greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

Te Awarua-o-Porirua Harbour catchment turbidity monitoring

Results of continuous turbidity monitoring 2012–2014

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Contents

1. Introduction

Between August 2012 and June 2013 GWRC installed continuous turbidity monitoring stations in the lower reaches of the three main tributaries of Te Awarua-o-Porirua Harbour (Porirua Harbour). This followed initial catchment sediment modelling using CLUES (Catchment Landuse for Environmental Sustainability) that identified the Horokiri, Pauatahanui and Porirua Stream subcatchments as delivering the most sediment to the harbour (Green et al. 2014). The turbidity monitoring will be used to quantify actual sediment inputs from these subcatchments.

1.1 Monitoring objectives

The objectives of GWRC's turbidity monitoring programme are to:

1. Collect continuous turbidity data from the three subcatchments identified as having the highest sediment yields;
2. Collect stream water samples across a range of turbidity measurements for the purposes of converting the continuous turbidity record into a suspended sediment concentration record; and
3. Use the suspended sediment concentration record to derive annual sediment yields for each of the three subcatchments being monitored.

1.2 Report purpose

This report outlines the monitoring site set-up, methods of data processing and analysis, and summarises the monitoring results obtained up until 30 June 2014.

2. Monitoring sites and methods

The physical locations of each of the three sites chosen for continuous turbidity monitoring were selected because they were already well established hydrological monitoring sites equipped with power and flow gauges (Figure 2.1). Stream flow has been monitored since September 1965 at the Porirua Stream site, since February 2002 at the Horokiri Stream site, and since May 1975 at the Pauatahanui Stream site[1]. Table 2.1 broadly summarises the land use types in the monitored catchments.

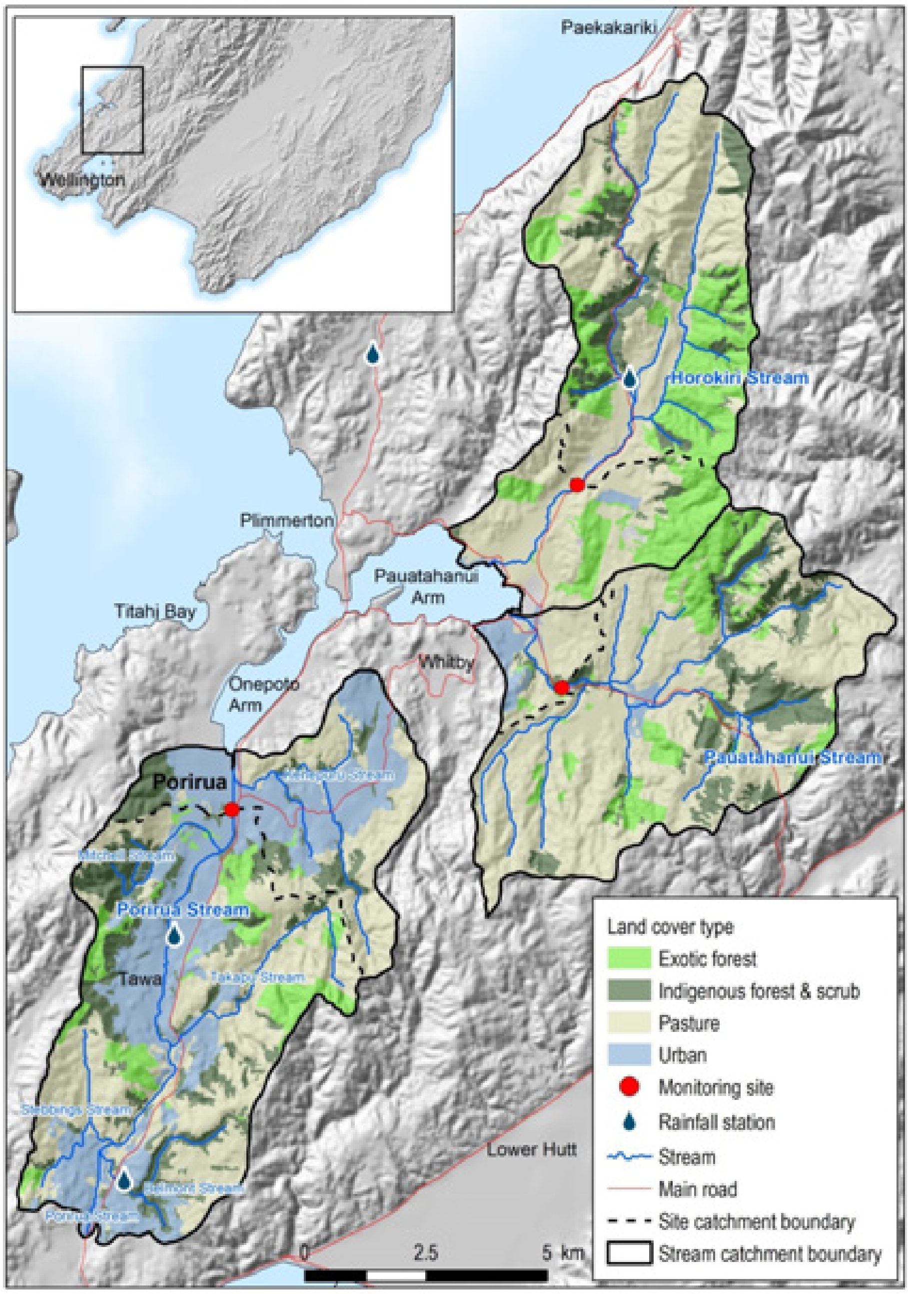

Figure 2.1: Location of the three continuous turbidity monitoring sites in the Porirua Harbour catchment and the major land cover types within each catchment. Areas downstream of the dashed site catchment line are not captured by the monitoring site

[1] The Pauatahanui Stream flow recording equipment is maintained by NIWA as part of their national freshwater monitoring network.

Table 2.1: Percentage of main land cover types in the catchment upstream of each turbidity monitoring site **(Source: LUCAS – MfE 2010)**

Land cover type (%)	Porirua Stream	Horokiri Stream	Pauatahanui Stream
Indigenous forest	17.3	15.2	17.1
Pasture	41.2	58.7	68.7
Urban	30.5	–	1.3
Exotic forest	11.0	26.2	12.9
Total	*100.0*	*100.0*	*100.0*
Total area of upstream catchment (Ha)	3,937	2,873	3,763

2.1 Site set up and maintenance

The three monitoring sites were established with guidance from environmental monitoring staff at Auckland Council, Horizons Regional Council and Andrew Hughes at NIWA. This predates the release of the National Environmental Monitoring Standards (NEMS) for Turbidity Recording (NEMS 2013). Table 2.2 lists the specific equipment deployed at each monitoring site and Figures 2.2 to 2.4 illustrate the site set up.

Turbidity monitoring commenced in the lower Porirua Stream at the end of August 2012. Broadly, the setup is a Hach Solitax T-line in-stream turbidity sensor housed in piping connected to an SC-200 control unit (Figure 2.2). This unit then outputs the turbidity data to a logger and the data are telemetered back to the GWRC office. An ISCO automatic water sampler was also installed at the site to collect samples for suspended sediment analysis with which to convert the turbidity sensor data into suspended sediment concentration (SSC) data.

Table 2.2: Turbidity-related monitoring equipment at each of the three sites

Equipment		Porirua Stream	Horokiri Stream	Pauatahanui Stream
		Easting Northing	Easting Northing	Easting Northing
		1754669 5443961	1761804 5450652	1761480 5446486
Data logger	Model	iQuest DS4483	iQuest DS4483	Campbell 850 logger
Turbidity sensor	Model	Hach Solitax T-line sensor with SC 200 module		
	Data collection start date	29/08/2012	14/11/2012	12/06/2013
	Log interval	5 minutes		
	Range	0.001–4,000 FNU		
	Wipe interval	30 minutes		
Automatic sampler	Model	ISCO 6712	ISCO 6712	ISCO 6700
	Installation date	27/03/2013	29/04/2013	12/06/2013
	No. of bottles	24		
	Sampler trigger type	Stage	Stage	Turbidity*
	Sampling interval	15 minutes		
	Bottle size	1000 mL		
Camera	Model	Jablocom EYE-20	-	-
	Log interval	5 minutes	-	-

*Stage data not available to our setup at this site so turbidity is used as a trigger instead.

Figure 2.2: Porirua Stream at Town Centre site. Top left inset: Turbidity sensor in the stream with lens and wiper showing. Bottom right inset: SC-200 control unit (top right) and logger (top left) setup

Similar monitoring set ups were deployed at existing hydrological monitoring sites in the lower reaches of Horokiri Stream (Figure 2.3) in November 2012 and Pauatahanui Stream (Figure 2.4) in June 2013.

Figure 2.3: Horokiri Stream at Snodgrass site with insets of the SC-200 control unit and logger setup (top left) and in-stream turbidity sensor (bottom right)

Figure 2.4: Pauatahanui Stream at Gorge site with insets of the SC-200 control unit and logger setup (top right) and in-stream turbidity sensor with auto-sampler intake hose attached to sensor housing (bottom left)

Routine site maintenance is carried out every five weeks. During these visits, the turbidity sensor lens and housing are cleaned, data are downloaded from the SC-200 unit if there have been issues with the telemetered record, and a manual water sample is collected for analysis of SSC at base flows. During early summer, algal growth on the sensor lens and housing is a persistent problem and site visits every three to five days are necessary. The routine site maintenance conforms with the NEMS (2013) site visit procedures.

2.2 Data collection

Turbidity, stage and flow time-series data have been collected continuously since site installation was completed. Data are telemetered via HydroTel and checked daily for faults, equipment malfunctions and wet weather events. Data are also collected from the SC-200 logger memory during routine site visits every five weeks.

The ISCO autosamplers can take up to 24 discrete water samples. Sampling is triggered by stage at the Porirua and Horokiri sites and by turbidity at Pauatahanui site, with the samplers programmed to collect samples at 15 minute intervals (Table 2.2). Sampling ceases when the stage or turbidity has dropped below a set trigger. All samples taken by the automatic samplers are dispatched to Hill Laboratories, typically within 48 hours, for determination of turbidity and suspended sediment concentration (SSC) (see Appendix 1 for a summary of laboratory methods). The lab turbidity data are used to validate whether the field sensor is operating correctly.

The total suspended solids (TSS) sediment analysis method was not considered for this monitoring programme because unlike SSC (where the sediment in the entire sample is weighed), TSS is measured by subsampling. This has been shown to introduce error due to the rapid settlement of larger particles, thus underestimating actual mass load. Measurement of SSC is the recommended analysis for validating turbidity measurements and calculating sediment loads (NEMS 2013, Hicks 2011).

2.3 Data processing

Turbidity data can be very ‘noisy’ and often need editing to remove erroneous values. Solitary spikes in the data can occur when debris float past the sensor face. These are easily recognised and removed. Figure 2.5 shows an example of unedited data where spikes occurred independently of stream water level.

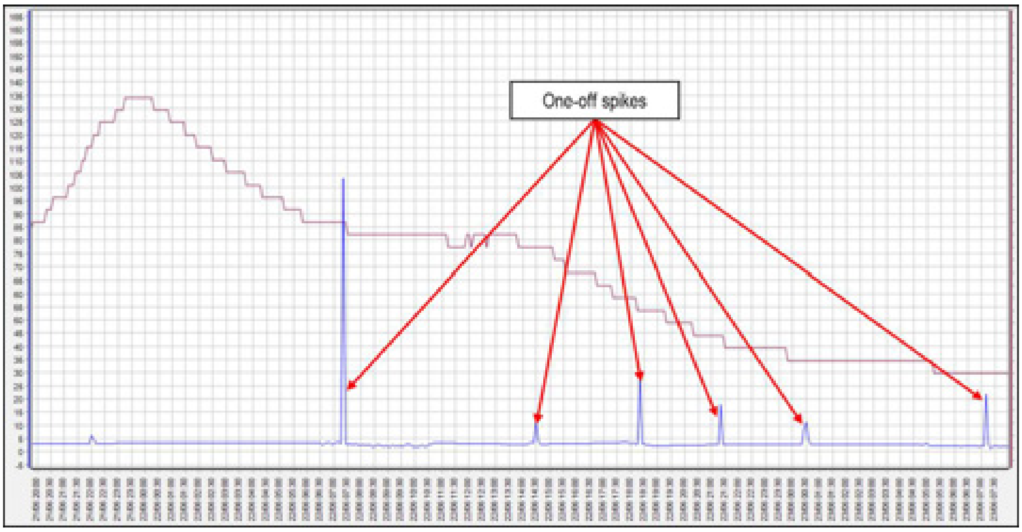

Figure 2.5: Solitary spikes in turbidity data due to debris floating past the sensor over two and a half days in Porirua Stream. The blue line is the turbidity trace and the red line is stream level (stage)

More patchy or persistent spiking (Figure 2.6) requires more vigorous editing and often means some sort of fouling of the turbidity sensor lens has occurred. Data from these periods are manually edited where possible or removed from the record and a data gap created as per the procedures outlined in NEMS (2013). During the reporting period, the cause of fouling at the three monitoring sites was typically debris (rubbish, leaves, branches, etc.) snagged around the sensor housing, algal growth on and around the sensor face/housing and loitering fish (Figure 2.7).

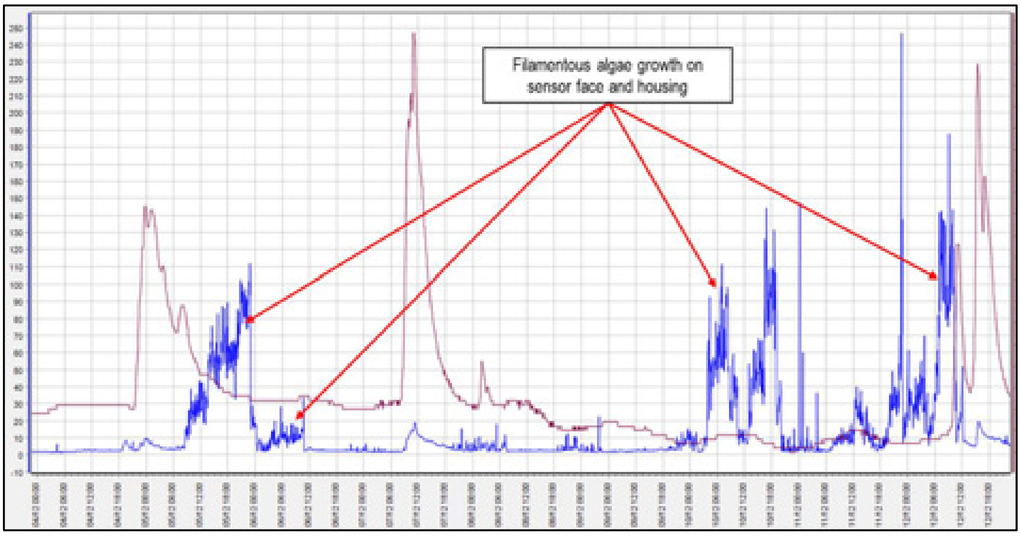

Figure 2.6: Spiking as a result of filamentous algae growth on the sensor face at Porirua Stream. The blue line is the turbidity trace and the red line is stream level (stage)

Other problems with the data included gaps when power to the site failed or when there were communication problems between the SC-200 control unit and the data logger. In the case of the latter, it was occasionally possible to recover the lost data from the memory of the SC-200 control unit. However for reasons not known, this data was sometimes incomplete.

Protocols in NEMS (2013) recommend that synthetic data generated from a rating relationship between turbidity and stream discharge be used to patch large periods of data lost due to sensor malfunction or discarded as a result of the editing process. However, developing a rating relationship is still a 'work in progress' so for the reporting period any data gaps were left in the record.

The NEMS (2013) also recommend assigning quality codes to archived turbidity data. This practice is still to be implemented.

Figure 2.7: Examples of 'fouling'. Debris snagged around the turbidity sensor housing at the Porirua site after a large flood in February 2013 (top left) and then the sensor again after the debris was removed (top right). A film of green algae which has built up on the edge of sensor lens at Porirua Stream (middle left) and filamentous algae growth on and around sensor housing at Horokiri Stream after several weeks of stable flow (middle right). Longfin eel which resides at the Pauatahanui Stream site (bottom)

2.4 Data analysis

In Section 3 linear regression is used to examine the field and laboratory turbidity data. While a strong linear relationship may exist between the two data sets, it is not unusual for there to be differences between field and lab turbidity data. This is because the instruments do not measure nephelometric turbidity in the same way (mainly due to differences in optical design), sensors sometimes drift and the field sensor calibration may not be as robust as the laboratory sensor calibration (Davies-Colley & Smith 2001; Hicks 2009).

Site-specific regression relationships between log-transformed field turbidity and SSC were used to convert the turbidity time series into a record of SSC. The resulting equations were then used to calculate an annual catchment sediment load for the Porirua Stream catchment. Retransformation bias was corrected for using the smearing estimate of Duan (1983).

The underlying relationship between SSC and flow is typically represented by a power-law model, therefore, the untransformed SSC and flow data are displayed with the corresponding power-law functions in Figures 3.5, 3.9 and 3.13.

3. Results

This section presents a summary of the data collected at each of the three turbidity monitoring sites between August 2012 and June 2014. Summary statistics for 'parallel' field and laboratory water samples collected during both low flows and when the site is in flood are presented in Appendix 2.

3.1 Porirua Stream

3.1.1 Continuous turbidity

A plot of turbidity, stream flow and total daily rainfall at Porirua Stream from 29 August 2012 until 30 June 2014 is shown in Figure 3.1.

There is a gap in the Porirua Stream turbidity data for nearly 15 days in September 2012 due to vandalism of equipment at the monitoring site. On 2 May 2014, the sensor and the SC-200 were removed for 35 days and sent away for repair following a period of corrupt data.

The highest turbidity value logged over the entire monitoring period was 1172 FNU on 2 December 2012, coinciding with an instantaneous stream flow of 4.5 m^3/s (Figure 3.1). This event was the result of 16.4 mm of rainfall at Seton Nossiter Park in the six preceding hours. On 4 February 2013, an almost one-in-five-year flood (44.3 m^3/s – the largest over the monitoring period) produced a turbidity reading of 1,131 FNU following 101.3 mm of rainfall in the preceding12 hours.

There were several low flow-related turbidity events, and although the cause of these is largely unknown (likely urban discharges) some turbidity spikes were easily explained by upstream activities such as stream bank mowing (Figure 3.2). The low flow turbidity events were generally small (< 30 FNU).

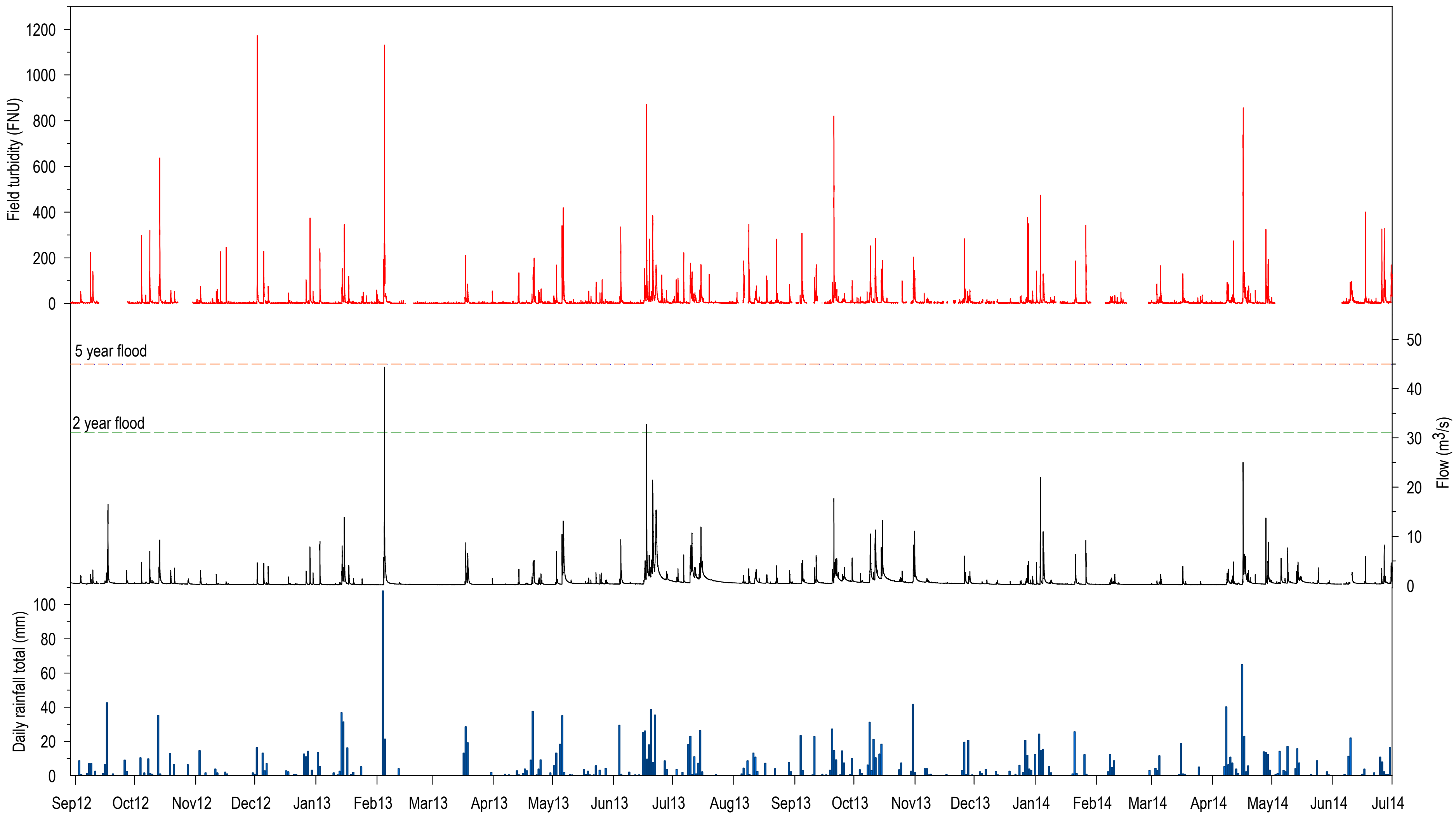

Figure 3.1: Plots of (continuous) turbidity and flow at the Porirua Stream monitoring site and total daily rainfall at Seton Nossitor Park (or Tawa Pool when data missing) between 29 August 2012 and 30 June 2014

Figure 3.2: A tractor in Porirua Stream on 13 February 2013 mowing the stream banks approximately 1 km upstream of our monitoring site. Turbidity peaked at 12.4 FNU during the eight hours it was elevated

3.1.2 Field vs lab turbidity

The relationship between lab turbidity and the field sensor turbidity is very close (R^2=0.98) (Figure 3.3). This indicates the field sensor was performing well during the reporting period.

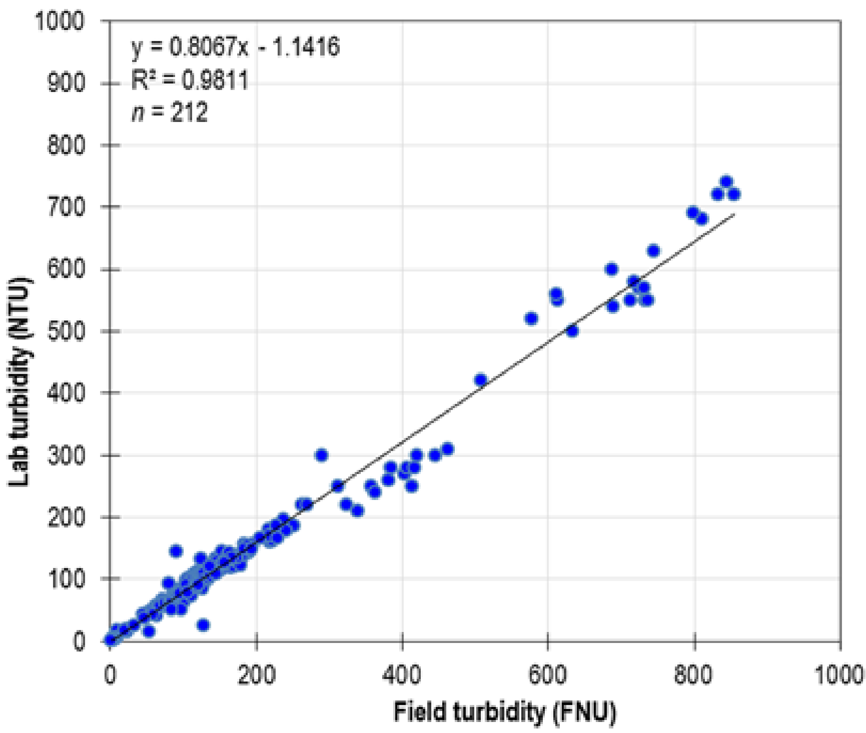

Figure 3.3: Relationship between lab turbidity and field turbidity at Porirua Stream

3.1.3 Suspended sediment concentration (SSC) data

There were 183 stream water samples taken by the ISCO autosampler across 17 different flow events over the reporting period. The field turbidity, lab turbidity and SSC results for these events are summarised in Table 3.1. On 20 September 2013, a SSC of 1,810 g/m^3 was recorded after 17 mm of rainfall in the six hours before the sample was taken. This was the highest SSC recorded at this site, with the second highest being 1,500 g/m^3 on 16 April 2014 after 35 mm rainfall in the preceding six hours.

Table 3.1: Range (minimum and maximum) of turbidity and suspended sediment concentrations (SSC) in water samples taken by the autosampler at Porirua Stream together with total rainfall recorded at Seton Nossiter Park prior to sample collection and field turbidity. Each date is a separate 'event' (ie, samples collected in sequence)

Date	Total rainfall (mm) prior to first		*n*	Lab turbidity (NTU)	Field turbidity (FNU)	SSC (g/m^3)
	0–6hr	6–24hr				
03/05/2013	12.6	0.8	8	25 – 119	88 – 164	124 – 320
05/05/2013	10.8	0	24	41 – 250	48 – 312	43 – 710
04/06/2013	16	2.2	14	56 – 300	62 – 290	63 – 600
22/06/2013	13.2	3.6	23[1]	43 – 145	45 – 161	101 – 280
10/07/2013	11.6	18.8	9	97 – 133	104 – 136	161 – 460
15/07/2013	9.8	14.2	6	105 – 135	128 – 170	240 – 350
20/09/2013	17	11.8	9	300 – 680	420 – 811	760 – 1,810
09/10/2013	18.2	14.8	10	101 – 187	134 – 251	260 – 550
11/10/2013	12	3.2	20	82 – 145	80 – 184	173 – 330
15/10/2013	11.8	12.4	18	61 – 156	82 – 188	145 – 400
31/10/2013	20	2.6	6	52 – 108	97 – 145	141 – 470
03/01/2014	21.4	0	9	210 – 300	339 – 445	460 – 1,090
04/01/2014	14.8	0	6	86 – 145	90 – 128	159 – 230
16/04/2014	35	4.8	12	250 – 740	413 – 855	860 – 1,500
28/04/2014	17.6	0	4	14.9 – 220	23 – 324	11 – 630
29/04/2014	11.2	9.6	2	16.9 – 120	19 – 136	13 – 240
27/06/2014	7.8	0.2	2	25 – 148	33 – 195	24 – 370

[1]24 samples were collected but one sample spilt during laboratory analysis and could not be tested.

Porirua Stream is a flashy stream; the stream rises rapidly after rainfall and falls very quickly once rainfall stops. This is due, in part, to the large areas of impervious urban land in the surrounding catchment from which rainfall flows quickly to the stream. With the trigger on the autosampler set to stream height (stage), the autosampler is often triggered to sample due to the rapid rise in stage but fills fewer bottles because stage drops away quickly; there were only three occasions where 20 or more samples were taken during an event with an average of eleven samples taken per event over the 17 events. Turbidity is also flashy meaning it rises rapidly but drops away quickly even if the stream water level remains high. As a result, setting a stage trigger at this site worked well.

3.1.4 SSC vs field turbidity and flow

For the reporting period, there was a close relationship between field turbidity and SSC at Porirua Stream ($R^2 = 0.9338$) (Figure 3.4).

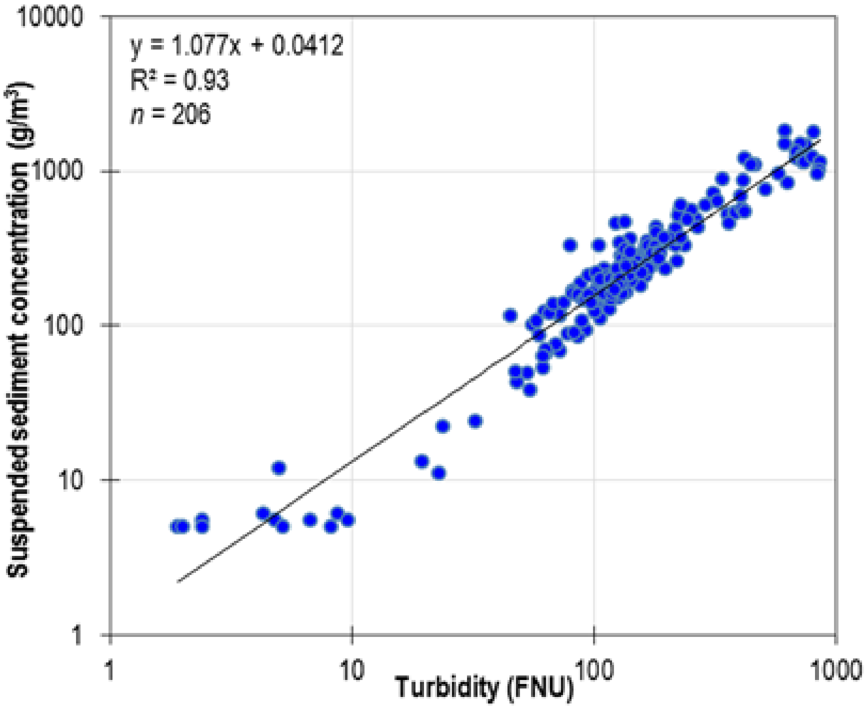

Figure 3.4: Relationship between suspended sediment concentration and field turbidity at Porirua Stream – note the log scale on both axes

The relationship between SSC and flow is shown in Figure 3.5 ($R^2 = 0.76$).

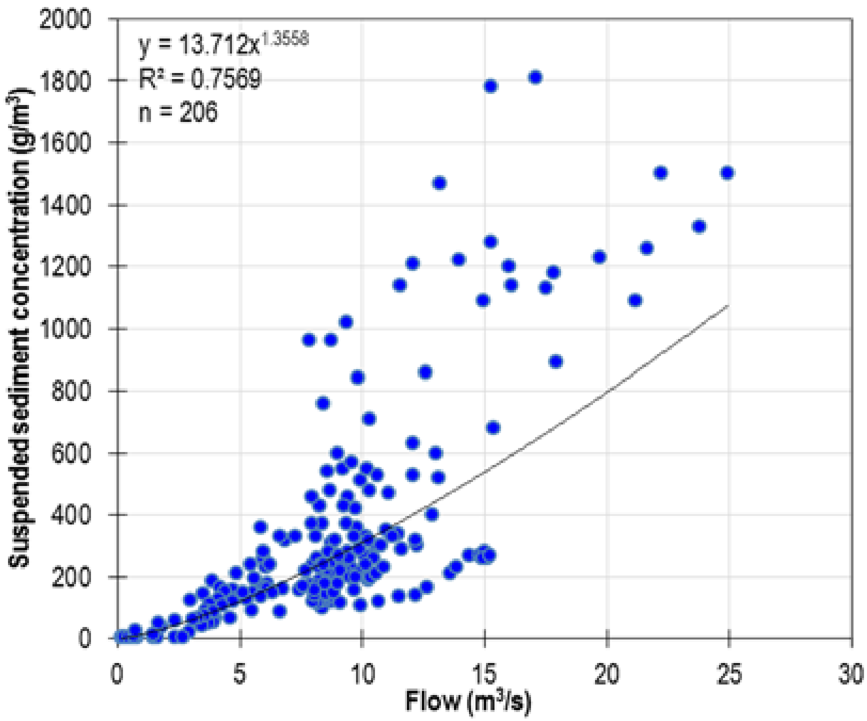

Figure 3.5: Relationship between suspended sediment concentration and flow at Porirua Stream

3.1.5 Sediment yield calculations

The site-specific regression relationship between field turbidity and SSC was used to convert the continuous turbidity time-series data into a SSC time-series. (Note there is currently insufficient data for the Horokiri and Pauatahanui sites to make the same calculations). This time series could then be used to calculate the annual suspended sediment yield for the Porirua Stream catchment.

The annual specific yield estimate for the Porirua Stream catchment in 2013 calculated following turbidity monitoring was 0.67 t/ha/yr[2]. For comparison, the estimates of catchment sediment yield predicted using the combined outputs of the CLUES (Catchment Land Use for Environmental Sustainability) model and a spreadsheet model for the same catchment was 2 t/ha/yr (Green et al. 2014).

Some discrepancy between the observed and predicted measurements is to be expected; the calculated yield is likely to be more accurate because it is based on actual measurements rather than model predictions, the catchment area being monitored is slightly smaller than that used in CLUES, and the complete range of catchment activities and rain events considered in the CLUES estimates may not have been captured in the short period of monitoring. It is important to note that the portion of the Porirua Stream catchment being monitored does not include inputs from the Kenepuru Stream.

This sediment yield calculation is strictly provisional as it will be necessary to collect many years of data before we can characterise the annual sediment yield for this catchment. However, it provides a useful illustration of how the field data may ultimately be used to calculate sediment yields.

3.2 Horokiri Stream

3.2.1 Continuous turbidity

Figure 3.6 displays the continuous turbidity, stream flow and total daily rainfall at Horokiri Stream from 14 November 2012 until 30 June 2014.

Communication problems between the SC-200 module and the IQuest logger plagued the first ten months of the monitoring period. As a result, data from the SC-200 memory was used. However, there were gaps in the SC-200's memory (for reasons unknown). The first major gap was between 17 December 2012 and 16 January 2013, while the second gap was between 18 July 2013 and 7 August 2013. Logger/SC-200 communication issues were finally resolved on 7 August 2013.

A turbidity reading of >4,000 FNU at Horokiri Stream during a one-in-two-year flood on 4 February 2013 was the highest recorded during the reporting period (Figure 3.6). This was the result of 96.4 mm of rainfall in the upper Horokiri Stream catchment (Battle Hill Park rain gauge) in the 11 hours prior to this measurement. This was also the largest flood during the reporting period (39.1 m^3/s). A turbidity of 2,347.8 FNU on 19 March 2013 was the second highest measurement recorded.

[2] There are approximately 38 days of turbidity data missing due to fouling or equipment failure.

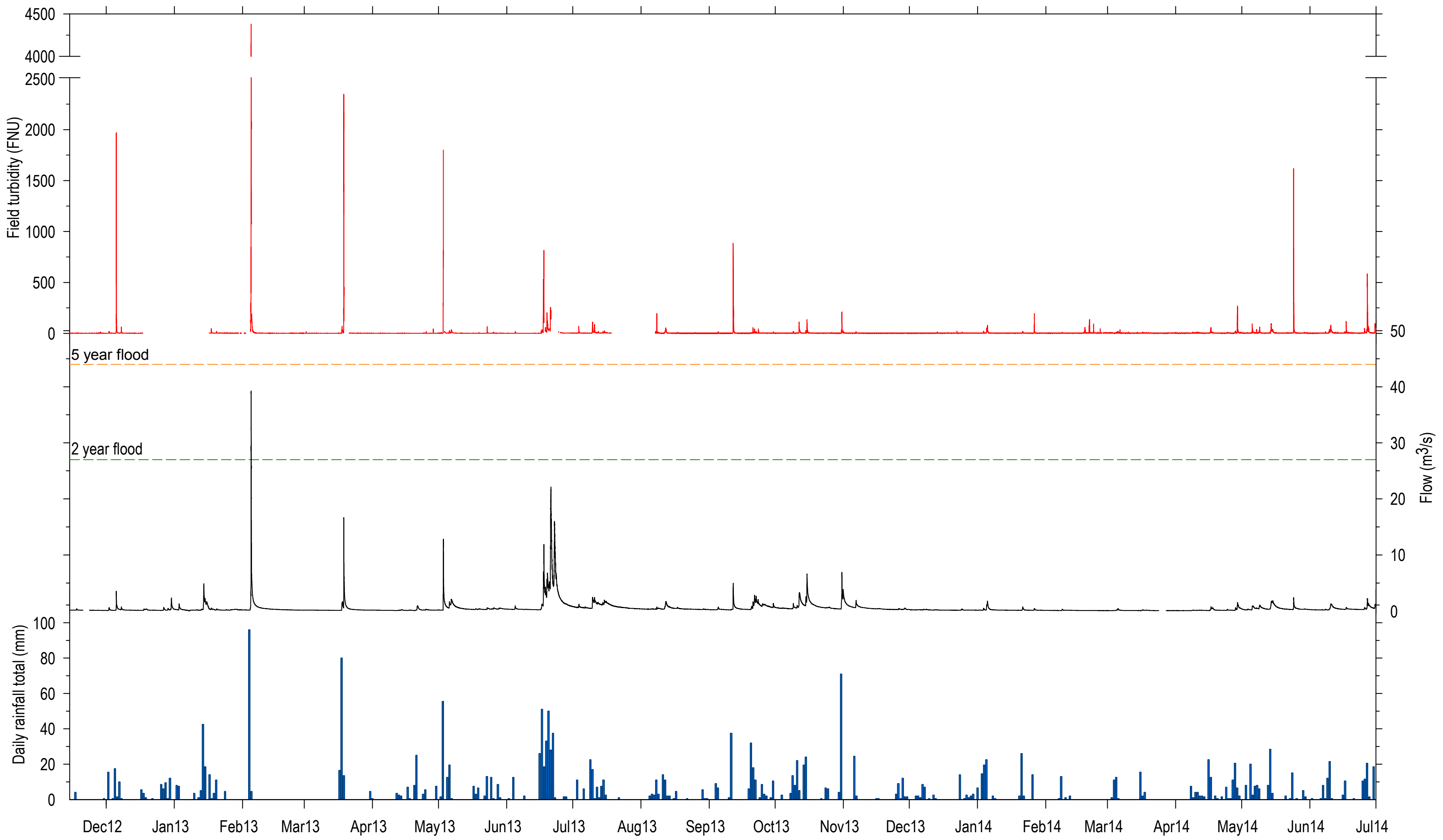

Figure 3.6: Plots of (continuous) turbidity and flow at the Horokiri Stream monitoring site and total daily rainfall at Battle Hill Park (or Taupo at Whenua Tapu when data missing) between 14 November 2012 and 30 June 2014

There were only a few low flow-related turbidity events in the Horokiri Stream. A series of three 'events' that lasted between 9–15 hours from 18 to 22 February 2014 were a result of a consented stream ford construction approximately 2.6 km upstream. Turbidity peaked at 58.8, 135.9 and 91.3 FNU respectively, across the three events. Another low flow turbidity event recorded on 28 April 2013 peaked at 43.3 FNU but only lasted an hour.

3.2.2 Field vs lab turbidity

Lab results for stream water samples collected using the autosampler during three storm events in October 2013, indicate that there may have been a problem with the field sensor during this period. The linear regression relationship between the lab turbidity and field turbidity is shown in Figure 3.7 (R^2 = 0.64) and illustrates that the data from October 2013 (shown in red) are distinct from the rest of the data. The relationship between lab and field turbidity is expected to improve with time as more data is collected and the anomalous data can be excluded from the data set.

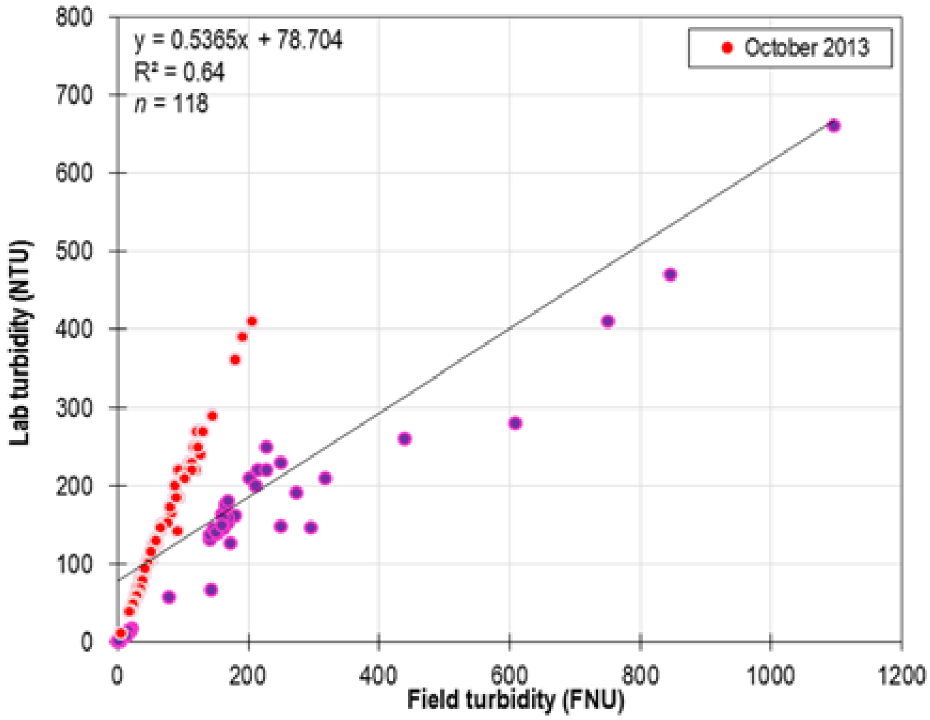

Figure 3.7: Relationship between lab turbidity and field turbidity at Horokiri Stream. Results in red are measurements made during storm events in October 2013

3.2.3 Suspended sediment concentration (SSC) data

One hundred and fifteen samples were collected from the Horokiri Stream during five storm events. The highest SSC of 1,270 g/m^3 was recorded on 3 May 2013 following 33.5 mm of rainfall (Table 3.2).

There were only five events where the autosampler was triggered. This was due to a high stage trigger that needed to be set at this site. Unlike the flashy Porirua Stream, runoff in the predominantly pastoral Horokiri Stream catchment is slowed through absorption into the soil. This means a slow increase in stage and an even slower drop in stage after a wet weather event. Setting the trigger higher stopped the sampler taking unnecessary samples well after the majority of sediment-laden water had flushed through.

Table 3.2: Range (minimum and maximum) of turbidity and suspended sediment concentrations (SSC) in water samples taken by the autosampler at Horokiri Stream together with total rainfall recorded at Battle Hill prior to sample collection and field turbidity. Each date is a separate 'event' (ie, samples collected in sequence)

Date	Total rainfall (mm) prior to first sample		*n*	Lab turbidity (NTU)	Field turbidity (FNU)	SSC (g/m³)
	0–6 hr	6–24 hr				
03/05/2013	33.5	0	24	16.7 – 700	23 – 1,097 (11[1])	34 – 1,270
20/06/2013	18	15	22	66 – 250	141 – 250	97 – 570
11/10/2013	15	4.5	24	69 – 230	35 – 110	115 – 410
15/10/2013	19.5	19	22	59 – 270	28 – 130	110 – 610
31/10/2013	42	4	23	38 – 410	19 – 206	63 – 850

[1] Field sensor malfunction during event.

3.2.4 SSC vs field turbidity and flow

The relationship between SSC and turbidity at the Horokiri Stream site using all available data is shown in Figure 3.8 (R^2=0.66). The relationship between SSC and turbidity improves (R^2=0.91) when the October 2013 data are removed (Figure 3.8).

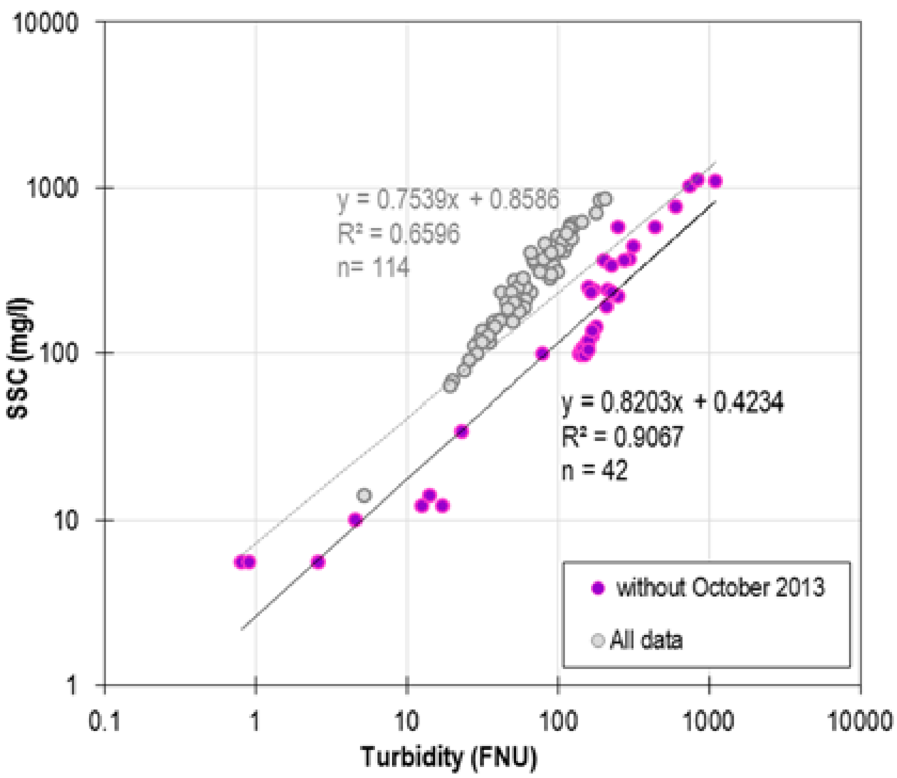

Figure 3.8: Relationship between suspended sediment concentration and field turbidity at Horokiri Stream – note the log scale on both axes

The relationship between SSC and flow is shown in Figure 3.9 (R^2=0.39).

(a) Flow event on 21 and 22 June 2013

Thirty three millimetres of rainfall over 24 hours on 20–21 June 2013 resulted in a high stage and flow at the site that set off the autosampler. However, the SSC results from these samples were not high, and even decreased as flow increased (Figure 3.9) during the event. It should be noted that the stream flow was already elevated following four days of steady rainfall (178.5 mm) which began on 16 June (see Figure 3.6). This would have likely seen most of the sediment from the upstream catchment flush through before the autosampler was triggered.

Evidence of this comes from our field sensor, which despite malfunctioning several times during this period (power issues), recorded a turbidity of 814.4 FNU on 17 June. However, during the event on 20–21 June, turbidity reached just 249 FNU and dropped as low 141 FNU as flows increased. It has been observed that turbidity readings in all three streams decrease following the initial period of heavy rainfall despite persistent rainfall and elevated stream flows.

As a result of this event and the lack of a strong relationship between flow and turbidity, the stage trigger was set very high (780 mm or 17 m^3/s) to target the highest of flood events. Unfortunately, two storm events on 24 May 2014 and 27 June 2014 where turbidity reached 1,617.3 FNU and 583.6 FNU, respectively, were missed for this reason.

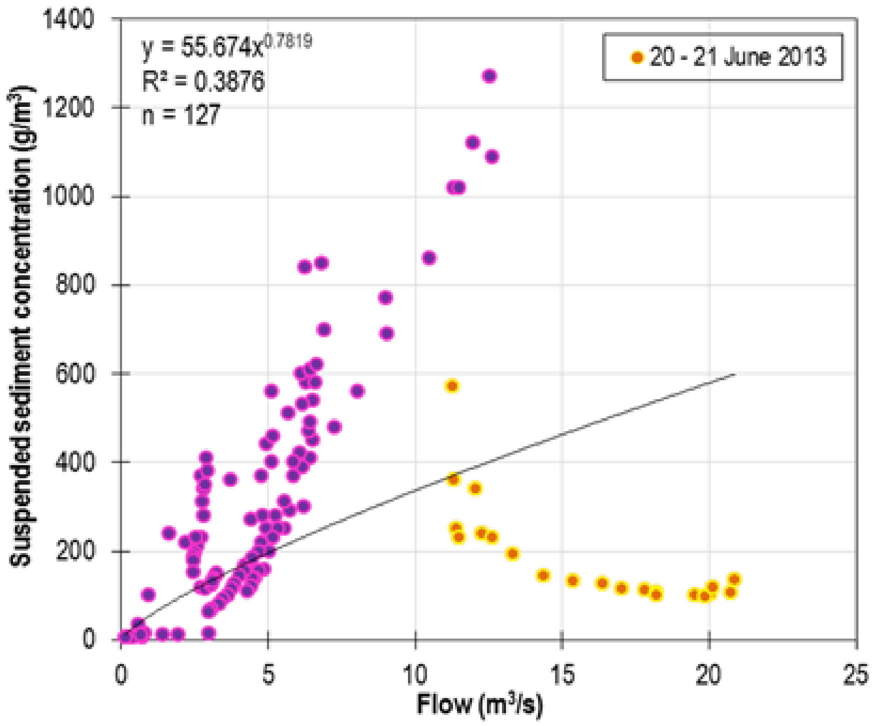

Figure 3.9: Relationship between suspended sediment concentration and flow at Horokiri Stream. Highlighted in orange are the results from the flow event on 20 and 21 of June 2013

3.3 Pauatahanui Stream

3.3.1 Continuous turbidity

The same SC-200 module communications problems experienced at the Horokiri Stream site also affected the first two months (12 June 2013–13 August 2013) of the turbidity record at Pauatahanui Stream (Figure 3.10). Once more, data from the SC-200 memory was used but there was a small gap (again, for unknown reasons) in this data from 6 August 2013 until the communication issues were fixed on 13 August 2013.

The SC-200 module was removed for maintenance between 3 March and 4 April 2014 creating a 32-day data gap.

Unusual data from 16 May 2014 to 4 June 2014 meant all but a 17-hour period during a flood event on 24 May 2014 had to be deleted from the record. The data showed signs of persistent fouling of the turbidity sensor lens and returned to normal once the lens was cleaned on 4 June 2014.

The maximum turbidity reading of >4,000 FNU was recorded at Pauatahanui Stream on 20 September 2013. This was the highest recorded during the monitoring period with stream flow peaking at 9.0 m^3/s following 13.5 mm of rainfall (Battle Hill Park rain gauge). The largest flood event was over 20–21 June 2013, where stream flow reached 36.4 m^3/s. Unfortunately the SC-200 malfunctioned at the same time meaning there was no turbidity record during this event.

There were three low flow turbidity events of note (>3 hours) in the Pauatahanui Stream during the monitoring period. The first one occurred on 16 September 2013, reaching 25.1 FNU and lasted just over five hours while the second was a three-hour event on 18 December 2013 which reached 22.0 FNU. The third event was on 20 January 2014 and lasted seven hours, with turbidity reaching a peak of 57.6 FNU. The cause of these three events is unknown.

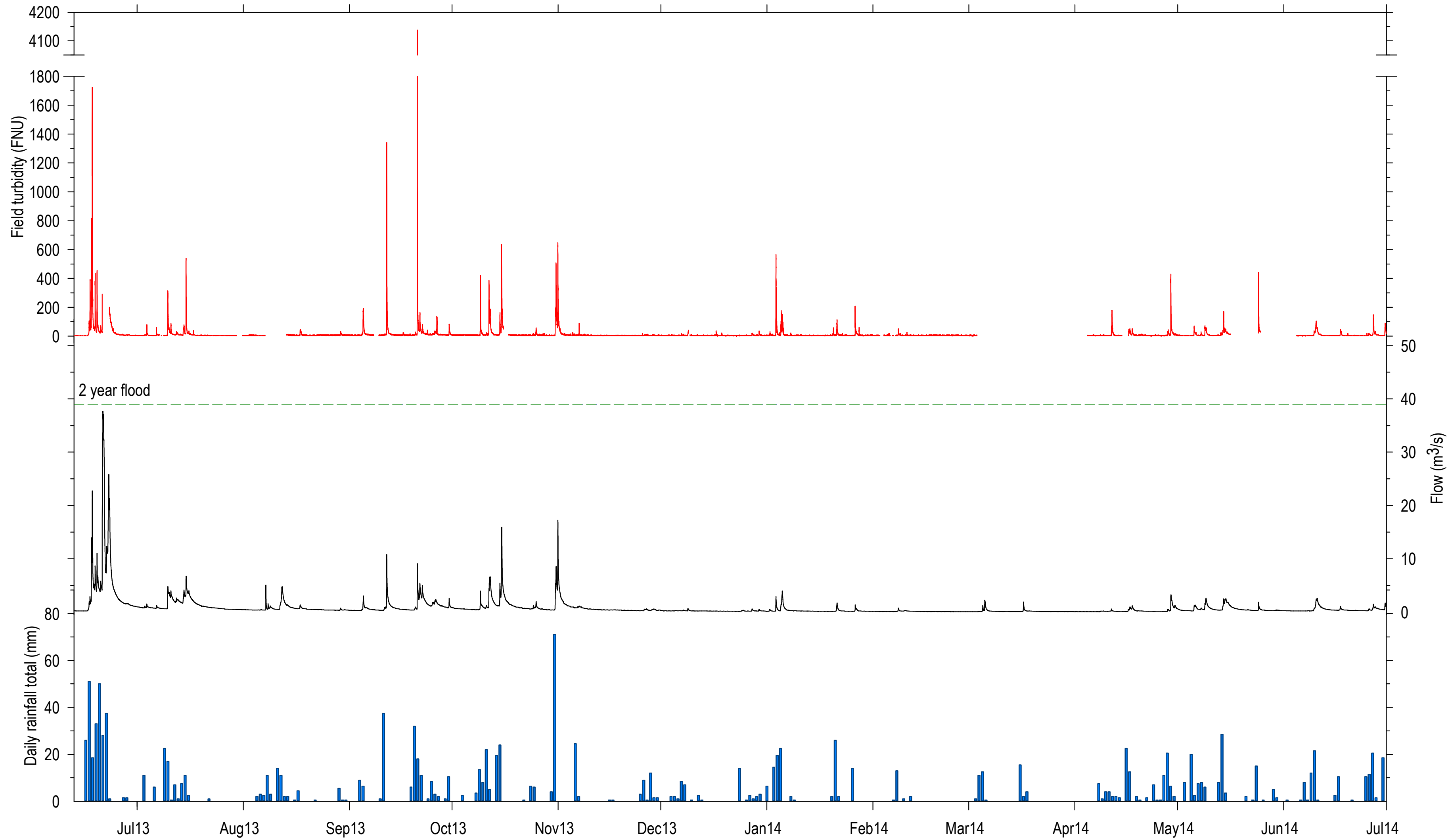

Figure 3.10: Plots of (continuous) turbidity and flow at the Pauatahanui Stream monitoring site and total daily rainfall at Battle Hill Park between 12 June 2013 and 30 June 2014

3.3.2 Field vs lab turbidity

Figure 3.11 shows the relationship between lab turbidity and field turbidity at Pauatahanui Stream was very close (R^2=0.995) (Figure 3.11). This indicates that the field sensor was performing well during the reporting period.

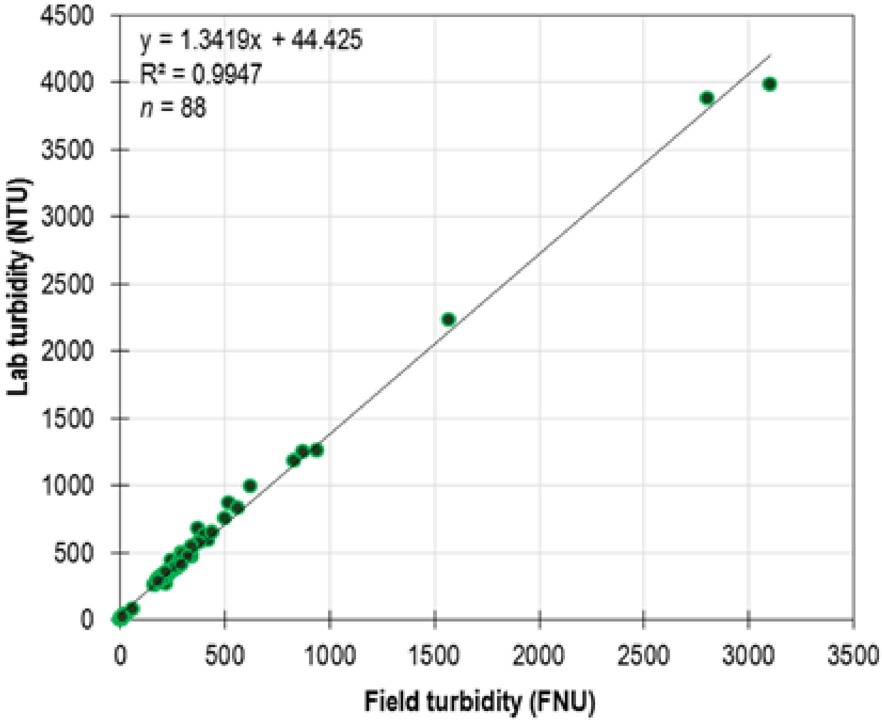

Figure 3.11: Relationship between lab turbidity and field turbidity at Pauatahanui Stream

3.3.3 Suspended sediment concentration (SSC) data

The Pauatahanui Stream autosampler collected 71 samples over the course of seven separate wet weather events. A SSC of 5,400 g/m^3 on 20 September 2013 was the highest result of any sample taken at any of the three monitoring sites (Table 3.3). This occurred following 13.5 mm of rainfall.

The trigger at this site was set by turbidity as access to NIWA's real-time stage data was not possible on site. In terms of data collection, having a turbidity trigger seemed to work better than a stage trigger as flow and turbidity were not always correlated. However, the autosampler would often trigger on the odd occasion when there was fouling of the sensor (ie, false turbidity).

Table 3.3: Range (minimum and maximum) of turbidity and suspended sediment concentrations (SSC) in water samples taken by the autosampler at Pauatahanui Stream with rainfall totals in the 6 hours before as well as between 6–24 hours before the first sample was taken and field turbidity. Each date is a separate 'event' (i.e. samples collected in sequence)

Date	Total rainfall (mm) prior to first sample		*n*	Lab turbidity (NTU)	Field turbidity (FNU)	SSC (g/m³)
	0–6hr	6–24hr				
11/09/2013	27	9	13	166 – 940	256 – 1,262	290 – 1,760
20/09/2013	13.5	18	11	186 – 3,100	280 – 3,985	280 – 5,400
09/10/2013	9	5.5	4	210 – 280	301 – 420	380 – 620
11/10/2013	1	11.5	4	192 – 260	271 – 377	280 – 420
15/10/2013	19.5	19	14	165 – 420	262 – 620	320 – 840
31/10/2013	34	23	18	182 – 440	278 – 647	290 – 830
03/01/2014	14.5	0	7	179 – 340	292 – 546	290 – 670

3.3.4 SSC vs field turbidity and flow

The relationship between turbidity and SSC at Pauatahanui Stream was close (R^2=0.97) (Figure 3.12). Like Porirua and Horokiri streams, there is a weaker linear relationship (R^2=0.53) between SSC and flow (Figure 3.13).

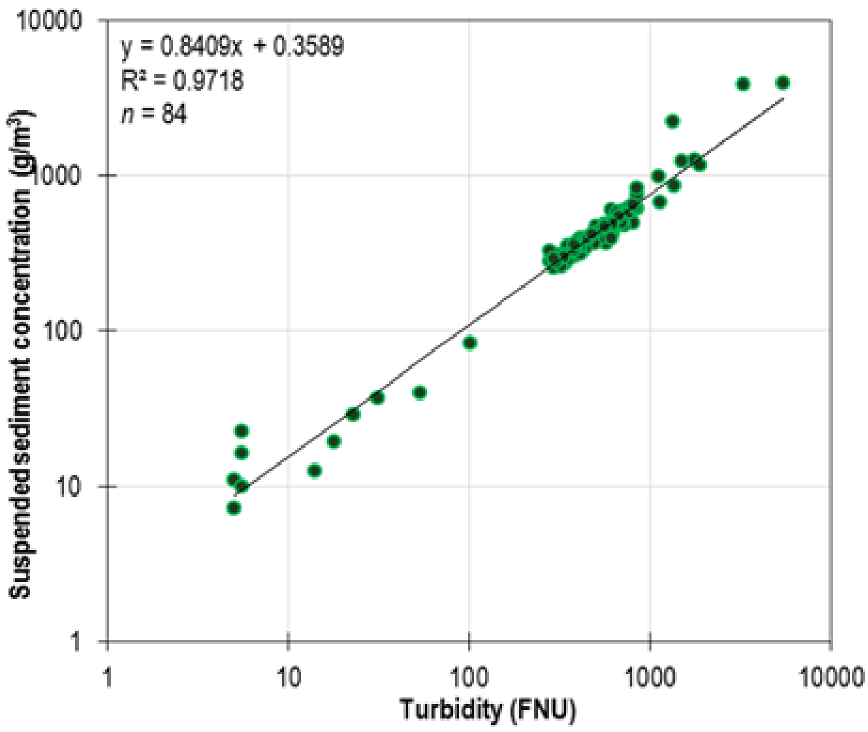

Figure 3.12: Relationship between suspended sediment concentration and field turbidity at Pauatahanui Stream – note the log scale on both axes

The storm event on 20 September 2013 resulted in very high suspended sediment concentrations. However this was the only event to produce such high concentrations and more data is needed before the accuracy of these results can be validated.

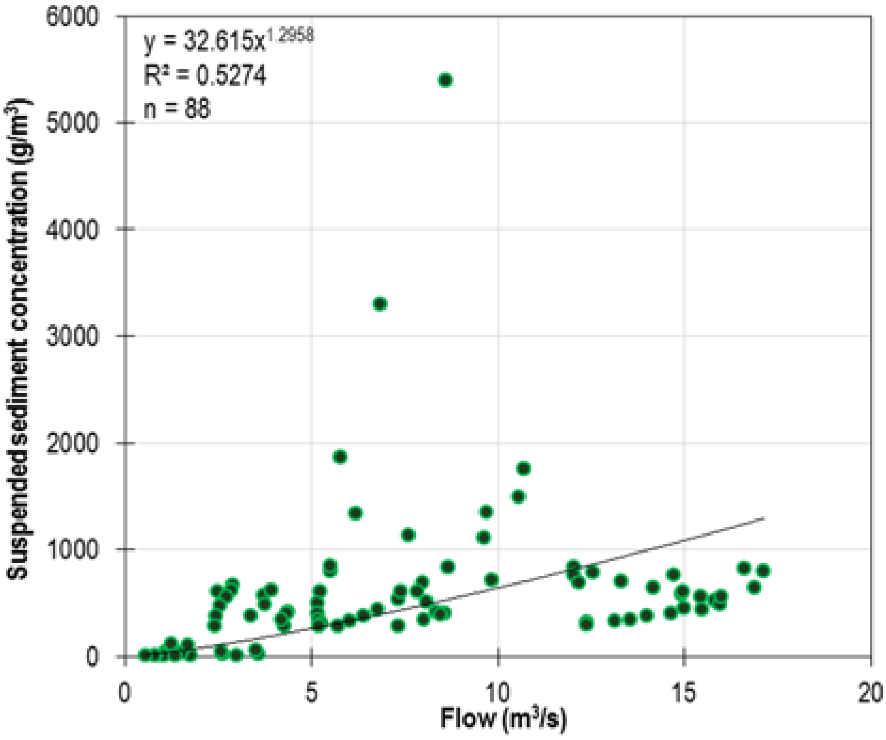

Figure 3.13: Relationship between suspended sediment concentration and flow at Pauatahanui Stream

4. Discussion

The first two-and-a-half years of turbidity monitoring have provided valuable information about the characteristics of turbidity and flow in the streams of the three largest sub-catchments of Porirua Harbour. The highest turbidity values and suspended sediment concentrations (SSC) were recorded at the Pauatahanui Stream monitoring site during both low flows and storm events. There is generally good agreement between the field and lab turbidity results and overall increases in turbidity and SSC correspond with increases in flow at all monitoring sites. However, there have been several occasions at the Porirua and Pauatahanui stream sites when increases in turbidity have occurred during low flows. The reasons for these turbidity spikes were not always obvious, though occasionally they could be linked to lawnmower activity or forestry road works.

A provisional sediment yield calculation was made for the Porirua Stream catchment based on one full year of data and this indicates that for the 2013 calendar year the specific yield was 0.67 t/ha/yr; this compares with the CLUES model estimate for the same catchment was 2 t/ha/yr (Green et al. 2014). As more turbidity and suspended sediment data are collected across a range of wet weather events, similar calculations will be made for the Horokiri and Pauatahanui sub-catchments.

The monitoring has highlighted several areas for ongoing development and validation. There were numerous instrument performance issues which resulted in gaps in the data record, particularly at the Horokiri Stream site. The problems stemmed from biofouling, physical damage, theft, the need to remove sensors for calibration, and module communication issues. Most of these problems can be eliminated with more regular site visits. Instrument upgrades, replacement and back-up will help to eliminate communication failures. Sediment gaugings to measure the suspended sediment load over the stream cross-section and particle size analyses should also be undertaken for the purposes of validating the turbidity record.

The monitoring site set-up and sampling protocols conform reasonably well with those prescribed by NEMS (2013), however, there are some areas that require further development and improvement. For example, NEMS recommends that site maintenance visits are made every four weeks and that quality codes are assigned to collected data prior to archiving.

4.1 Recommendations

The key recommendations following the first two-and-a-half years of continuous turbidity monitoring are to:

- Carry out routine site maintenance visits every four weeks, instead of five;
- Consider moving the Horokiri Stream turbidity sensor downstream to reduce fouling of the lens and the effects that the upstream weir may be having on the turbidity recording (eg, resuspension and bubble formation);

- Focus SSC sampling across a broader range of turbidity measurements, particularly those at the high flow and high turbidity range;
- Acquire an additional turbidity sensor and autosampler as back-up in the event that existing equipment fails or requires ex-situ calibration;
- Carry out sediment gaugings at each site to determine whether the turbidity sensor data are representative of suspended sediment concentrations over the entire stream width;
- Undertake particle size analyses concurrent with sediment gaugings to characterise the catchment sediments and the influence sediment grain size has on suspended sediment concentrations;
- Consider how NEMS quality codes can be applied to collected turbidity data; and
- Consider how discarded and/or missing segments of the turbidity record might be replaced with supplementary or synthetic data.

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Appendix 1: Laboratory and field methods

Core water quality variables measured/analysed at each site are presented in Table A1.1. Manual water samples are collected via hand or a standard sample pole approximately 200 mm below the water surface within 0.6 m of turbidity sensor. Autosampler samples are collected from an intake hose attached to the bottom of the turbidity sensor housing. Samples requiring laboratory analysis are placed in chilli bins with ice and couriered overnight to RJ Hill Laboratories in Hamilton.

Table A1.1: Field and analytical water quality methods and detection limits

Variable	Sample type	Method	Detection limit(s)
Field turbidity	In-stream sensor	Hach Solitax T-line sensor (ISO7027 compliant) with SC 200 module.	0.001– 4,000 FNU
Lab turbidity	Water sample collected manually or by auto-sampler	Analysis using a Hach 2100N, Turbidity sensor. APHA 2130 B 22nd Ed. 2012.	0.05 NTU
Suspended sediment concentration (SSC)	Water sample collected manually or by auto-sampler	Filtration using Advantec GC-50 or equivalent 125mm 1 –12 diameter filters (nominal pore size 1.2 – 1.5µm), gravimetric determination. Entire sample filtered (includes aliquot previously sub-sampled for turbidity [when in autosampler bottle] and returned to bottle). No correction for density. ASTM D3977-97 (Modified).	10 g/m^3

Appendix 2: Summary statistics

Table A2.1 presents summary statistics for stream water samples sent from each monitoring site to the lab during both low flow and 'flood' conditions.

Table A2.1: Summary of turbidity and suspended sediment concentration sampling results during 'low' and high flows at all three monitoring sites. Field turbidity values correspond to a lab sample being taken. Results included are all samples taken by the autosampler as well as any samples taken by hand

Variable and site	Low flow (< median flow)				Flood (>3 x median flow)			
	Median	Min	Max	*n*	Median	Min	Max	*n*
Field turbidity (FNU)								
Porirua Stream at Town Centre	2.4	1.6	4.3	9	134.1	5	854.8	199
Horokiri Stream at Snodgrass	2.9	0.8	3.6	6	88.45	4.6	1,097.2	108
Pauatahanui Stream at Gorge	4.7	4.6	7.3	3	398.3	12.7	3,985.1	80
Lab turbidity (NTU)								
Porirua Stream at Town Centre	1.59	1.1	3	10	111.5	3.5	740	200
Horokiri Stream at Snodgrass	0.8	0.48	1.54	7	147	5.6	700	121
Pauatahanui Stream at Gorge	1.65	1.14	3.8	3	260	6.3	3,100	83
Suspended sediment concentration (g/m^3)								
Porirua Stream at Town Centre	<10	<10	<12	5	230	<10[1]	1,810	199
Horokiri Stream at Snodgrass	<11	<10	<11	3	230	<10[1]	1,270	121
Pauatahanui Stream at Gorge	-	-	-	0[2]	490	<11[1]	5,400	83

[1] The occasional sample taken during flood conditions at all three sites also resulted in SSC results below the analytical detection limit.

[2] Early low flow sampling at both the Porirua and Horokiri sites resulted in SSC results below the analytical detection limit. As a result, low flow sampling for SSC was stopped and due to the late establishment of the Pauatahanui site, no SSC samples were ever taken at low flow conditions from this site.