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Waikato suspended sediment indicators: State and trend

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Waikato suspended sediment indicators

State and Trend

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Executive summary

This report provides Waikato Regional Council (WRC) with up-to-date regional indicators of state and trend for suspended sediment based on 24 monitored catchments in the Waikato region.

State is reported by mean annual suspended sediment yield. NIWA last calculated sediment yields for 23 catchments in the Waikato region in 2011. This report provides an update of those calculations using flow and suspended sediment records updated through to December 2013 and the rating relationships developed by NIWA in 2011. An additional catchment has been added in this study (Ohinemuri at Karangahake), with a new rating relationship developed for this catchment. The mean annual yields were calculated using two different approaches: (i) applying a suspended sediment concentration vs. water discharge rating to the water discharge record; (ii) applying an event sediment yield vs. event hydrological magnitude (peak discharge or quickflow) rating to either a peaks-over-threshold series of peak discharges or event quickflows, each extracted from the discharge record. This second approach could only be used where there was sufficient suspended sediment data collected during storm events (nine catchments). These sediment yields were then converted to specific mean annual sediment yields (normalised by catchment area) to enable comparison among catchments.

Trend for the monitored catchments was assessed by testing for time dependence in the residuals from the relationship between suspended sediment concentration and water discharge. Trends are reported for all 24 catchments. For the nine catchments where updated suspended sediment data were available, these trends have been updated to the end of 2013. Trends for the remaining 15 catchments are based on analysis of data from the 2011 study.

During their respective periods of data collection, the basin specific mean annual sediment yields (averaged from the estimates from the two analysis approaches where available) were:

Waipa at Otewa	166 t/km^2/y (28.3 yrs flow data)
Matahuru Stream at Myjers	165 t/km^2/y (7.5 yrs flow data)
Waitomo at Aranui Caves Bridge	150 t/km^2/y (26.4 yrs flow data)
Opitonui at d/s of Awaroa confl.	107 t/km^2/y (21.8 yrs flow data)
Ohinemuri at Karangahake	99 t/km^2 (56.9 yrs flow data)
Waipa at Otorohanga	96 t/km^2/y (32.4 yrs flow data)
Waingaro at Ruakiwi Road	83 t/km^2/y (12.0 yrs flow data)
Tauranga-Taupo at Te Kono Slackline	79 t/km^2/y (37.9 yrs flow data)
Mangapu at SH3 Bridge	68 t/km^2/y (13.2 yrs flow data)
Waipa at Whatawhata	59 t/km^2/y (40.8 yrs flow data)
Waihou at Te Aroha Bridge	57 t/km^2/y (48.7 yrs flow data)
Mangaokewa at Te Kuiti Pumping Station	54 t/km^2/y (29.9 yrs flow data)

Waihou at Okauia	52 t/km^2/y (31.7 yrs flow data)
Matahuru at Waiterimu Road	50 t/km^2/y (26.8 yrs flow data)
Oraka at Pinedale	41 t/km^2/y (34.1 yrs flow data)
Whakapipi at SH22 Bridge	41 t/km^2/y (29.6 yrs flow data)
Wharekawa at Adams Farm Bridge	37 t/km^2/y (22.0 yrs flow data)
Mangatutu at Walker Road Bridge	34 t/km^2/y (9.4 yrs flow data)
Tapu at Tapu-Coroglen	28 t/km^2/y (22.5 yrs flow data)
Waikato at Rangiriri	21 t/km^2/y (48.4 yrs flow data)
Piako at Paeroa Tahuna Road Bridge	20 t/km^2/y (40.9 yrs flow data)
Waitoa at Mellon Road Bridge	14 t/km^2/y (27.6 yrs flow data)
Mangaonua at Dreadnought	9 t/km^2/y (33.1 yrs flow data)
Waikato at Hamilton Traffic Bridge	8 t/km^2/y (36.3 yrs flow data)

Annual yields vary substantially about the mean annual yield due to inter-annual weather variation. Over all catchments, the standard deviation in annual yield averaged 49% of the mean annual yield.

Four catchments showed a statistically significant (at 5% significance level) increase in suspended sediment yields over time (over the full period of available data). These sites were: Matahuru Stream at Myjers, Waitomo at Aranui Caves Bridge, Wharekawa at Adams Farm Bridge and Mangatutu Stream at Walker Road Bridge. Four catchments showed a statistically significant (at 5% significance level) decrease in sediment yields over time. These sites were: Waipa at Otewa, Waihou at Okauia, Piako at Paeroa Tahuna Road Bridge and Waitoa at Mellon Road Bridge. The remaining catchments showed no statistically significant trend over time.

1 Introduction

1.1 Background and purpose

As part of the sustainable management of the Waikato region's land and aquatic environment, Waikato Regional Council (WRC) monitors sediment loads and yields for 23 catchments in the region. This information is used to identify and quantify sources of sediment, manage the effects of this sediment, and measure trends and the effectiveness of management efforts.

NIWA last calculated annual suspended sediment yields for 23 catchments in the Waikato region in 2011 (based on flow data records up to August 2011 and suspended sediment records of varying span before that; Hoyle et al., 2011). Since this previous study one of the monitored catchments (Matahuru at Waiterimu Road) has been replaced with an alternative catchment (Ohinemuri at Karangahake). WRC requested that NIWA updates the suspended sediment yield calculations using flow and suspended sediment records (where available) updated through to December 2013, and to incorporate the new catchment.

WRC requires this information so that it can produce up-to-date regional sediment indicators of state and trend. State is reported in terms of mean annual yield of the monitored catchment, while trend is examined from residuals in the relationship between suspended sediment concentration (SSC) and water discharge (Q). WRC has also requested that NIWA prepares example suitable graphics for illustrating the results on a webpage.

Towards this understanding, this report presents results from sediment yield studies at 24 catchments (including both the Matahuru at Waiterimu Road and Ohinemuri at Karangahake catchments) in the Waikato region. These catchments cover a range of land uses and have catchment areas ranging from 26.4 to 12421 km^2 (Figure 1-1, Table 1-1).

1.2 Objectives

The objectives of the study are to use updated flow and suspended sediment concentration (SSC) data (supplied by WRC) to:

- calculate annual sediment yields over the period of flow record for 24 catchments in the Waikato region based on rating relationships developed for the 23 basins in the 2011 study (Hoyle et al., 2011) and adding in results for the Ohinemuri at Karangahake catchment based on a newly developed rating relationship
- calculate specific mean annual sediment yield for each of the 24 basins (normalising by catchment area) in order to provide a comparison between catchments
- where updated SSC data is available (nine catchments), provide plots of residuals (observed SSC/predicted SSC) over time
- assess whether these residuals plots show a significant trend over time
- provide tables and plots presenting the results described above.

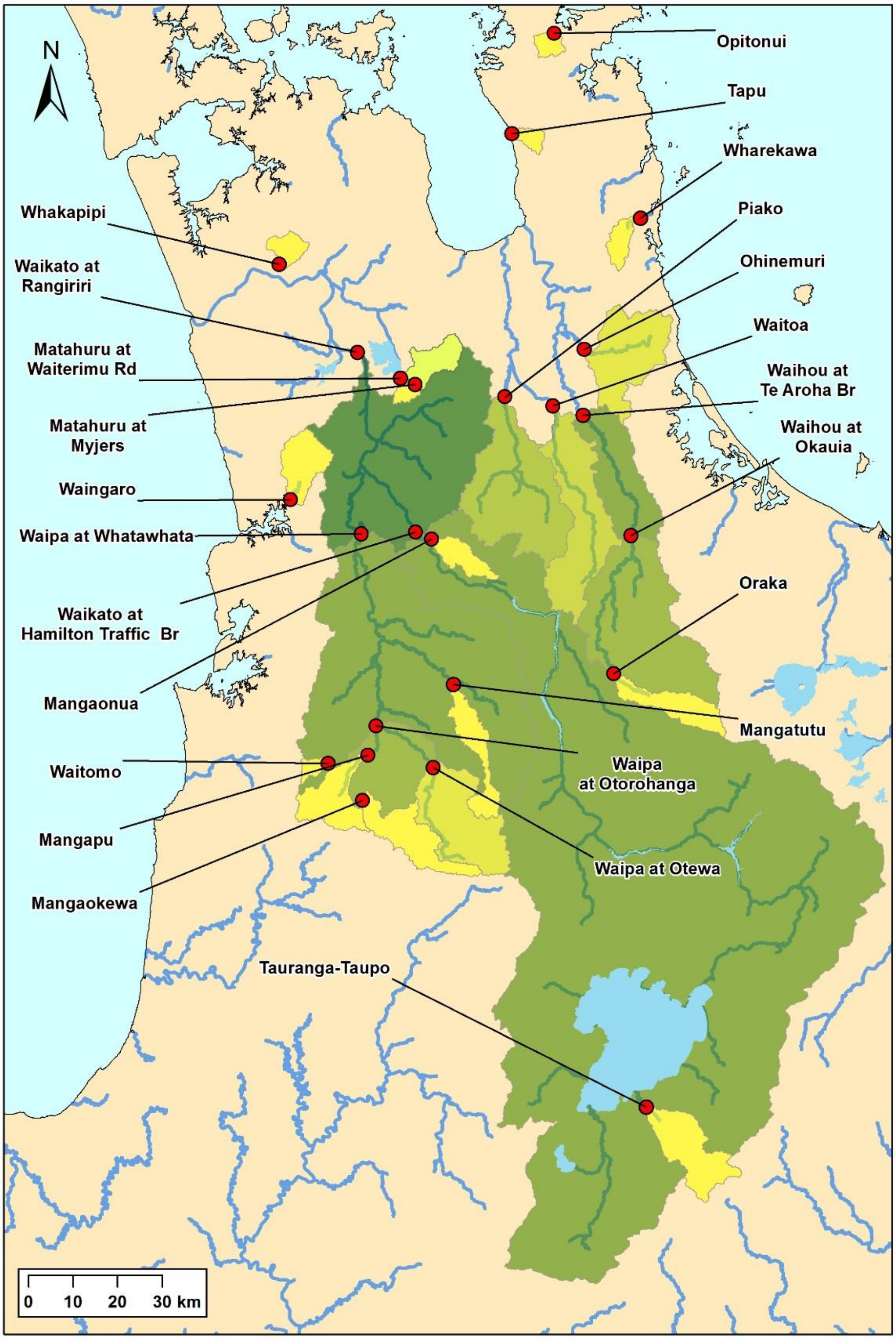


Figure 1-1: Study catchment locations within the Waikato region. Note – Catchment colouring is purely to help distinguish catchments from each other (as some catchments are nested within others), but is approximately shaded according to catchment size, i.e., the larger the catchment the darker the shade.

1.3 Catchment locations

The locations of the flow recorders for each catchment are provided in Table 1-1.

Table 1-1: NZTM coordinates of flow recorders in each catchment. The sampling method is listed as either M, denoting manual sampling, or A denoting auto-sampling.

Catchment	Sampling	Flow Recorder No.	Easting	Northing
Mangaokewa at Te Kuiti	M	1643462	2699840	6316096
Mangaonua at Dreadnought	M	1543497	2715375	6374751
Mangapu at SH3 Br	A	1043444	2701061	6326277
Mangatutu at Walker Rd Br	A	1943459	2720300	6342200
Matahuru at Myjers	A	3043490	2711644	6409530
Matahuru at Waiterimu Rd	A	43489	2708300	6410900
Ohinemuri at Karangahake	M	9213	2749644	6417389
Opitonui River at d/s Awaroa confl	A	11310	2742873	6488366
Oraka at Pinedale	M	1009213	2756300	6344600
Piako at Paeroa Tahuna Rd Br	M	9140	2731800	6406800
Tapu at Tapu-Coroglen	M	9701	2733364	6465803
Tauranga-Taupo at Te Kono	M	1543413	2763600	6247300
Waihou at Okauia	M	9224	2760200	6375600
Waihou at Te Aroha Br	M	9205	2749400	6402600
Waikato at Hamilton Traffic Br	M	43466	2711800	6376400
Waikato at Rangiriri	M	43420	2698700	6416700
Waingaro at Ruakiwi Road	A	42601	2683700	6383700
Waipa at Otewa	A	43481	2715700	6323500
Waipa at Otorohanga	M	43468	2702900	6332900
Waipa at Whatawhata	M	43433	2699600	6376000
Waitoa at Mellon Rd	M	9179	2742600	6404700
Waitomo at Aranui Caves	A	1943481	2692077	6324406
Whakapipi at SH22-Tuakau	M	1643457	2681052	6436497
Wharekawa at Adams Farm Br	A	12509	2762313	6446823

1.4 Data availability for sediment yield analysis

Table 1-2 presents the periods of flow and SSC data for each of the study catchments. The second column shows the number of years of flow record (excluding gaps) that were used to calculate sediment yields in this report. The second column also shows the number of runoff events for which there were sufficient SSC data to develop the Event-yield rating during the 2011 study (only possible for nine catchments). Additional SSC data were provided by WRC for nine catchments during this study, however, these data were not used to develop new rating relationships as this was beyond the scope of this study. For these sites, it is likely that additional events will have been captured which could be used to improve Event-yield rating relationships in future studies. The span of record in Table 1-2 indicates the beginning and end dates of data collection (or if end date is December 2013, the most recent data used in this study).

Table 1-2: Data availability for the study sites.

Site	No. well-sampled events / years of flow data	Span of record	
Mangaokewa at Te Kuiti			
Sediment Data	None	Aug-90	Jun-04
Flow Data	29.93	Mar-83	Dec-13
Mangaonua at Dreadnought			
Sediment Data	None	Aug-91	Aug-04
Flow Data	33.12	Nov-80	Dec-13
Mangapu at SH3 Bridge			
Sediment Data	46	Dec-00	May-12
Flow Data	13.21	Oct-00	Dec-13
Mangatutu at Walker Rd Bridge			
Sediment Data	34	Jun-04	Dec-13
Flow Data	9.40	Jun-04	Dec-13
Matahuru at Myjers			
Sediment Data	22	Jul-06	Dec-13
Flow Data	7.46	Jul-06	Dec-13
Matahuru at Waiterimu Rd			
Sediment Data	18	Jul-03	Oct-08
Flow Data	26.86	Jul-84	Aug-11
Ohinemuri at Karangahake			
Sediment Data	None	May-86	Jul-97
Flow Data	56.9	Nov-56	Dec-13
Opitonui at d/s Awaroa confluence			
Sediment Data	60	Jul-91	Dec-13
Flow Data	21.76	Jun-91	Dec-13
Oraka at Pinedale			
Sediment Data	None	Apr-86	Dec-03
Flow Data	34.09	Jul-79	Dec-13
Piako at Paeroa Tahuna Rd Bridge			
Sediment Data	None	Apr-86	Jun-04
Flow Data	40.94	Jul-72	Dec-13
Tapu at Tapu-Coroglen			
Sediment Data	None	Jul-91	Apr-99
Flow Data	22.50	Jul-91	Dec-13
Tauranga-Taupo at Te Kono Slackline			
Sediment Data	None	Aug-90	Aug-10
Flow Data	37.89	Feb-76	Dec-13
Waihou at Okauia			
Sediment Data	None	May-86	Jul-06
Flow Data	31.67	Mar-82	Dec-13

Site	No. well-sampled events / years of flow data	Span of record	
Waihou at Te Aroha Bridge			
Sediment Data	None	Apr-86	Aug-07
Flow Data	48.72	Jan-65	Dec-13
Waikato at Hamilton Traffic Bridge			
Sediment Data	None	Aug-91	Mar-04
Flow Data	36.34	Dec-75	Dec-13
Waikato at Rangiriri			
Sediment Data	None	Sep-91	Aug-07
Flow Data	48.38	Apr-65	Dec-13
Waingaro at Ruakiwi Rd			
Sediment Data	41	May-02	Oct-13
Flow Data	12.00	Nov-01	Dec-13
Waipa at Otewa			
Sediment Data	25	Aug-90	Oct-13
Flow Data	28.30	May-85	Dec-13
Waipa at Otorohanga			
Sediment Data	None	Aug-90	Aug-91
Flow Data	32.42	May-81	Dec-13
Waipa at Whatawhata			
Sediment Data	None	May-90	Sep-10
Flow Data	40.75	Apr-72	Dec-13
Waitoa at Mellon Rd			
Sediment Data	None	May-86	Aug-07
Flow Data	27.62	May-86	Dec-13
Waitomo at Aranui Caves Bridge			
Sediment Data	35	Aug-90	Oct-13
Flow Data	26.35	Oct-86	Dec-13
Whakapipi at SH22 Bridge			
Sediment Data	None	Aug-91	Nov-99
Flow Data	29.64	Mar-84	Dec-13
Wharekawa at Adams Farm Bridge			
Sediment Data	17	Sep-91	Dec-13
Flow Data	21.96	Jun-91	Dec-13

1.5 Catchment characteristics

This section outlines key characteristics of the 23 of the catchments examined in this report (Table 1-3). These data were generated during the 2011 study and further details and methods of establishing these characteristics are described in the 2011 report (Hoyle et al., 2011). Results are presented in this report as they provide useful information when comparing catchments. Results are not presented for the Ohinemuri at Karangahake catchment as that catchment was not part of the 2011 study.

Table 1-3: Key characteristics of study catchments. Summarised from (Hoyle et al. 2011).

Site	Catchment area (km^2)	Mean catchment slope	Mean annual rainfall (mm)	Mean annual runoff (mm)	% Pasture
Mangaokewa at Te Kuiti	173.2	0.25	1635	953	73.6
Mangaonua at Dreadnought	166	0.08	1167	409	86.3
Mangapu at SH3 Bridge	150.7	0.21	1745.4	1078	86.8
Mangatutu at Walker Rd Bridge	123	0.26	1692.8	1044	54.9
Matahuru at Myjers	82.6	0.25	1293.4	579	90.6
Matahuru at Waiterimu Rd	105	0.28	1209.9	579	89.3
Opitonui River at d/s Awaroa confl	29	0.43	1966.9	1192	2.7
Oraka at Pinedale	136	0.27	1508	651	29.3
Piako at Paeroa Tahuna Rd Br	534	0.11	1134.6	415	91.5
Tapu at Tapu-Coroglen	26.4	0.42	1903.7	1121	4.1
Tauranga-Taupo at Te Kono	199	0.36	2020.2	1550	1.9
Waihou at Okauia	816	0.19	1505.2	1036	55.5
Waihou at Te Aroha Bridge	1137	0.19	1528.4	1131	58.2
Waikato at Hamilton Traffic Bridge	8230	0.18	1509	994	36.3
Waikato at Rangiriri	12421	0.18	1506.6	933	49.4
Waingaro at Ruakiwi Rd	117	0.33	1499.2	737	63.2
Waipa at Otewa	317	0.3	1789.3	1277	42.6
Waipa at Otorohanga	919	0.2	1671.6	1020	75.8
Waipa at Whatawhata	2826	0.24	1617.4	976	69.7
Waitoa at Mellon Rd	357	0.07	1177.2	448	90.5
Waitomo at Aranui Caves Bridge	30.8	0.33	2171	1800	59.9
Whakapipi at SH22 Bridge	48.9	0.11	1275.6	576	64.1
Wharekawa at Adams Farm Bridge	46.5	0.36	2040.8	1232	1.4

2 Analysis methods

Two approaches were used to establish mean annual sediment yields for the catchments in this investigation. The first was to using a 'sediment concentration rating' relationship between instantaneous suspended sediment concentration and water discharge. The second was to use an 'event sediment yield rating' relationship between individual event sediment yields and event hydrological magnitude (indexed by either event peak discharge or quickflow). This second approach could only be applied to the nine auto-sampled sites, with data collected at adequate intervals across individual events. The suspended sediment concentration ratings and the event sediment yield ratings were both developed during the 2011 study (Hoyle et al., 2011), other than the rating relationship developed during this study for Ohinemuri at Karangahake as that catchment did not have an existing rating. Each rating relationship was applied across the full updated flow record to compute annual and mean annual sediment yields. Further details on each approach are given below. The rating relationships used in this study are all provided in Appendix A (Tables A-1 and A-2).

2.1 The sediment concentration rating approach

For each site a sediment concentration rating was established by plotting instantaneous suspended sediment concentration (SSC) versus instantaneous water discharge (Q) – This is referred to as the SSC-Q rating. This rating was then applied to the full water discharge record allowing integration of the sediment yield over the longest period possible for each site. The sediment yield was also integrated during quickflow periods only, as defined in section 2.2, to establish the proportion of the sediment load that is carried during storm events.

A LOWESS (Locally-Weighted Scatterplot Smoothing) approach was used to fit the ratings for each catchment, with the LOWESS ratings represented by a series of power step-functions. As the data were transformed to their logarithms for curve-fitting, the LOWESS curve was adjusted for log-transformation bias using the approach of Ferguson (1986). This adjustment scales with the exponential of the local standard error of the curve-fitting in log units, and was calculated during the LOWESS fitting process (in a process similar to that detailed by Hicks et al., 2000). The LOWESS-fit rating curve for the Ohinemuri at Karangahake site, developed during this study, is shown in Figure 2-1. Approximating the bias-adjusted LOWESS curves with step-functions simplifies the calculation of yields and induces no significant error.

2.2 The storm event sediment yield rating approach

The aim of this approach is to accurately measure the sediment yield from storm runoff events with adequate data, and from these determine relationships between storm sediment yield and an appropriate index of event hydrological magnitude, such as peak flow or quickflow runoff. The ratings developed using this approach are referred to as the Event-yield ratings.

For each of the catchments with auto-sampled sediment concentration records (Mangapu at SH3 Bridge, Mangatutu at Walker Road Bridge, Matahuru at Myjers, Opitonui River at downstream Awaroa confluence, Waipa at Otewa, Waingaro at Ruakiwi Road, Matahuru at Waiterimu Road, Waitomo at Aranui Caves Bridge, Wharekawa at Adams Farm Bridge), individual storms with sufficient sediment concentration data were identified. Typically, we then added synthetic SSC data points to the beginning and end of the events, since the auto-samplers usually missed sampling these. The synthetic SSC values we assigned to the start and end of events were based on an appreciation of the typical concentrations at the tails of storm events at a given site.

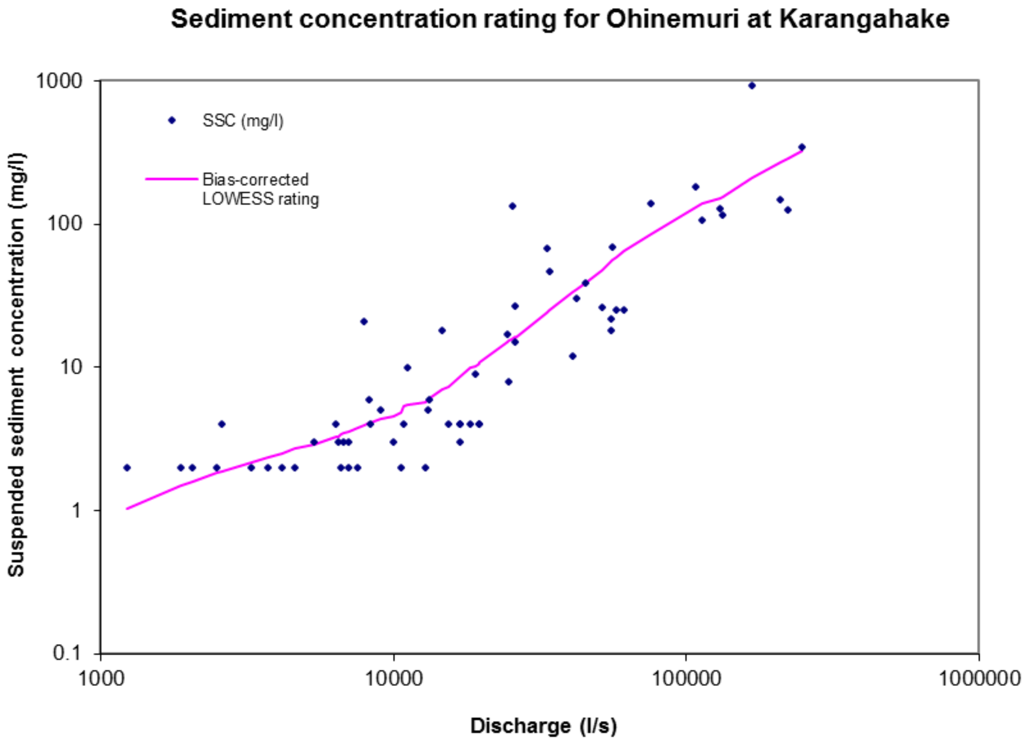


Figure 2-1: Example of a suspended sediment concentration rating for the Ohinemuri at Karangahake site. The rating function is a bias-corrected LOWESS fit.

The times for the beginning and end of each event were based on the beginning and end of quickflow. Quickflow is the part of the water runoff from a rainstorm that moves quickly through a basin; the remainder of the runoff, termed the 'delayed flow', arrives in the stream channels more slowly after moving through the ground and other areas of temporary storage. Following the procedure of Hewlett and Hibbert (1967), hydrographs were examined to assess the typical quickflow separation slope for each site. Also, a minimum value of quickflow runoff of 1 mm was set for each site in order to discard tiny quickflow 'events' generated by noise in the stage record. This approach provides an objective, repeatable way of identifying the beginning and end of storm events and for deciding whether a multi-peak hydrograph represents one event or several. The same approach was used for generating series of events when the event ratings were applied to determine mean annual sediment yields. The quickflow separation slopes for each site are included with the sediment concentration ratings in the Appendix (Table A-1).

The sediment yield over discrete events was computed by direct integration of the sediment concentration and discharge records using the PSIM module of the TIDEDA hydrological software package. The PSIM module was also used to extract various hydrological measures of each event, including the peak discharge.

For each catchment, the event sediment yields were plotted against peak discharge (l/s), quickflow runoff (mm), and total runoff (mm). The event sediment yields generally correlated best with the storm peak discharge, as has been found in previous studies of a similar nature (Hicks, 1990). The exceptions were Mangatutu at Walker Road Bridge, Mangapu River at SH3 Bridge upstream Mangaokewa confluence and Waipa at Otewa, which correlated best with quickflow. In each case, the Event-yield vs. peak discharge or quickflow relationship was represented best by a power-law regression. The power-fit regressions were adjusted for log-bias using the bias-correction factor of Duan (1983), which gave essentially the same correction as did Ferguson's (1986) method. The Event-yield vs. peak discharge or quickflow rating relationships established for each catchment were then used to estimate the yields from all events over the duration of the flow record, providing average annual sediment yield estimates. The rating for each catchment where this approach was possible is present in Table A-2.

An example Event-yield rating is shown below for the Waitomo at Aranui Caves Bridge site (Figure 2.2).

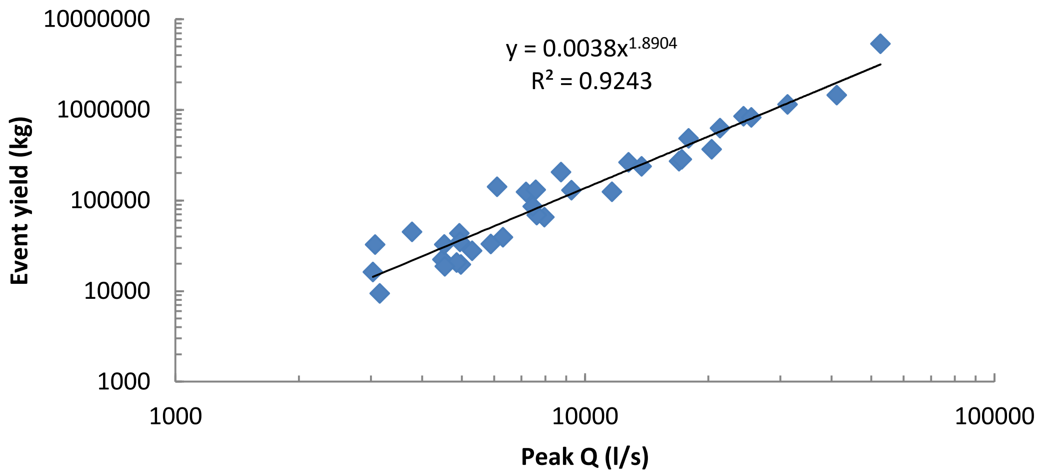


Figure 2-2: Example of an Event-yield rating from Waitomo at Aranui Caves Bridge catchment. This rating has a power relationship.

2.3 Testing for time trends

Time trends for the monitored catchments were assessed based on residuals in the relationship between suspended sediment concentration and water discharge (SSC-Q rating). In all cases, the residuals of the observed log SSC values compared to the log SSC values predicted by the LOWESS fit were examined for normality and for any time trend. Normality was evaluated using both the Kolmogorov-Smirnov (K-S) and Lilliefors tests at the 5% significance level, while a time-trend was evaluated using a Student's t-test, testing 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. No trend is indicated if the slope is not significantly different from zero. For the nine catchments where updated suspended sediment data was available, these trends have been updated to the end of

2013. Trends for the remaining fifteen catchments are based on analysis of data from the 2011 study.

While testing for time trends, the residuals from the SSC-Q ratings were tested to see if there is a trend with discharge. Checking for these trends is important as it demonstrates the quality of the rating fit, notably over the flow range doing the most transport. If the fit is poor at the high flow range, this points to an over or underestimate in the yield. Plots of the SSC-Q rating residuals vs discharge are provided in Appendix B. These trend with discharge results are summarised alongside the time trend results in Section 3.2.

Time trends in the Event-yield rating were also tested for significance using the same method used for the SSC-Q ratings. Identifying new events from the updated SSC data was outside the scope of this project so the trends stated for the residuals of the Event-yield ratings are based on data from the 2011 study only. The residuals of the Event-yield ratings were also tested to see if there are trends with Qpeak or QF, again to demonstrate the quality of the rating fit. These results are presented with the time trend results.

3 Results

3.1 State of suspended sediment yields in Waikato region

The annual specific suspended sediment yields (t/km^2) for each catchment are presented in Figures 3-1 to 3.24. These figures show the annual yields derived from the sediment concentration rating approach and the Event-yield rating approach (where possible) over the full period of available flow data. Each figure also shows the 3-year moving average specific yield. These figures show the degree of variability in sediment yield to be expected from year-to-year due to hydrological variability. For example, Figure 3-1 shows that over the 30 years of flow record at Mangaokewa at Te Kuiti the specific annual sediment yield has ranged from 3.9 t/km^2 (in 1984) to 141 t/km^2 (in 1998). This site has a mean annual specific sediment yield of 53.8 t/km^2, a standard deviation of 29.5 t/km^2, and the standard error of the mean is 5.4 t/km^2 (statistics for each catchment provided in Table 3-1).

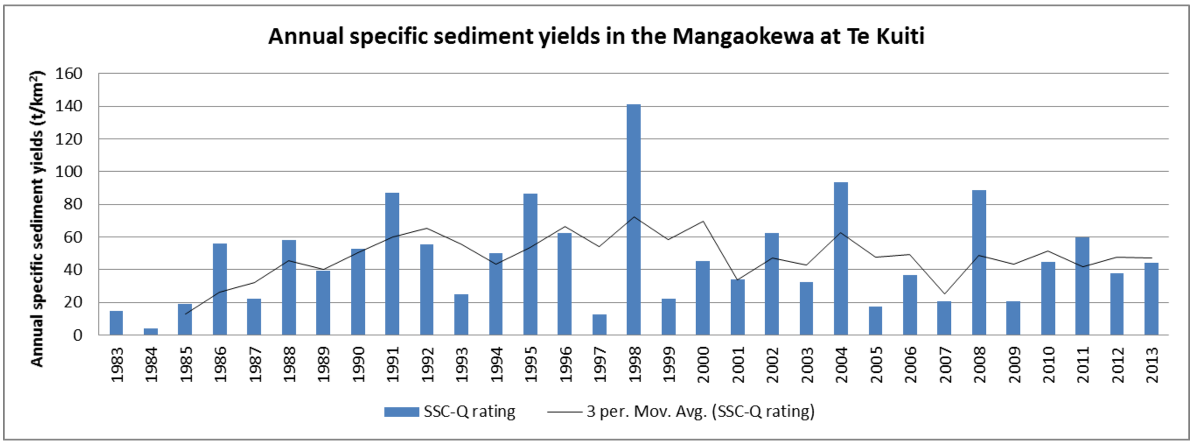


Figure 3-1: Annual specific suspended sediment yields for Mangaokewa at Te Kuiti.

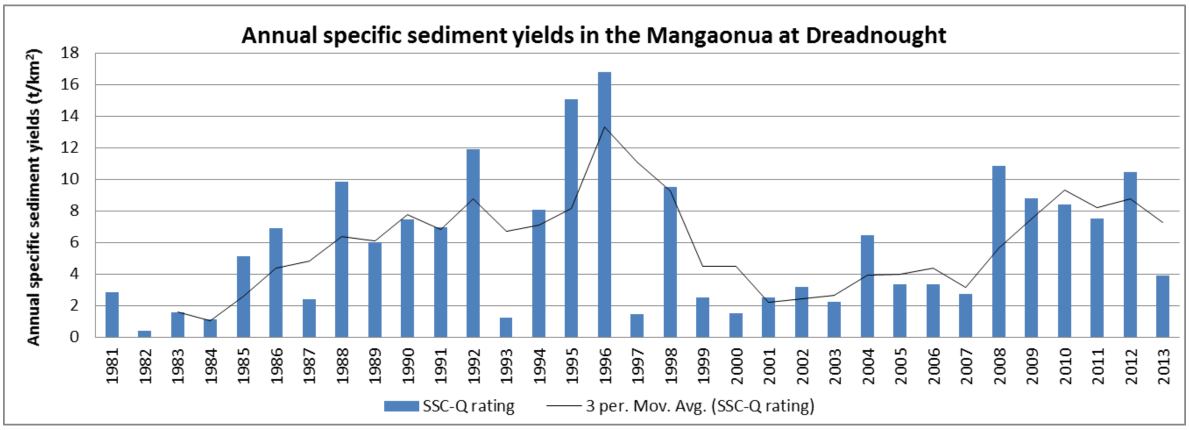


Figure 3-2: Annual specific suspended sediment yields for Mangaonua at Dreadnought.

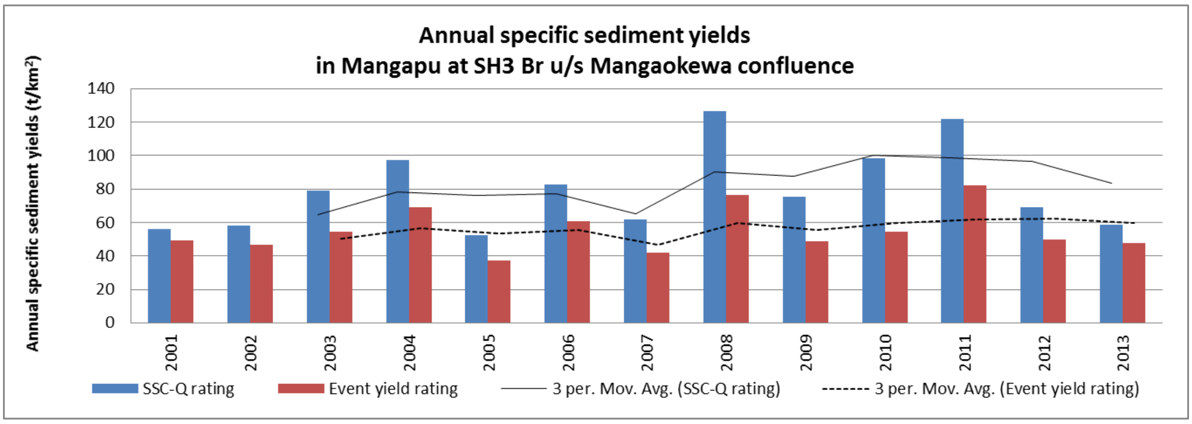


Figure 3-3: Annual specific suspended sediment yields for Mangapu at SH3 Bridge upstream of Mangaokewa confluence.

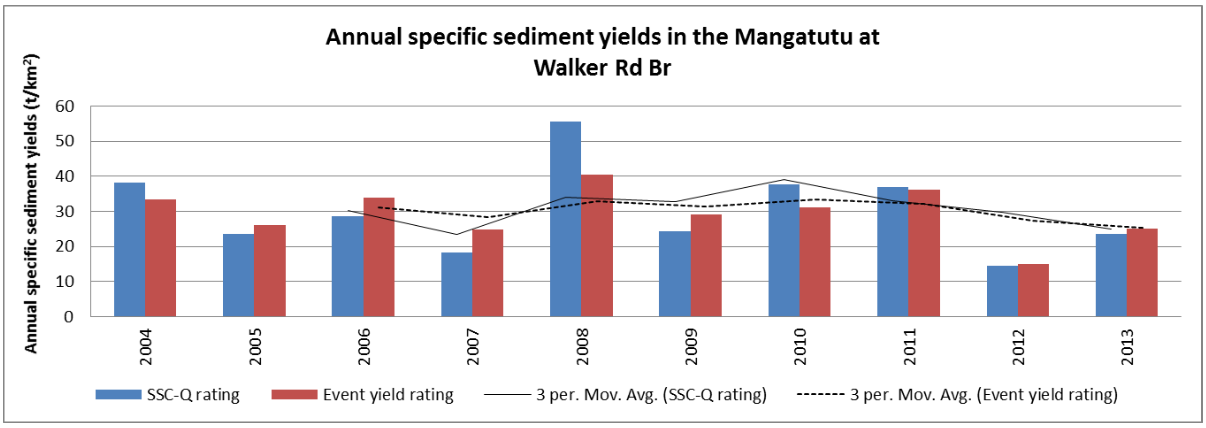


Figure 3-4: Annual specific suspended sediment yields for Mangatutu at Walker Road Bridge.

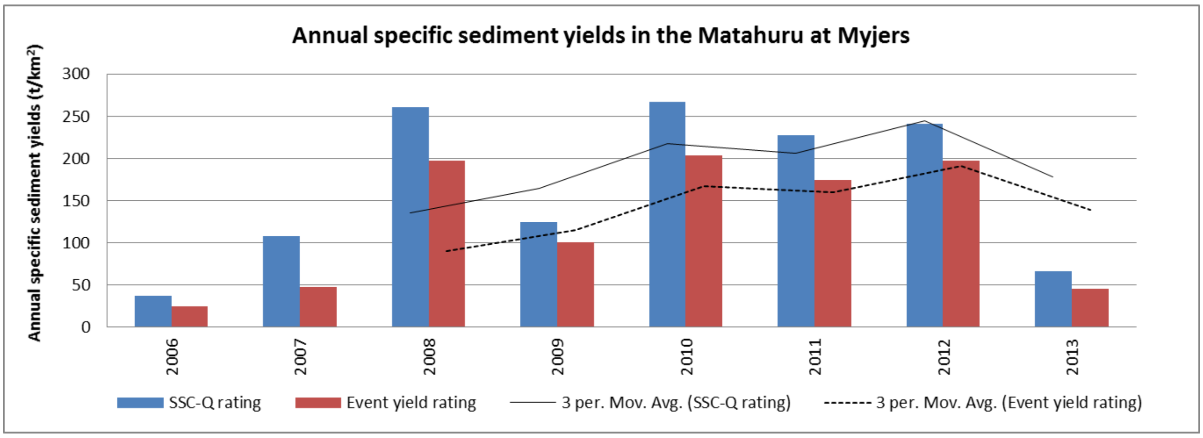


Figure 3-5: Annual specific suspended sediment yields for Matahuru at Myjers.

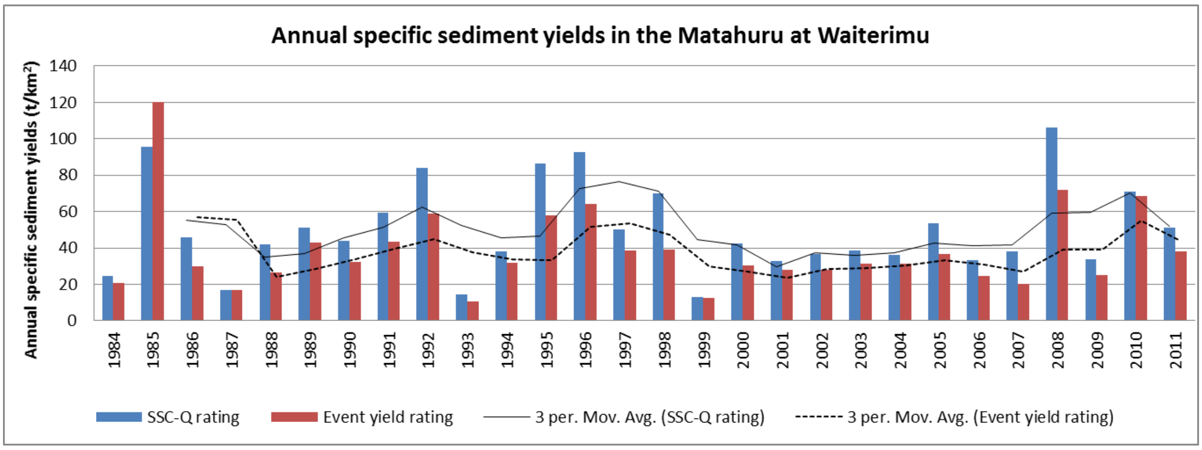


Figure 3-6: Annual specific suspended sediment yields for Matahuru at Waiterimu Road.

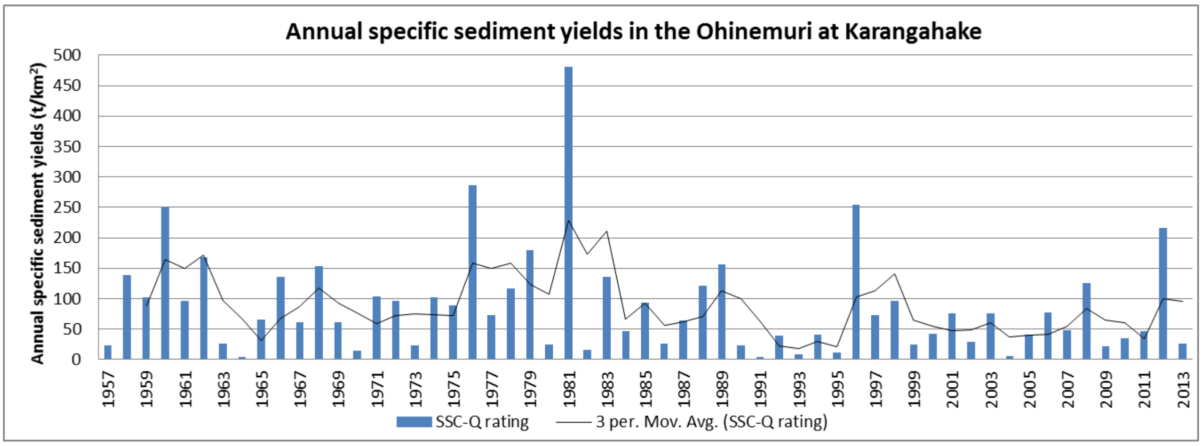


Figure 3-7: Annual specific suspended sediment yields for Ohinemuri at Karangahake.

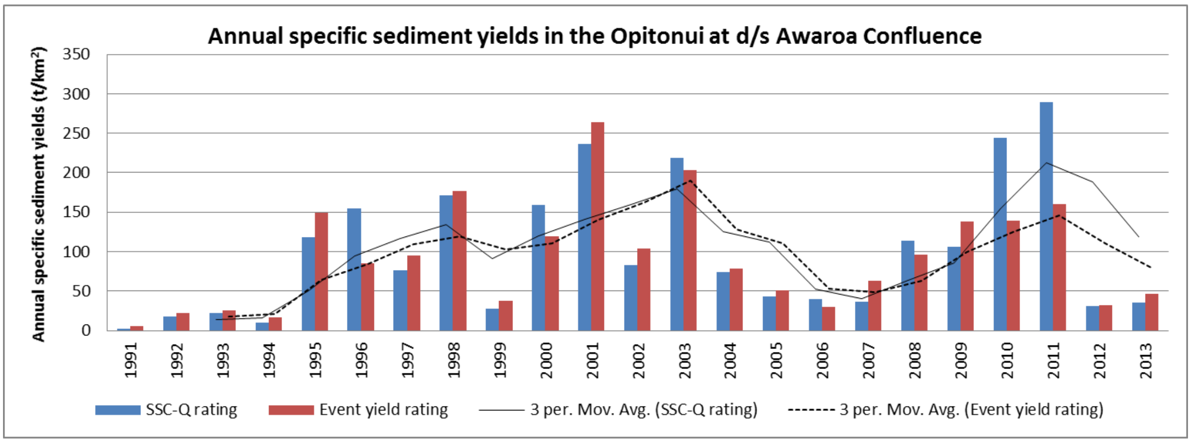


Figure 3-8: Annual specific suspended sediment yields for Opitonui at downstream of Awaroa confluence.

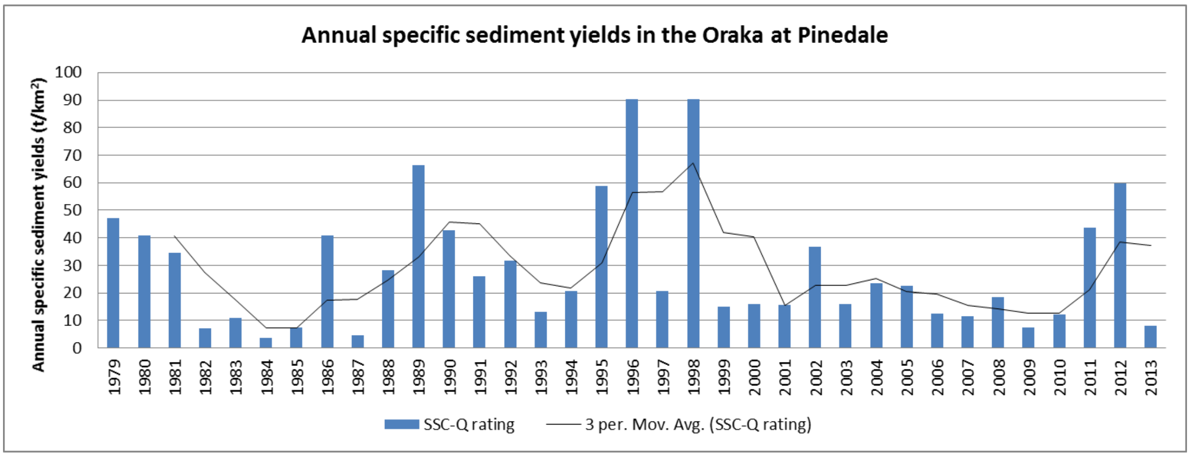


Figure 3-9: Annual specific suspended sediment yields for Oraka at Pinedale.

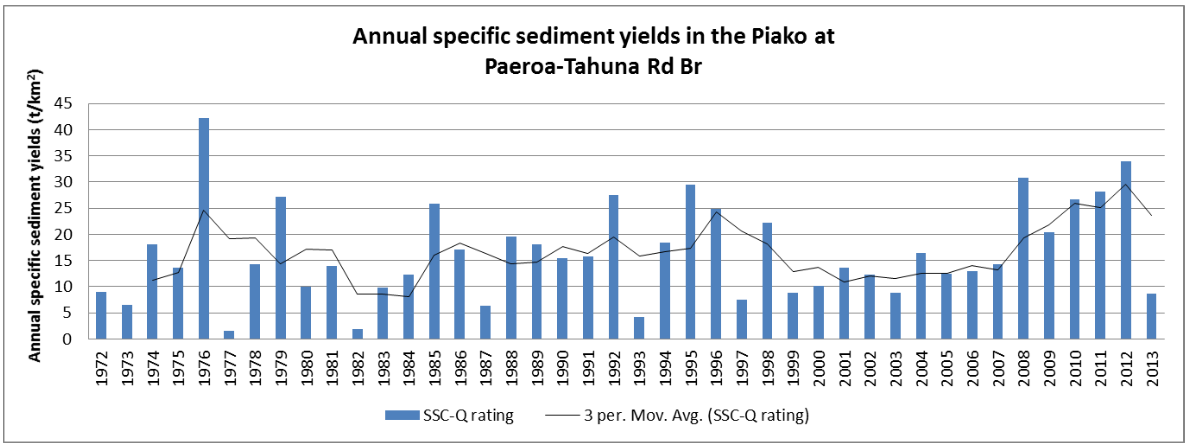


Figure 3-10: Annual specific suspended sediment yields for Piako at Paeroa-Tahuna Road Bridge.

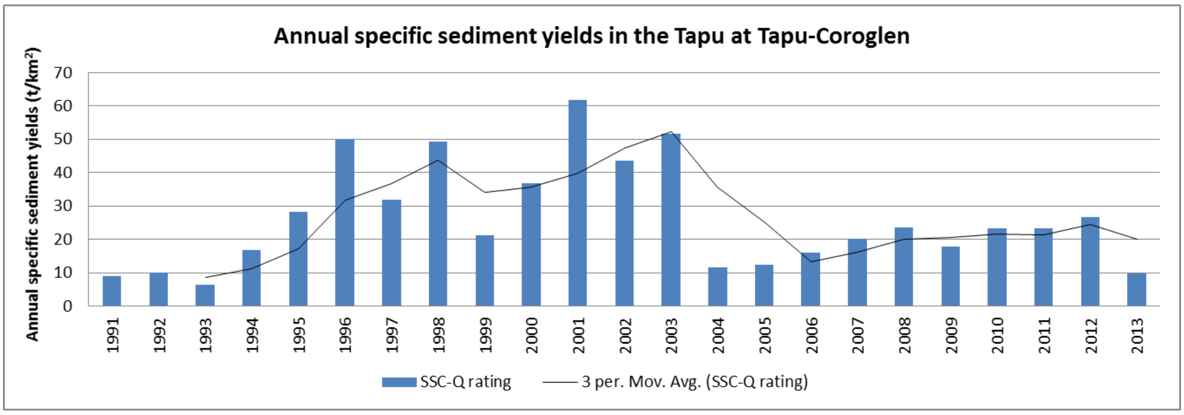


Figure 3-11: Annual specific suspended sediment yields for Tapu at Tapu-Coroglen.

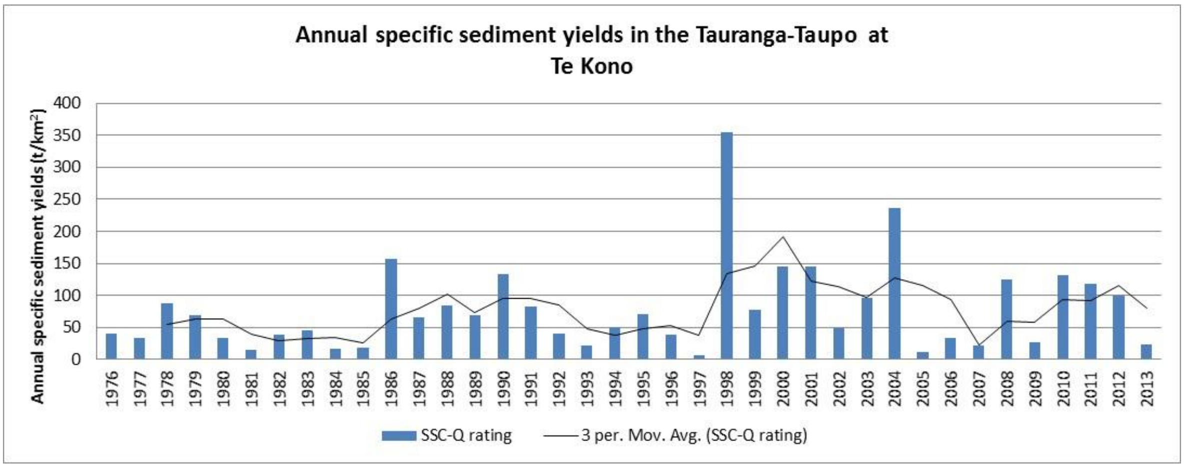


Figure 3-12:Annual specific suspended sediment yields for Tauranga-Taupo at Te Kono.

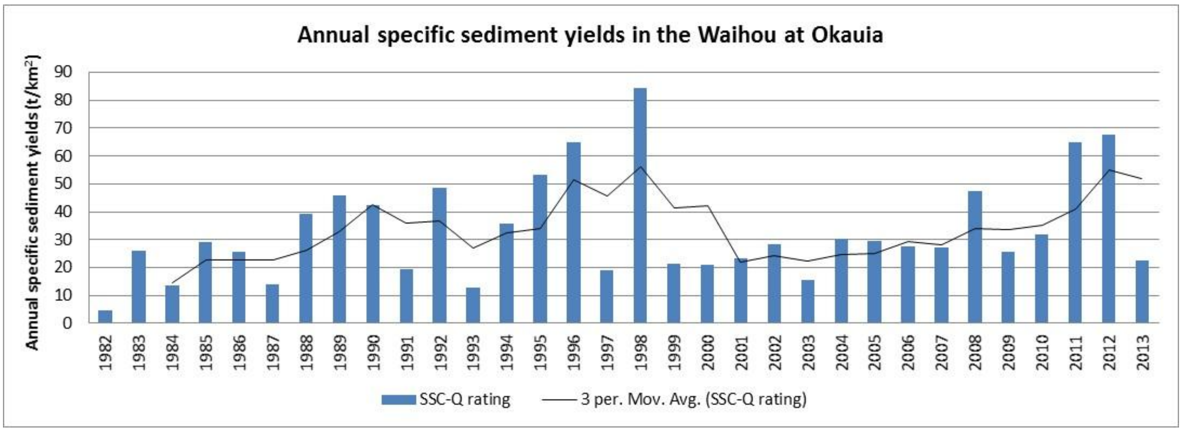


Figure 3-13:Annual specific suspended sediment yields for Waihou at Okauia.

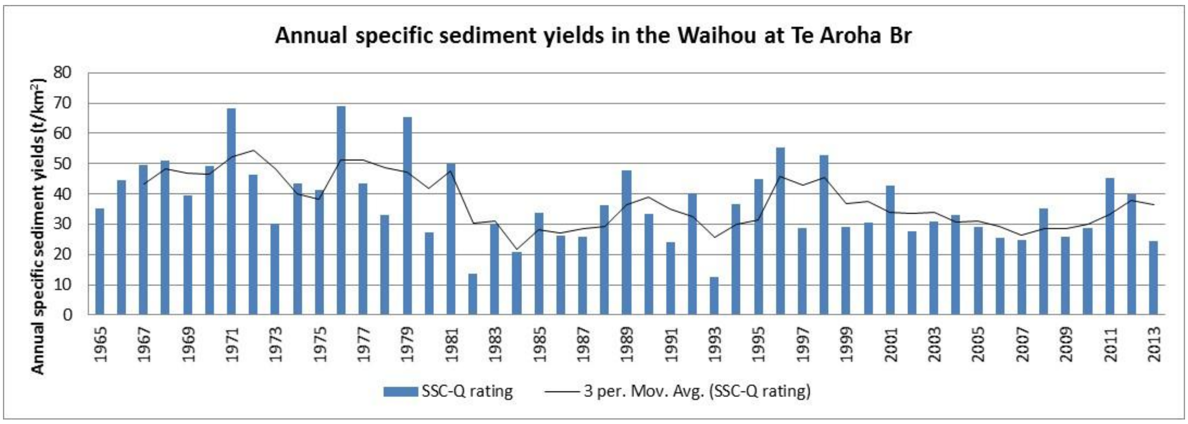


Figure 3-14:Annual specific suspended sediment yields for Waihou at Te Aroha.

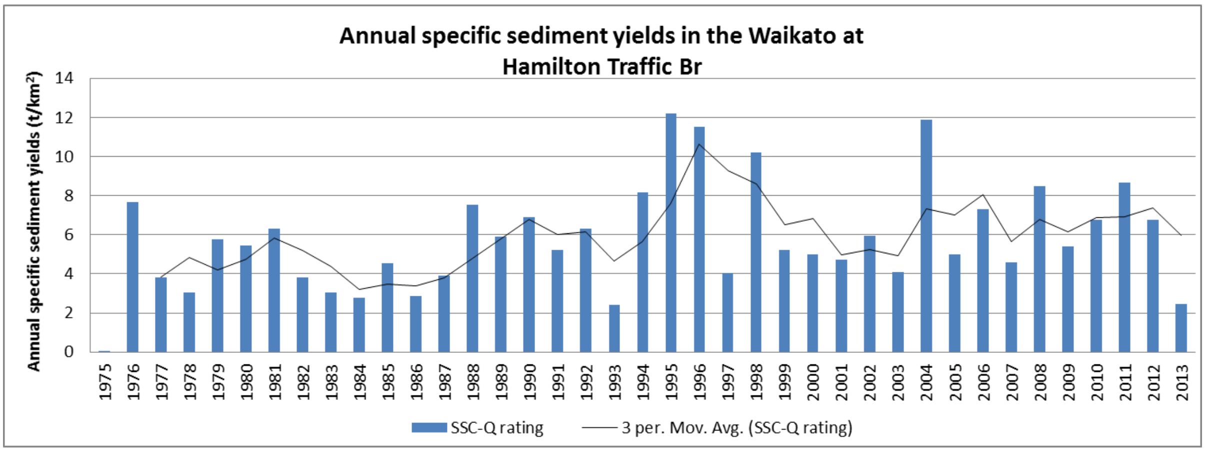


Figure 3-15:Annual specific suspended sediment yields for Waikato at Hamilton Traffic Bridge.

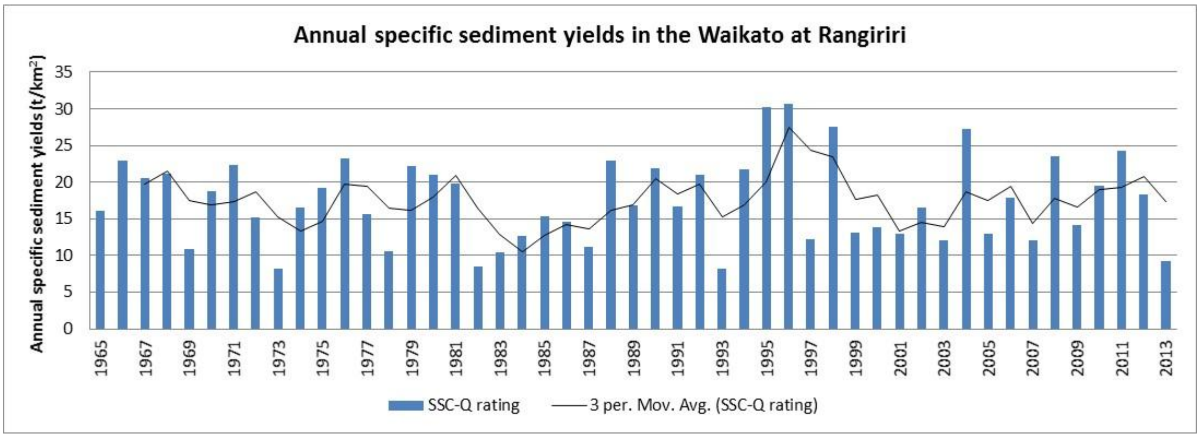


Figure 3-16:Annual specific suspended sediment yields for Waikato at Rangiriri.

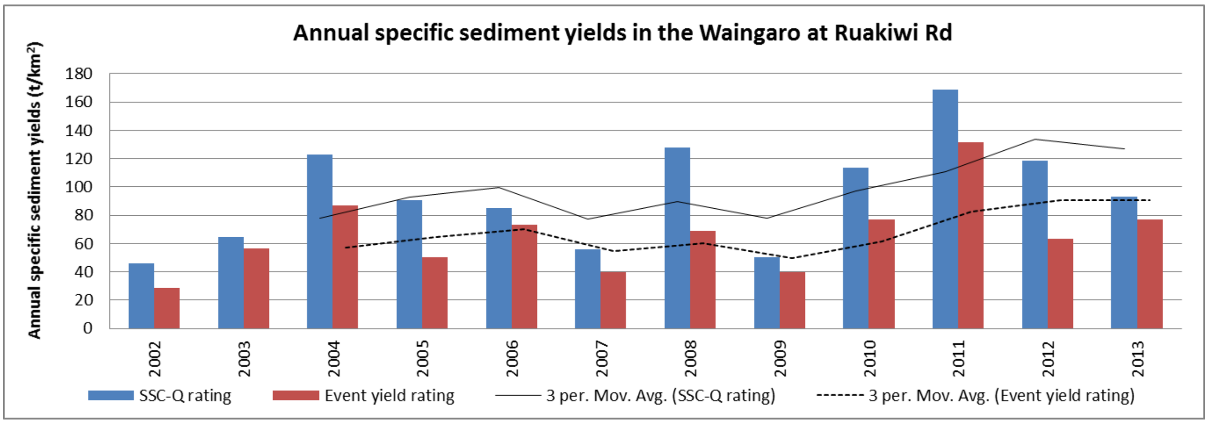


Figure 3-17:Annual specific suspended sediment yields for Waingaro at Ruakiwi Road.

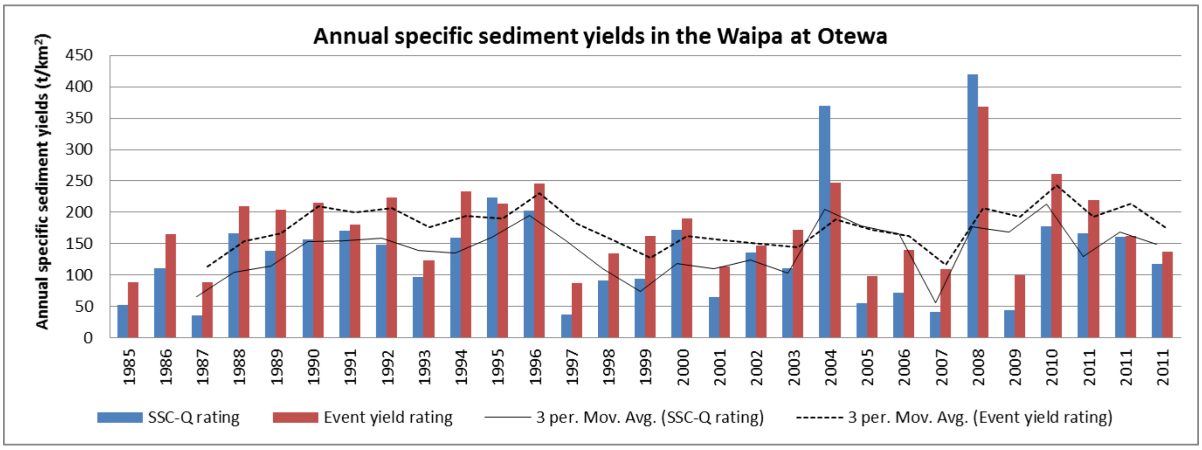


Figure 3-18:Annual specific suspended sediment yields for Waipa at Otewa.

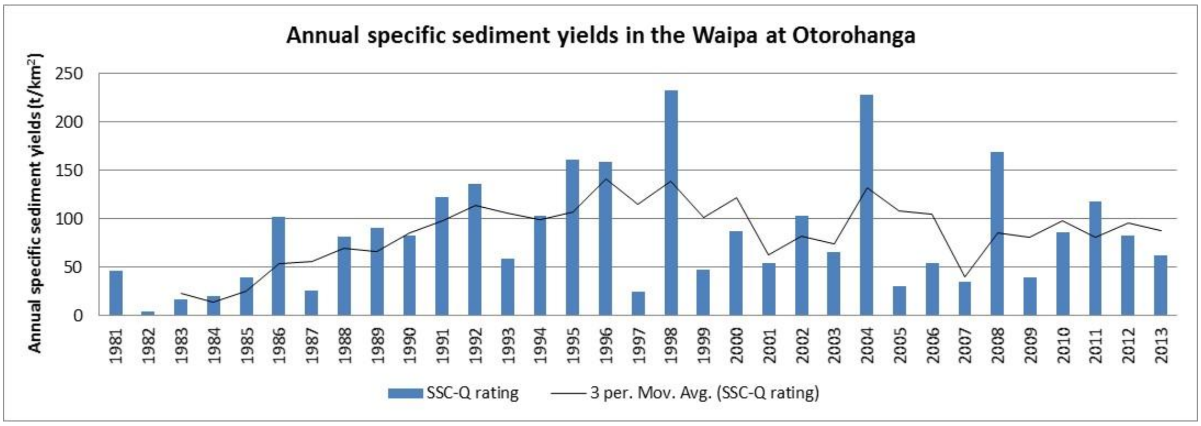


Figure 3-19:Annual specific suspended sediment yields for Waipa at Otorohanga.

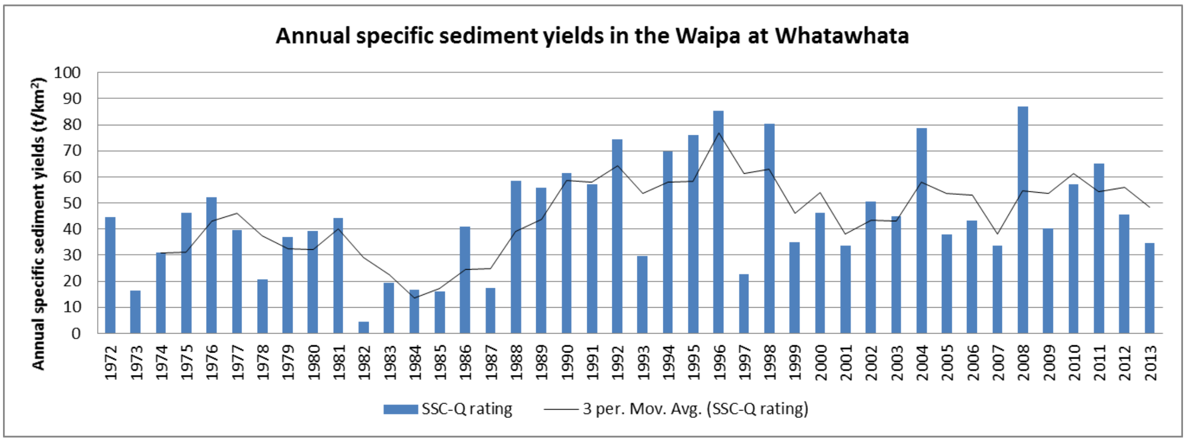


Figure 3-20:Annual specific suspended sediment yields for Waipa at Whatawhata.

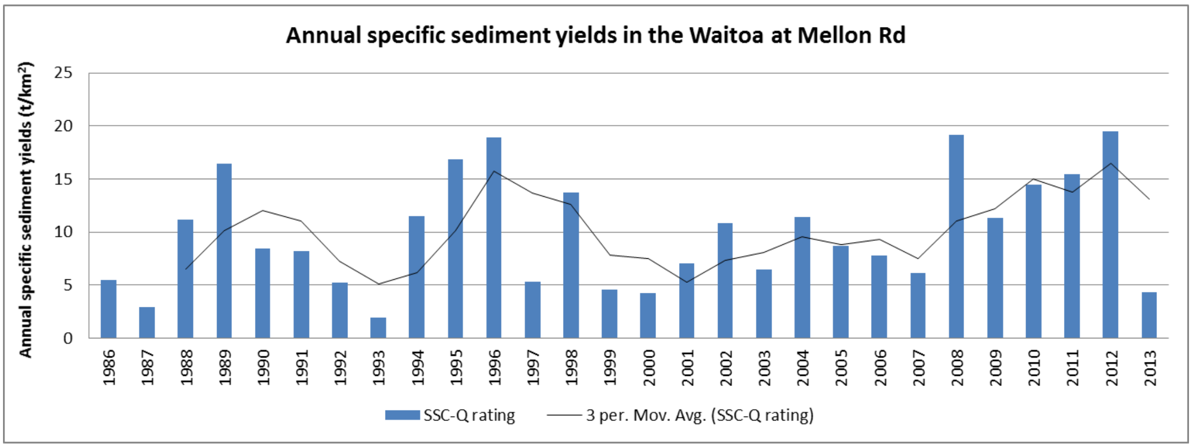


Figure 3-21:Annual specific suspended sediment yields for Waitoa at Mellon Road.

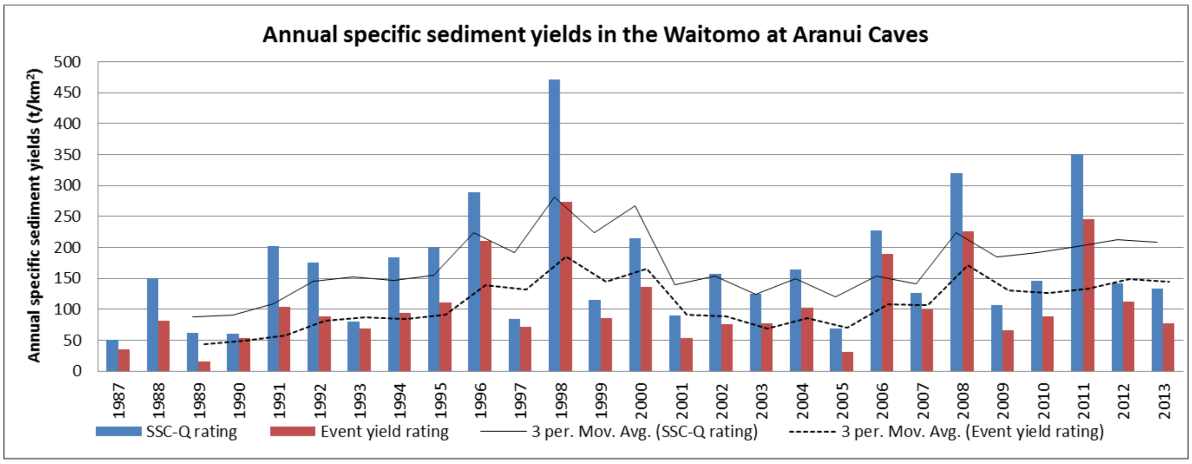


Figure 3-22:Annual specific suspended sediment yields for Waitomo at Aranui Caves.

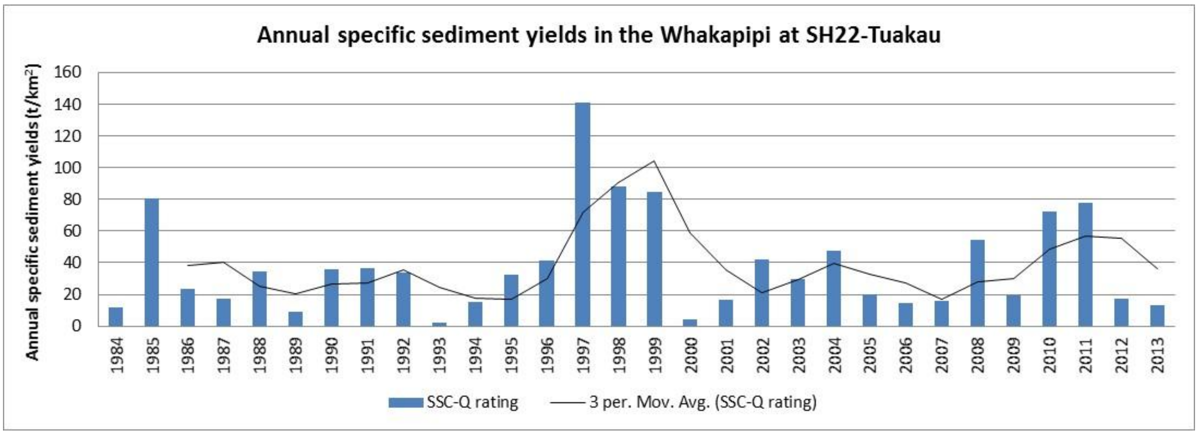


Figure 3-23:Annual specific suspended sediment yields for Whakapipi at Sh22-Tuakau.

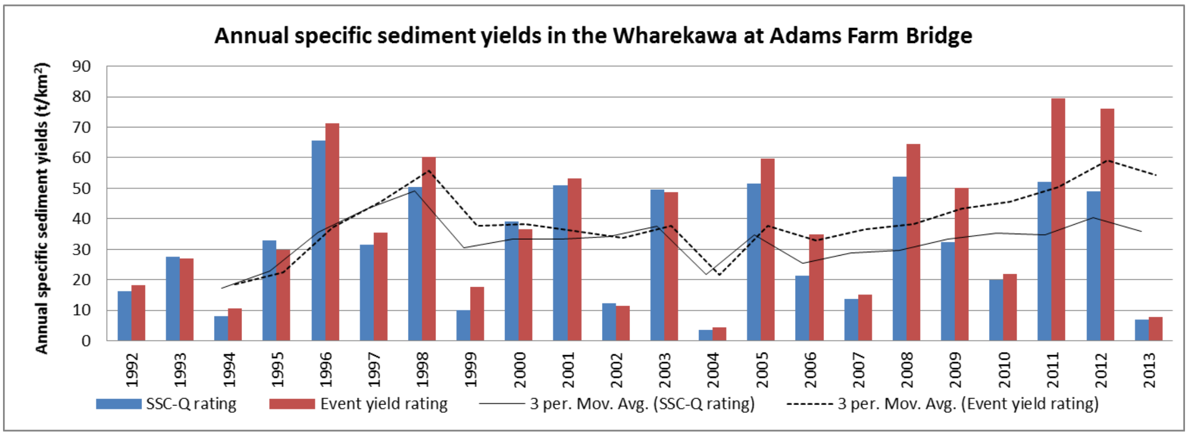


Figure 3-24:Annual specific suspended sediment yields for Wharekawa at Adams Farm Bridge.

The coefficient of variation of annual yields (i.e., standard deviation / mean) across all catchments averages 49% and ranges up to 88%. The extent of this hydrologically-driven annual variability indicates that mean annual yield estimates among catchments with short record periods (e.g., Mangatutu, Matahuru, Waingaro – refer Table 1-2) should be compared with caution.

The results show that yields agree reasonably well across both approaches, but that the sediment concentration rating approach tends mostly to give a higher result than the Event-yield approach. This is to be expected, as the Event-yield approach (which defines events in terms of discrete quickflow events that exceed a threshold quickflow runoff) ignored sediment carried by the delayed flow (i.e., on event recessions after the cessation of quickflow) and also ignored the sediment load carried by very small events (typically with return periods less than 1 month). A measure of this effect was found by using the sediment concentration rating approach to total just the sediment load carried during quickflow events. The proportion of the load carried during quickflow varied from 64.9% to 97.2% (Table 3-1). While this accounts for much of the difference among yield estimates, some of the difference appears to be due more to sampling error in the rating relations (which tends to be larger for the sediment concentration ratings). For some sites, it may be that the sediment concentration rating approach is inclined to overestimate the load during high winter base flows. Both the approaches for estimating yields have advantages and disadvantages, therefore, where both are calculated we suggest taking the average of the two results as representative, with the average standard error being indicative of the annual variability (Table 3-1).

For direct comparison between catchments the average annual specific sediment yields for all catchments are presented in Figures 3-25a & b. Figure 3-25a shows the results for both the SSC-Q rating and the Event-yield rating, while Figure 3-25b shows the results averaged over the SSC-Q rating and Event-yield rating approaches where both are available.

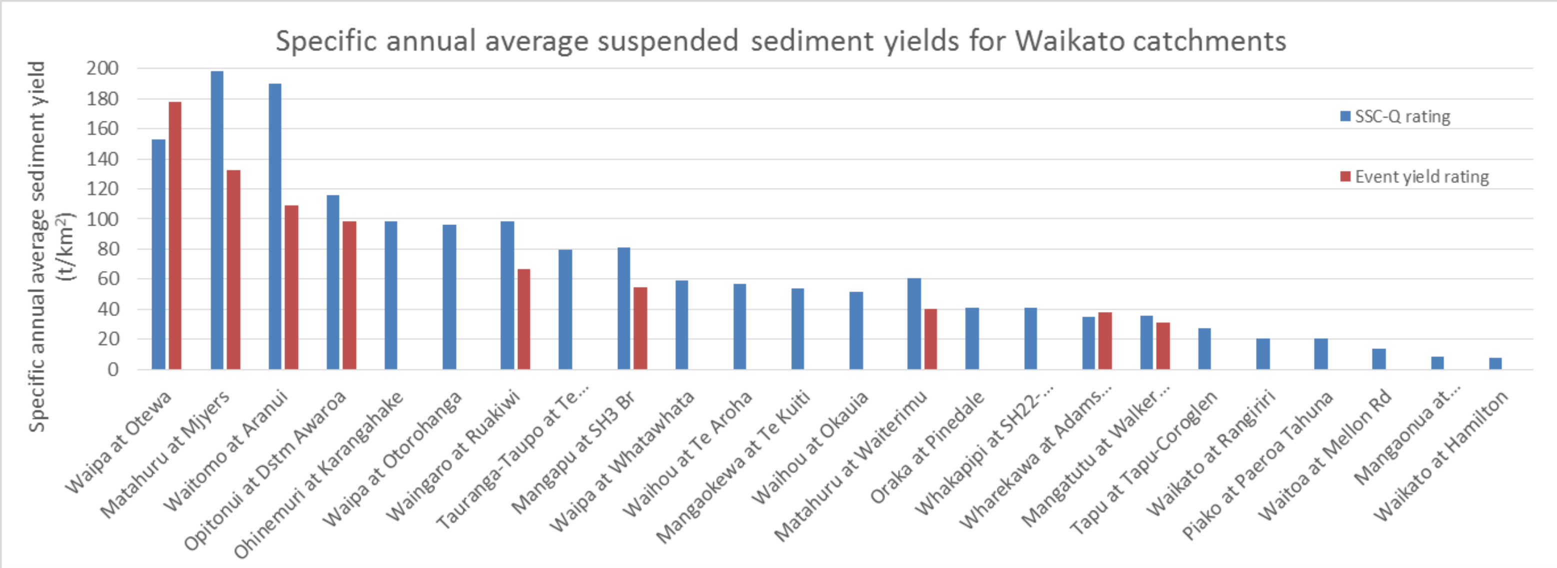
Yield results (based on the average of both approaches where possible) range from 7.9 t/km^2/y at Waikato at Hamilton Traffic Bridge to 165.5 t/km^2/y at Waipa at Otewa. For most sites the yield falls between 20-100 t/km^2/y. As found in the 2011 study, Waipa at Otewa, Matahuru at Myjers (165.4 t/km^2/y) and Waitomo at Aranui Caves (149.7 t/km^2/y) all have noticeably higher yields.

Table 3-1: Mean annual specific sediment yield estimates. Event-yield based estimates are not available at all sites. Results in this table are presented from highest to lowest mean annual specific sediment yield (averaged across both approaches).

			SSC-Q rating approach						Event-yield rating approach						Average of approaches	
Site	Basin area	Annual avg	Spec ann avg	Spec min	Spec max	Spec SD	SE of spec mean	% during storms	Ann avg	Spec ann avg	Spec min	Spec max	Spec SD	SE of spec mean	Spec ann avg	Avg SE
Waipa at Otewa	317	48466.1	152.9	36.2	419.2	89.0	16.7	92.2	56439.0	178.0	86.9	368.8	64.2	12.1	165.5	9%
Matahuru at Mjyers	82.6	16369.9	198.2	65.9	266.7	82.8	30.3	90.0	10957.2	132.7	45.4	203.3	71.6	26.2	165.4	18%
Waitomo at Aranui	30.8	5850.9	190.0	50.3	470.8	98.2	19.1	90.0	3367.7	109.3	15.1	274.2	66.2	12.9	149.7	11%
Opitonui at Dstm Awaroa	29	3354.2	115.7	9.9	289.1	83.9	18.0	91.9	2852.9	98.4	16.6	263.6	66.1	14.2	107.0	15%
Ohinemuri at Karangahake	287	28301.1	98.6	4.0	480.4	84.8	11.2	88.7							98.6	11%
Waipa at Otorohanga	919	88097.2	95.9	5.0	232.1	57.7	10.1	89.2							95.9	11%
Waingaro at Ruakiwi	117	11548.5	98.7	45.8	168.5	37.0	10.7	96.3	7775.1	66.5	28.7	131.9	27.3	7.9	82.6	11%
Tauranga-Taupo at Te Kono	199	15772.9	79.3	7.1	354.2	69.4	11.3	97.1							79.3	14%
Mangapu at SH3 Br	150.7	12212.0	81.0	52.2	126.6	24.7	6.8	97.2	8273.6	54.9	37.3	82.2	13.3	3.7	68.0	8%
Waipa at Whatawhata	2826	167606.1	59.3	4.4	86.8	20.8	3.3	78.2							59.3	6%
Waihou at Te Aroha	1137	64874.3	57.1	12.4	69.1	12.7	1.8	65.5							57.1	3%
Mangaokewa at Te Kuiti	173.2	9314.2	53.8	3.9	141.0	29.5	5.4	89.8							53.8	10%
Waihou at Okauia	816	42194.7	51.7	12.7	84.3	17.9	3.2	64.9							51.7	6%

Site	Basin area	Annual avg	Spec ann avg	Spec min	Spec max	Spec SD	SE of spec mean	% during storms	Ann avg	Spec ann avg	Spec min	Spec max	Spec SD	SE of spec mean	Spec ann avg	Avg SE
			SSC-Q rating approach						Event-yield rating approach						Average of approaches	
Matahuru at Waiterimu	105	6356.8	60.5	13.1	106.3	24.8	4.8	86.2	4217.3	40.2	10.6	120.1	22.8	4.4	50.4	9%
Oraka at Pinedale	136	5615.6	41.3	3.8	90.4	22.7	3.9	71.4							41.3	9%
Whakapipi at SH22-Tuakau	48.9	1991.5	40.7	2.5	141.1	31.6	5.8	94.0							40.7	14%
Wharekawa at Adams Farm	46.5	1640.6	35.3	3.5	65.6	18.9	4.0	90.2	1769.0	38.0	4.5	79.4	23.6	5.0	36.7	12%
Mangatutu at Walker Road	123	4441.6	36.1	14.6	55.5	12.5	4.1	88.8	3854.1	31.3	14.9	40.4	7.5	2.4	33.7	10%
Tapu at Tapu-Coroglen	26.4	733.1	27.8	6.3	61.9	15.6	3.3	96.1							27.8	12%
Waikato at Rangiriri	12421	254461.6	20.5	8.2	30.7	5.8	0.8	86.2							20.5	4%
Piako at Paeroa Tahuna	534	10859.7	20.3	1.5	42.2	9.1	1.4	83.1							20.3	7%
Waitoa at Mellon Rd	357	4830.7	13.5	2.0	19.5	5.2	1.0	74.3							13.5	7%
Mangaonua at Dreadnought	166	1405.6	8.5	0.4	16.8	4.2	0.7	68.5							8.5	9%
Waikato at Hamilton	8230	65250.6	7.9	2.4	12.2	2.6	0.4	78.4							7.9	6%

a)



b)

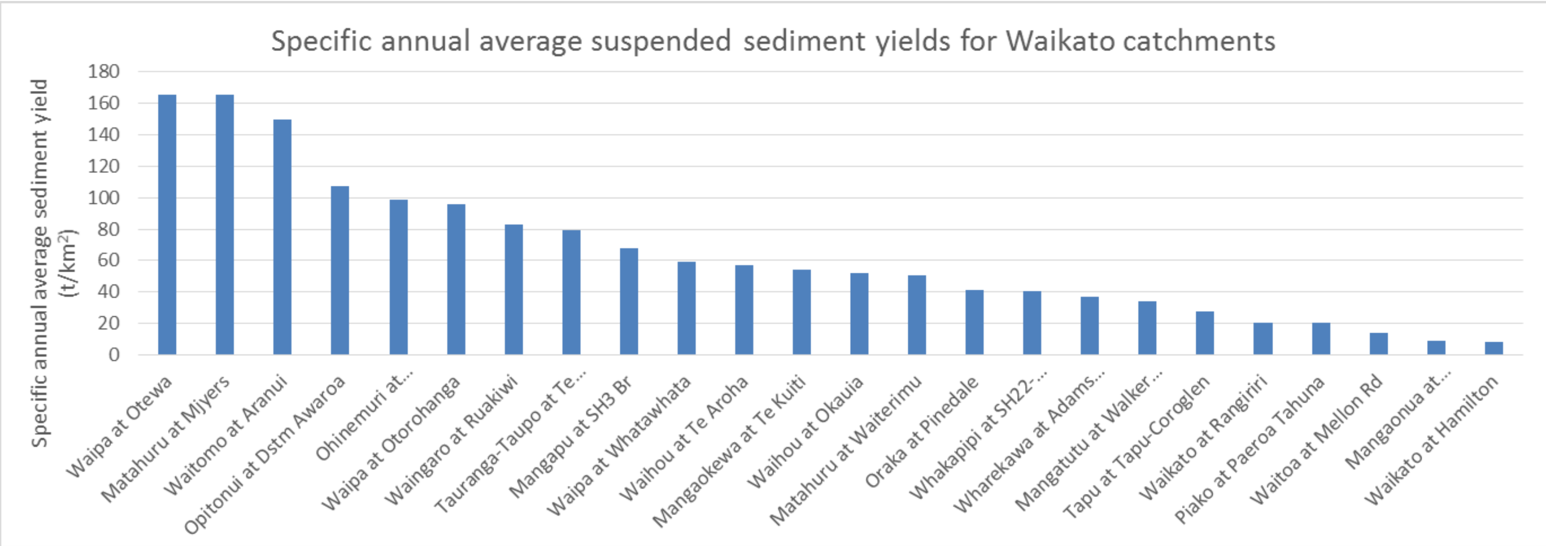


Figure 3-25:Specific annual average suspended sediment yields for Waikato catchments. a) showing both the SSC-Q and Event-yield rating approaches, and b) showing averaged results from both approaches. Results are presented from highest to lowest mean annual specific sediment yield.

3.2 Trends in suspended sediment yields in Waikato region

There were nine catchments with updated suspended sediment concentration data since the 2011 study. For each of these catchments the residuals of the SSC-Q rating relationship were plotted against time to test for a trend. These plots are presented in Figures 3-26 to 3-34. The results of the trends tests are presented in Table 3-2. This table gives the results of trend tests from the 2011 study for all sites alongside trend results for the nine catchments with updated data. Table 3-3 provides results of trends tests for the residuals of the Event-yield ratings. These data are all from the 2011 study but are presented here for completeness.

Four of the nine catchments with new SSC data show a trend in SSC-Q residuals over time. Of these, the Waipa at Otewa is the only one showing a decreasing trend, with Waitomo at Aranui, Waingaro at Ruakiwi, Wharekawa at Adams Farm and Mangatutu at Walker Road all showing an increasing trend over time. Having said this, none of these residuals are normally distributed and, therefore, the statistical significance of these trends should be treated with a degree of uncertainty.

The time trends indicated by the 2014 data are fairly consistent with those indicated in the 2011 study. While some time trends that were previously significant may no longer be significant (or vice versa) the direction of trends have remained consistent.

Figure 3-31 reveals that there may be an error with some of the data for Waingaro at Ruakiwi Road. Further examination of these data revealed very low discharge values for the measured SSC data for an event occurring on 21-22 March 2013. We recommend that WRC examine these data further. It should be noted that the time trend at this site is still significant even if these erroneous data are excluded from the analysis.

These time trends may possibly reflect changes in land use, but can also be influenced by sediment supply variations stemming from large storms. We note that all the sites that are showing increasing trends over time are those with up-to-date monitoring, indicating that WRC are focusing their monitoring efforts on the appropriate catchments.

Time trends in the residuals of the Event-yield rating (based on data from the 2011 study) are typically insignificant, with the exception of Wharekawa at Adams Farm. It should be noted, however, that less data are available to develop these ratings and subsequently it is more difficult statistically to disprove the null hypothesis of no trend. These ratings would benefit from additional data and we suggest that these ratings are regularly updated as new data becomes available.

Six of the nine catchments with updated SSC data show a significant trend with discharge. This indicates that the rating fit may not be particularly good. In some cases the rating fit was not particularly good in 2011 either and this may just indicate that it is difficult to fit a good rating to the data available. However, in some cases, the trends have become significant with the addition of new data and it would be worth revisiting these ratings to see if the fit can be improved.

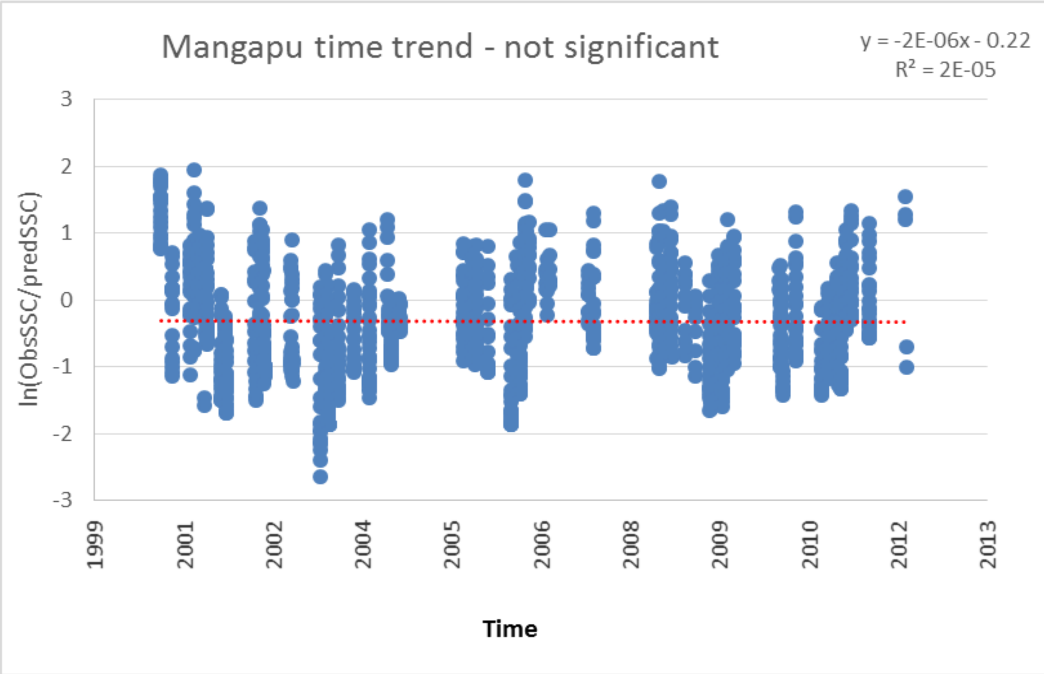


Figure 3-26:Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time for Mangapu at SH3. If the gradient of the trendline is statistically different from zero then there is considered to be a trend. Note: The rating relationship for this site is particularly poor (Figure A-3 in Hoyle et al. (2011)).

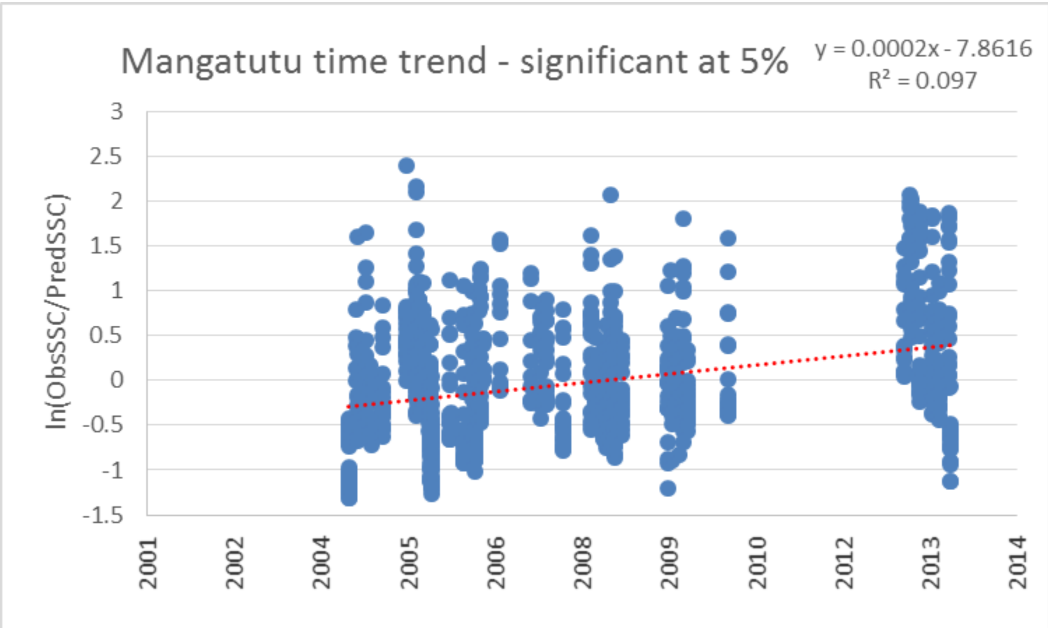


Figure 3-27:Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time for Mangatutu at Walker Road. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

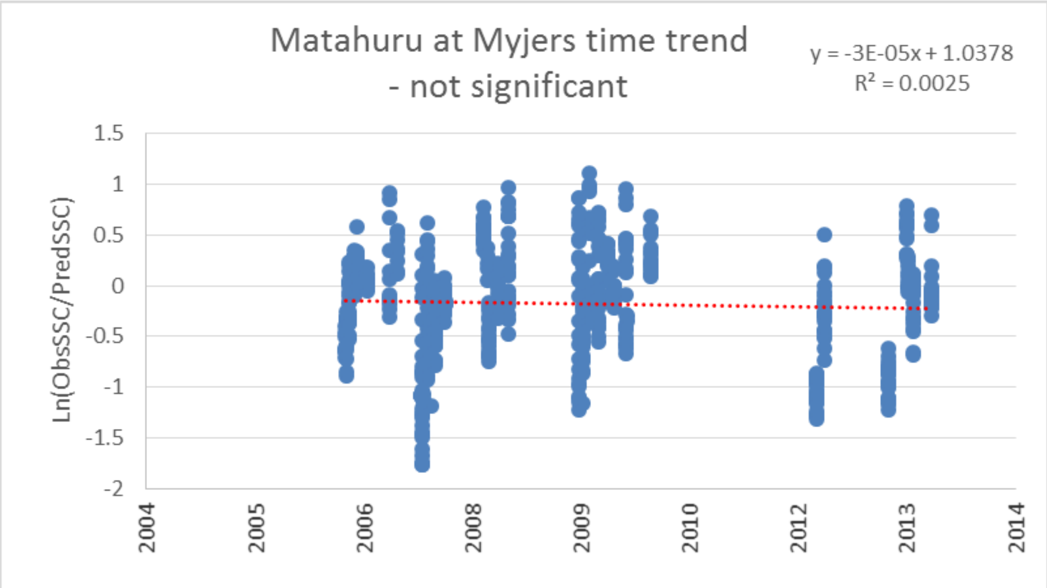


Figure 3-28:Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time for Matahuru at Myjers. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

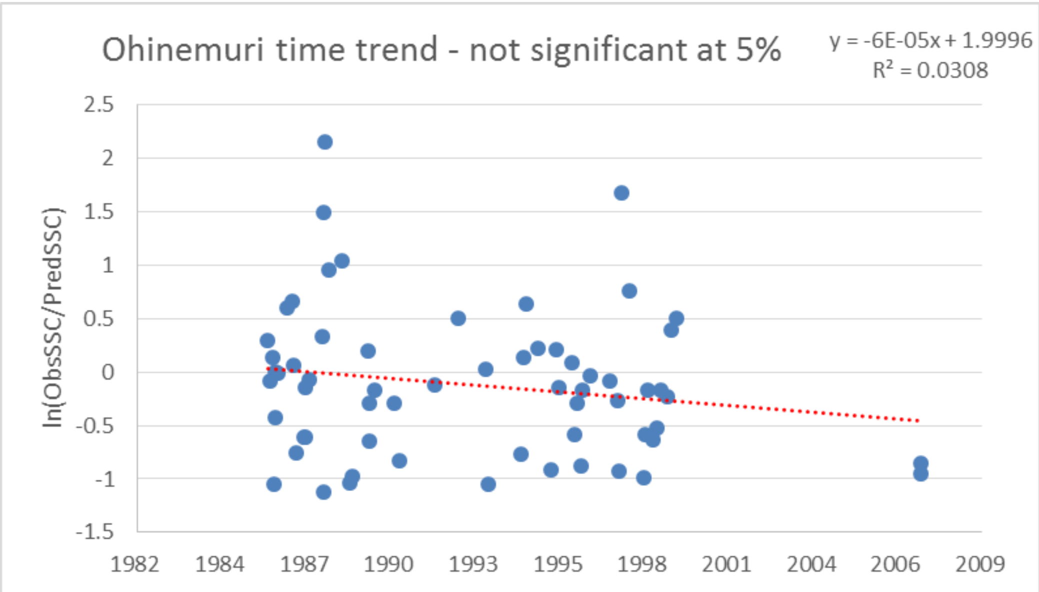


Figure 3-29:Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time for Ohinemuri at Karangahake. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

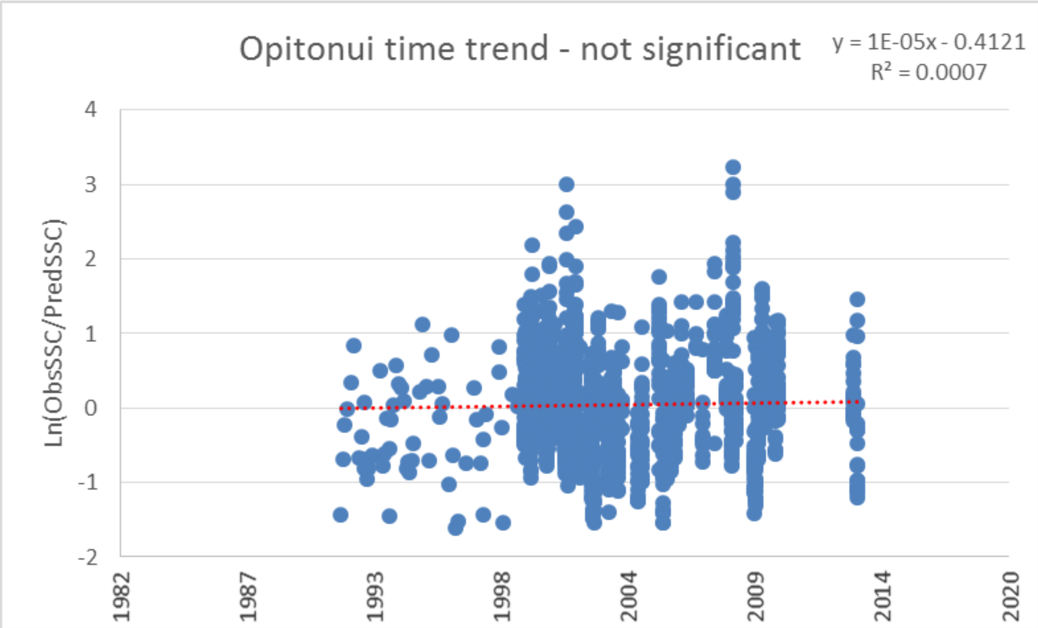


Figure 3-30:Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time discharge for Opitonui at Awaroa. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

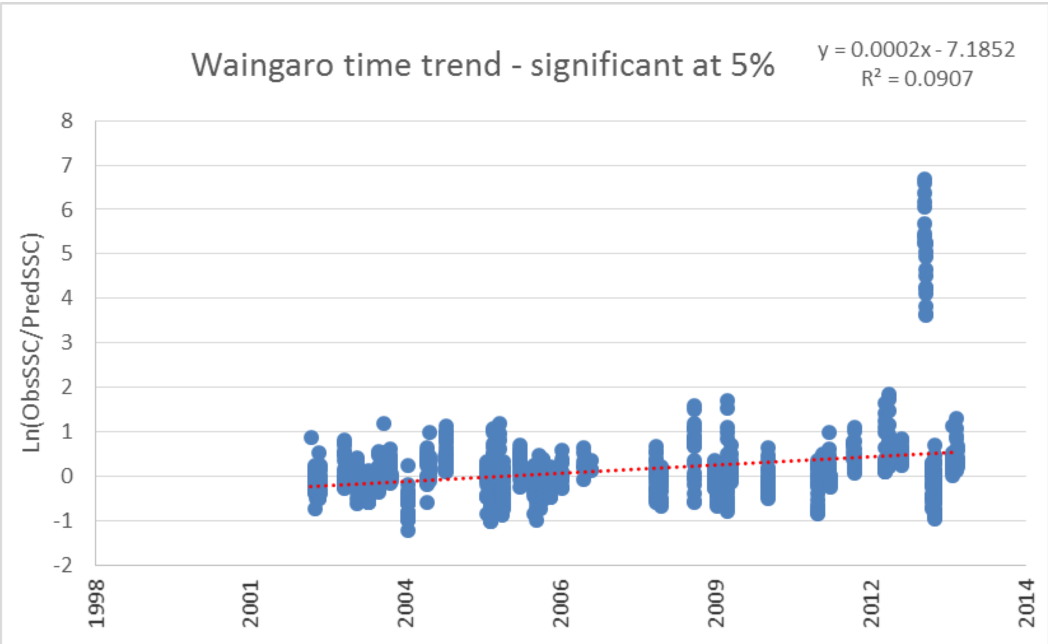


Figure 3-31:Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time for Waingaro at Ruakiwi. If the gradient of the trendline from these plots is statistically different from zero then there is considered to be a trend. Note outlying data on this plot are from an event on 21-22 March 2013 when Q values are low relative to measured SSC data. This trends remain significant even if outlying data is excluded from the analysis.

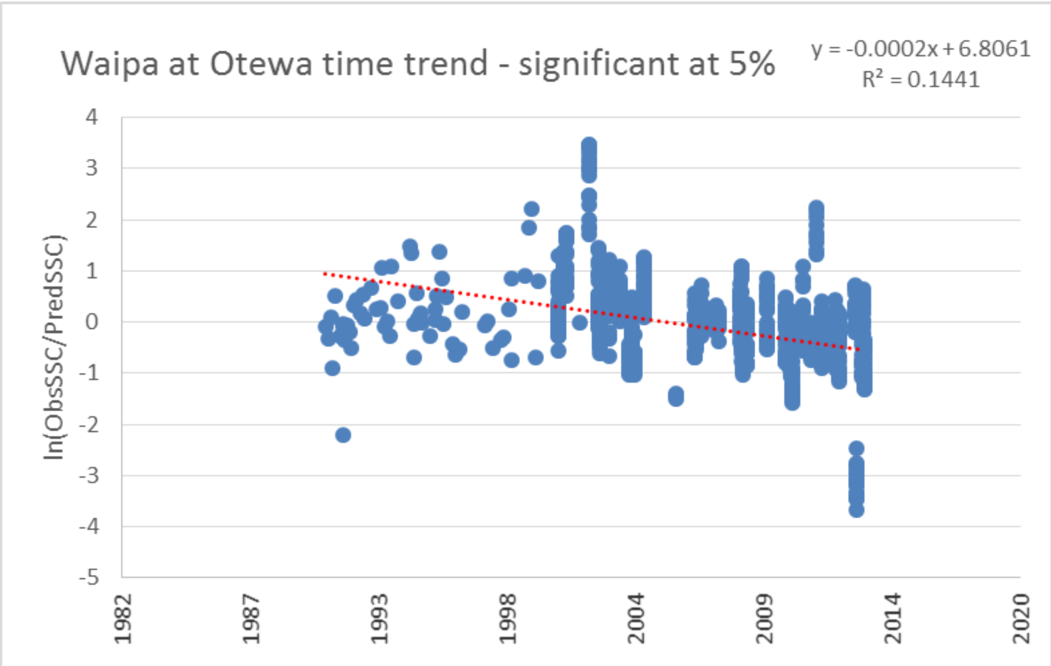


Figure 3-32:Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time for Waipa at Otewa. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

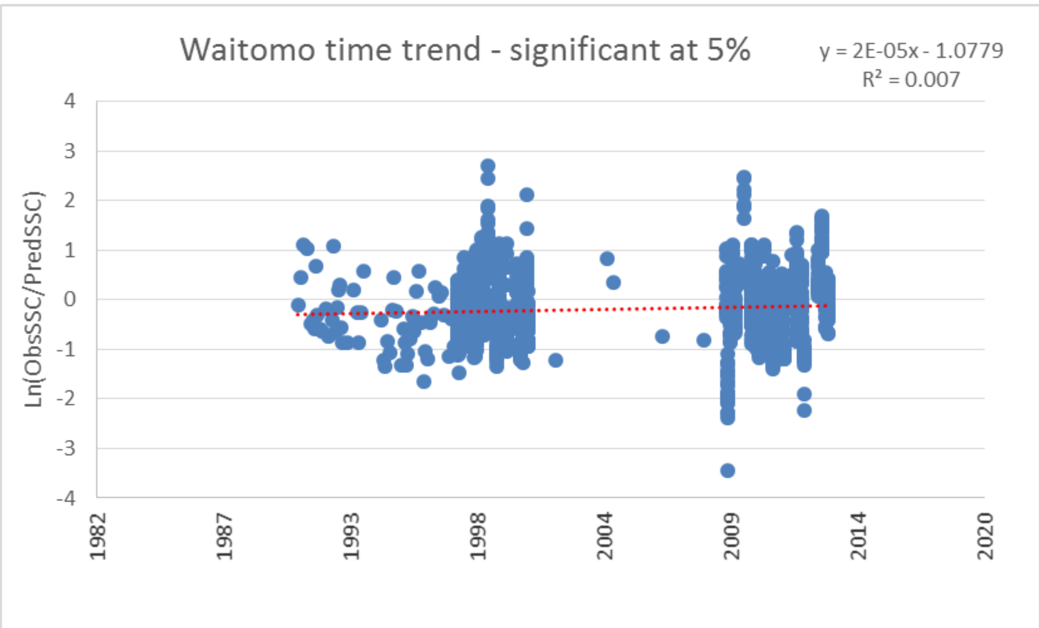


Figure 3-33:Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time for Waitomo at Aranui Caves. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

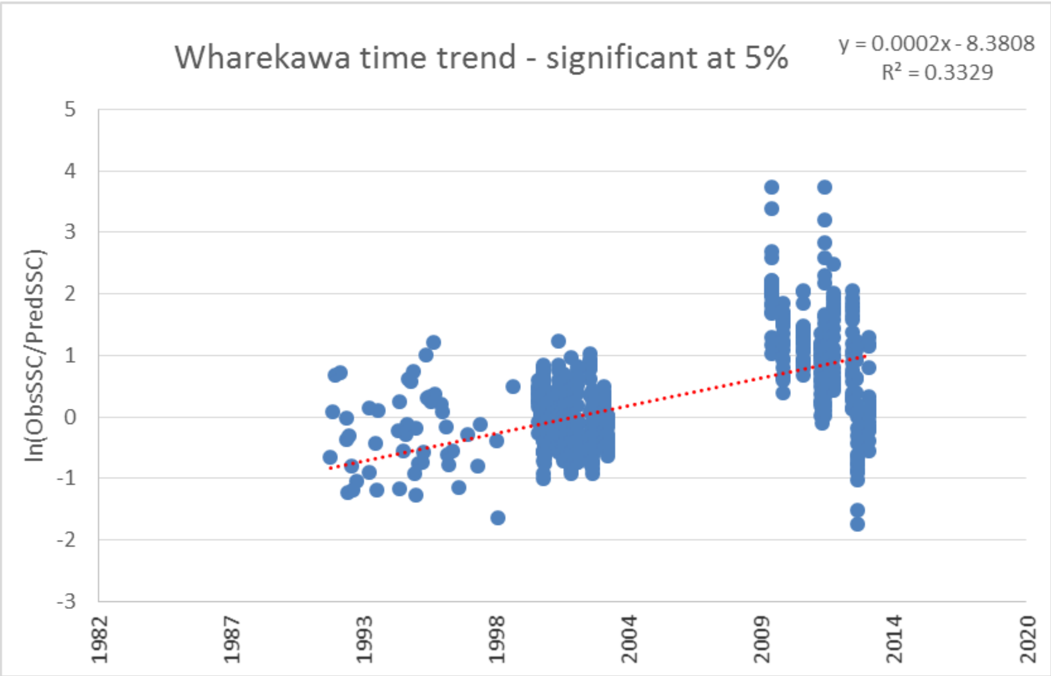


Figure 3-34:Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time for Wharekawa at Adams Farm. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

Table 3-2: Trends in the residuals of the SSC-Q rating with both time and discharge. Trends with Q are stated as these demonstrate the quality of the rating fit. Where there is a significant trend with Q then the rating may not be very reliable. The residuals distribution was considered to be normal if p > 0.05 for both the K-S and Lilliefors tests. Where residuals are not normally distributed (i.e. when the test p value is < 0.05) the indicated trend should be considered less certain.

	SSC-Q rating 2011 trends		SSC-Q rating 2014 trends		Residuals normally distributed?		
Site	time	Q	time	Q	K-S p	Lilliefors p	Result
Waipa at Otewa	Sig decr	Sig decr	Sig decr	Sig decr	<0.01	<0.01	Not normal
Matahuru at Mjyers	Sig incr	Sig decr	Not signif	Sig decr	<0.05	<0.01	Not normal
Waitomo at Aranui	Sig incr	Not signif	Sig incr	Not signif	<0.10	<0.01	Not normal
Opitonui at Dstm Awaroa	Not signif	Sig incr	Not signif	Not signif	<0.01	<0.01	Not normal
Ohinemuri at Karangahake			Not signif	Not signif	>0.20	>0.20	Normal
Waipa at Otorohanga	Not signif	Not signif			>0.20	<0.15	Normal
Waingaro at Ruakiwi	Not signif	Sig decr	Sig incr	Sig decr	<0.01	<0.01	Not normal
Tauranga-Taupo at Te Kono	Not signif	Not signif			<0.10	<0.01	Not normal
Mangapu at SH3 Br	Not signif	Not signif	Not signif	Sig incr	<0.01	<0.01	Not normal
Waipa at Whatawhata	Not signif	Not signif			>0.20	>0.20	Normal
Waihou at Te Aroha	Not signif	Not signif			>0.20	<0.10	Normal
Mangaokewa at Te Kuiti	Not signif	Not signif			>0.20	<0.15	Normal
Waihou at Okauia	Sig decr	Not signif			>0.20	<0.05	Not normal
Matahuru at Waiterimu	Not signif	Not signif			>0.20	>0.20	Normal
Oraka at Pinedale	Not signif	Sig decr			>0.20	<0.05	Not normal
Whakapipi at SH22-Tuakau	Not signif	Not signif			>0.20	<0.10	Normal
Wharekawa at Adams Farm	Sig incr	Not signif	Sig incr	Sig incr	<0.01	<0.01	Not normal
Mangatutu at Walker Road	Sig incr	Not signif	Sig incr	Sig decr	<0.01	<0.01	Not normal
Tapu at Tapu-Coroglen	Not signif	Not signif			<0.01	<0.01	Not normal
Waikato at Rangiriri	Not signif	Not signif			>0.20	>0.20	Normal
Piako at Paeroa Tahuna	Sig decr	Not signif			>0.20	<0.05	Not normal
Waitoa at Mellon Rd	Sig decr	Not signif			>0.20	>0.20	Normal
Mangaonua at Dreadnought	Not signif	Not signif			>0.20	>0.20	Normal
Waikato at Hamilton	Not signif	Not signif			>0.20	<0.05	Not normal

Table 3-3: Trends in the residuals of the Event-yield rating with both time and either peak discharge (Q_{peak}) or quickflow (QF), depending on which is used in the rating. Trends with Q_{peak} or QF are stated as these demonstrate the quality of the rating fit. As none of these trends were found to be significant the ratings can be considered reliable. The residuals distribution was considered to be normal if p > 0.05 for both the K-S and Lilliefors tests. Where residuals are not normally distributed (i.e. when the test p value is < 0.05) the indicated trend should be considered less certain.

	Event-yield rating 2011 trends		Residuals normally distributed?		
Site	**time**	**Q_{peak} or QF**	**K-S p**	**Lilliefors p**	**Result**
Waipa at Otewa	Not signif	Not signif	>0.20	>0.20	Normal
Matahuru at Mjyers	Not signif	Not signif	>0.20	>0.20	Normal
Waitomo at Aranui	Not signif	Not signif	>0.20	<0.05	Not normal
Opitonui at Dstm Awaroa	Not signif	Not signif	>0.20	>0.20	Normal
Waingaro at Ruakiwi	Not signif	Not signif	>0.20	>0.20	Normal
Mangapu at SH3 Br	Not signif	Not signif	>0.20	<0.05	Not normal
Matahuru at Waiterimu	Not signif	Not signif	>0.20	>0.20	Normal
Wharekawa at Adams Farm	Sig incr	Not signif	>0.20	>0.20	Normal
Mangatutu at Walker Road	Not signif	Not signif	>0.20	>0.20	Normal

4 Conclusions and recommended further work

Suspended sediment specific yield results (based on the average of both rating approaches where possible) range from 8 to 166 t/km^2/y but with yields for most sites falling in the range of 20-100 t/km^2/y. As found in the 2011 study, Waipa at Otewa, Matahuru at Myjers and Waitomo at Aranui Caves all have noticeably higher yields (150-166 t/km^2/y).

Four of the nine catchments with new SSC data show a trend in SSC-Q residuals over time. Waipa at Otewa is showing a decreasing trend and Waitomo at Aranui, Waingaro at Ruakiwi, Wharekawa at Adams Farm and Mangatutu at Walker Road are all showing an increasing trend over time. The trends indicated by the 2014 data are fairly consistent with those indicated in the 2011 study. While some trends that were previously significant may no longer be significant (or vice versa) the direction of trends have remained consistent. These trends may reflect changes in landuse, but can also be influenced by sediment supply variations stemming from large storms. We note that all the sites that are showing increasing trends over time are those with up-to-date monitoring, indicating that WRC are focusing their monitoring efforts on the appropriate catchments.

Six of the nine catchments with updated SSC data also show a trend with discharge, with varying direction of trend. This tends to indicate that the rating relationships may not be particularly reliable. The ratings used in this study were all developed during the 2011 study and, therefore, are not making use of all of the data currently available. We recommend that these ratings be updated for the sites with new data available.

5 References

Duan, N. (1983) Smearing estimate: a non-parametric retransformation method. *Journal of the American Statistical Association,* 78: 605-610.

Ferguson, R.I. (1986) River loads underestimated by rating curves*. Water Resources Research,* 22: 74-76.

Hewlett, J.D., Hibbert, R.A. (1967*) Factors affecting the response of small watersheds to precipitation in humid areas*. PP. 275-290. In: *Forest Hydrology*. Sopper, WE.; Lull, H.W. (Eds.). Pergamon.

Hicks, D.M. (1990) Suspended sediment yields from pasture and exotic forest basins. *In*: Proceedings of the 1990 NZ Hydrological Society Symposium, Taupo, November 1990.

Hicks, D.M., Gomez, B., Trustrum, N.E. (2000) Erosion thresholds and suspended sediment yields, Waipaoa River Basin, New Zealand. *Water Resources Research,* 36: 1129-1142.

Hoyle, J., Hicks, M, Roulston, H. (2011. Sampled suspended sediment yields from the Waikato region. Prepared by NIWA for Waikato Regional Council. *NIWA Client Report*, EVW11504.

Appendix A Rating relationships

Table A-1: Sediment concentration ratings for each catchment. Also listed are the overall regression coefficient of determination (R^2), standard factorial error (SFE), and the average bias correction factor (BCF) incorporated in each set of rating step-functions. It is also stated whether or not the residuals are normally distributed and whether there is an increasing, decreasing, or neutral trend in the residuals over time based on the most up to date data available. If residuals are not normally distributed then the time trend assessment should be considered less reliable.

Site	SSC (mg/l) vs Q (l/s) ratings SSC =	Quickflow separation slope (ml/s²/km²)	R^2	SFE	Avg BCF	Residuals normally distrib.	Time trend
Mangaokewa at Te Kuiti Pumping Station	For Q<3600: $0.008Q^{0.879}$ For Q<13000: $0.005Q^{1.215}$ For Q>13000: $4.53E^{-5}Q^{1.469}$	0.0245	0.94	1.65	1.14	Yes	Neutral
Mangaonua at Dreadnought Culvert	For Q<2000: $0.0358Q^{0.742}$ For Q >2000: $0.0121Q^{0.883}$	0.0221	0.62	1.64	1.14	Yes	Neutral
Mangapu at SH3	For Q<9000: $1.1739Q^{0.000533}$ For Q>9000: 142	0.028	0.16	2.12	N/A	No	Neutral
Mangatutu at Walker Road Bridge	For Q<5000: $0.00315Q^{1.0156}$ For Q<8500: $0.1778Q^{0.5422}$ For Q<17000: $1.8E^{-8}Q^{2.322}$ For Q>17000: $0.1221Q^{0.707}$	0.0169	0.59	1.73	1.17	No	Incr
Matahuru at Myjers	For Q<4000: $0.259Q^{0.828}$ For Q<5700: $0.014Q^{1.182}$ For Q<8500: $0.005Q^{1.305}$ For Q>8500: $0.755Q^{0.745}$	0.0202	0.61	1.62	1.13	No	Neutral
Matahuru at Waiterimu Road	For Q<7100: $0.039Q^{0.915}$ For Q<8600: $2.87E^{-7}Q^{2.248}$ For Q>8600: $2.041Q^{0.506}$	0.0219	0.34	1.56	1.1	Yes	Neutral
Ohinemuri at Karangahake	For Q <13000: $0.00658Q^{0.719}$ For Q<108000: $9.06E^{-6}Q^{1.415}$ For Q>108000: $4.57E^{-5}Q^{1.275}$	0.87	0.84	2.02	1.3	Yes	Neutral
Opitonui at d/s Awaroa Confluence	For Q<3700: $0.006724Q^{1.0228}$ For Q<6000: $0.01484Q^{0.6462}$ For Q<13000: $9.36E^{-4}Q^{1.2255}$ For Q>23000: $0.3325Q^{0.6085}$ For Q>23000: $1.668E^{-3}Q^{1.1358}$	0.157	0.65	2.00	1.27	No	Neutral

Site	SSC (mg/l) vs Q (l/s) ratings SSC =	Quickflow separation slope (ml/s^2/km^2)	R^2	SFE	Avg BCF	Residuals normally distrib.	Time trend
Oraka at Pinedale	For Q<2700: $5.02E^{-11}Q^{3.387}$ For Q<4100: $1.49E^{-15}Q^{4.707}$ For Q<5300: $0.013Q^{1.121}$ For Q>5300: $3.55E^{-6}Q^{2.081}$	0.0041	1.09	1.84	1.23	No	Neutral
Piako at Paeroa-Tahuna Road Bridge	For Q<6000: $0.079Q^{0.640}$ For Q<12000: $0.005Q^{0.964}$ For Q<25000: $0.680Q^{0.434}$ For Q>25000: $0.122Q^{0.604}$	0.01943	0.63	1.94	1.25	No	Decr
Tapu at Tapu-Coroglen Road	For Q<700: $0.444Q^{0.230}$ For Q<2400: $1.46E^{-4}Q^{1.454}$ For Q>2400: $0.017Q^{0.839}$	0.0793	0.91	2.41	1.55	No	Neutral
Tauranga Taupo at Te Kono Slackline	For Q<11000: $0.055Q^{0.460}$ For Q<17000: $1.25E^{-8}Q^{2.105}$ For Q<35000: $1.08E^{-10}Q^{2.592}$ For Q>35000: $1.90E^{-7}Q^{1.878}$	0.0476	0.94	1.72	1.17	No	Neutral
Waihou at Okauia	For Q<25000: $7.15E^{-5}Q^{1.257}$ For Q<31000: $6.13E^{-14}Q^{3.318}$ For Q<55000: $3.79E^{-7}Q^{1.806}$ For Q>55000: $1.81E^{-5}Q^{1.452}$	0.0091	0.84	1.73	1.16	No	Decr
Waihou at Te Aroha	For Q<42000: $7.58E^{-5}Q^{1.266}$ For Q<74000: $7.454Q^{0.18}$ For Q<122000: $0.041Q^{0.649}$ For Q>122000: $8.47E^{-4}Q^{0.981}$	0.0055	0.37	1.73	1.17	Yes	Neutral
Waikato at Hamilton Traffic Road Bridge	For Q<318000: $1.066Q^{0.144}$ For Q<360000: $2.45E^{-18}Q^{3.350}$ For Q<450000: $6.12E^{-13}Q^{2.378}$ For Q<620000: $2.680E^{-8}Q^{1.557}$ For Q>620000: $0.140Q^{0.397}$	0.0048	0.36	1.79	1.2	No	Neutral
Waikato at Rangiriri Bridge	For Q<466000: $0.003Q^{0.680}$ For Q<730000: $1.33E^{-5}Q^{1.097}$ For Q>730000: $6.47E^{-9}Q^{1.662}$	0.0021	0.42	1.72	1.17	Yes	Neutral
Waingaro at Ruakiwi Road	For Q<7000: $0.004Q^{1.052}$	0.0378	0.96	1.49	1.08	No	Incr

Site	SSC (mg/l) vs Q (l/s) ratings SSC =	Quickflow separation slope (ml/s^2/km^2)	R^2	SFE	Avg BCF	Residuals normally distrib.	Time trend
	For Q<14600: $7.69E^{-6}Q^{1.765}$ For Q>14600: $2.36E^{-4}Q^{1.408}$						
Waipa at Otewa	For Q<10500: $5.24E^{-5}Q^{1.318}$ For Q<18000: $0.008Q^{0.781}$ For Q<31000: $1.93E^{-8}Q^{2.096}$ For Q<53000: $4.42E^{-15}Q^{3.574}$ For Q>53000: $0.001Q^{1.142}$	0.0314	1.023	2.16	1.38	No	Decr
Waipa at SH3 Bridge Otorohanga	For Q<32000: $1.91E^{-5}Q^{1.381}$ For Q<73000: $1.47E^{-4}Q^{1.185}$ For Q>73000: $1.14E^{-6}Q^{1.618}$	0.0303	1.01	1.24	1.03	Yes	Neutral
Waipa at SH23 Bridge Whatawhata	For Q<44000: $1.71E^{-4}Q^{1.076}$ For Q<69000: $1.07E^{-5}Q^{1.335}$ For Q<102000: $0.200Q^{0.453}$ For Q<210000: $2.53E^{-5}Q^{1.231}$ For Q>210000: $0.065Q^{0.590}$	0.0265	0.81	1.84	1.22	Yes	Neutral
Waitoa at Mellon Road	For Q<2300: $0.012Q^{0.872}$ For Q<4300: $0.001Q^{1.186}$ For Q<7700: $0.050Q^{0.723}$ For Q<250000: $2.399Q^{0.289}$ For Q>250000: $0.337Q^{0.483}$	0.00816	0.63	1.88	1.22	Yes	Decr
Waitomo at Aranui Caves Bridge	For Q<2400: $0.003Q^{1.238}$ For Q<9000: $0.001Q^{1.356}$ For Q>9000: $0.008Q^{1.142}$	0.0567	0.8	1.92	1.24	No	Incr
Whakapipi at SH22 Bridge	For Q<812: $4.359Q^{0.011}$ For Q<1900: $7.78E^{-5}Q^{1.643}$ For Q>1900: $8.98E^{-4}Q^{1.319}$	0.0552	0.74	1.81	1.21	Yes	Neutral
Wharekawa at Adams Farm Bridge	For Q<4800: $0.019Q^{0.752}$ For Q<9000: $0.003Q^{0.951}$ For Q<19400: $0.370Q^{0.438}$ For Q<30000: $8.93E^{-7}Q^{1.748}$ For Q>30000: $0.030Q^{0.736}$	0.0775	0.84	1.71	1.16	No	Incr

Table A-2: Event-yield ratings determined for the catchments with automatically sampled sediment concentration. Ratings are based either on peak discharge (Q_{pk}) or quickflow (QF), depending on which had the strongest relationship, and the coefficients shown are not bias corrected. The overall regression coefficient of determination (R^2), standard factorial error (SFE), and bias correction factor (BCF) for each relationship are provided. The direction of any trends in the residuals over Q_{pk} or QF and over time are also stated along with whether the residuals are normally distributed or not. If the residuals are not normally distributed then the time trend assessment should be considered less reliable. These trends are all based on the 2011 data.

Site	Event-yield (Y) ratings Q_{pk} (l/s) or QF (mm) Y (kg) =	R^2	SFE	BCF	Residuals normally distributed	Trend in residuals over Q_{pk} or QF	Trend in residuals over time
Mangapu at SH3	$38672QF^{0.8314}$	0.72	1.48	1.09	No	Neutral	Neutral
Mangatutu at Walker Road Bridge	$16728QF^{0.9092}$	0.75	1.56	1.09	Yes	Neutral	Neutral
Matahuru at Myjers	$0.0175Q_{pk}^{1.8364}$	0.91	1.41	1.06	Yes	Neutral	Neutral
Matahuru at Waiterimu Road	$0.2086Q_{pk}^{1.4977}$	0.86	1.29	1.03	Yes	Neutral	Neutral
Opitonui at d/s Awaroa Confluence	$0.0246Q_{pk}^{1.4926}$	0.83	1.71	1.16	Yes	Neutral	Neutral
Waingaro at Ruakiwi Road	$0.0011Q_{pk}^{1.9446}$	0.87	1.54	1.07	Yes	Neutral	Neutral
Waipa at Otewa	$34709QF^{1.3584}$	0.93	1.48	1.07	Yes	Neutral	Neutral
Waitomo at Aranui Caves Bridge	$0.0038Q_{pk}^{1.8904}$	0.92	1.52	1.08	No	Neutral	Neutral
Wharekawa at Adams Farm Bridge	$0.0044Q_{pk}^{1.6122}$	0.89	1.67	1.14	Yes	Neutral	Incr

Appendix B Residual plots showing trends with discharge

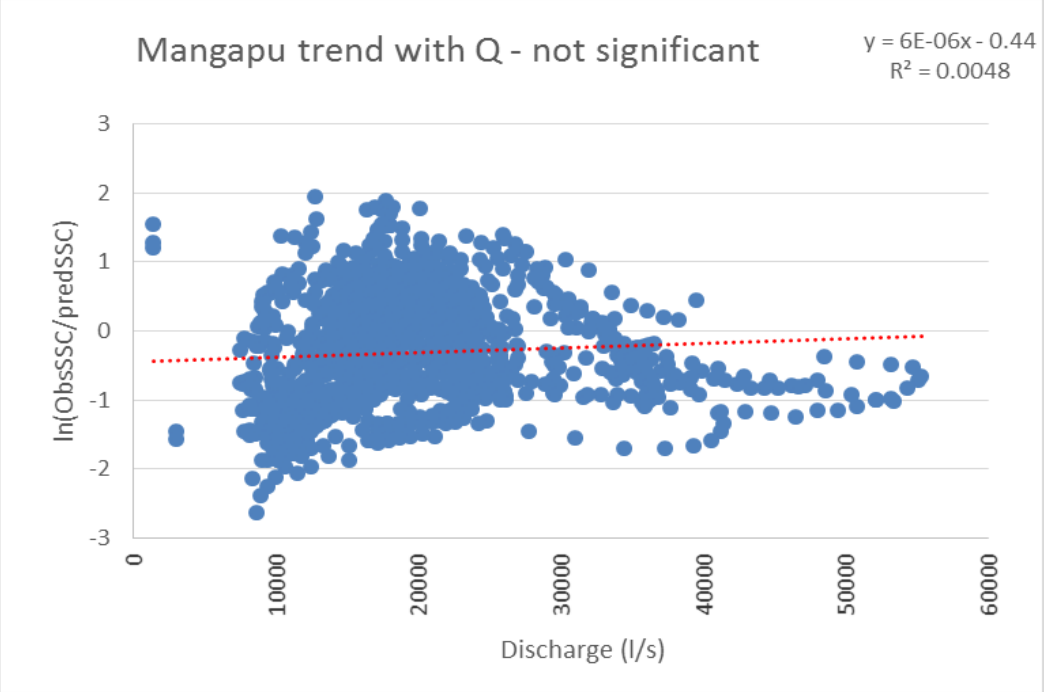


Figure B-1: Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus discharge for Mangapu at SH3. If the gradient of the trendline is statistically different from zero then there is considered to be a trend. Note: The rating relationship for this site is particularly poor (Figure A-3 in Hoyle et al. (2011)).

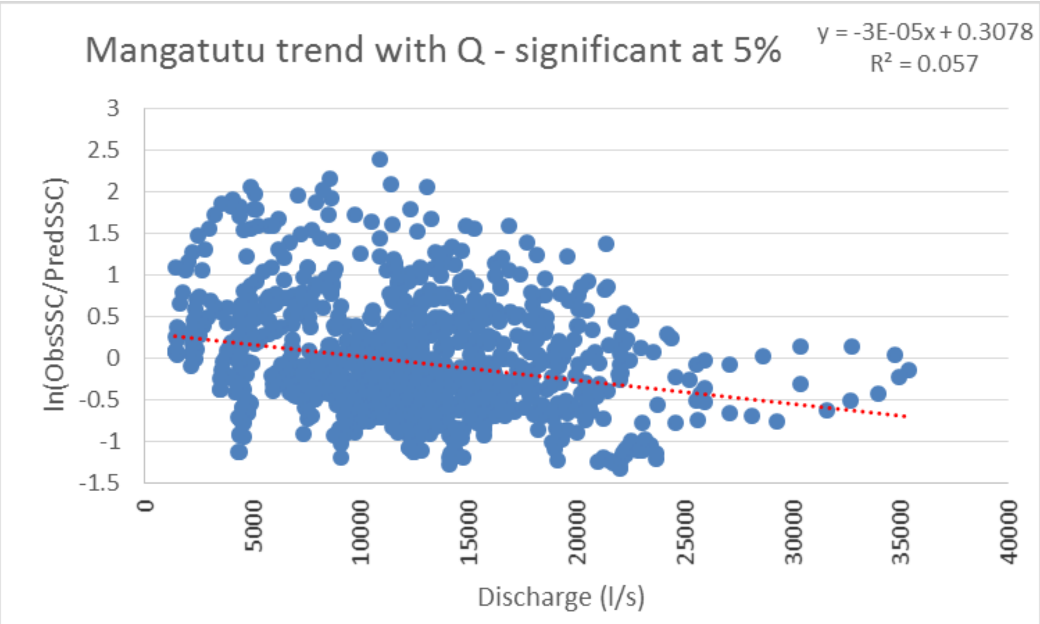


Figure B-2: Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus discharge for Mangatutu at Walker Road. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

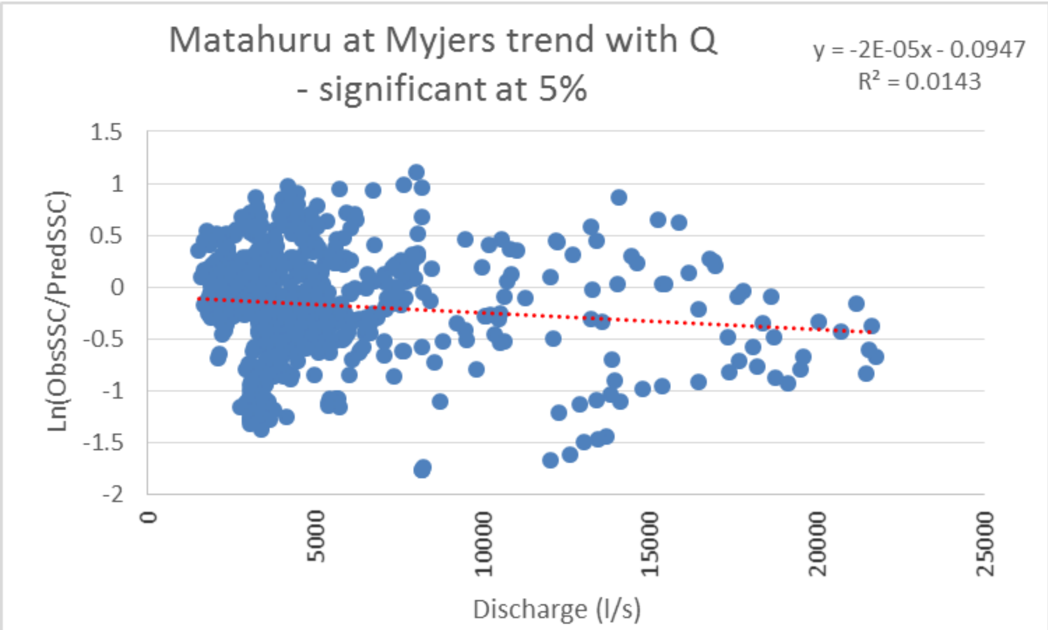


Figure B-3: Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus discharge for Matahuru at Myjers. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

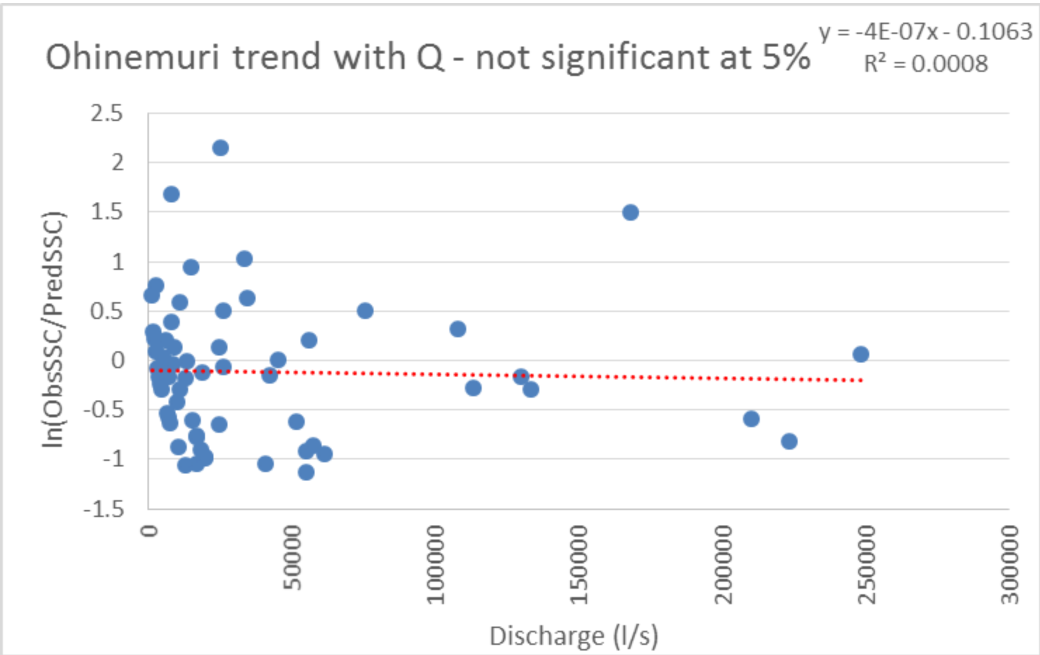


Figure B-4: Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus discharge for Ohinemuri at Karangahake. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

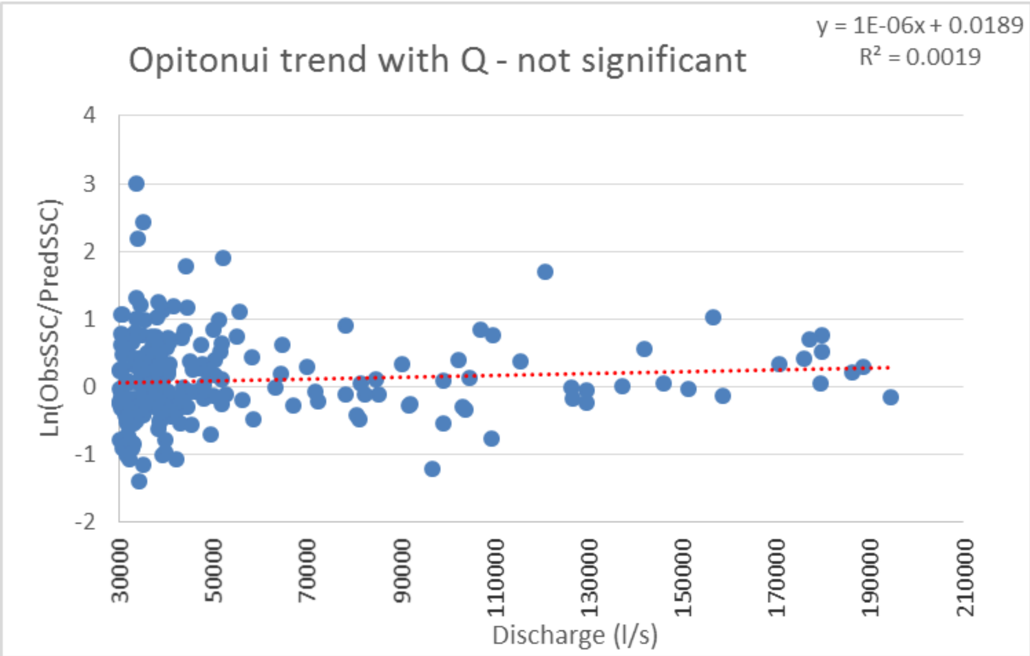


Figure B-5: Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time discharge for Opitonui at Awaroa. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

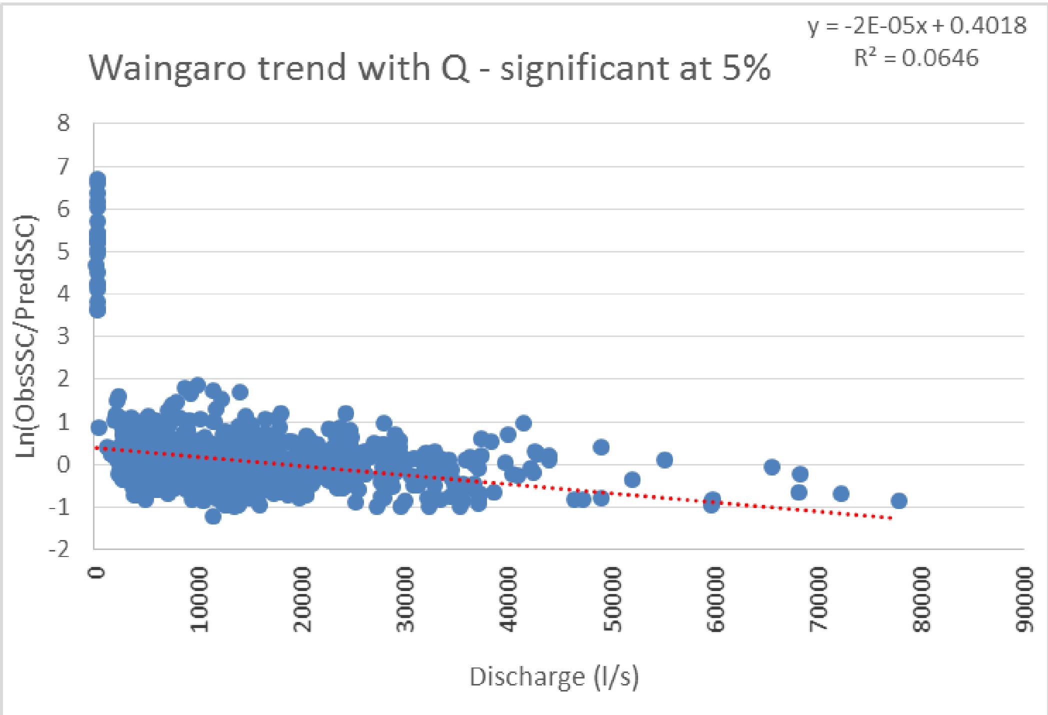


Figure B-6: Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus discharge for Waingaro at Ruakiwi. If the gradient of the trendline from these plots is statistically different from zero then there is considered to be a trend. Note outlying data on this plot are from an event on 21-22 March 2013 when Q values are low relative to measured SSC data. This trends remain significant even if outlying data is excluded from the analysis.

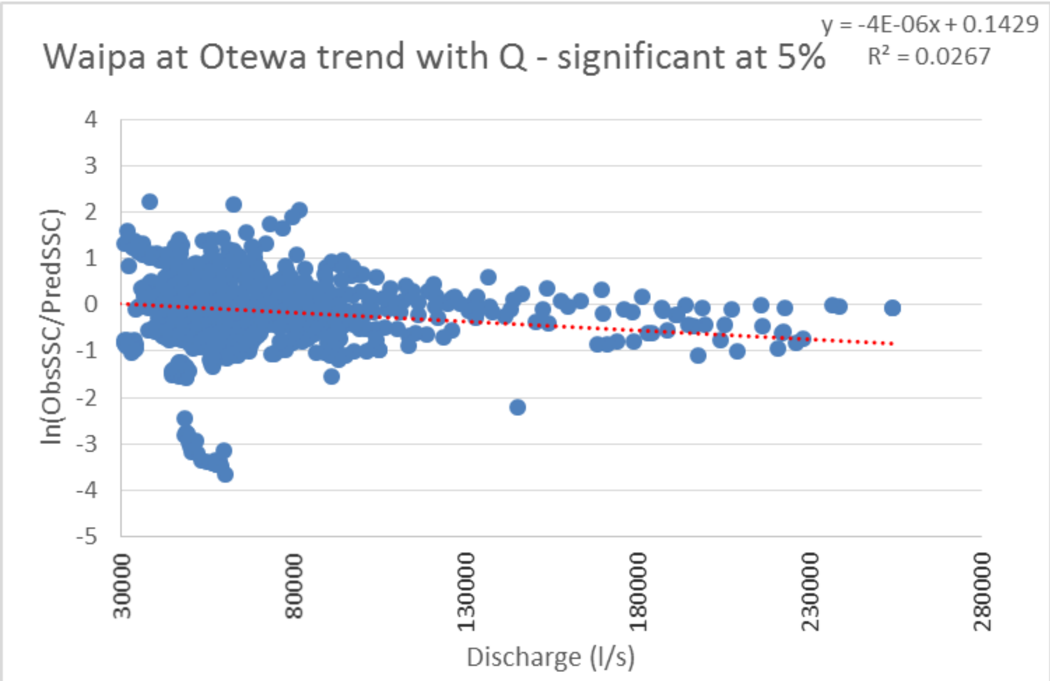


Figure B-7: Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus time for Waipa at Otewa. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

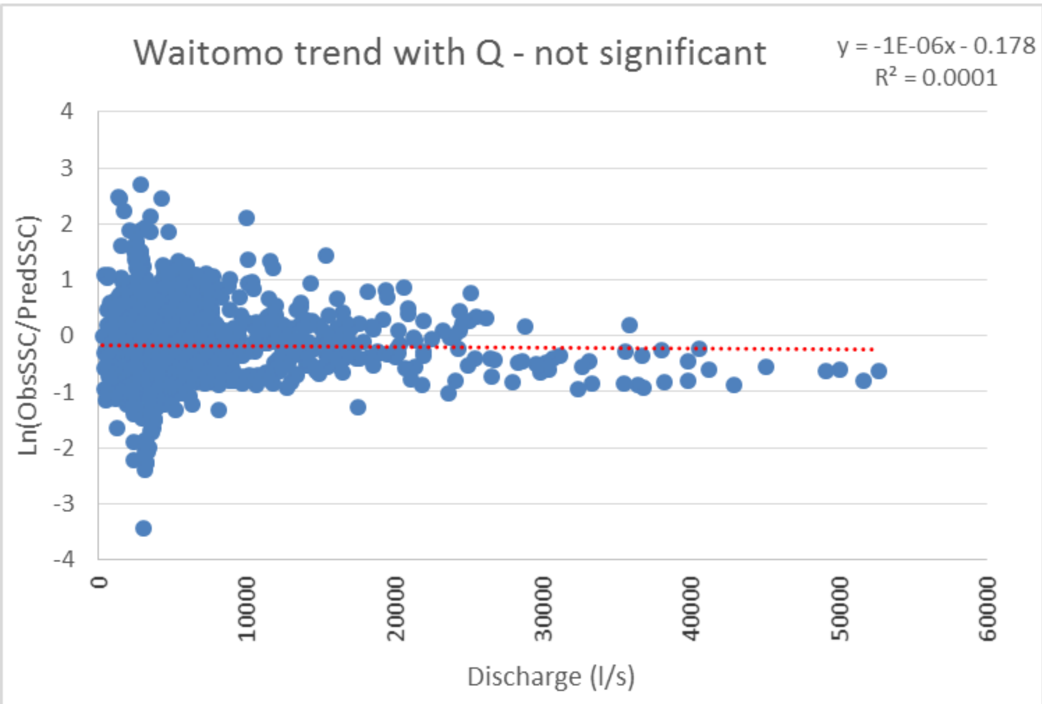


Figure B-8: Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus discharge for Waitomo at Aranui Caves. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.

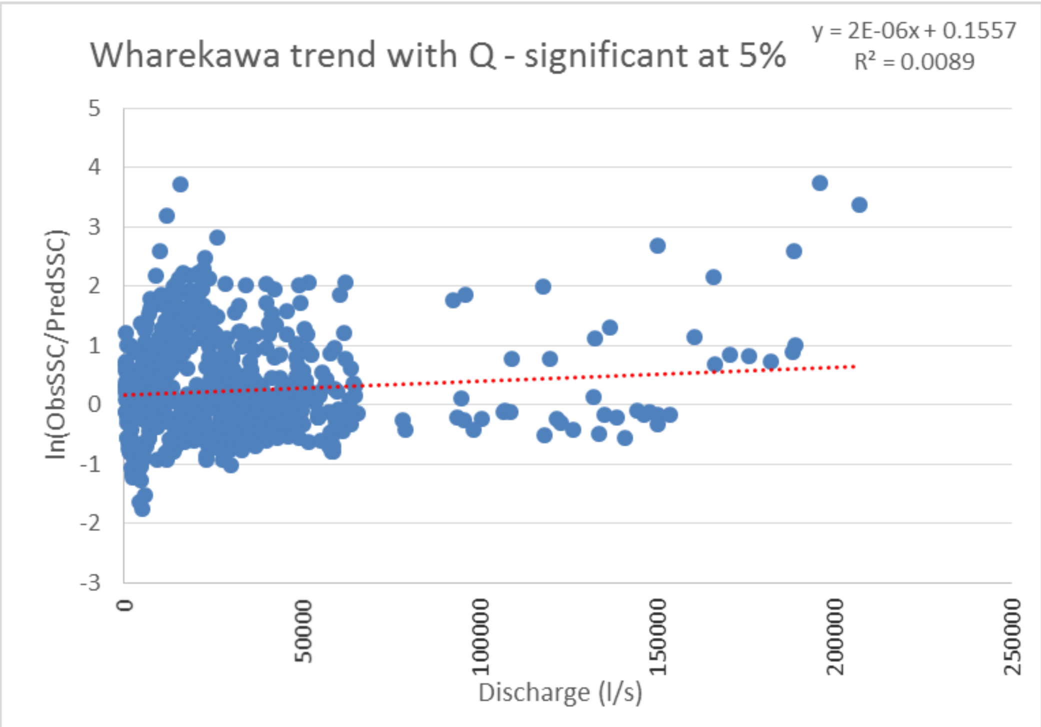


Figure B-9: Plots of SSC-Q rating residuals (ln(observedSSC/predictedSSC)) versus discharge for Wharekawa at Adams Farm. If the gradient of the trendline is statistically different from zero then there is considered to be a trend.