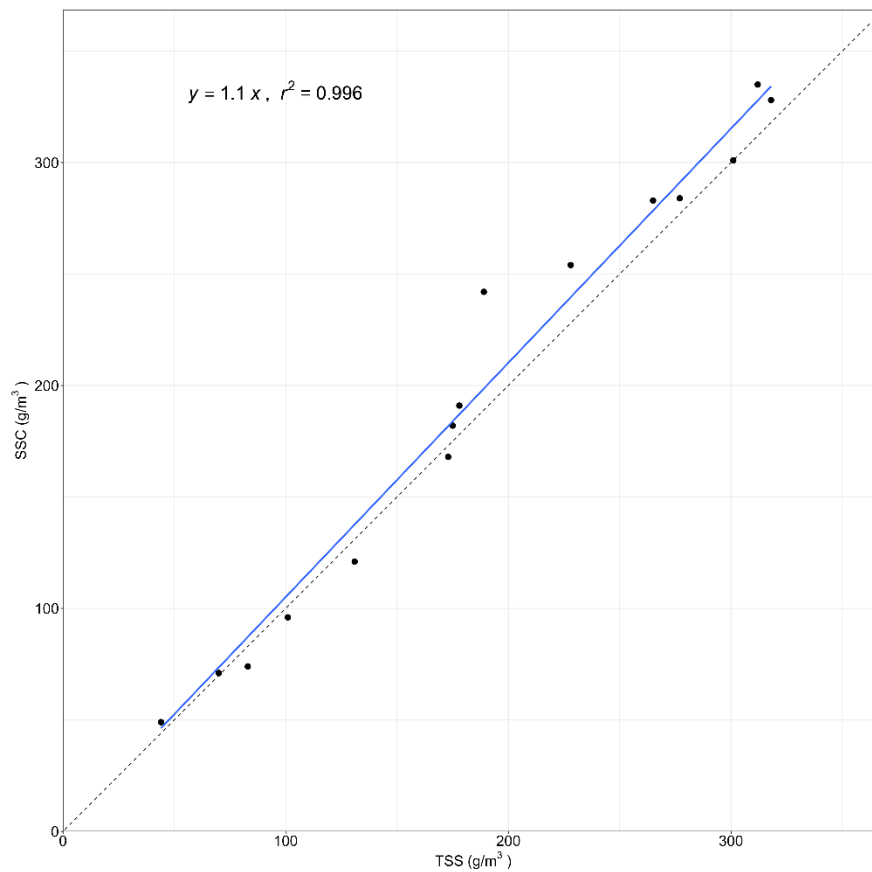


Figure A3-1: TSS vs SSC for Kaniwhaniwha at Wright Rd.

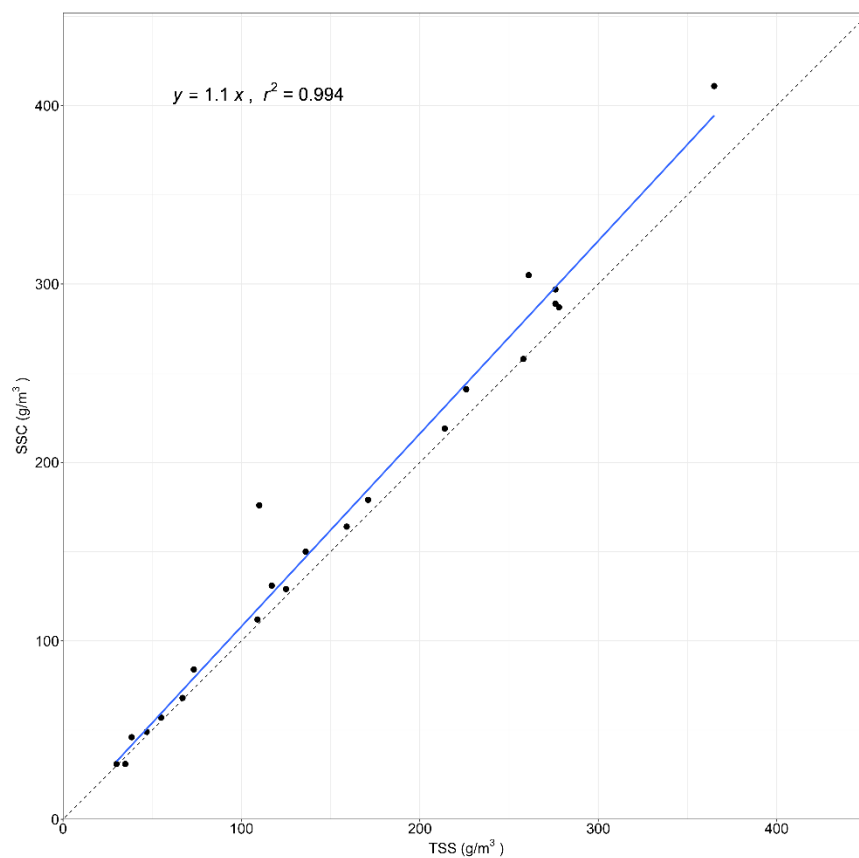


Figure A3-2: TSS vs SSC for Mangaokewa at Te Kuiti.

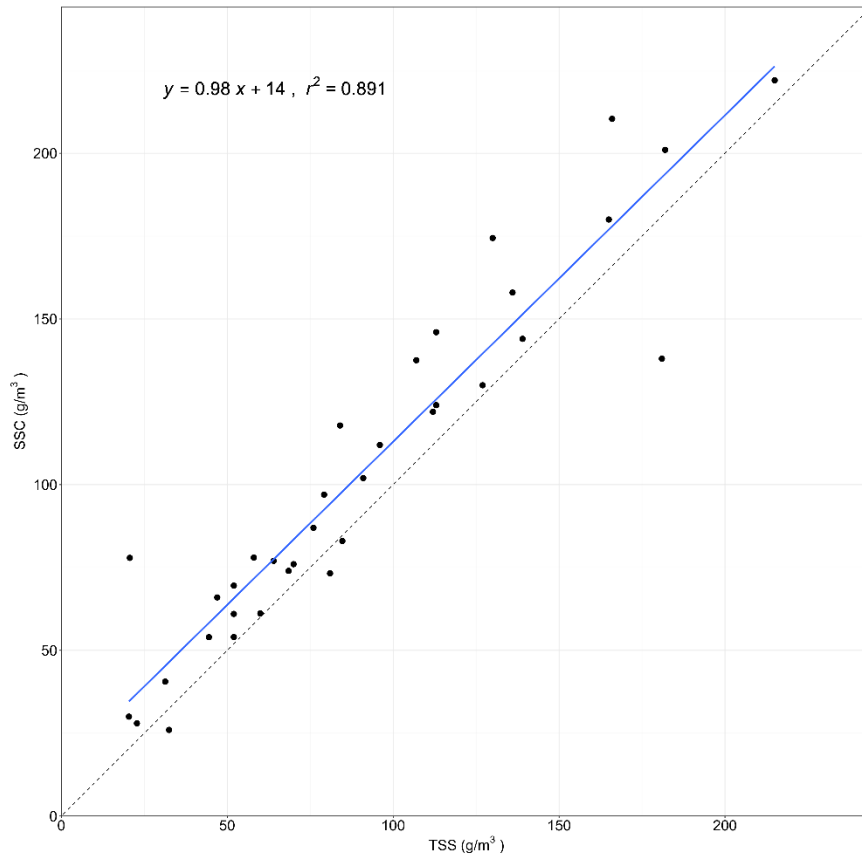


Figure A3-3: TSS vs SSC for Mangatutu at Walker Rd Br.

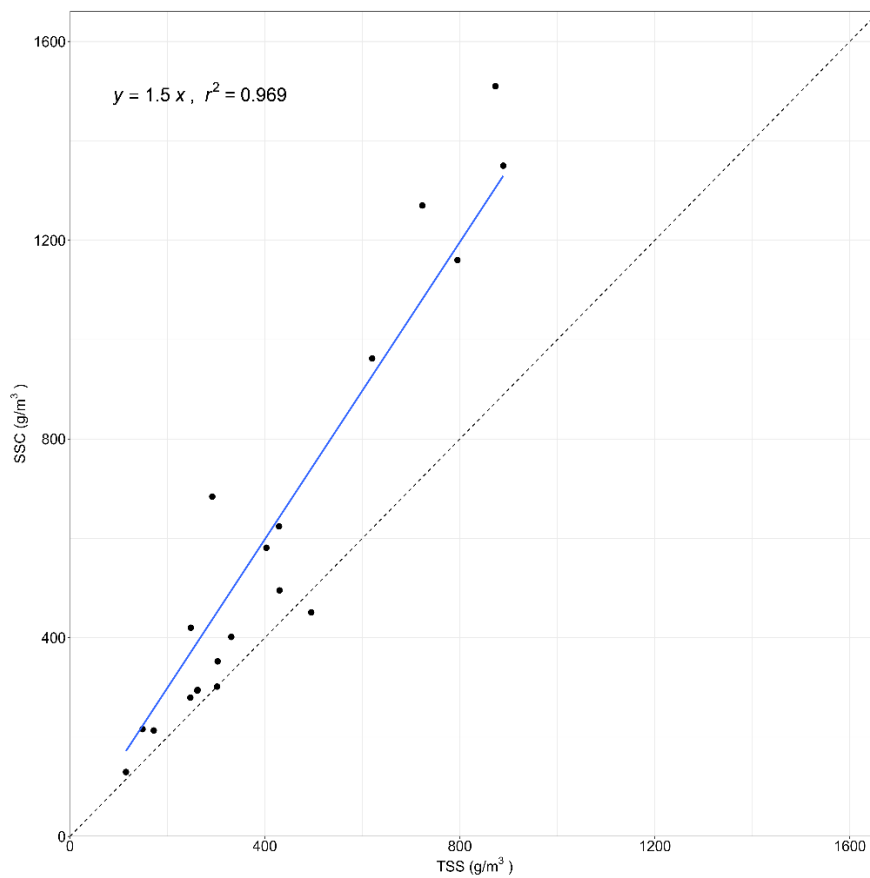


Figure A3-4: TSS vs SSC for Matahuru at Myjers.

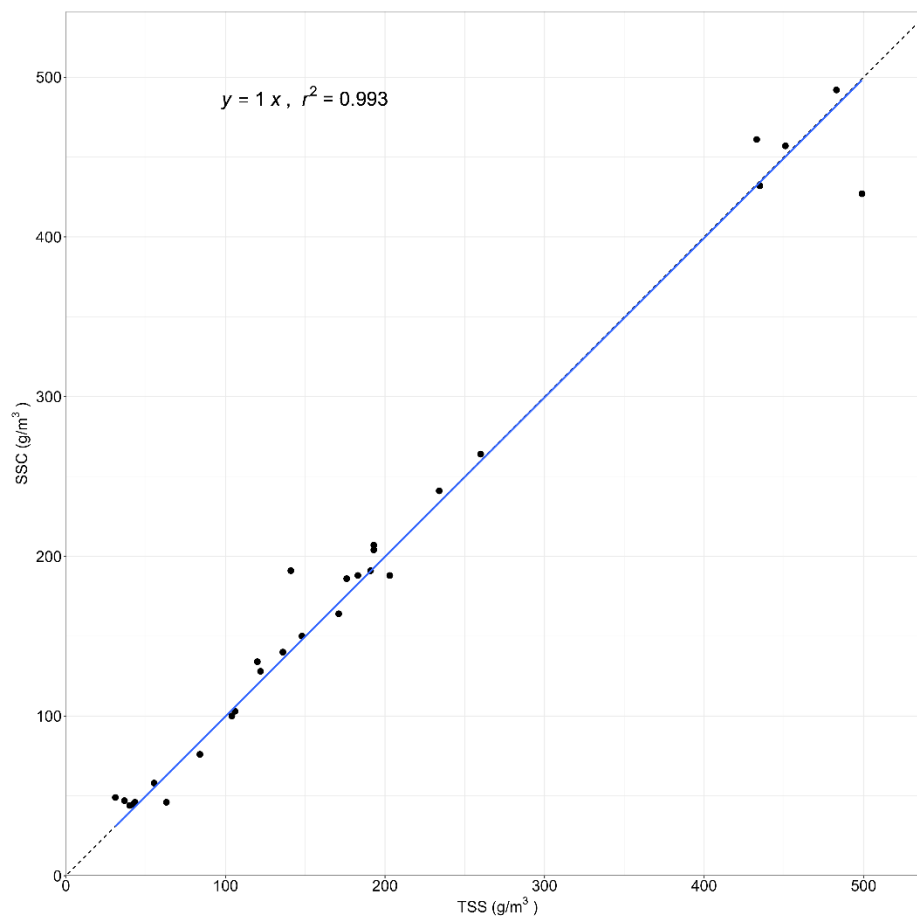


Figure A3-5: TSS vs SSC for Moakurarua at Warratah Farm Br.

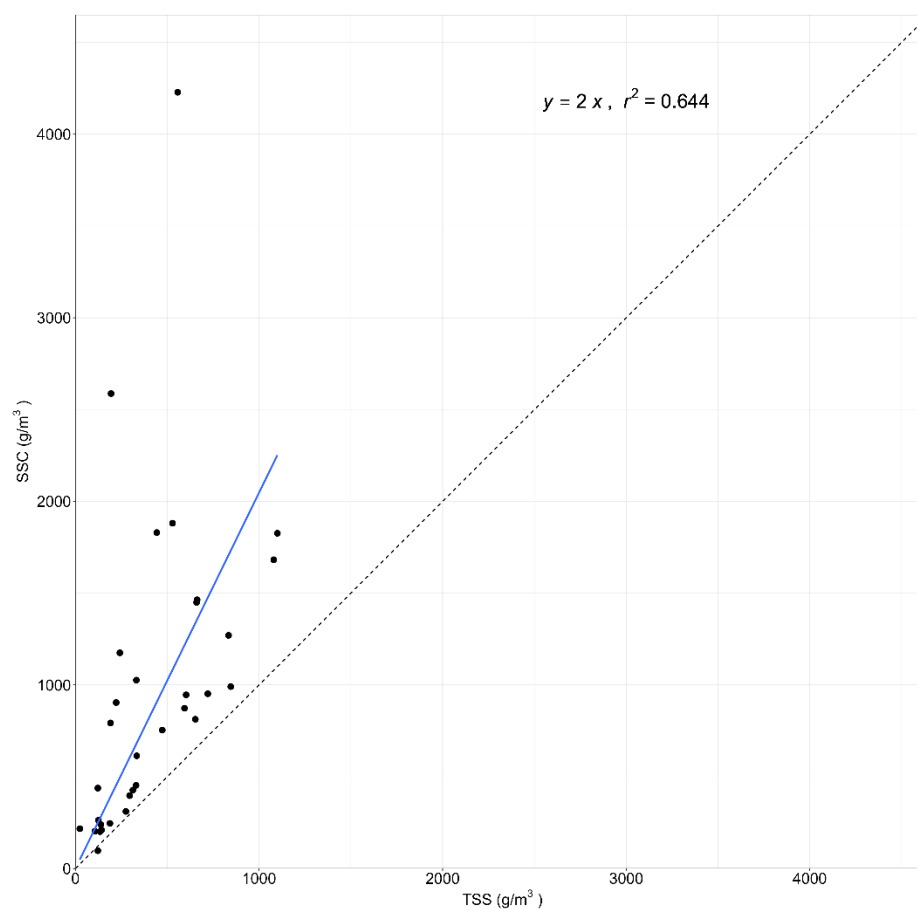


Figure A3-6: TSS vs SSC for Opitonui at d/s Awaroa confl.

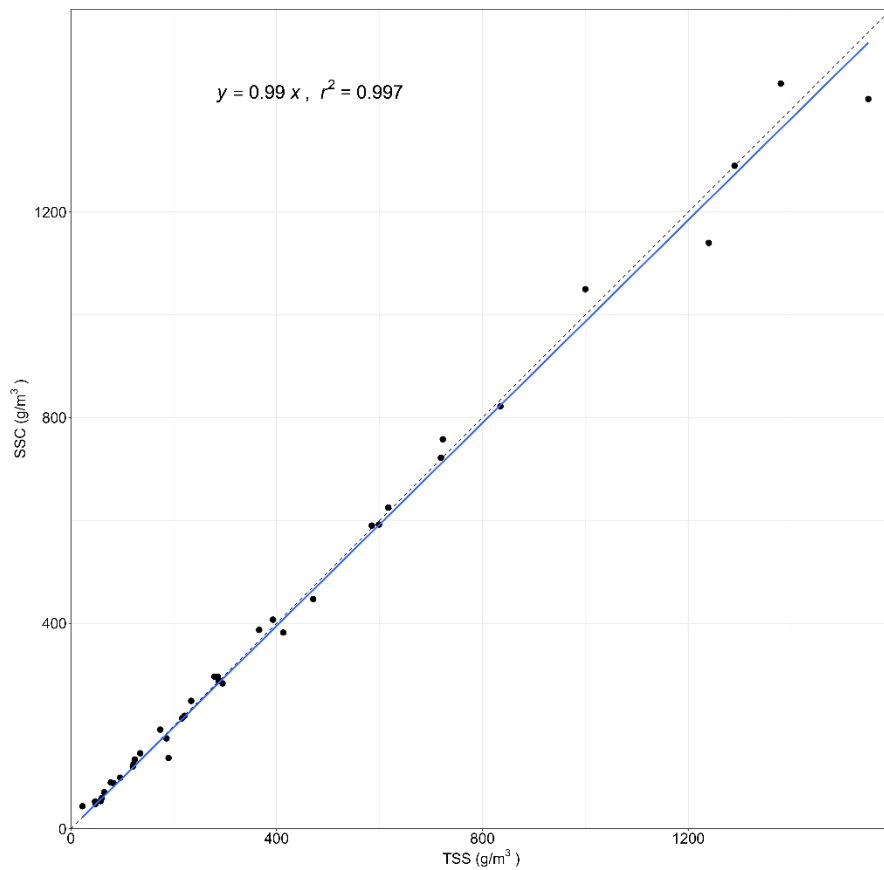


Figure A3-7: TSS vs SSC for Waingaro at Ruakiwi Rd.

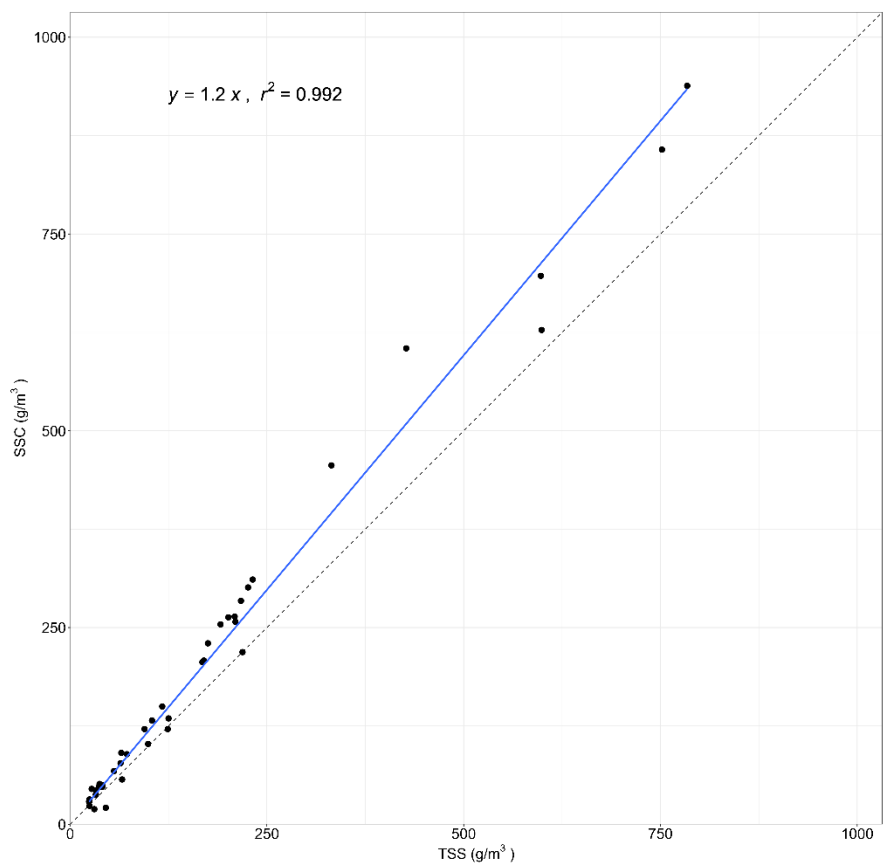


Figure A3-8: TSS vs SSC for Waitomo at Aranui Caves.

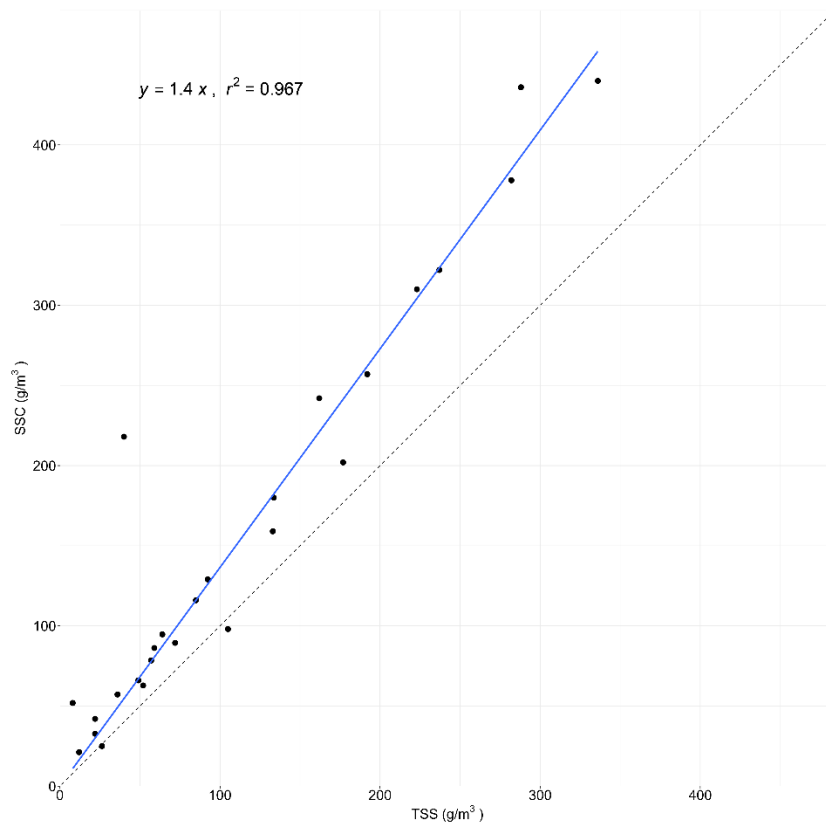


Figure A3-9: TSS vs SSC for Wharekawa at Adams Farm Bridge.

Appendix 4: Maximum load associated with TSS vs SSC comparison

Table A4-1: Maximum instantaneous sediment loads (kg/s) calculated using the long-term sediment record (G) and from samples collected for TSS vs SSC comparison (S). S/G represents the ratio of S to G. Values > 0.8 indicate that sampling requirements were met during the TSS vs SSC sampling campaign.

Site name	Site number	G (kg/s)*	S (kg/s) ⁺	S/G
Waingaro at Ruakiwi Rd	1167_4	100.14	99.81	1.00
Waitomo at Aranui Caves	1253_3	57.47	8.07	0.14
Wharekawa at Adams Farm Bridge	1312_1	298.60	59.10	0.20
Kaniwhaniwha at Wright Rd	222_16	18.90	3.40	0.18
Mangaokewa at Te Kuiti	414_13	61.27	6.38	0.10
Mangatutu at Walker Rd Br.	476_7	12.81	3.35	0.26
Matahuru at Myjers	516_22	30.95	11.83	0.38
Moakurarua at Warratah Farm	553_12	148.19	14.65	0.10
Opitonui at d/s Awaroa Confl.	660_1	1460.23	167.75	0.11

* G: Maximum instantaneous loads (sediment concentration * flow) for extracted from the long-term sediment record at each site.

⁺S: Maximum instantaneous loads calculated from samples collected during the TSS vs. SSC sampling campaign.

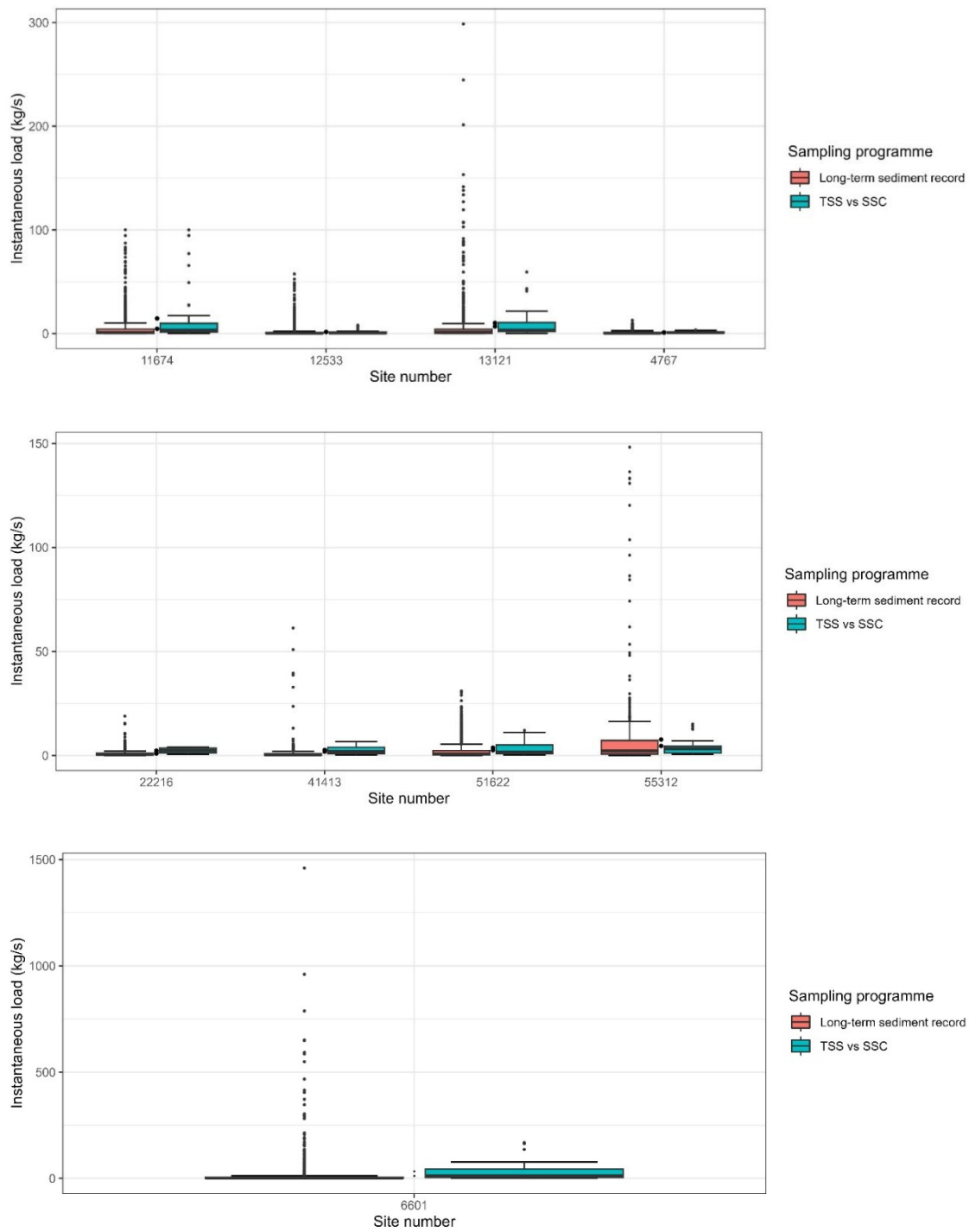


Figure A4-1: Instantaneous sediment load derived from the long-term sediment record and recent TSS/SSC sampling.

Appendix 5: Point to cross-section mean calibrations

Autosampler site calibration graphs, including C_{mean} versus C_{point} and the ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow.

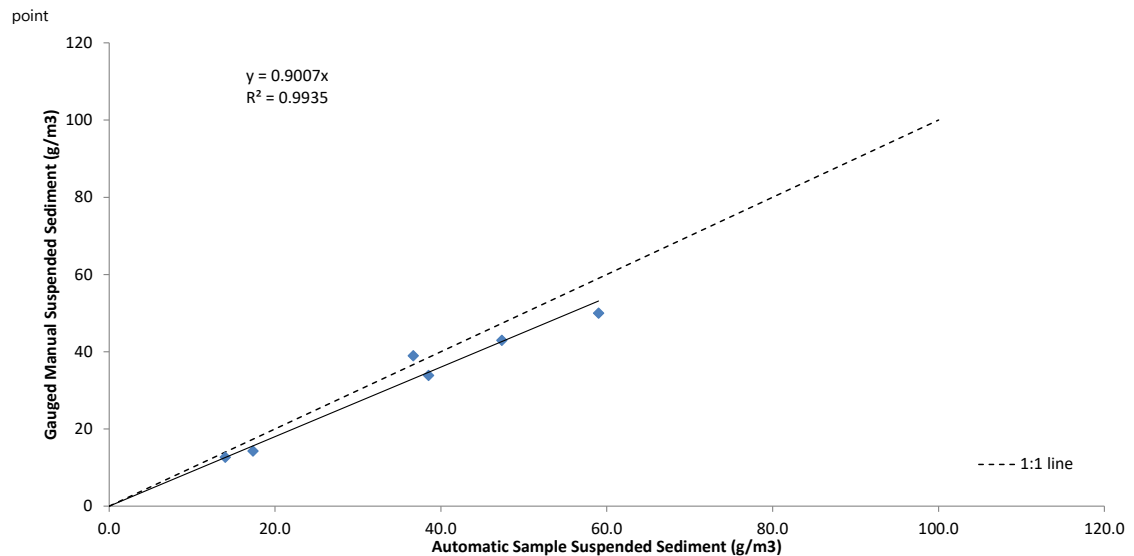


Figure A5-1: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Mangatutu at Walker Rd Br.

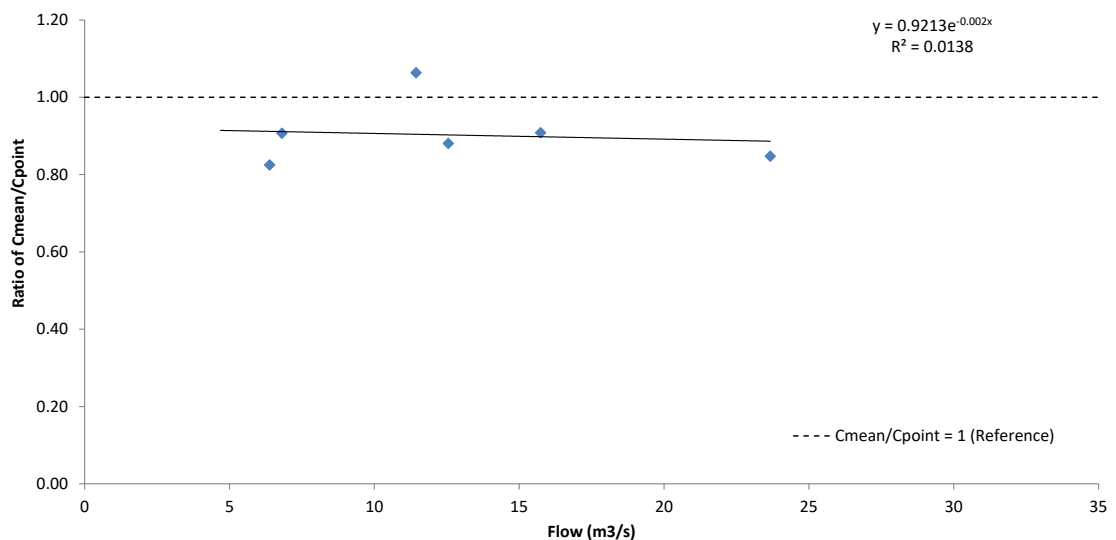


Figure A5-2: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Mangatutu at Walker Rd Br.

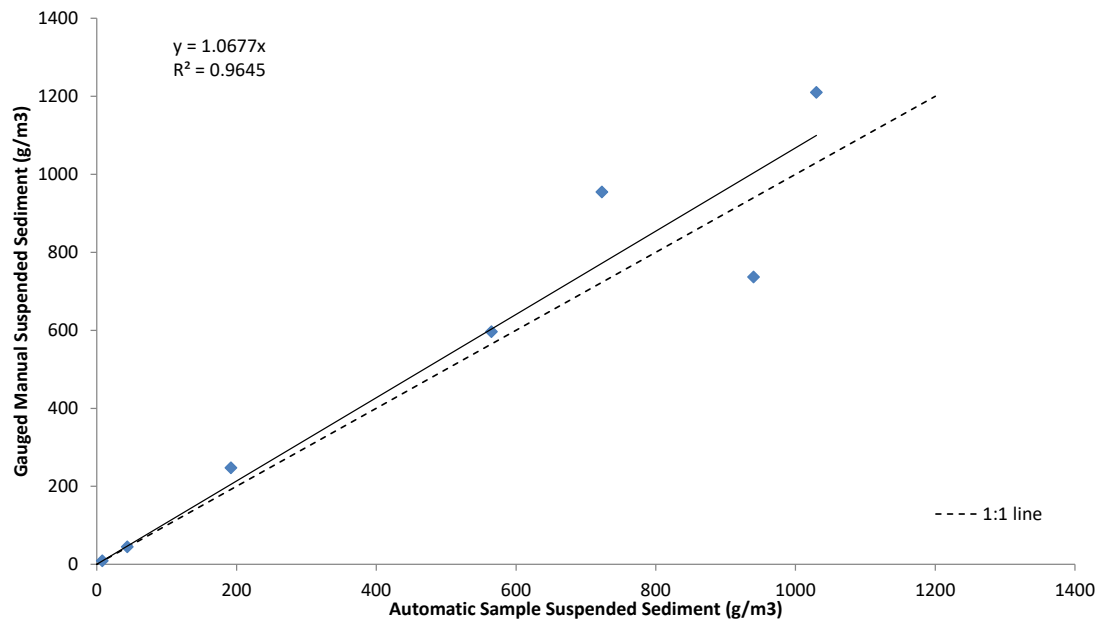


Figure A5-3: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Waipā at Otewa.

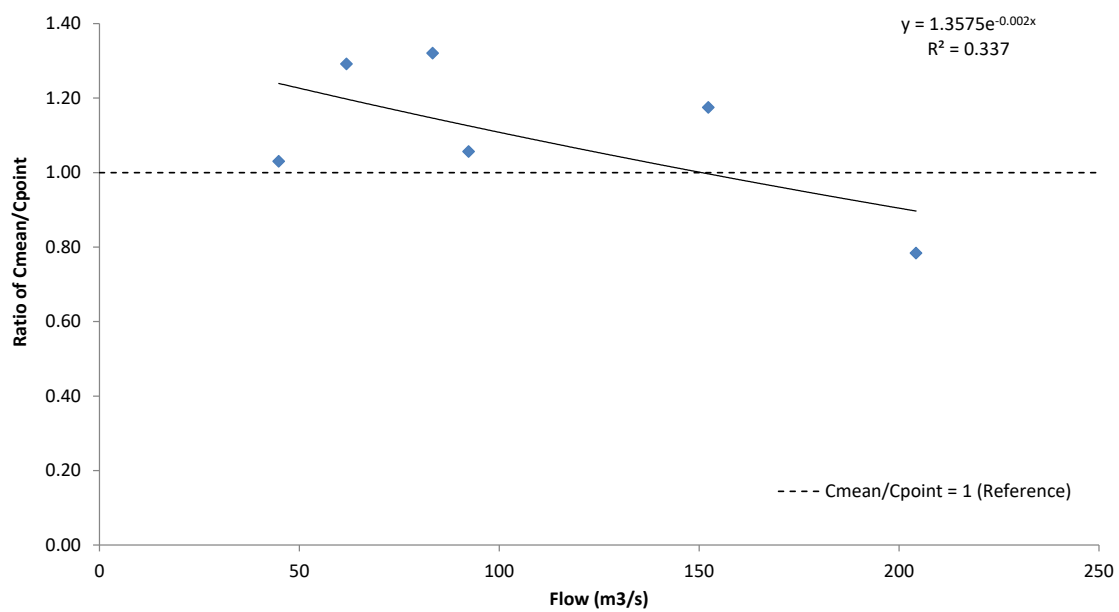


Figure A5-4: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Waipā at Otewa.

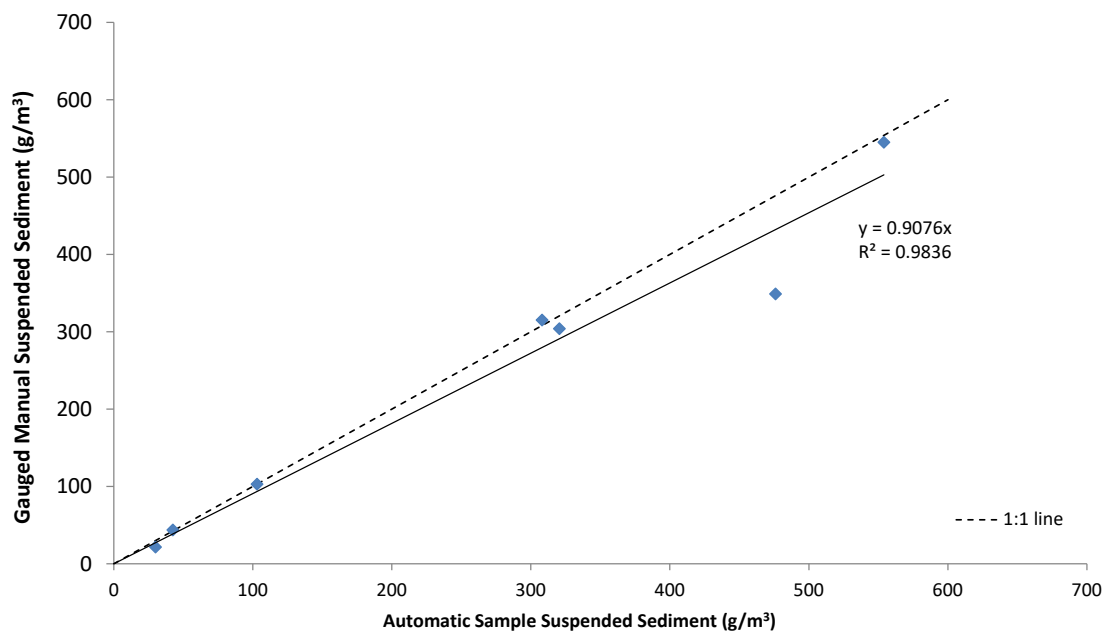


Figure A5-5: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Waitomo at Aranui Caves.

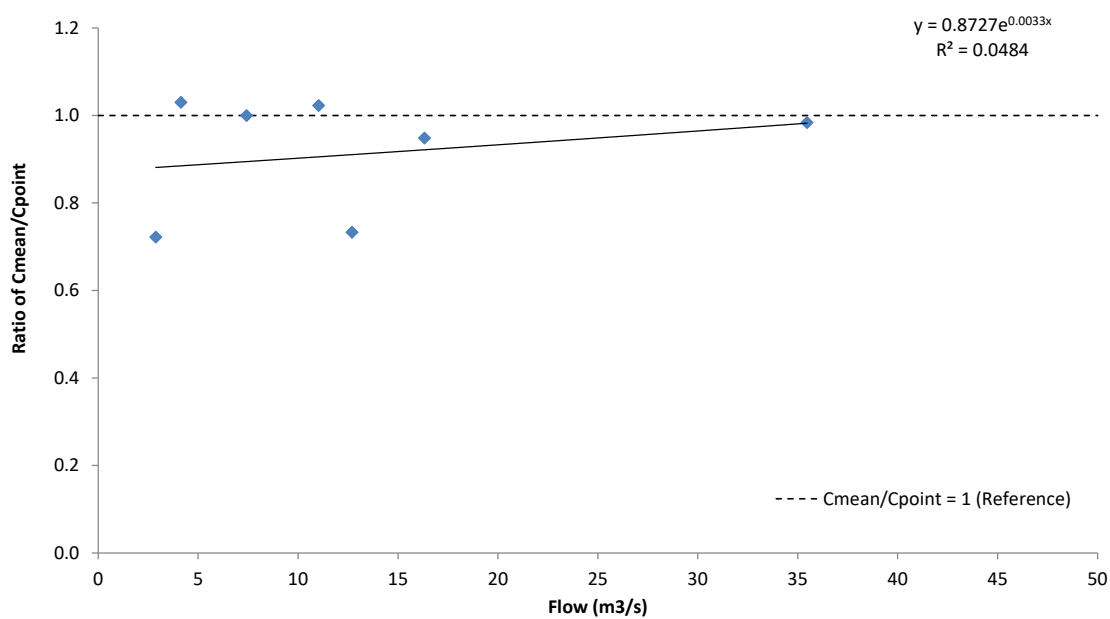


Figure A5-6: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Waitomo at Aranui Caves.

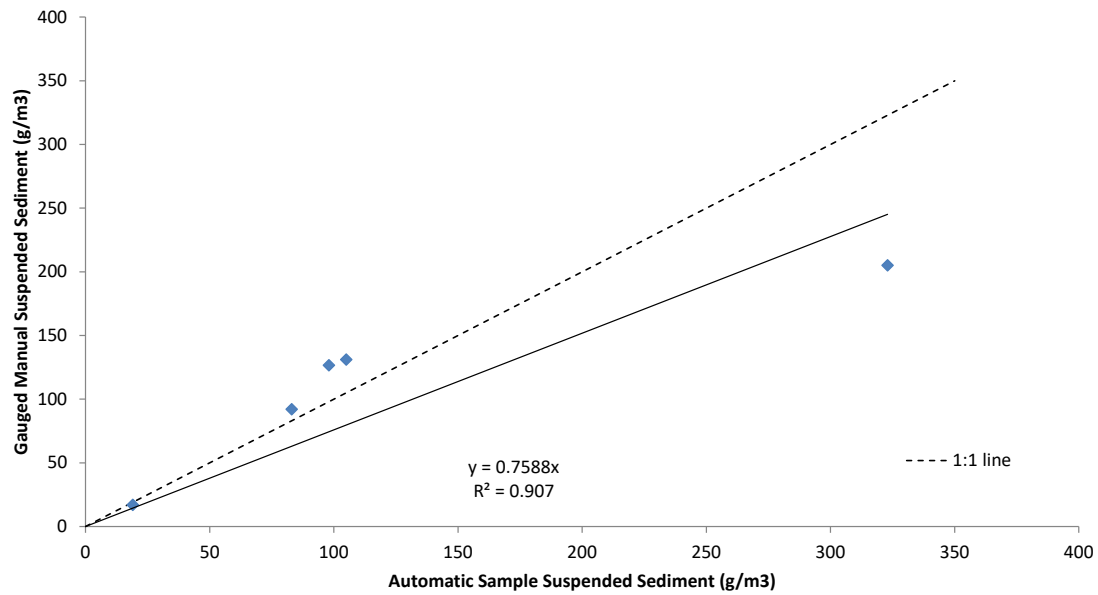


Figure A5-7: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Mangapu at SH3 Br.

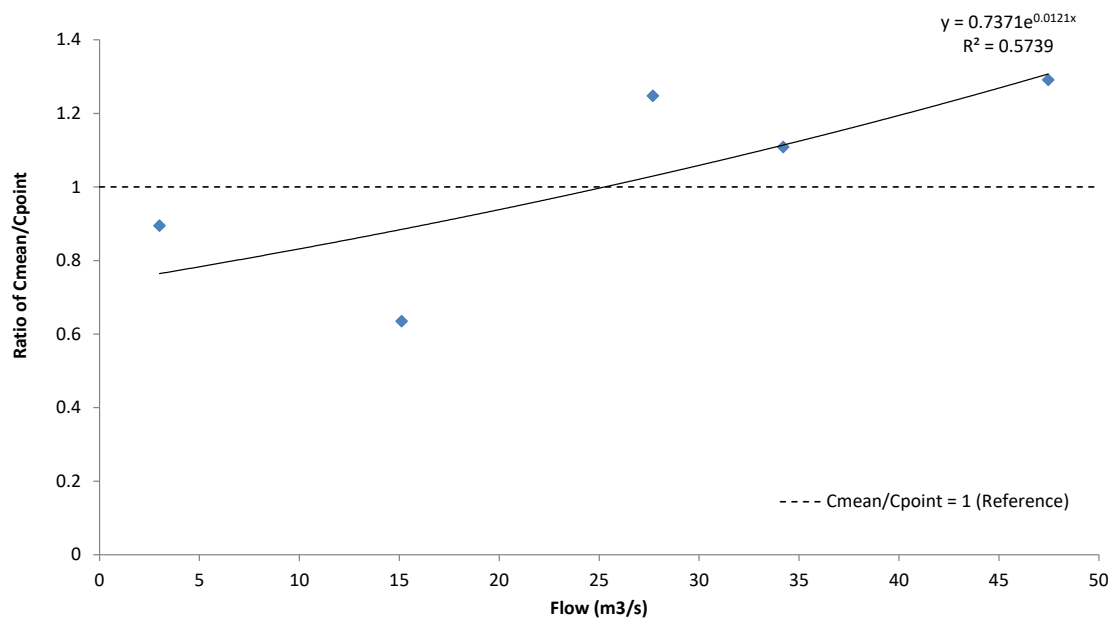


Figure A5-8: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Mangapu at SH3 Br.

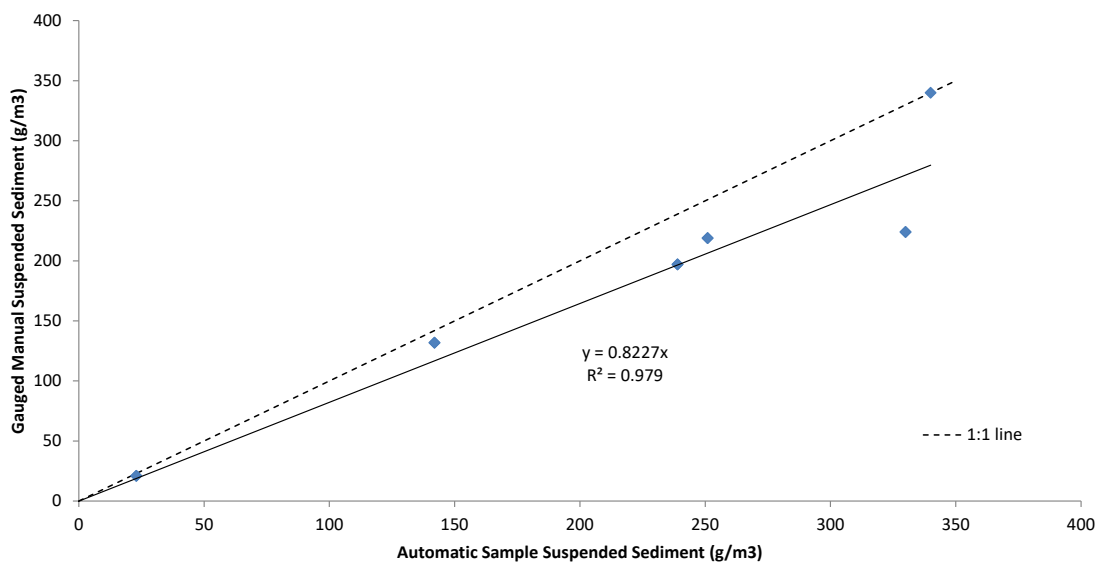


Figure A5-9: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Waingaro at Ruakiwi Road.

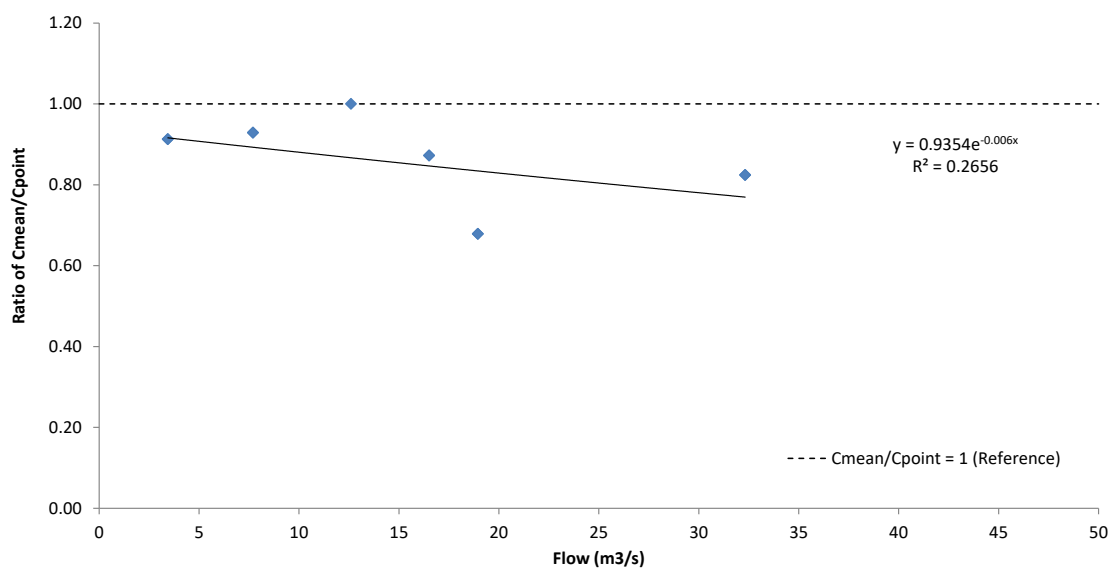


Figure A5-10: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Waingaro at Ruakiwi Road.

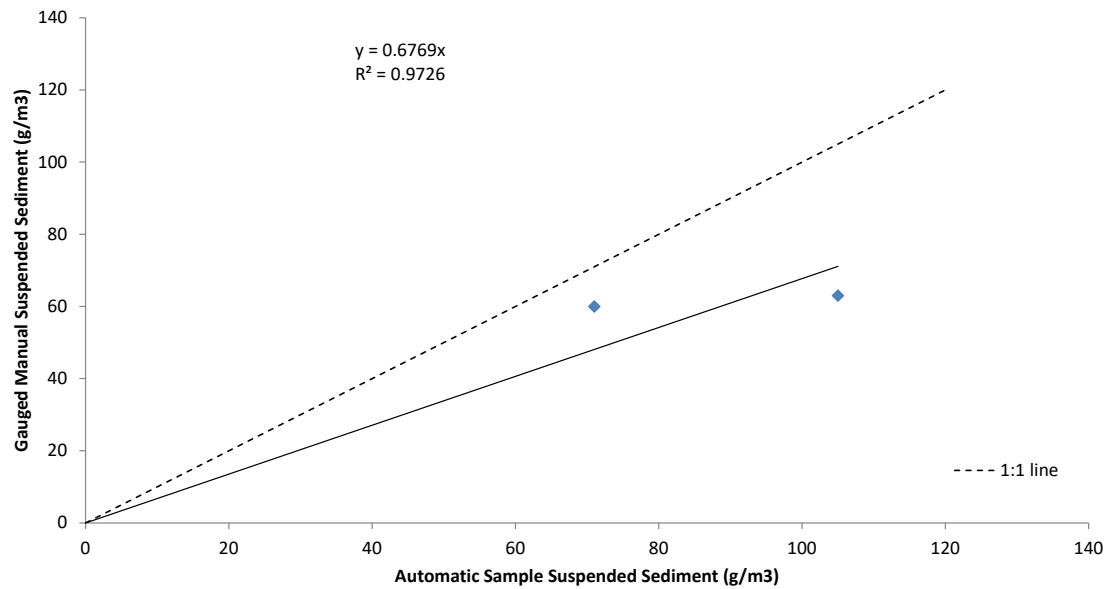


Figure A5-11: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Opitonui at d/s Awaroa confl.

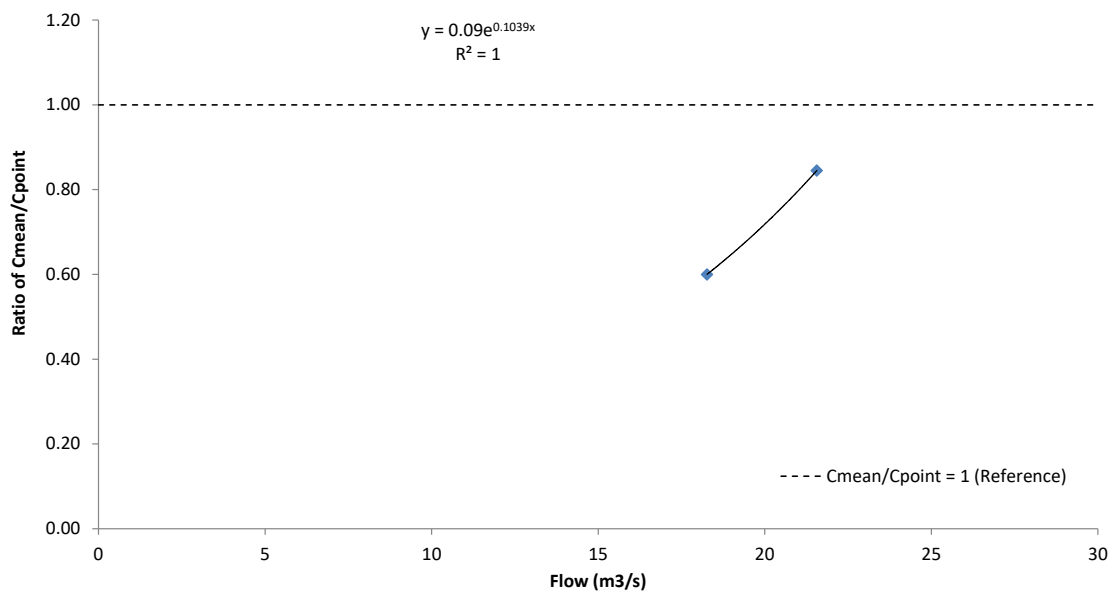


Figure A5-12: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Opitonui at d/s Awaroa Confl.

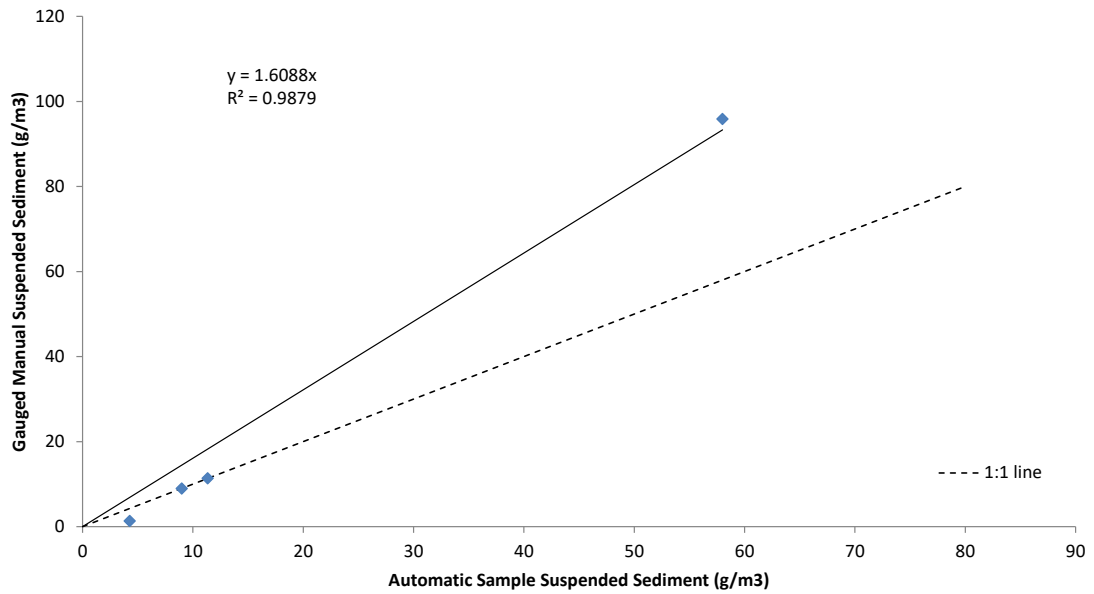


Figure A5-13: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Wharekawa at Adams Farm Br.

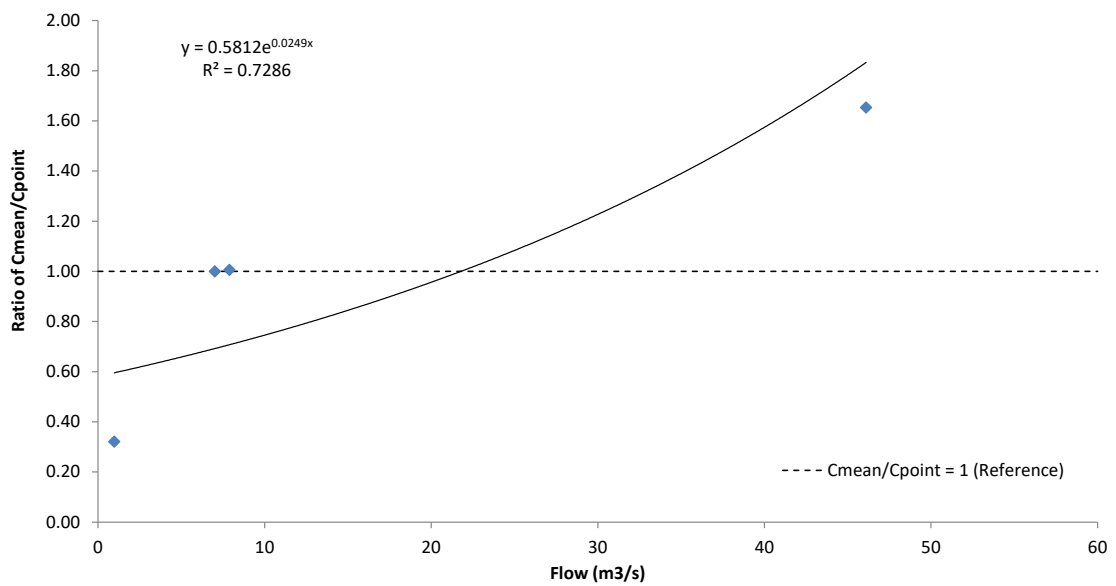


Figure A5-14: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Wharekawa at Adams Farm Br.

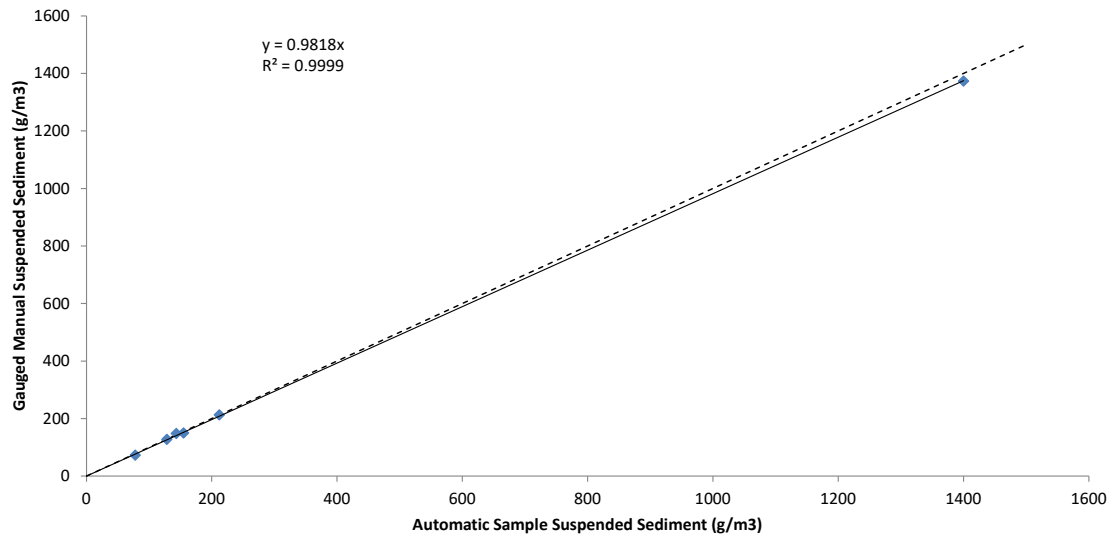


Figure A5-15: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Matahuru at Myjers'.

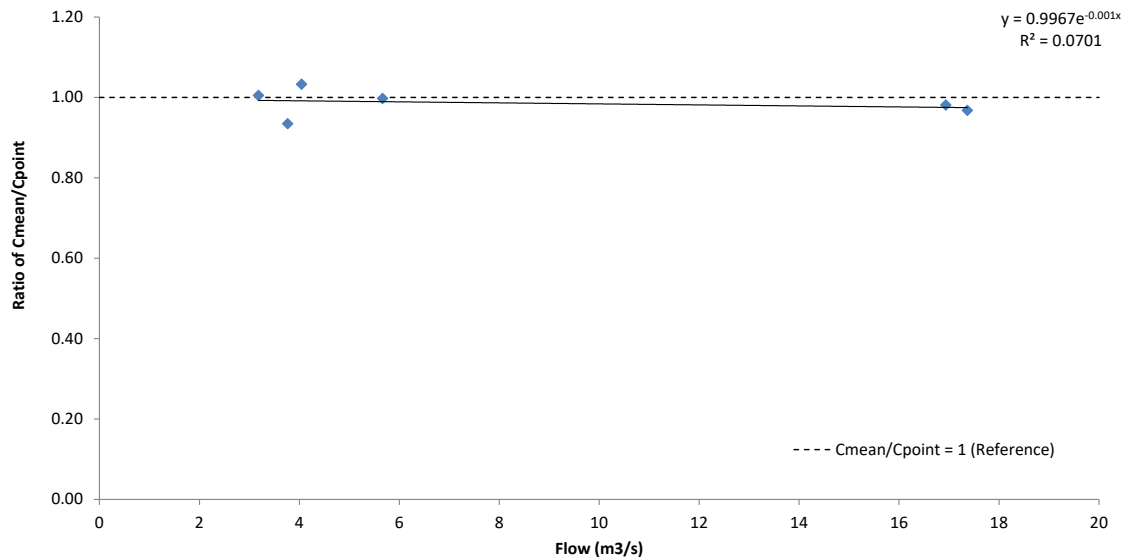


Figure A5-16: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Matahuru at Myjers'.

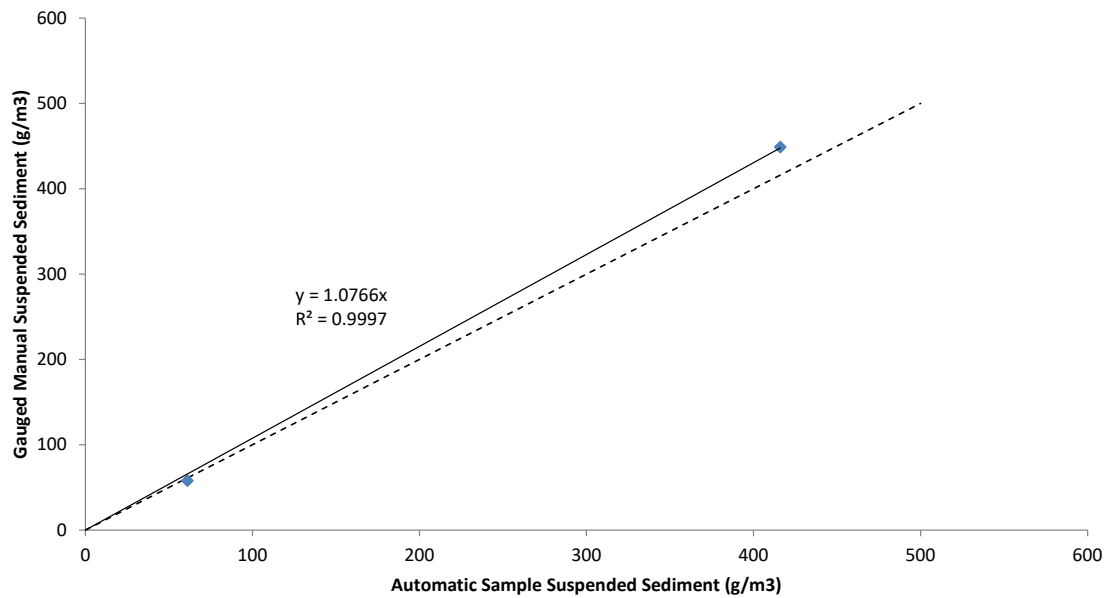


Figure A5-17: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Matahuru at Waiterimu Rd.

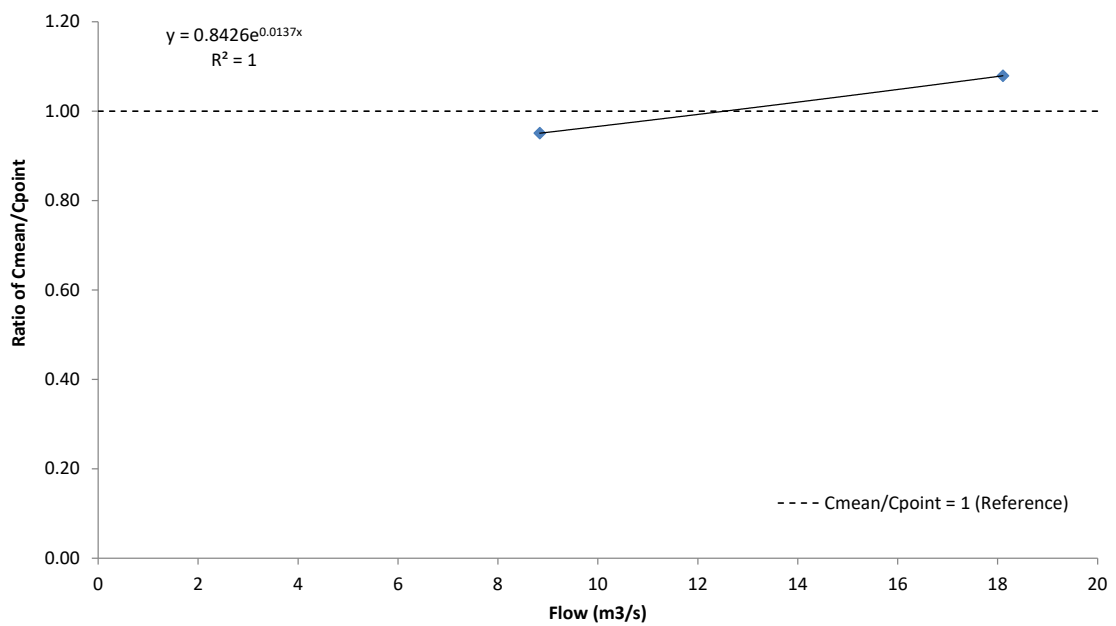


Figure A5-18: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Matahuru at Waiterimu Rd.

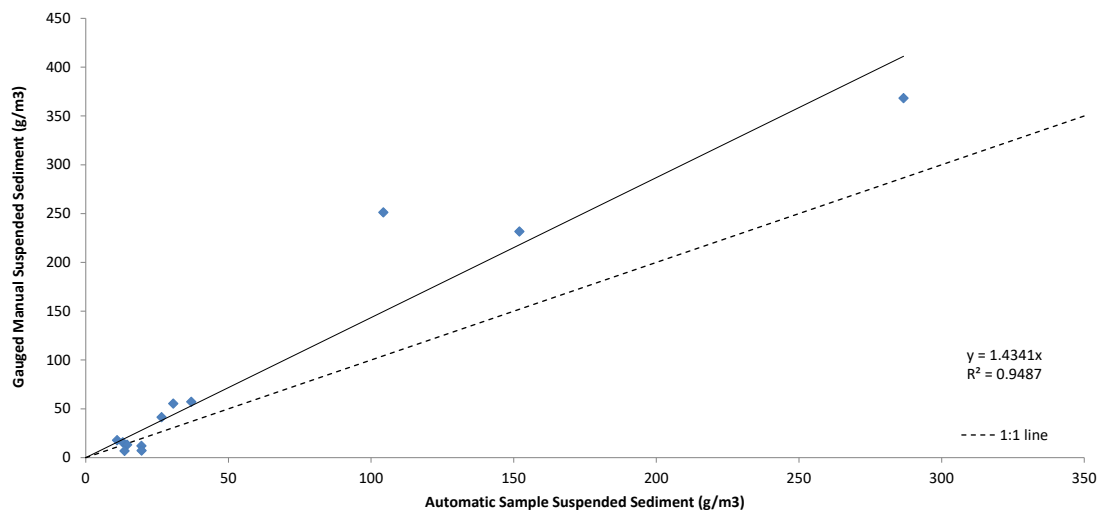


Figure A5-19: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Moakurarua at Warratah Farm Br.

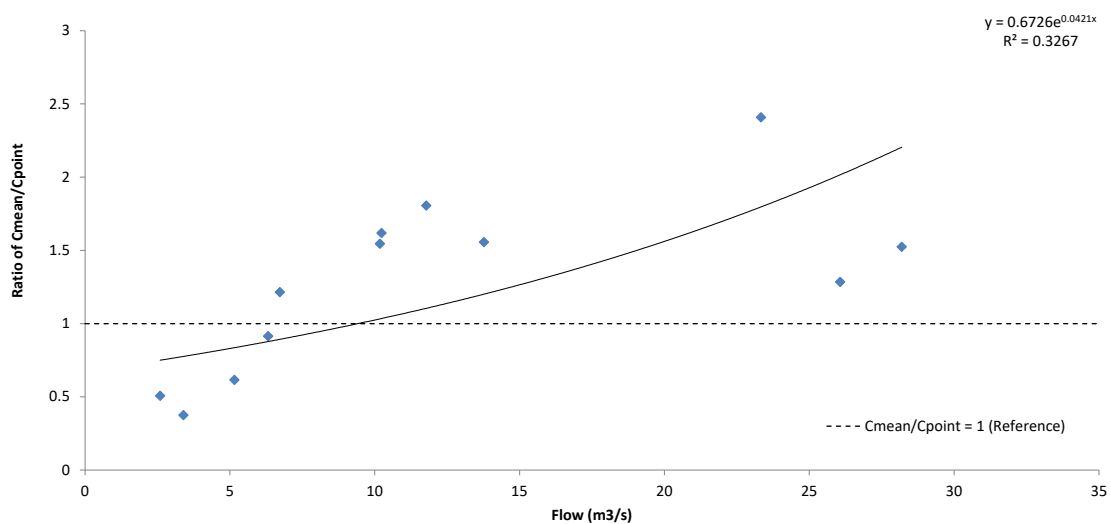


Figure A5-20: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Moakurarua at Warratah Farm Br.

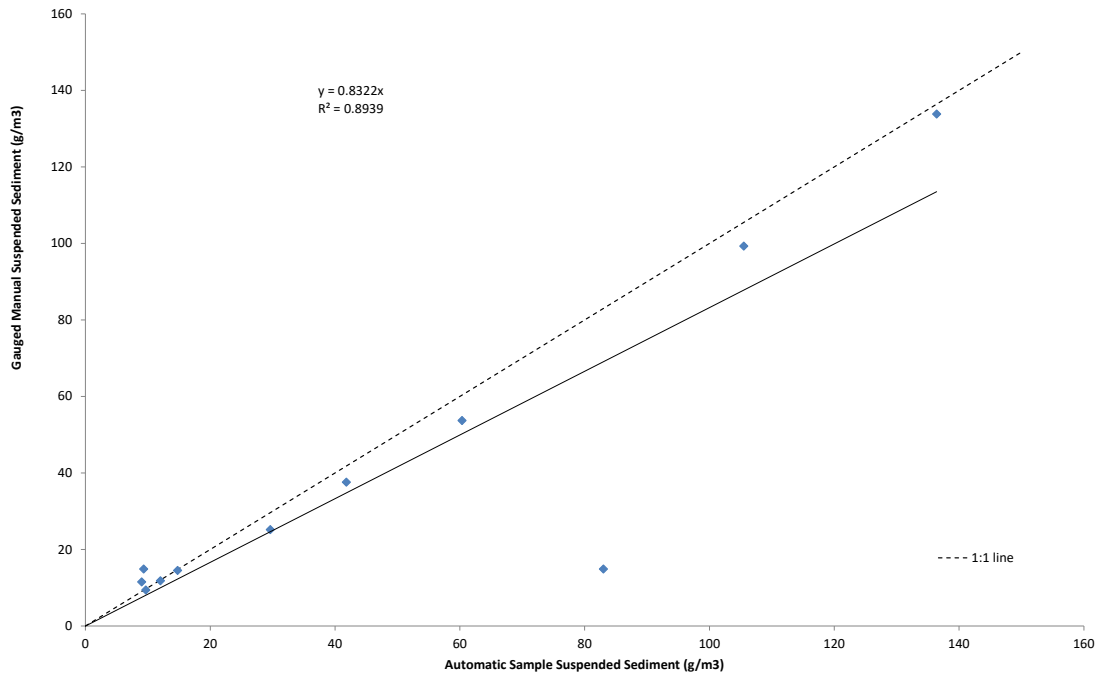


Figure A5-21: Manual depth integrated suspended sediment sampling (C_{mean}) versus Automatic point suspended sediment sampling (C_{point}) at Kaniwhaniwha at Wright Rd.

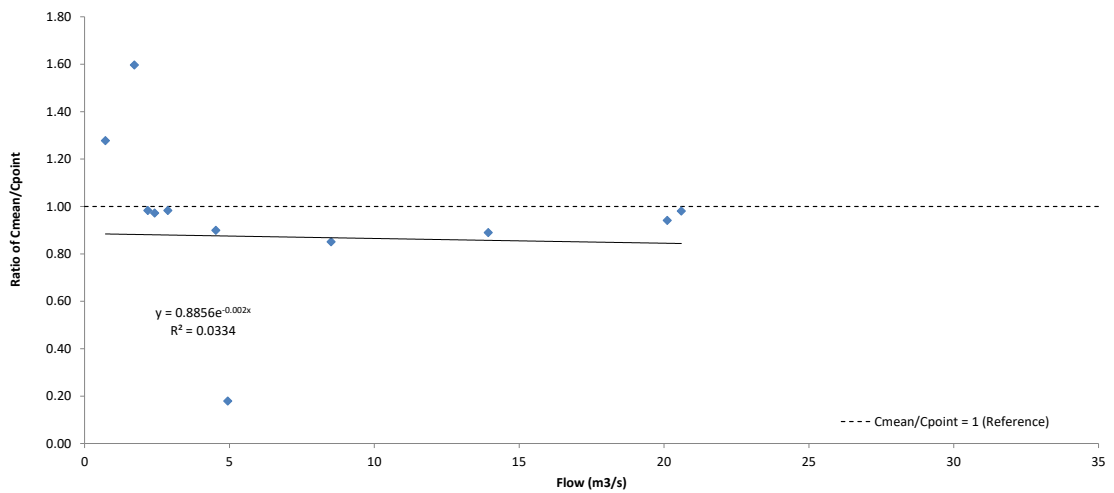


Figure A5-22: Ratio of $C_{\text{mean}}/C_{\text{point}}$ versus flow at Kaniwhaniwha at Wright Rd.

Appendix 6: SSC vs discharge ratings

Site suspended sediment concentration - discharge rating.

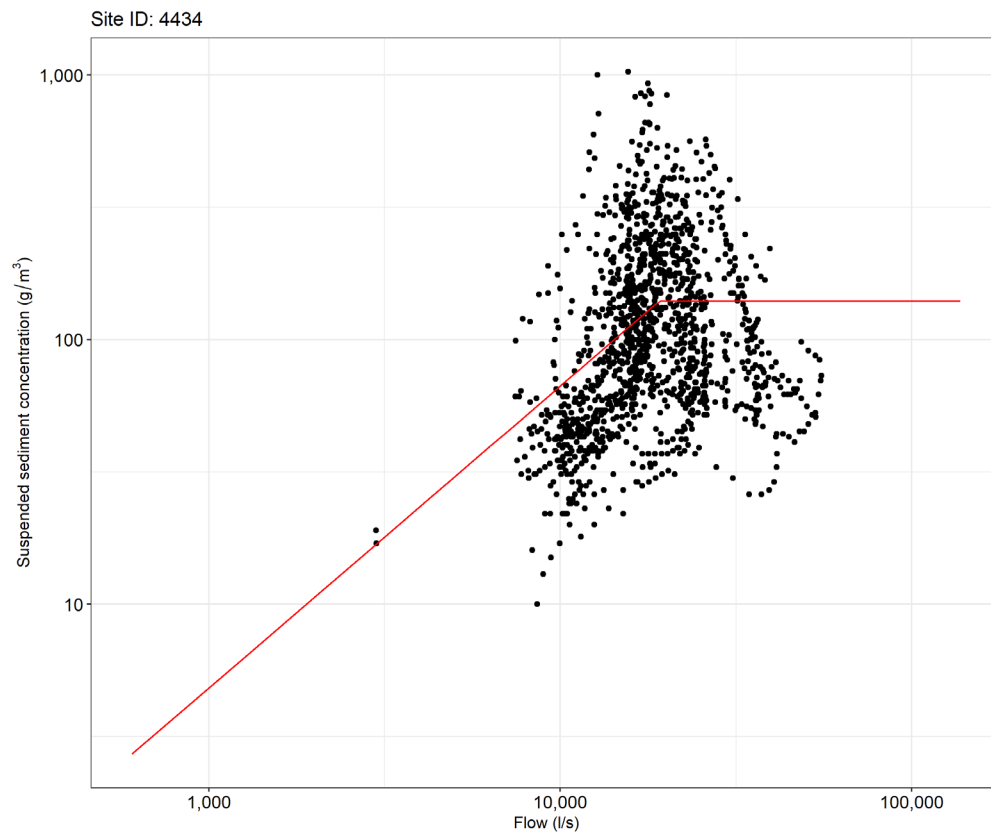


Figure A6-1: Suspended sediment concentration versus discharge rating for Mangapu at SH3 Br.

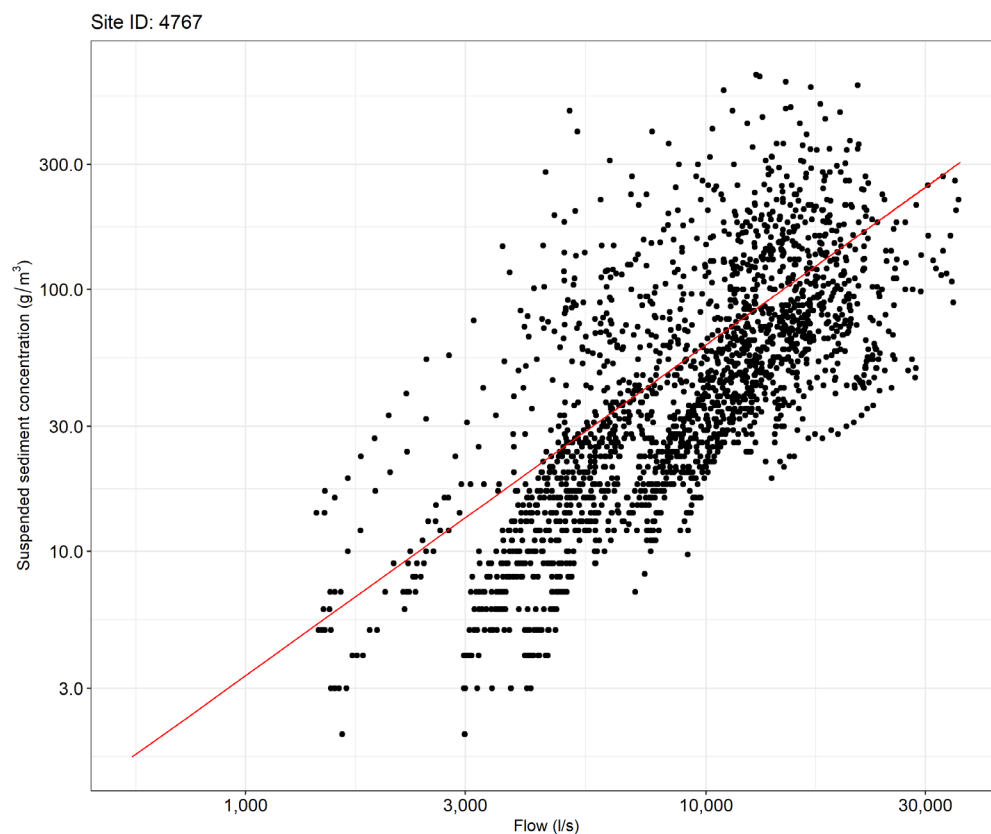


Figure A6-2: Suspended sediment concentration versus discharge rating for Mangatutu at Walker Rd Br.

Site ID: 6601

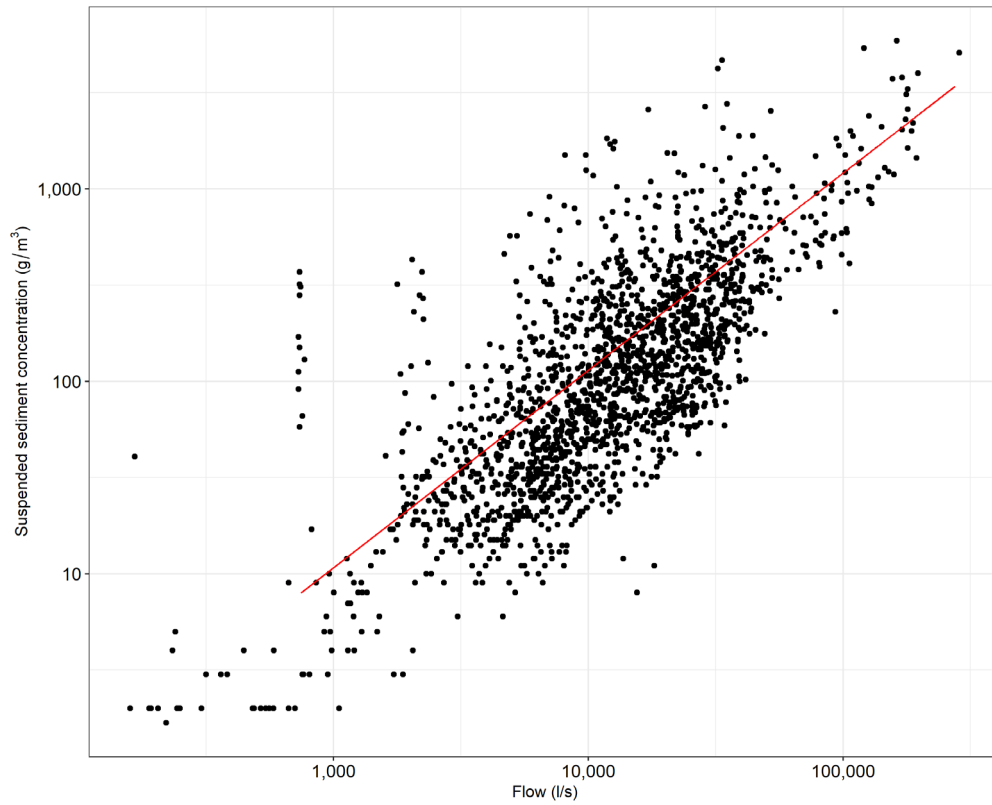


Figure A6-3: Suspended sediment concentration versus discharge rating for Opitonui at d/s Awaroa Confl.

Site ID: 9545

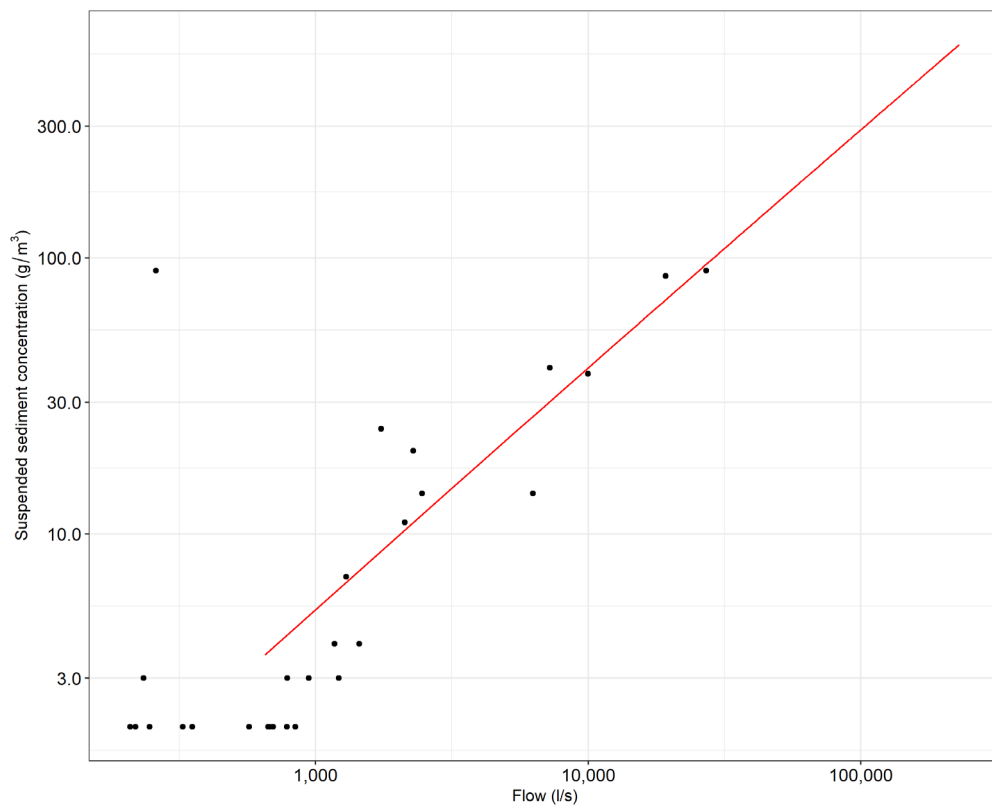


Figure A6-4: Suspended sediment concentration versus discharge rating for Tapu at Coroglen.

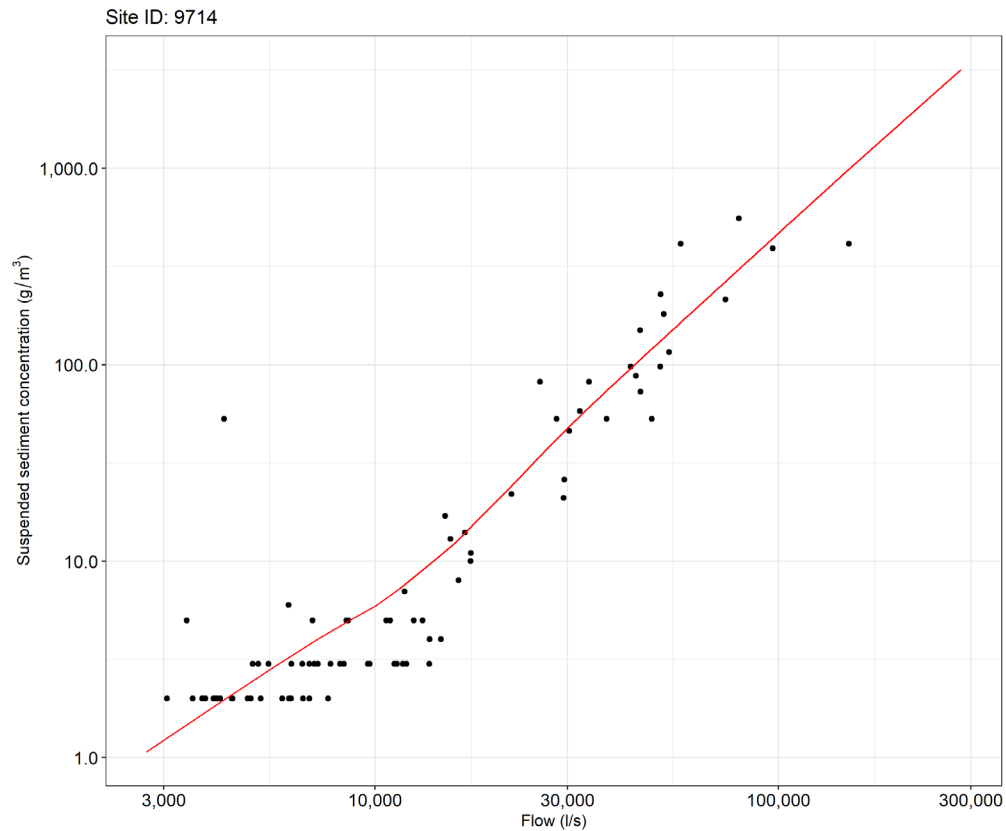


Figure A6-5: Suspended sediment concentration versus discharge rating Tauranga-Tapo at Te Kono.

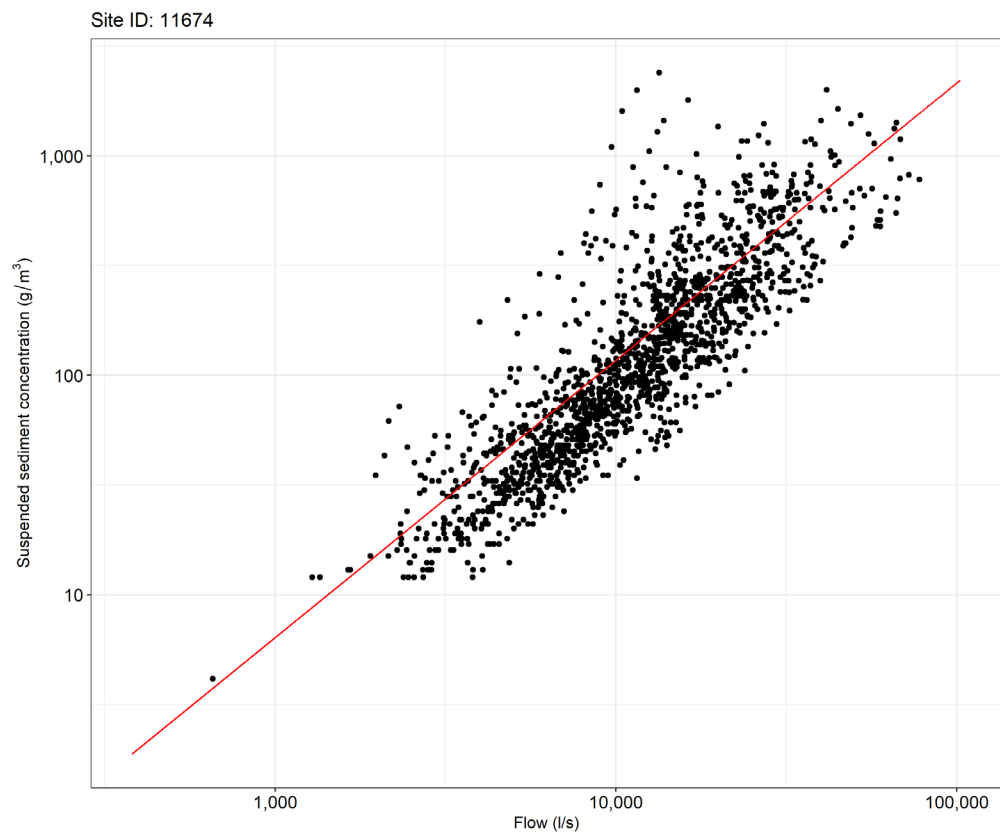


Figure A6-6: Suspended sediment concentration versus discharge rating for Waingaro at Ruakiwi Road.

Site ID: 11917

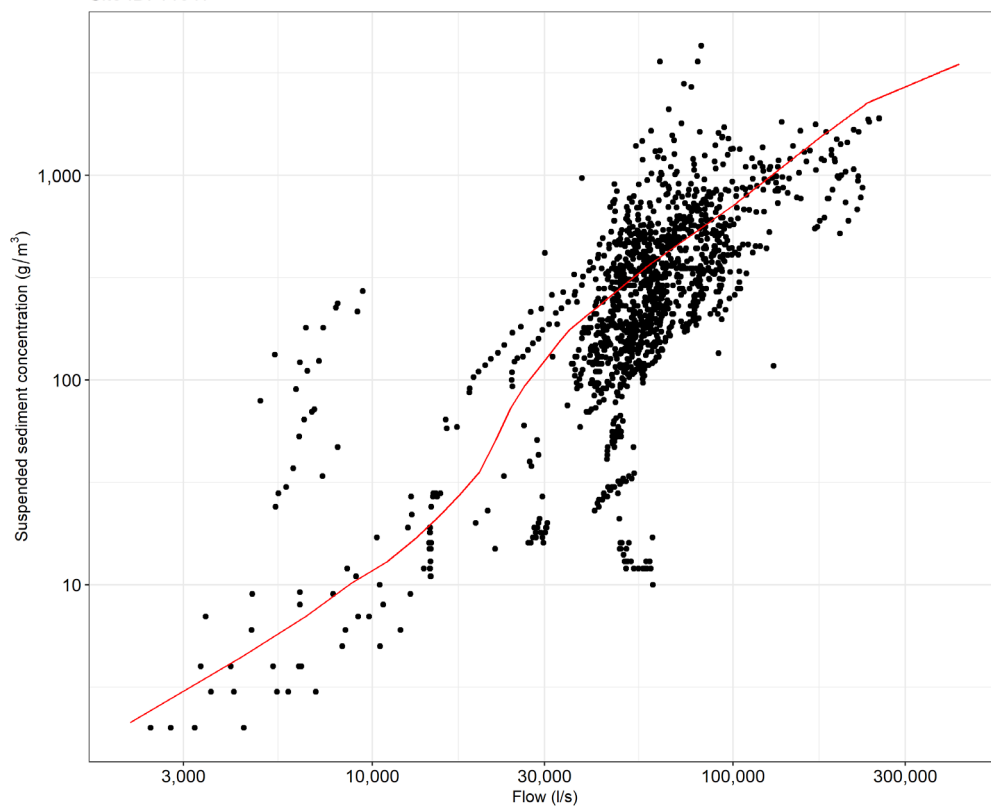


Figure A6-7: Suspended sediment concentration versus discharge rating for Waipā at Otewa.

Site ID: 12533

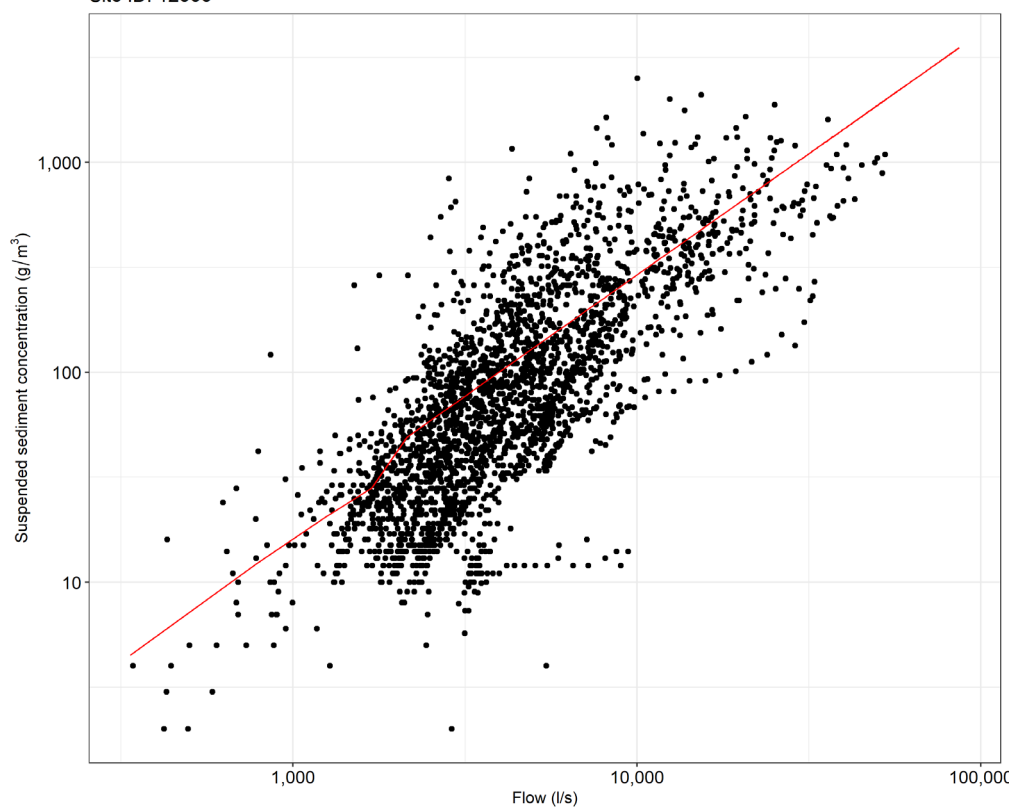


Figure A6-8: Suspended sediment concentration versus discharge rating for Waitomo at Aranui Caves.

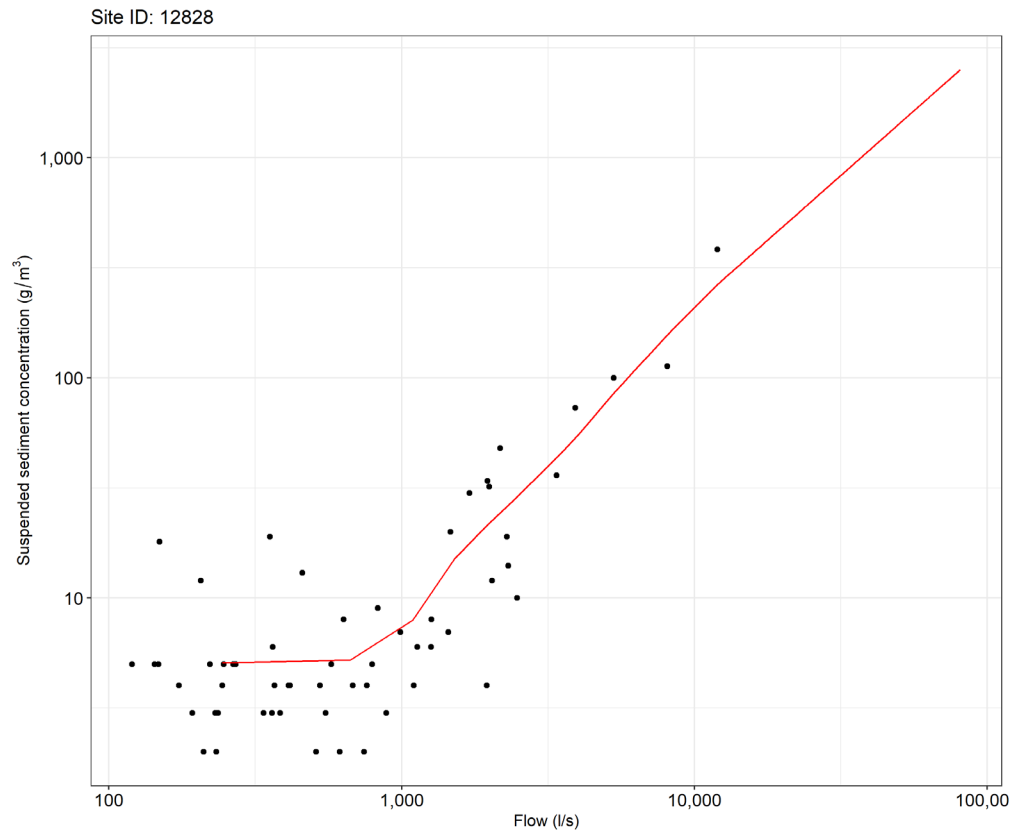


Figure A6-9: Suspended sediment concentration versus discharge rating for Whakapipi at SH22-Tuakau.

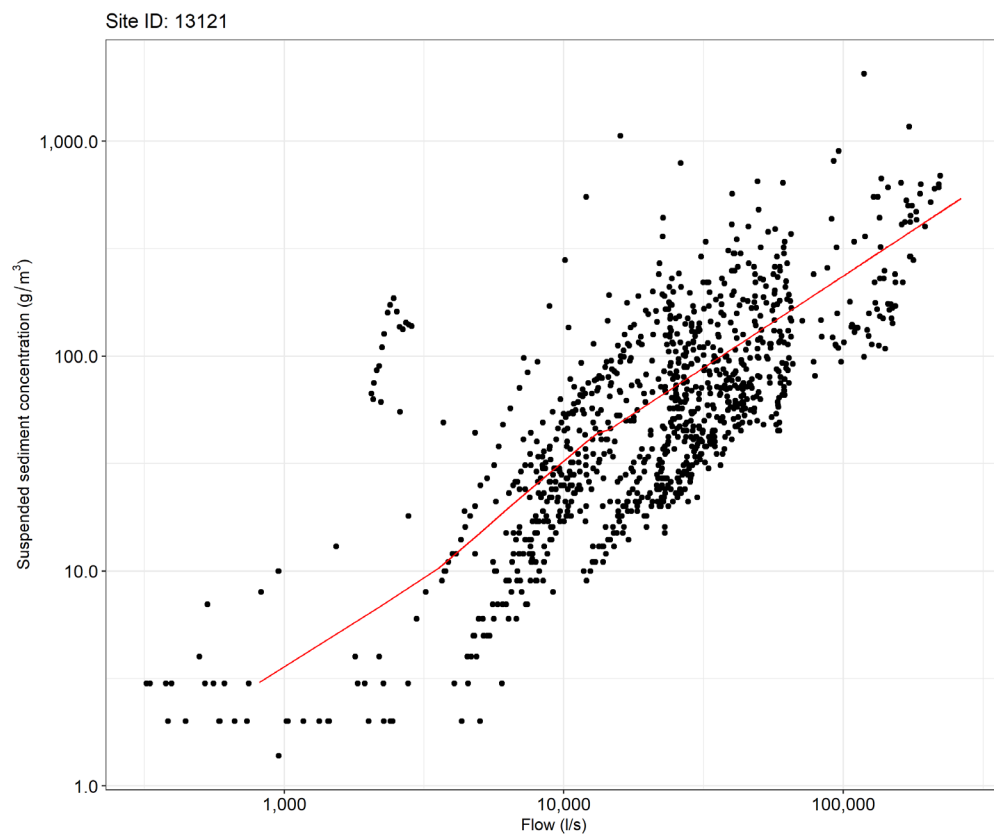


Figure A6-10: Suspended sediment concentration versus discharge rating for Wharekawa at Adam Farm Br.

Site ID: 22216

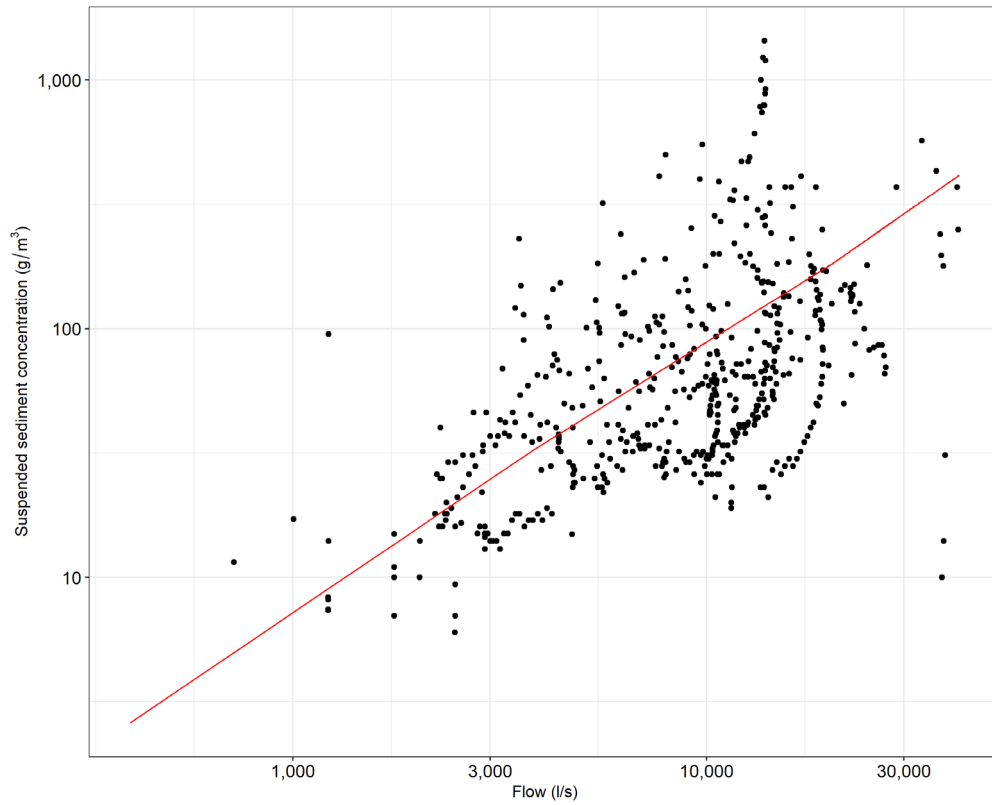


Figure A6-11: Suspended sediment concentration versus discharge rating for Kaniwhaniwha at Wright Rd.

Site ID: 41413

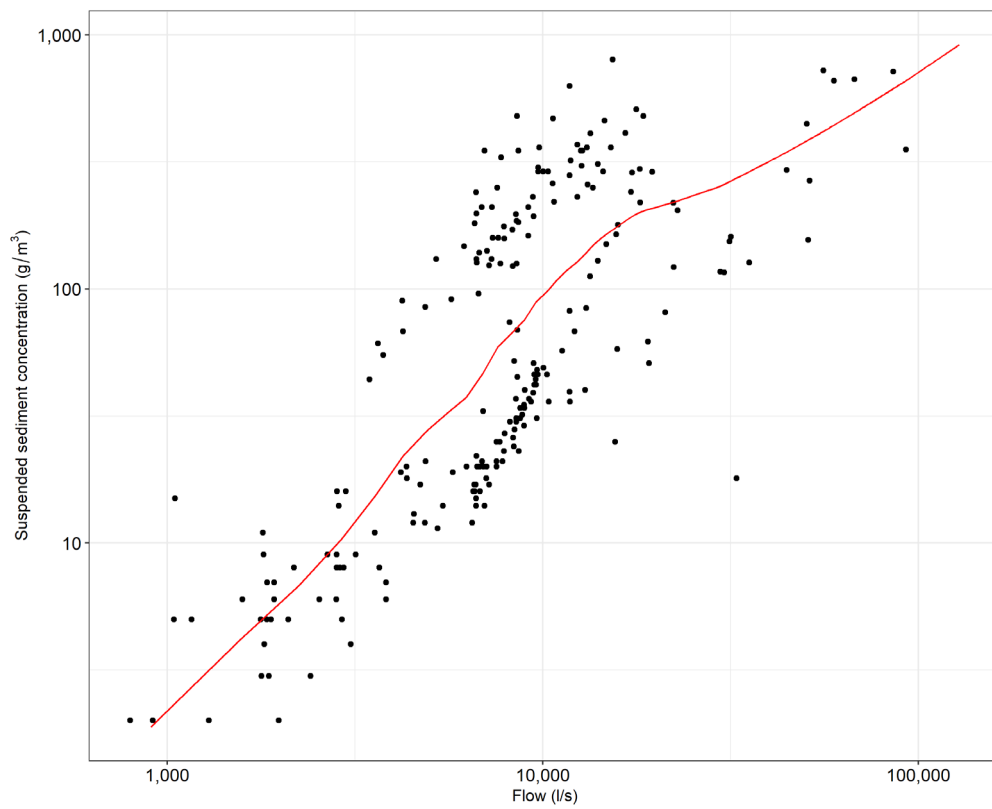


Figure A6-12: Suspended sediment concentration versus discharge rating for Mangaokewa at Te Kuiti.

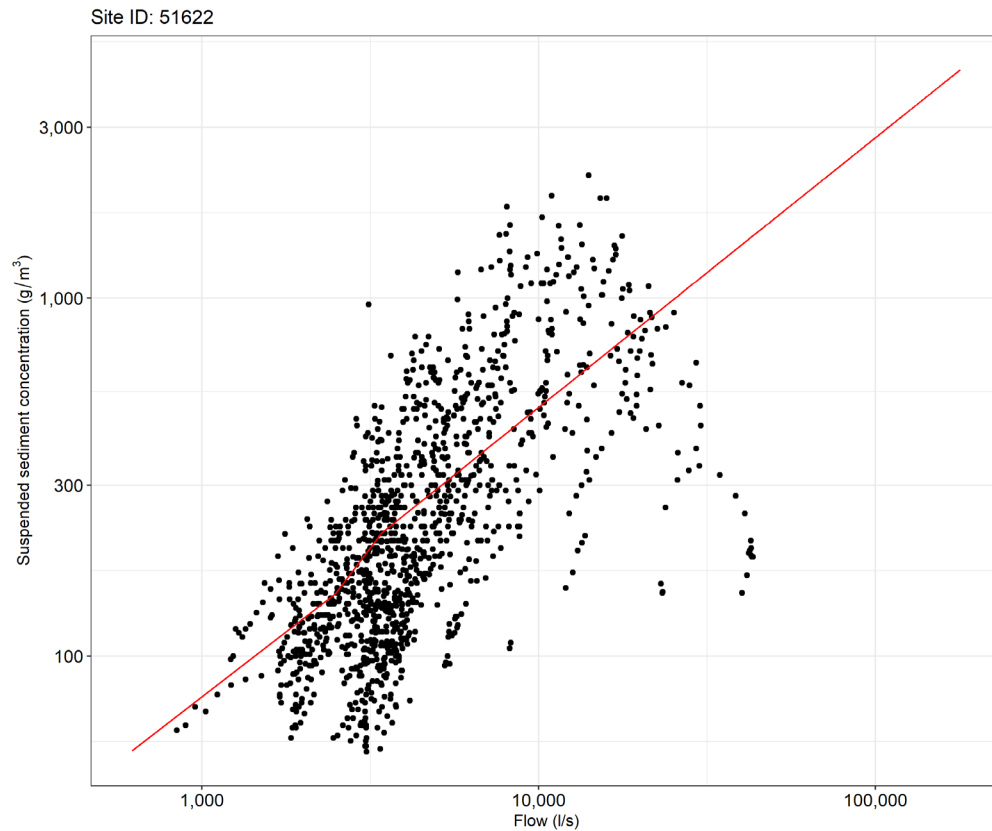


Figure A6-13: Suspended sediment concentration versus discharge rating for Matahuru at Myjers'.

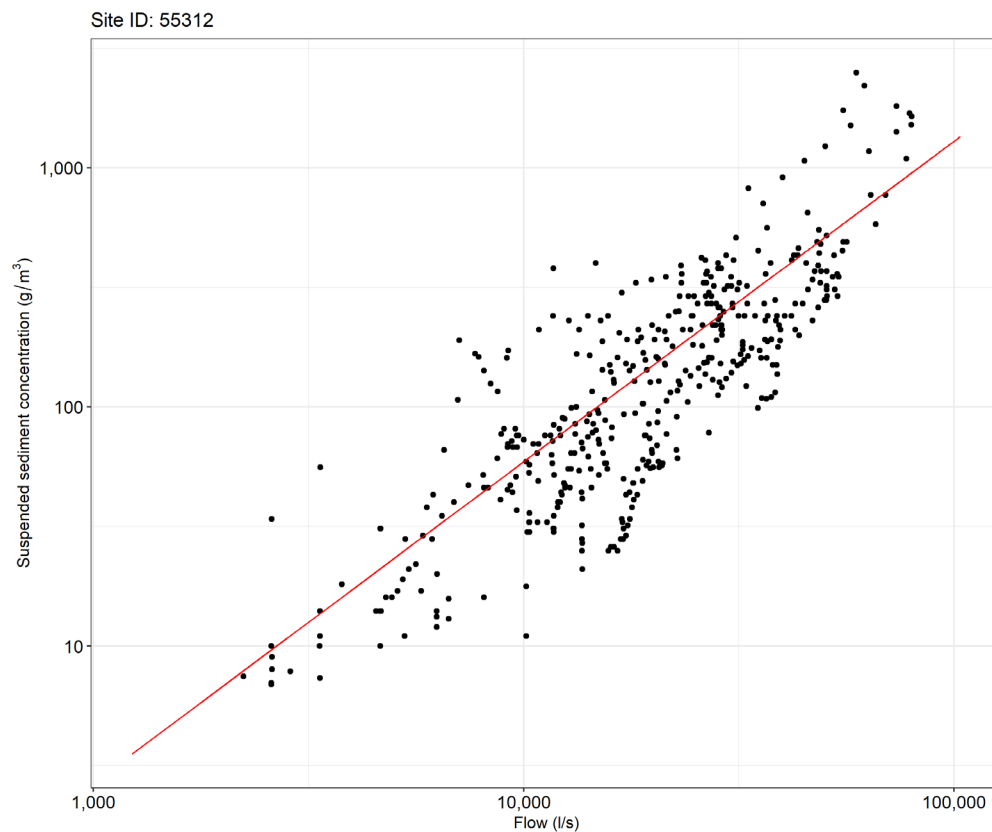


Figure A6-14: Suspended sediment concentration versus discharge rating for Moakururua at Warratah Farm Br.

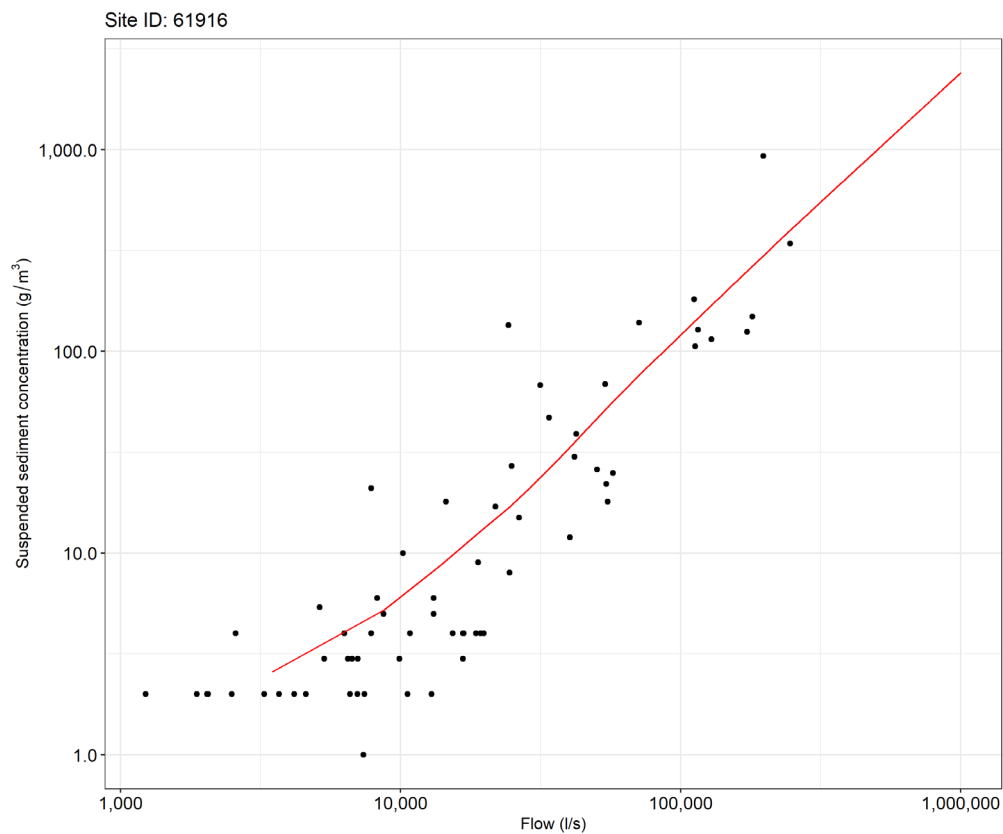


Figure A6-15: Suspended sediment concentration versus discharge rating for Ohinemuri at Karangahake.

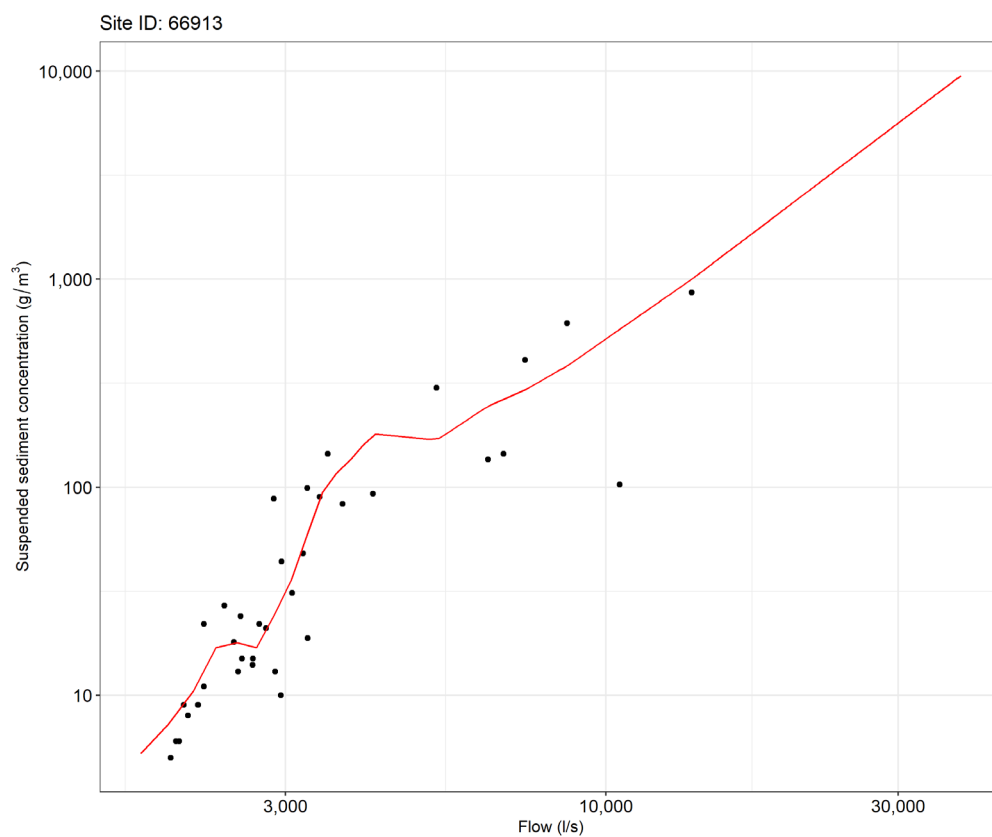


Figure A6-16: Suspended sediment concentration versus discharge rating for Oraka at Pinedale.

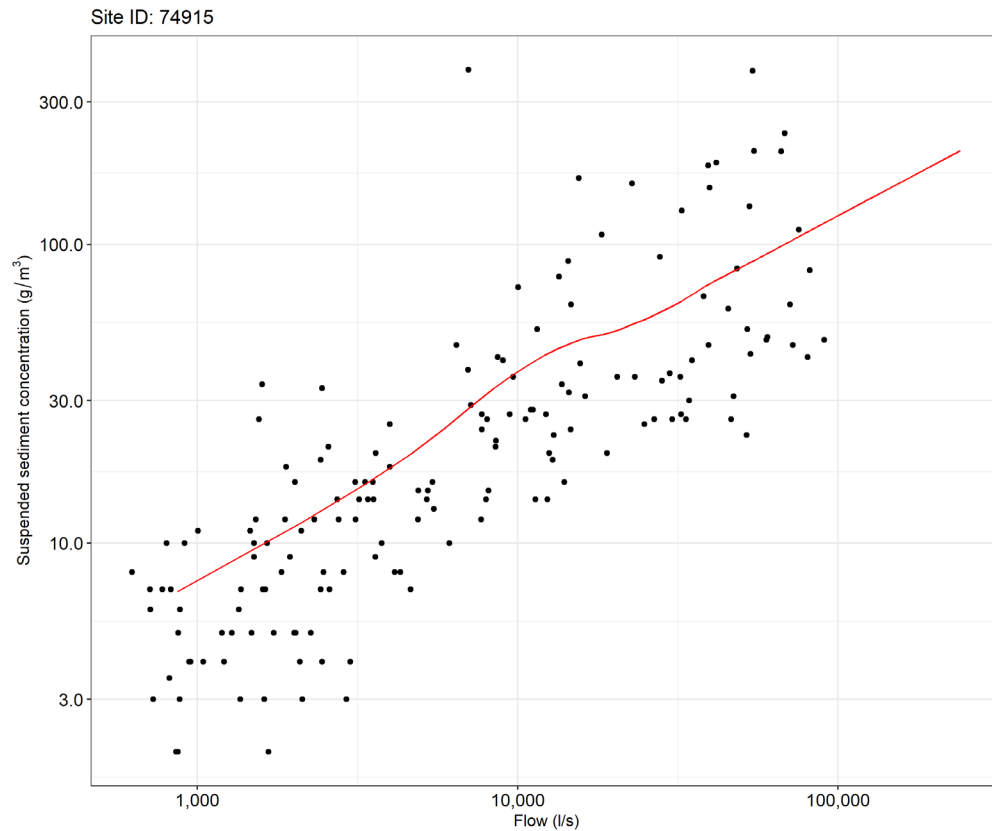


Figure A6-17: Suspended sediment concentration versus discharge rating for Piako at Paeroa-Tahuna Rd.

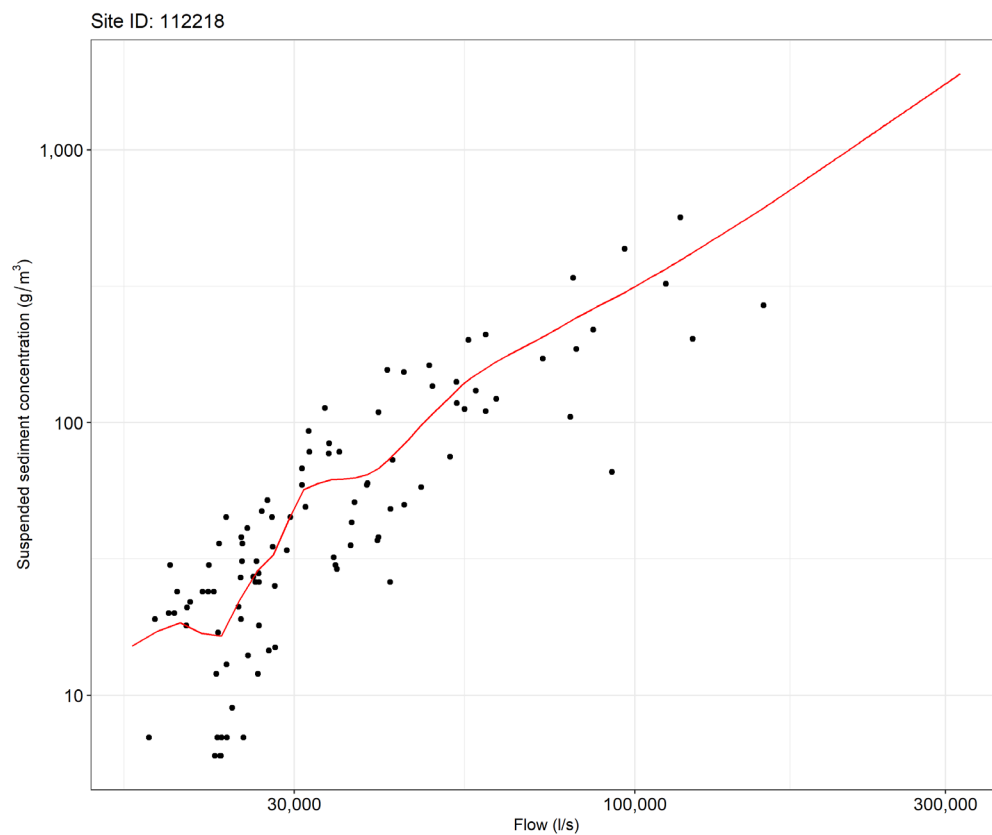


Figure A6-18: Suspended sediment concentration versus discharge rating for Waihou at Okauia.

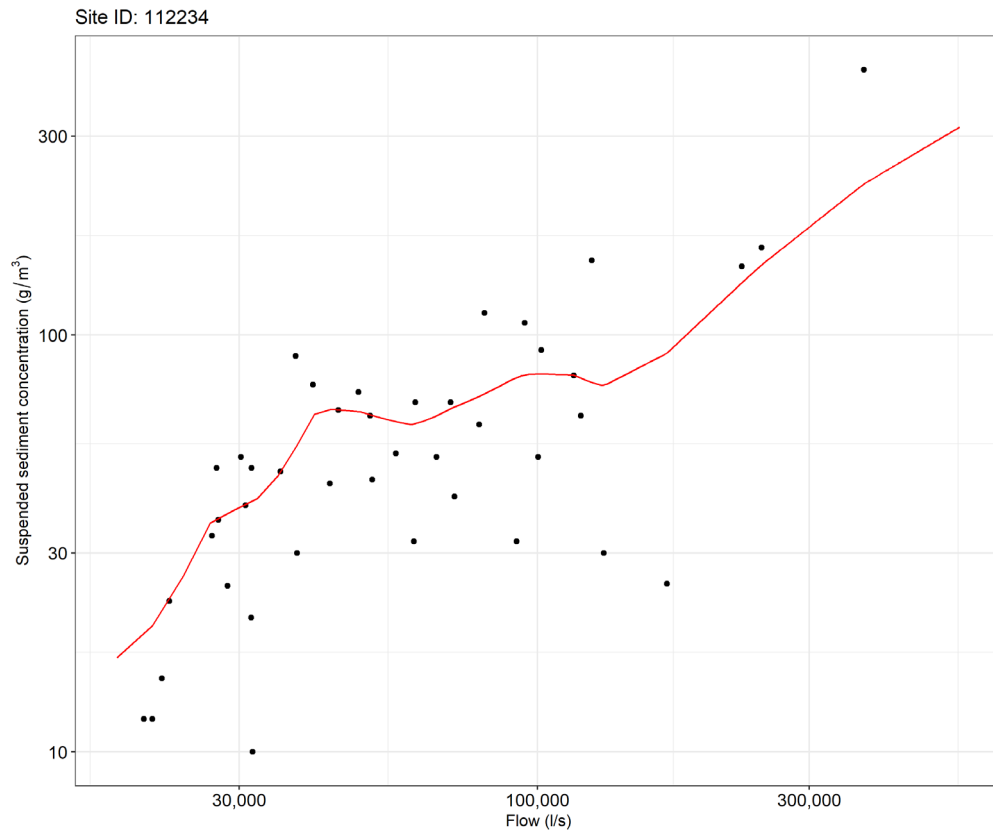


Figure A6-19: Suspended sediment concentration versus discharge rating for Waihou at Te Aroha.

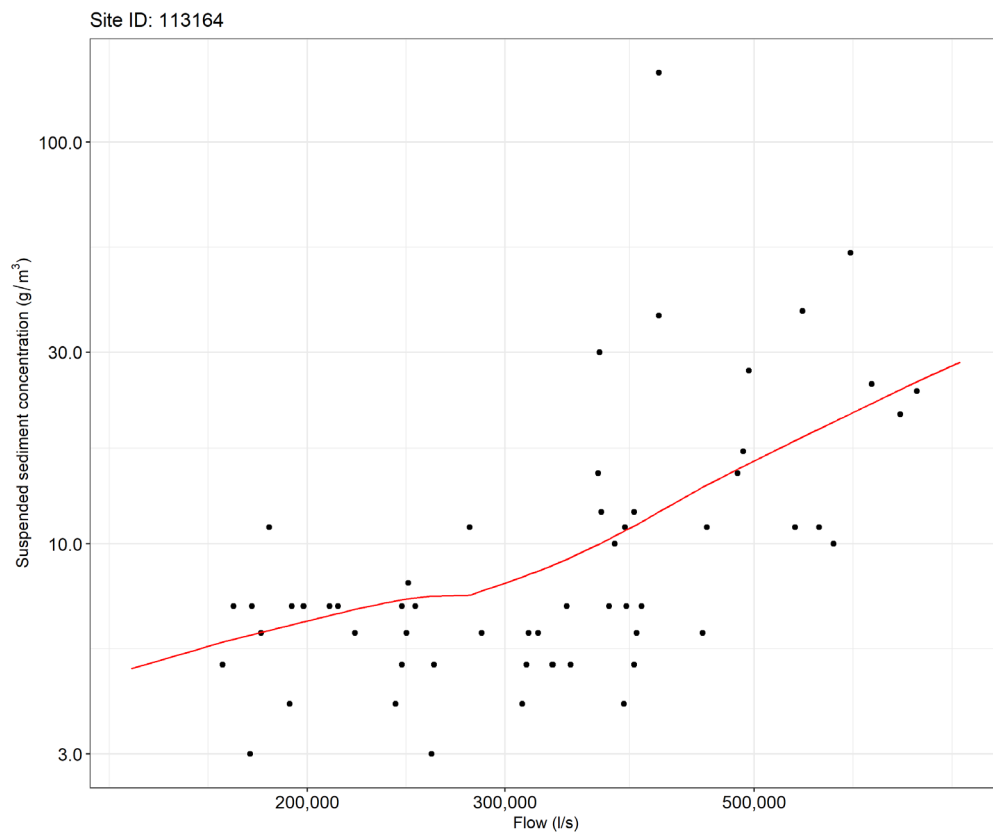


Figure A6-20: Suspended sediment concentration versus discharge rating for Waikato at Hamilton Traffic Br.

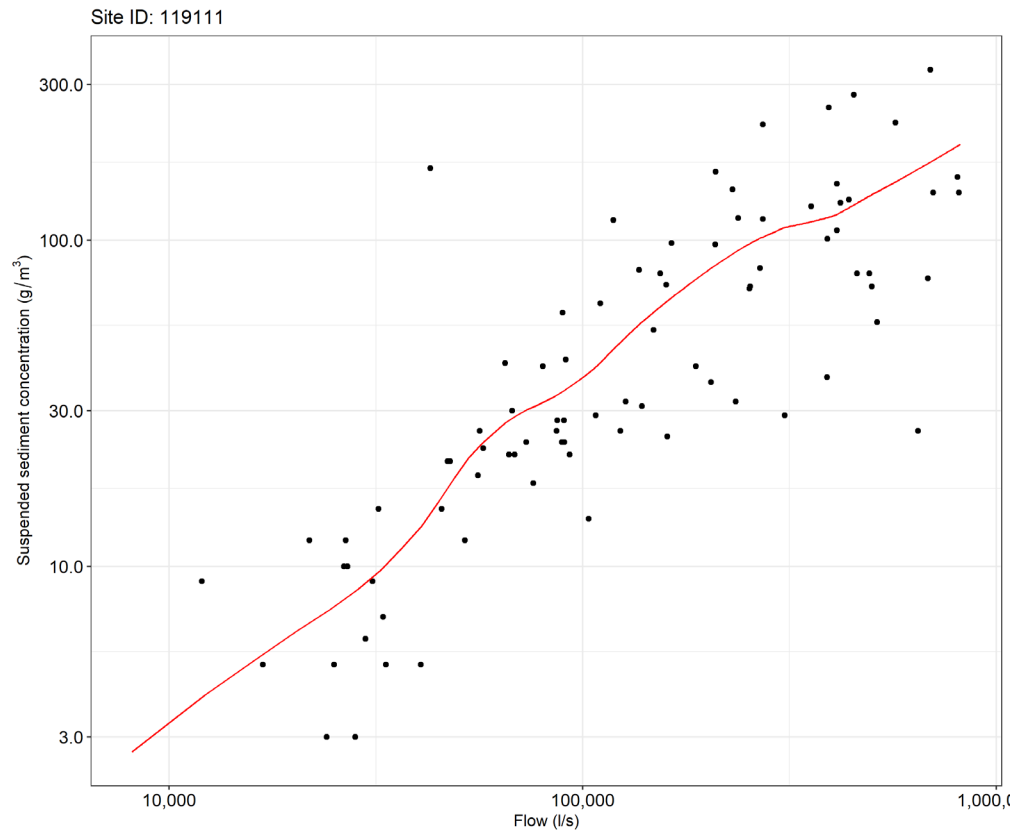


Figure A6-21: Suspended sediment concentration versus discharge rating for Waipā at Whatawhata.

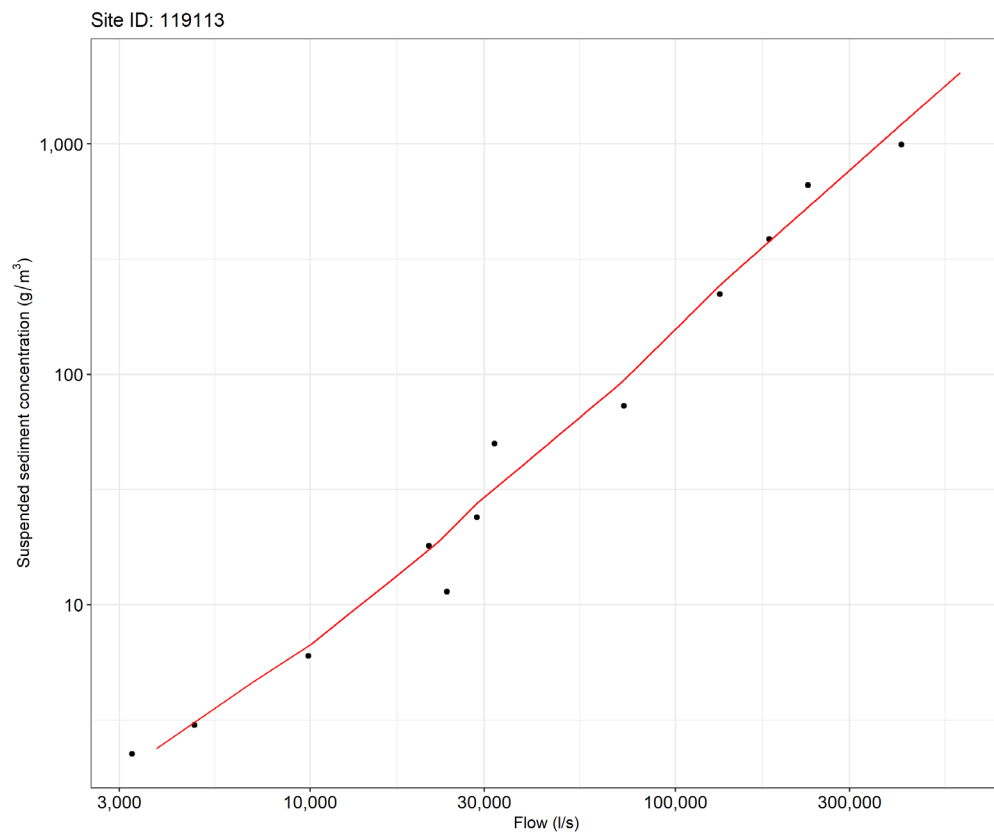


Figure A6-22: Suspended sediment concentration versus discharge rating for Waipā at Otorohanga.

Site ID: 124918

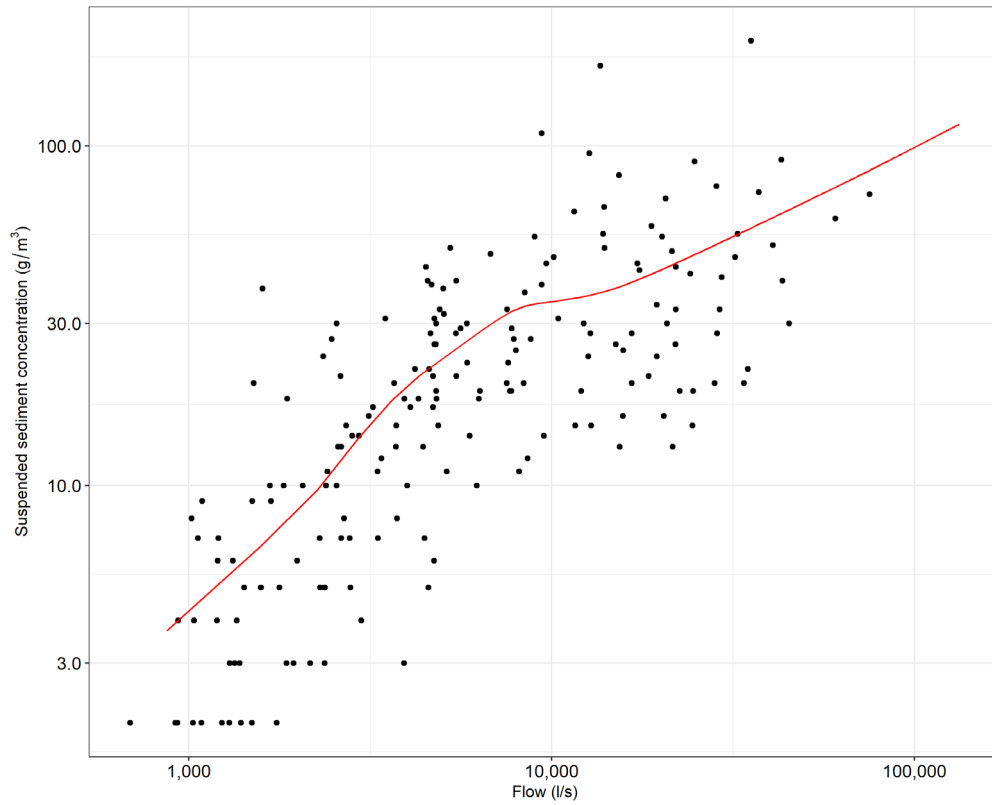


Figure A6-23: Suspended sediment concentration versus discharge rating for Waitoa at Mellon Rd.

Site ID: 1131117

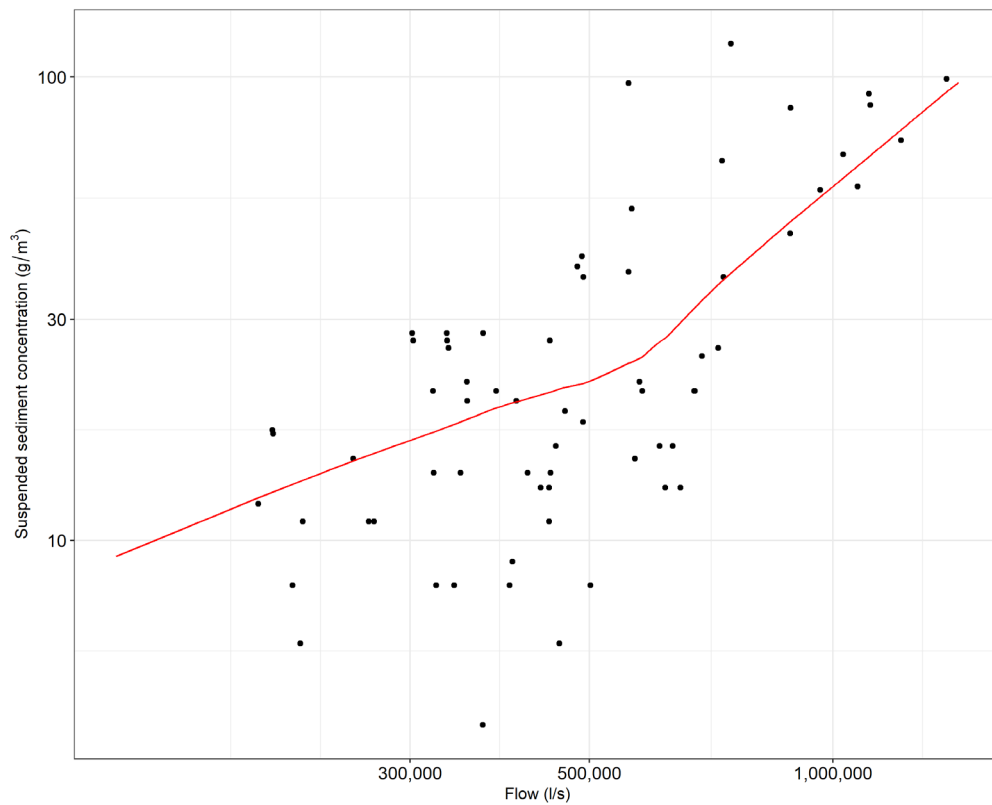


Figure A6-24: Suspended sediment concentration versus discharge rating for Waikato at Rangiriri.