Weiti Forest Sediment Yields

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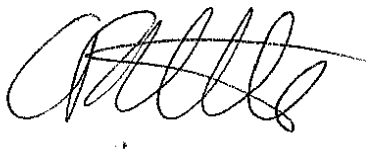

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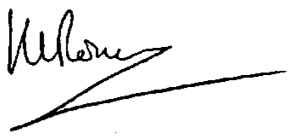


Helen Rouse

Executive Summary

Auckland Council (AC) has identified that harvesting of the Weiti Forestry Block at Okura, planned for the next 3 years, has the potential for adverse environmental effects on the Okura Estuary.

AC have commissioned NIWA to analyse approximately four years of available flow and suspended sediment concentration data to provide baseline sediment yield relationships, to inform AC of the minimum magnitude of sediment yields that may be expected during the harvesting period and to establish relationships between event sediment yields and rainfall-based hydrological driving parameters.

This information will help AC to forecast event sediment yields during the harvesting period from rainfall forecasts and so be able to mobilise surveys of the estuary to check for adverse environmental effects. Establishing baseline relationships will also enable AC to quantify any change in event sediment yields (at given frequency of occurrence) during the harvesting period so it can be managed appropriately. Clearly, if such changes do occur then the magnitude-frequency calculations will be updated.

Event sediment yields were calculated for the 74 storm events occurring during the 4.15-year period (2008 to 2012) of flow monitoring in the Weiti Forest catchment.

The total sediment yield from storms over the monitoring period was 209.4 t, equating to a specific sediment yield of 29.7 t/km^2/yr.

Rainfall-based hydrological parameters were calculated for each of the storm events in the monitoring period and these were each assessed to see which were the best potential predictors of event sediment yield.

The strongest multiple regression model, with an adjusted R^2 of 0.51 and a standard factorial error of 2.24, is Event Yield = $0.0534 \times AP_{60}^{\ 0.887} \times EI_{60}^{\ 0.674}$, where AP_{60} is the total rainfall occurring over the 60 days immediately preceding the rainfall event (60 day antecedent rainfall) and EI_{60} is the product of the total rainfall energy of the rainfall event and maximum hourly intensity of the rainfall event. We recommend that this relationship be used to forecast event yields from forecasts of hourly precipitation.

A partial duration series analysis of event sediment yields provided the following magnitude-frequency results. These may be assumed to provide initial estimates of expected yields during the harvest period until monitoring demonstrates otherwise, whereby estimates will then be updated.

Return Period	Event sediment yield (t)
5 year	26.87
3 year	19.03
2 year	15.48
1 year	8.71
6 month	7.17
3 month	4.09
1 month	0.93

1.0 Introduction

Sustainable management of the Auckland region's land and aquatic environment requires ongoing monitoring of various environmental parameters. This includes the monitoring of sediment loads and yields from rivers and streams and the potential adverse effects of fine-sediment delivery, dispersal and deposition in receiving-water bodies.

Auckland Council (AC) has identified that harvesting of the Weiti Forestry Block at Okura, planned for the next 3 years, has the potential for adverse environmental effects on the Okura Estuary. AC have been monitoring flow and suspended sediment concentrations in the 1.7 km^2 Weiti Forest catchment (Figure 1.1) since 2008 in order to establish a robust set of baseline data for this catchment.

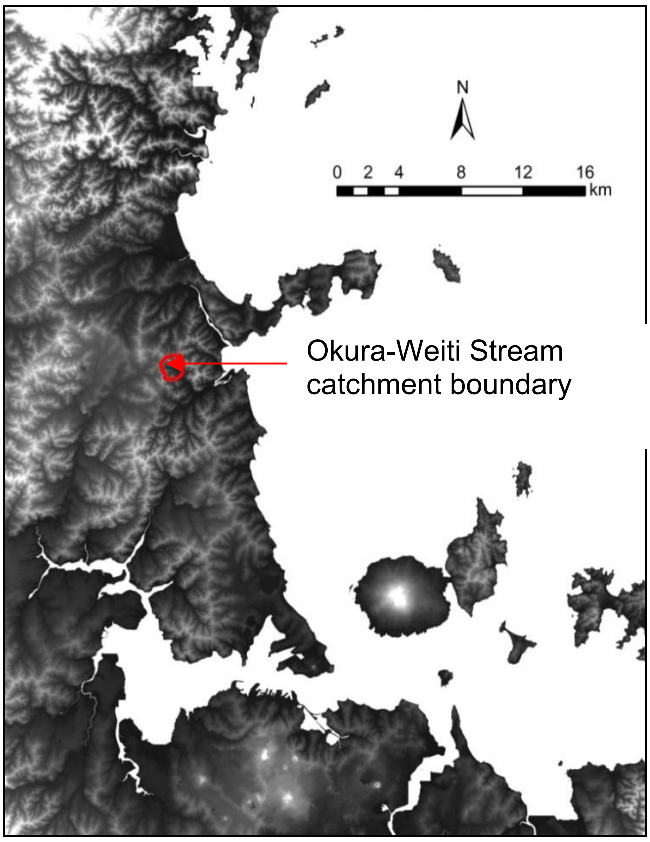


Figure 1.1: Map showing the location of the Weiti Forest catchment in the Auckland Region.

AC have commissioned NIWA to analyse these data to inform AC of the minimum magnitude of event sediment yields that may be expected during the harvesting period and to establish relationships between event sediment yields and rainfall-based hydrological driving parameters. This will enable rainfall-based forecasts of event sediment yield which AC will then be able to combine with coastal forecasts of wind and tides to predict potential adverse environmental effects in the estuary so they can be managed appropriately. An additional benefit of this work is that the relationship derived between event sediment yield and rainfall-driving parameter will be able to be used as a baseline relationship that should - when over-plotted with data from the imminent harvesting period - provide an immediate indication of gross increases in sediment yields as a consequence of forest harvesting.

1.1 Objectives

The objectives of the study are to:

- Calculate event sediment yields over the period of flow record for the Weiti Forest catchment, using the baseline ‘pre-harvest’ suspended sediment concentration data.
- Calculate rainfall-based hydrological driving parameters.
- Provide a relationship that will enable AC to predict event sediment yields based on rainfall forecasts.
- Determine the magnitude-frequency relationship for event sediment yields over the sampling period for the Weiti Forest catchment to inform AC of the scale of event yields that may be expected over the 3 years of harvesting.

1.2 Past studies of sediment yield in the Weiti catchment

A previous sediment yield related study was undertaken in the Okura region in 1999. This aimed to predict the risks of ecologically damaging sediment events occurring in the estuary as a consequence of land disturbance associated with varying degrees of rural intensification. Various aspects of this investigation and their findings are presented in reports by Stroud et al. (1999), Norkko et al. (1999), and Green and Oldman (1999). Stroud et al. (1999) used the computer simulation model WAM (Watershed Assessment Model) to make predictions of sediment input to the Okura Estuary from the surrounding Okura catchment (covering the Weiti and Awanohi sub-catchments, which both flow into the Okura estuary). WAM is a physically based model that does not need calibration, and therefore no sediment concentration data were collected in the Weiti Forest or Awanohi Stream catchments as part of that Okura study (Stroud et al., 1999).

Hicks et al. (2009) analysed sediment concentration data from nine basins in the Auckland Region, including both the Weiti Forest and Awanohi Stream basins, in order to determine event sediment yields and mean annual sediment yields. These yield data were then related to catchment characteristics (i.e. rainfall, catchment slope, land use and lithology) in order to develop a predictive model that can be used to estimate yields from unmonitored catchments. At the time of this 2009 study there was only a 0.56 yr span of flow data available for the Weiti Forest catchment and there was sediment concentration data from six storm events. These data were used to provide an estimate of magnitude-frequency relationships for storm sediment yields for the Weiti Forest catchment. This 2009 study estimated that the mean annual sediment yield from the Weiti Forest catchment was 82 ± 13 t/km^2/yr.

On-going monitoring of flow and sediment concentration in the Weiti catchment means that there is now ~ 4 years of data available which can be used to update the finding of the Hicks et al. (2009) study.

1.3 Summary of available data

Flow data at the Weiti Forest site is available from 14 April 2008 to 7 June 2012. Five hundred and thirty eight discrete sediment samples were collected in this catchment using an automatic ISCO sampler between April 2008 and March 2012. These sediment data covered 33 storm events; with peak discharges (Q_{peak})

ranging from 75 to 2,606 l/s. The V-notch weir installed at the Okura – Weiti Stream flow recording station can be seen in Figure 1.2. Key catchment data for the Weiti catchment are provided in Table 1.1.

Figure 1.2: Photograph of the v-notch weir at Okura - Weiti Stream flow recording station.

Table 1.1: Key data for the Weiti Forest catchment.

Weiti Forest Catchment	
Flow recorder number	7505
Flow recorder location	E 1751872 N 5940969
Catchment area	1.70 km^2
Quickflow separation slope (see section 2.1 for definition)	1.0 $ml/s^2/km^2$
Catchment slope	Mean 0.25 SD 0.15
Dominant lithologies	43% mudstone or fine siltstone, 21% sandstone or coarse siltstone
Land use (from LCDB2)	83.3 % exotic vegetation, 14.5 % pastoral, 2.2 % native vegetation
Mean annual rainfall	1226 mm/yr
Span of flow record	14/4/2008 - 7/6/2012 (4.15 yrs)
Span of sediment record	14/4/2008 - 25/3/2012 (3.96 yrs)

2.0 Analysis Methods

2.1 Event sediment yields

The suspended sediment concentration (C) data provided by AC for the Weiti Forest catchment has been calculated from discrete samples using two different laboratory methods. Prior to July 2011 AC used the total suspended solids method (TSS-C) and from July 2011 AC changed to using the suspended sediment concentration method (SSC-C). In both methods C is measured in the laboratory using the bottled samples collected either manually or by auto-sampler. The TSS-C laboratory procedure involves analysing only a small sub-sample of the total collected from the field. As discussed by Hicks (2011), this is unfortunate because the method can provide erratic and biased results due to the sediment-settling that occurs while the sub-sample is extracted – particularly where there is sand in the mixture. To remove this bias, we developed a relationship between SSC-C and TSS-C (Figure 2.1), based on a set of samples which AC analysed using both methods. This relationship is:

$$\text{SSC-C} = 0.8214\ \text{TSS-C}$$

This relationship was applied to the data analysed with the TSS-C method, thereby providing a series of C data no longer biased by laboratory analysis method. Fifty-nine samples were used to establish the relationship between SSC-C and TSS-C. These samples represent three flow events, one of nine samples and two of 24 samples. All three of these events were well sampled with samples spaced out properly over the event, and are representative of the flow conditions over the entire record, with peak flows between 1088 and 1132 l/sec.

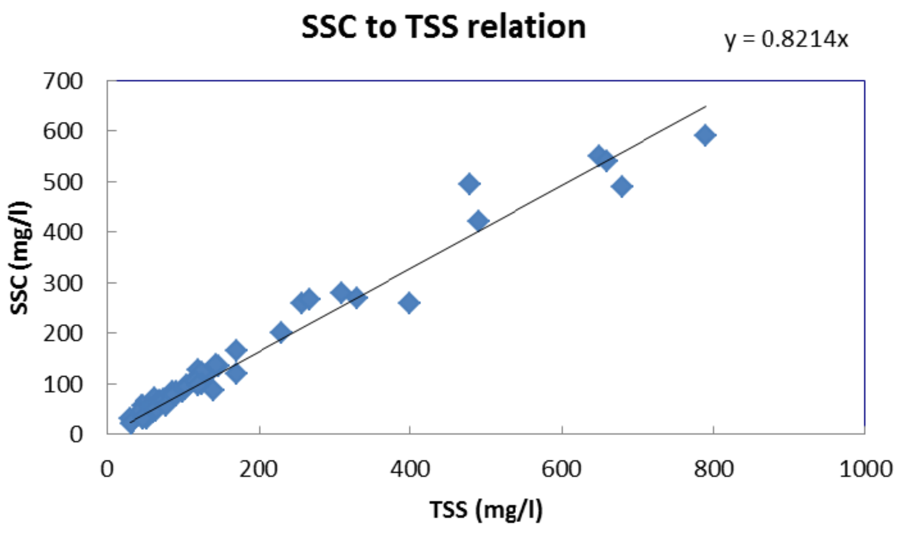


Figure 2.1: Relationship between sediment concentration measured using the SSC method versus the TSS method.

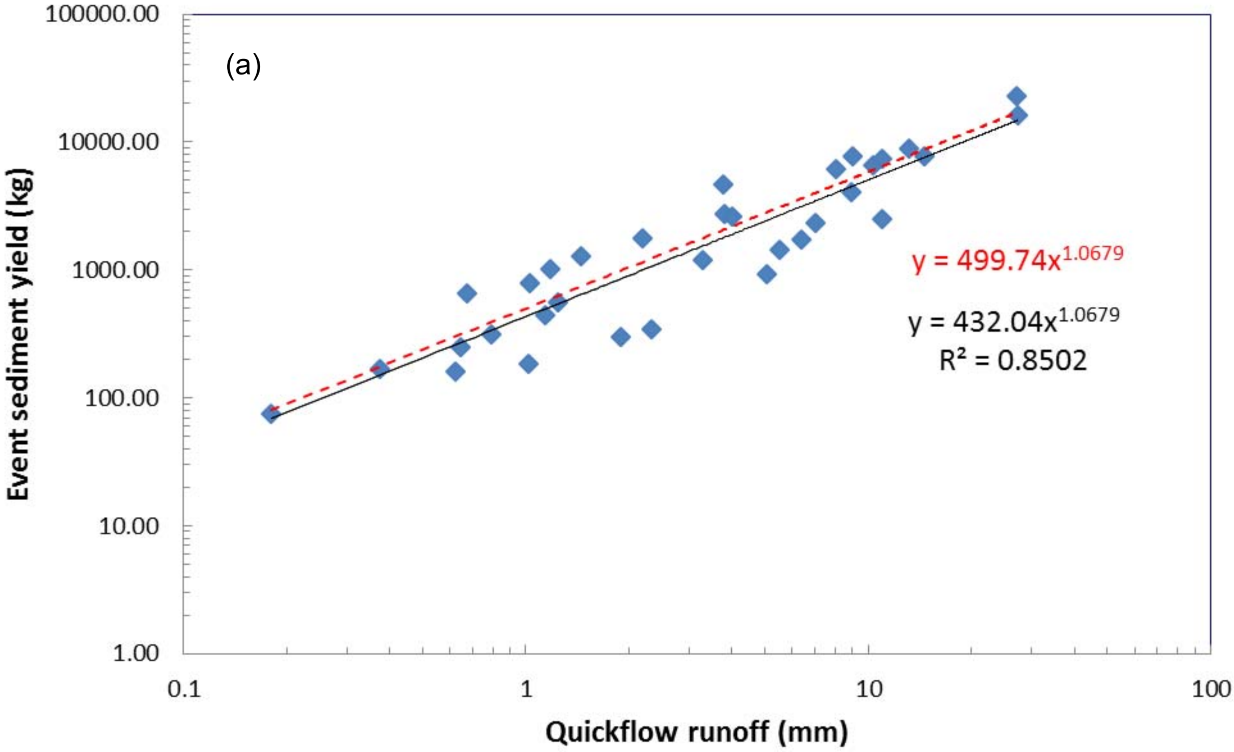
The C data was then inspected to assess the adequacy of the data for use in calculating event sediment yields. The data were generally patchy, both in terms of there being gaps in the data (i.e., not all runoff events were sampled) and in terms of data quality (e.g., too few samples during a runoff event). Accordingly, the strategy was 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 event quickflow runoff) which could then be used to patch gaps in the record of event yields.

With this strategy, the first step is to identify individual storms with sufficient C data. The next step is to add synthetic C data points to the beginning and end of these storm events, as the autosamplers usually miss sampling these. If we did not add these synthetic values the TIDEDA software used could interpolate high C values between adjacent events. The C values assigned to the start and end of events were based on an appreciation of the typical concentrations at the tails of storm events. This value tended to be around 10 mg/l.

The times for the beginning and end of events 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), the Weiti hydrograph was examined to assess a typical quickflow separation slope. A minimum value of quickflow runoff of 1 mm was set 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 sediment yield over discrete events was then computed by direct integration of the C and flow records using the PSIM (Process SIMulate) module of the TIDEDA (Time Dependent Data) hydrological software package. The PSIM module was also used to extract various hydrological measures of each event, including the peak discharge and quickflow runoff. This provided event yields for 33 discrete events.

The event sediment yields (in kg) were then plotted against quickflow runoff (in mm) (Figure 2.2a) and peak discharge (in l/s) (Figure 2.2b) to establish which of these would provide the statistically strongest rating relationship. The storm sediment yields were found to correlate best with the quickflow runoff, with the relationship represented best by a power-law regression (Figure 2.2a). The power-fit regression was adjusted for bias using the bias-correction factor of Duan (1983).



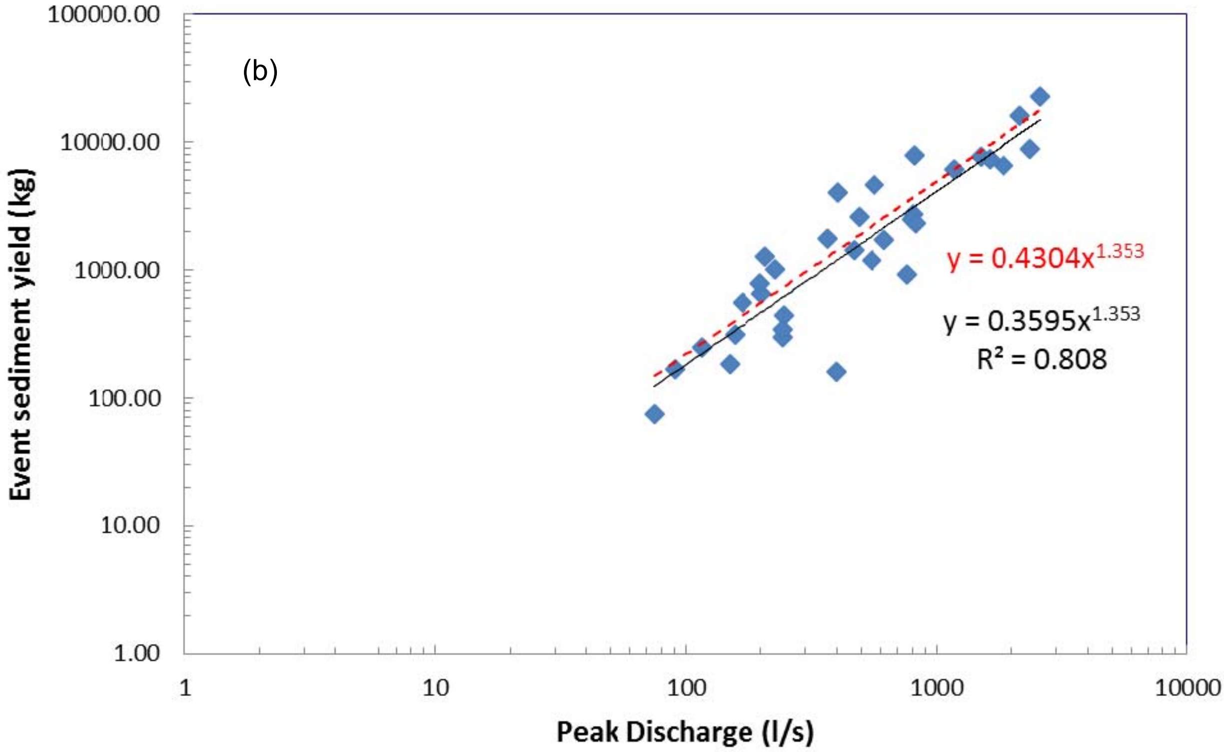


Figure 2.2: Plot showing relationship between a) event sediment yield and quickflow runoff and b) event sediment yield and peak discharge. The non-bias corrected trend lines and functions are shown in black and the bias-corrected functions and trendlines are shown in red. The bias corrected relationship for the quickflow relationship has a standard factorial error-of-the-estimate of 1.79 and for the peak discharge relationship has a standard factorial error-of-the-estimate of 1.94.

Inspection of the residuals of the event yield rating plot in log-log space (i.e., log of observed event yield minus log of predicted event yield, or log of the ratio of observed to predicted yield) showed that the residuals were homoschedastic (i.e., the scatter was of similar magnitude irrespective of quickflow). The residuals were also tested for a time-trend using the Student's t test. This tests the hypothesis that the coefficient on a linear relation between log (observed/predicted event yield) and time is significantly different from zero at the 5% significance level (Figure 2.3). This test confirmed that there is a significant time trend in the residuals. This means that, if anything, we might be slightly underestimating event yields assuming this time trend continues.

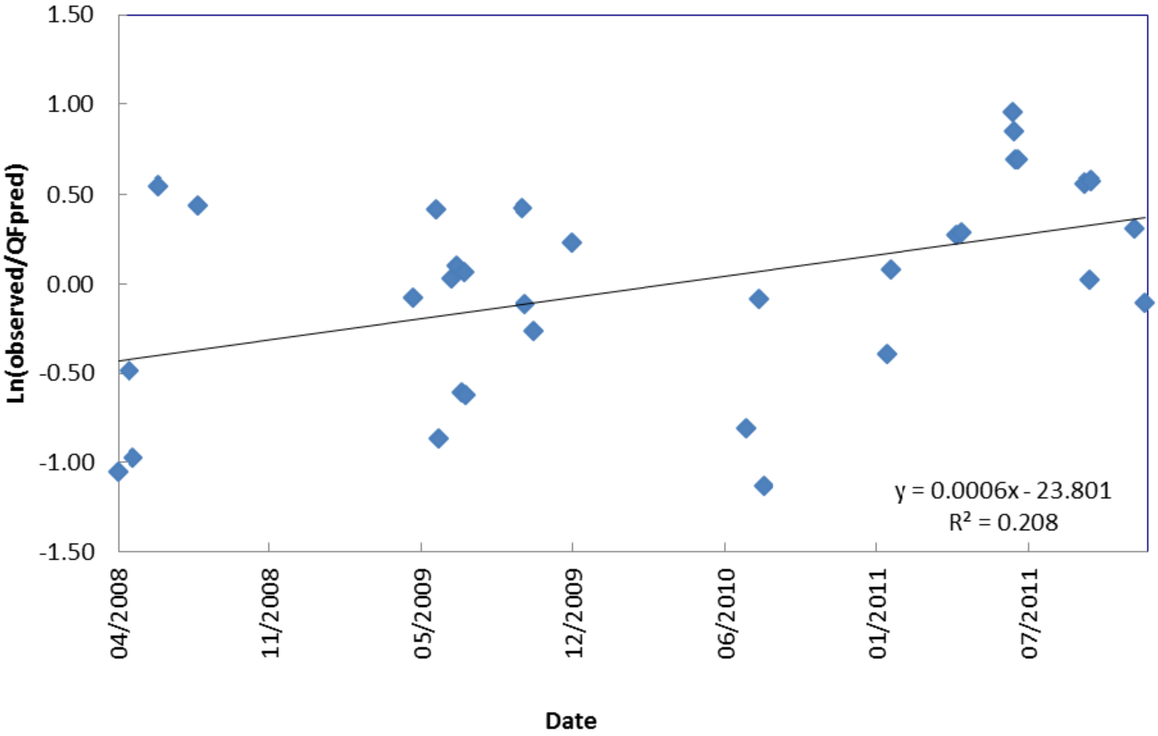


Figure 2.3: Plot of bias-corrected event yield residuals (based on quickflow rating) over time to assess whether there is a time trend in the quickflow rating relationship. A Student's t test showed that there is a significant trend with time at the 5% level (t statistic of 2.85, p of 0.007).

The sediment yields for all events occurring over the duration of the flow record were then computed from the bias corrected event yield vs. quickflow rating relationship using the PSIM module of the TIDEDA hydrological software package. This provided event yields for 74 events in total. These data were used to fill the gaps for the 41 events that had been missed by the sediment concentration monitoring.

2.2 Rainfall statistics

The next step in this investigation was to calculate a series of rainfall-based parameters that could potentially be used to predict event sediment yield given a rainfall forecast. These calculations were based on the 15 minute rainfall data supplied by AC. These rainfall data were converted to hourly intensities as these are the intensities that would be provided by rainfall forecasts. The parameters calculated are as follows:

Total event rainfall, P (mm) – summed from the start to the end of the rainfall event. Where the start and end of the event were unclear, a judgement was made based on quickflow (i.e., the start of the rainfall events tended to be approximately 2 hours before the start of quickflow).

Maximum hourly rainfall intensity, I_{60} (mm/hr) – the 15 minute rainfall data were summed to give hourly totals (equating to hourly intensities) and the maximum intensity occurring between the start and end of rainfall was assigned to I_{60}.

Average hourly rainfall intensity, I_{avg} (mm/hr) – the hourly intensities were averaged for each rainfall event.

2nd moment of rainfall intensity, SP2 $(mm/hr)^2$ – the hourly intensities were squared and these values were summed for each event.

3rd moment of rainfall intensity, SP3 $(mm/hr)^3$ – the hourly intensities were cubed and these values were summed for each event.

Storm rainfall total energy/unit area, E (J/m^2) – calculated and summed across the rainfall event as follows:

$$E = \sum E_m . I . \Delta t$$

Where I is the hourly intensity (mm/hr), Δt is the time increment (hr) and E_m is based on the relation of Wischmeier and Smith (1958):

$$E_m = 11.9 + 8.7 \log_{10} I$$

Storm rainfall total energy x maximum hourly intensity, EI_{60} $(J.mm/m^2.hr)$

Antecedent rainfall, APi (mm) – where i is the number of days prior to the start of the rainfall event over which rainfall is summed. We calculated AP_7, AP_{14}, AP_{30}, AP_{55} and AP_{60} to see which has the strongest relationship with event yield.

Antecedent baseflow, AQi (m^3/s) - where i is the number of hours prior to the start of the rainfall event over which flow is averaged. We calculated AQ_{12}, AQ_{24}, and AQ_{48} to see which has the strongest relationship with event yield.

2.3 Magnitude-frequency relationships

The full series of 74 event sediment yields, calculated as described in section 2.1, were used to produce event sediment yield magnitude-frequency plots, using a standard return period (T) partial duration series approach. The return period was also rescaled to the extreme value (yT) scale, as past experience has indicated event sediment yields are often linearly related to yT. The two magnitude-frequency distributions, T and yT, were plotted against event yield to see which fitted the data best.

For the standard return period series the events are ranked and the return period (T, yrs) is calculated from the span of data (in years) divided by the rank of the event. For the extreme event series, yearly return periods are converted to monthly return periods (T' = 12T) and the extreme value parameter (yT) is calculated as follows:

$$yT = -\ln\left(-\ln\left(1 - \frac{1}{T'}\right)\right)$$

The magnitude-frequency distribution which fitted the data best was the standard return period series, T (see section 3.3). This distribution was used to calculate the event sediment yields that could be expected over the 3 year period of harvest, providing predicted event yields for the 1 month, 3 month, 6 month, 1 year, 3 year and 5 year return periods.

3.0 Results

3.1 Event sediment yields

The sediment yields for the storm events that occurred during the period of flow monitoring in the Weiti catchment are presented in Table 3.1. The total sediment yield from storms over the monitoring period was 209.4 t, which equates to a specific sediment yield of 29.7 t/km^2/yr.[1]

Table 3.1: Event sediment yields for the Weiti catchment between 14/4/2008 and 7/6/2012. Note event numbers marked with a * are those events missed by the sediment monitoring so have been predicted based on the quickflow rating relationship.

Event no.	Event start date	Event yield (kg)	Event no.	Event start date	Event yield (kg)	Event no.	Event start date	Event yield (kg)
1	15/04/2008	298	26	3/10/2009	443	51*	26/05/2011	3231
2	29/04/2008	160	27	15/10/2009	1185	52*	10/06/2011	1579
3*	1/05/2008	648	28	4/12/2009	6589	53*	17/06/2011	3154
4	4/05/2008	923	29*	21/05/2010	1654	54*	18/06/2011	1078
5	8/06/2008	7824	30*	24/05/2010	1394	55*	25/06/2011	608
6*	16/06/2008	1129	31*	28/05/2010	1626	56*	28/06/2011	520
7*	22/06/2008	3686	32*	1/06/2010	3036	57	8/07/2011	4642
8*	28/06/2008	794	33*	25/06/2010	1311	58	10/07/2011	660
9*	26/07/2008	7532	34*	5/07/2010	4202	59	11/07/2011	1020
	29/07/2008	22704	35	21/07/2010	2493	60	14/07/2011	1277
11*	12/08/2008	532	36*	23/07/2010	1169	61*	21/07/2011	707
12*	13/08/2008	999	37	7/08/2010	311	62*	22/07/2011	6339
13*	15/08/2008	978	38	13/08/2010	344	63	10/10/2011	1752
14*	16/08/2008	855	39*	7/09/2010	565	64*	13/10/2011	926
15*	24/08/2008	4551	40*	16/09/2010	922	65	17/10/2011	557
16*	28/02/2009	785	41*	19/12/2010	1072	66	19/10/2011	793
17	10/05/2009	250	42	23/01/2011	2324	67*	1/11/2011	940
18	9/06/2009	6098	43	28/01/2011	16061	68	14/12/2011	2593
19	12/06/2009	184	44*	21/03/2011	6341	69	29/12/2011	4020
20	28/06/2009	7789	45*	26/03/2011	1107	70*	30/12/2011	2328
21	4/07/2009	168	46*	16/04/2011	559	71*	15/02/2012	1890
22	11/07/2009	1713	47	25/04/2011	8896	72*	11/03/2012	2206
23	14/07/2009	74	48	2/05/2011	7449	73*	19/03/2012	10662
24	17/07/2009	1427	49*	7/05/2011	1072	74*	21/03/2012	6203
25	29/09/2009	2759	50*	11/05/2011	1777			

[1] This value is substantially less than the specific annual sediment yields by Hicks et al. (2009) (ranging from 66.1 - 90.7 t/km^2/yr depending on the method used). However in 2009 there was only 0.56 yrs of monitoring data available and calculations were based on uncorrected TSS-C data, which this investigation shows would overestimate C.

3.2 Calculating event yields from rainfall forecast

The first step in this analysis was to calculate potential driving parameters from rainfall data. The results of these parameters for each event are presented in Table 3.2.

Table 3.2: Potential hydrological driving parameters for the storm events during the monitoring period. Note event numbers relate to the event yields presented in Table 3.1. Event numbers marked with a * are those events missed by the sediment monitoring and are therefore predicted based on the quickflow rating. Abbreviations defined in section 2.1.

Event no.	Start of rain	End of rain	P (mm)	I_{60} (mm/hr)	I_{avg} (mm/hr)	SP2 $(mm/hr)^2$	SP3 $(mm/hr)^3$	E (J/m^2)	EI_{60} $(J.mm/m^2.hr)$	AP_{60} (mm)	AQ_{48} (m^3/s)
1	15/04/2008 7:40	15/04/2008 16:10	34.5	9	4.06	200	1357	627	5639	15	0.020
2	28/04/2008 23:40	29/04/2008 6:40	22	8	3.14	110	687	381	3046	71	0.002
3*	1/05/2008 4:55	1/05/2008 10:25	17	5	2.83	66	286	282	1408	118	0.052
4	4/05/2008 10:55	5/05/2008 2:25	42.5	8.5	2.74	222	1427	742	6307	142	0.010
5	7/06/2008 23:10	8/06/2008 3:25	13.42	5.96	3.16	58	290	227	1350	239	0.002
6*	16/06/2008 6:40	16/06/2008 22:55	30.36	4.96	1.76	89	331	464	2302	201	0.002
7*	22/06/2008 3:55	22/06/2008 10:40	36.71	14.88	5.24	322	3791	709	10546	238	0.007
8*	28/06/2008 0:10	28/06/2008 11:10	15.4	3.97	1.28	37	110	226	898	321	0.069
9*	26/07/2008 4:25	27/07/2008 0:40	49.66	6.44	2.36	180	817	803	5171	329	0.043
10	29/07/2008 10:25	30/07/2008 7:55	69.99	10.4	3.26	365	2395	1231	12798	387	0.114
11*	12/08/2008 0:25	12/08/2008 10:40	17.5	5.5	1.59	60	253	279	1536	497	0.033
12*	13/08/2008 5:55	13/08/2008 11:40	9.5	3	1.58	23	62	139	418	516	0.057
13*	14/08/2008 11:40	15/08/2008 5:40	19	8	2.71	94	618	322	2576	531	0.106
14*	16/08/2008	16/08/2008	10	5	1.67	34	144	158	789	530	0.104

Event no.	Start of rain	End of rain	P (mm)	I_{60} (mm/hr)	I_{avg} (mm/hr)	SP2 $(mm/hr)^2$	SP3 $(mm/hr)^3$	E (J/m^2)	EI_{60} $(J.mm/m^2.hr)$	AP_{60} (mm)	AQ_{48} (m^3/s)
	0:10	5:40									
15*	23/08/2008 17:40	24/08/2008 12:40	34.5	7.5	1.73	134	741	548	4111	497	0.040
16*	27/02/2009 19:55	28/02/2009 10:40	50.14	11.31	3.34	310	2475	903	10207	128	0.000
17	9/05/2009 22:55	10/05/2009 4:55	17.06	10.92	2.84	132	1332	313	3422	133	0.010
18	9/06/2009 1:25	10/06/2009 6:40	71.5	15.5	13.62	391	4183	1202	18627	213	0.001
19	12/06/2009 11:10	12/06/2009 21:25	17	4.5	1.66	46	154	255	1149	286	0.045
20	28/06/2009 3:40	29/06/2009 0:10	60.5	17	2.95	528	6599	1148	19513	306	0.007
21	4/07/2009 12:40	4/07/2009 18:25	6.82	2.93	1.19	18	50	102	299	349	0.015
22	11/07/2009 7:55	12/07/2009 1:55	34.64	5.35	1.92	99	382	522	2795	313	0.011
23	14/07/2009 18:25	14/07/2009 22:25	7.32	6.34	1.83	41	255	129	816	334	0.030
24	17/07/2009 17:25	18/07/2009 7:55	30.19	6.32	2.08	114	518	489	3091	344	0.029
25	29/09/2009 13:10	29/09/2009 19:40	30.98	15.98	4.77	354	4832	636	10168	176	0.006
26	3/10/2009 6:25	3/10/2009 19:40	11.09	5.32	0.84	35	161	167	890	204	0.018
27	14/10/2009 23:55	15/10/2009 18:40	34.08	6.72	1.82	132	650	556	3736	214	0.004
28	3/12/2009 23:55	4/12/2009 20:55	93.78	19.16	4.47	980	14142	1830	35067	133	0.002

Event no.	Start of rain	End of rain	P (mm)	I_{60} (mm/hr)	I_{avg} (mm/hr)	SP2 $(mm/hr)^2$	SP3 $(mm/hr)^3$	E (J/m^2)	EI_{60} $(J.mm/m^2.hr)$	AP_{60} (mm)	AQ_{48} (m^3/s)
29*	20/05/2010 14:25	21/05/2010 14:40	111	12	4.44	761	6176	2069	24834	79	0.126
30*	24/05/2010 0:25	24/05/2010 6:40	32.5	18	4.64	375	6049	644	11588	187	0.007
31*	27/05/2010 19:55	28/05/2010 5:40	27	8.5	2.70	122	774	451	3835	253	0.028
32*	31/05/2010 21:55	1/06/2010 12:40	44	8.5	2.93	215	1325	762	6474	283	0.071
33*	25/06/2010 5:10	25/06/2010 21:40	28.31	6.71	1.67	94	426	442	2968	380	0.006
34*	4/07/2010 13:25	5/07/2010 13:40	37.7	4.3	1.51	89	272	545	2345	414	0.109
35	21/07/2010 8:55	22/07/2010 5:55	46.29	7.15	2.20	184	946	753	5383	342	0.009
36*	23/07/2010 10:25	23/07/2010 16:40	11.46	4.29	1.64	31	103	173	742	354	0.159
37	7/08/2010 7:10	7/08/2010 23:10	15.54	2.92	0.97	23	44	200	584	275	0.036
38	13/08/2010 19:25	14/08/2010 13:10	24.76	3.4	1.39	52	130	352	1198	265	0.016
39*	6/09/2010 17:25	7/09/2010 13:25	21.2	3.3	1.01	37	83	272	897	274	0.011
40*	16/09/2010 4:25	16/09/2010 9:40	15.55	4.24	2.59	52	189	252	1067	311	0.021
41*	19/12/2010 8:40	19/12/2010 8:40	34.61	6.82	3.85	176	993	613	4177	104	0.013
42	22/01/2011 14:40	23/01/2011 13:25	90.5	15.5	3.98	816	9792	1731	26833	157	0.001
43	28/01/2011 12:25	29/01/2011 2:55	113.5	15.5	7.83	1187	14371	2301	35662	251	0.003

Event no.	Start of rain	End of rain	P (mm)	I_{60} (mm/hr)	I_{avg} (mm/hr)	SP2 $(mm/hr)^2$	SP3 $(mm/hr)^3$	E (J/m^2)	EI_{60} $(J.mm/m^2.hr)$	AP_{60} (mm)	AQ_{48} (m^3/s)
44*	21/03/2011 7:25	22/03/2011 2:55	81	19	3.86	998	16028	1647	31286	338	0.001
45*	25/03/2011 11:25	26/03/2011 15:40	28.5	3	0.98	48	94	383	1149	317	0.024
46*	16/04/2011 7:25	16/04/2011 17:40	27	8.5	2.45	154	1103	475	4042	253	0.002
47	24/04/2011 23:40	26/04/2011 2:25	75.5	21.5	27.45	723	11808	1401	30121	259	0.004
48	1/05/2011 19:55	2/05/2011 14:25	20.5	4	1.11	46	131	293	1173	350	0.015
49*	7/05/2011 0:55	7/05/2011 3:40	15	7.5	5.00	85	529	273	2048	341	0.043
50*	11/05/2011 6:55	11/05/2011 23:40	26.5	7	1.56	88	439	408	2854	358	0.021
51*	26/05/2011 3:55	26/05/2011 16:40	40	6	3.08	173	840	679	4075	277	0.007
52*	10/06/2011 0:40	10/06/2011 18:40	29.1	5.42	1.53	79	289	433	2349	323	0.011
53*	17/06/2011 19:10	18/06/2011 7:40	36.49	16.27	2.80	337	4656	688	11189	320	0.011
54*	18/06/2011 14:10	18/06/2011 18:40	14.8	7.4	2.96	97	670	277	2050	357	0.090
55*	25/06/2011 16:10	26/06/2011 5:40	13.8	2.96	0.98	24	51	186	552	329	0.076
56*	28/06/2011 16:40	29/06/2011 1:55	9.37	2.46	0.85	12	22	115	284	334	0.063
57	8/07/2011 0:40	8/07/2011 13:25	25.32	6.82	1.99	94	466	407	2775	276	0.021
58	10/07/2011 3:55	10/07/2011 14:40	4.39	1.95	0.41	8	15	61	118	302	0.056

Event no.	Start of rain	End of rain	P (mm)	I_{60} (mm/hr)	I_{avg} (mm/hr)	SP2 $(mm/hr)^2$	SP3 $(mm/hr)^3$	E (J/m^2)	EI_{60} $(J.mm/m^2.hr)$	AP_{60} (mm)	AQ_{48} (m^3/s)
59	11/07/2011 20:10	12/07/2011 7:25	11.69	2.93	1.04	22	50	163	477	281	0.052
60	14/07/2011 9:10	14/07/2011 22:10	14.12	3.41	1.09	32	86	201	687	298	0.056
61*	21/07/2011 7:40	21/07/2011 21:10	15.09	8.28	1.00	76	578	242	2007	309	0.025
62*	22/07/2011 2:25	23/07/2011 7:10	36.52	6.33	1.22	138	661	588	3725	324	0.072
63	10/10/2011 16:25	10/10/2011 22:25	16.65	6.36	2.78	61	301	267	1699	143	0.002
64*	12/10/2011 21:55	13/10/2011 8:55	16.65	8.81	1.39	85	692	268	2364	161	0.022
65	17/10/2011 20:10	18/10/2011 1:40	17.14	3.92	3.12	53	178	275	1078	166	0.017
66	19/10/2011 2:25	19/10/2011 20:25	17.14	2.94	0.95	29	59	226	666	184	0.047
67*	1/11/2011 13:10	1/11/2011 20:55	29.38	15.67	3.26	295	4086	567	8884	191	0.008
68	14/12/2011 17:25	15/12/2011 17:10	62.71	6.42	2.64	202	816	993	6377	148	0.004
69	29/12/2011 16:55	30/12/2011 11:25	8.5	7.41	0.46	211	1108	837	6200	200	0.004
70*	30/12/2011 15:10	31/12/2011 10:40	30.12	4.44	1.5	70	204	439	1948	249	0.086
71*	15/02/2012 0:40	15/02/2012 13:55	37.55	660.88	2.5	215	1604	10	6278	201	0.003
72*	11/03/2012 21:25	12/03/2012 1:25	28.72	8.42	5.74	212	1706	549	4627	163	0.006
73*	18/03/2012 23:25	20/03/2012 9:40	85.17	6.43	2.43	288	1152	1369	8802	181	0.005

Event no.	Start of rain	End of rain	P (mm)	I_{60} (mm/hr)	I_{avg} (mm/hr)	SP2 $(mm/hr)^2$	SP3 $(mm/hr)^3$	E (J/m^2)	EI_{60} $(J.mm/m^2.hr)$	AP_{60} (mm)	AQ_{48} (m^3/s)
74*	21/03/2012 13:55	21/03/2012 20:40	32.19	10.4	4.60	215	1712	598	6217	269	0.249

Relationships between event sediment yields and the rainfall-based driving parameters presented in Table 3.2 were examined in two ways: firstly by plotting event yield versus each of the rainfall parameters to examine the strength of individual relationships (e.g., Figure 3.1), and secondly by multiple regression analysis.

The relationships between event yields and the individual hydrological parameters were all relatively weak. The strongest of these was with total event rainfall (Figure 3.1).

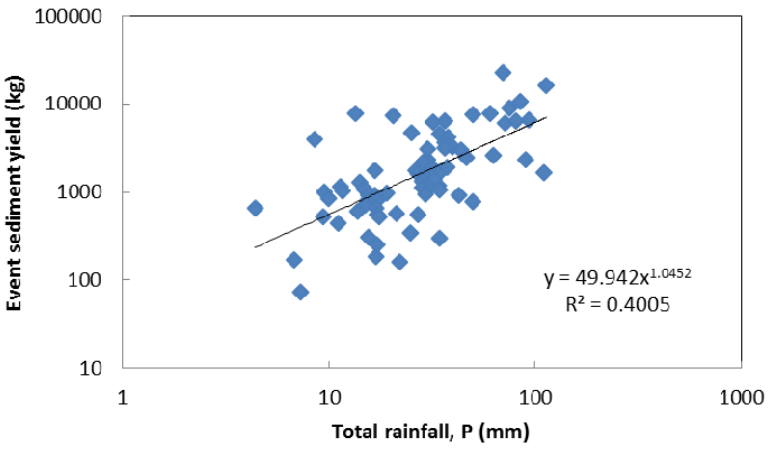


Figure 3.1: Relationship between event sediment yield and total event rainfall. This relationship is significant at the 1% level.

The multiple regression analysis found that predictive relationships could be strengthened by incorporating several additional parameters. The strongest multiple regression model, with an adjusted R^2 of 0.51 and a standard factorial error of 2.24, is:

$$\text{Event Yield} = 0.0534 \times AP_{60}^{\,0.887} \times EI_{60}^{\,0.674}$$

The plot of observed event sediment yield against the event sediment yield predicted by the above multiple regression model is presented in Figure 3.2. We recommend that this model be used to predict event yields from a forecast rainfall record.

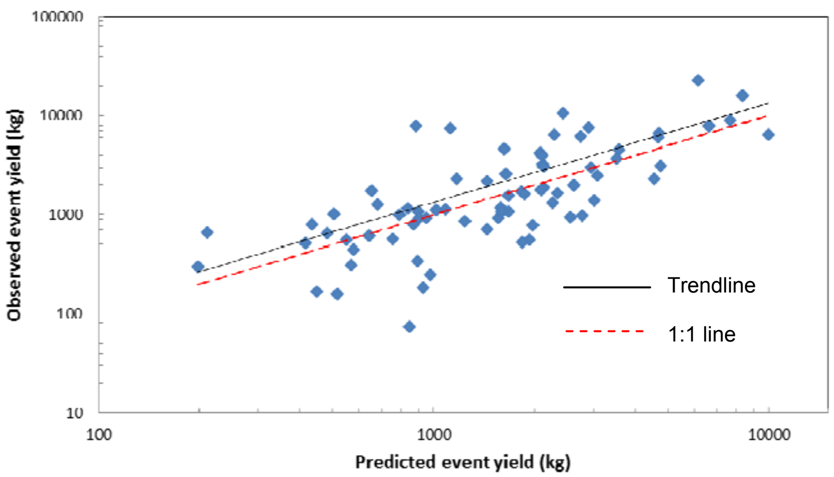


Figure 3.2: Observed event sediment yield plotted against the event sediment yield predicted by the multiple regression model. The multiple regression relationship is significant at the 4% level.

3.3 Event yield magnitude-frequency relations

The magnitude-frequency distribution which fitted the data best was the standard return period series, T (yrs). This distribution was used to calculate the size of event sediment yields that could be expected over the 3 year period of harvest, providing predicted event yields for the 1 month, 3 month, 6 month, 1 year, 3 year and 5 year return periods. These data are presented in Table 3.3. These data provide an initial estimate of event yields during the harvesting period assuming no change in sediment supply and delivery from the baseline conditions. Clearly, if such changes do occur – as should be detected by the monitoring instrumentation - then the magnitude-frequency relation will need to be updated.

Table 3.3: Return periods of event sediment yields for the Weiti Forest harvest period.

Return Period	Event sediment yield (t)
5 year	26.87
3 year	19.03
2 year	15.48
1 year	8.71
6 month	7.17
3 month	4.09
1 month	0.93

4.0 Summary and Conclusions

Event sediment yields were calculated for the 74 storm events occurring during the 4.15 year period of flow monitoring in the Weiti Forest catchment. The sediment yield delivered by these events ranged from 0.7 – 22.7 t. The total sediment yield from storms over the monitoring period was 209.4 t, equating to a specific sediment yield of 29.7 t/km^2/yr.

Rainfall-based hydrological parameters were calculated for each of the storm events in the monitoring period and these were each assessed to see which were the best potential predictors of event sediment yield. The best prediction model was based on a multiple regression incorporating the 60 day antecedent rainfall and the product of the total event rainfall energy and the maximum event rainfall intensity. This multiple regression relationship is: Event Yield = $0.0534 \times AP_{60}^{0.887} \times EI_{60}^{0.674}$.

The event sediment yield magnitude-frequency analysis provided an estimate of the minimum event sediment yields that could be expected over the 3 year period of harvest (i.e. the 1 month, 3 month, 6 month, 1year, 2 year, 3 year and 5 year return period events).

The results provided in this report are generated from baseline data collected in the pre-harvest period. An additional benefit of this work is that the relationship derived between event sediment yield and rainfall driving parameter will be able to be used as a baseline relationship that should - when over-plotted with data collected during the harvesting period - provide an immediate indication of gross increases in sediment yields as a consequence of forest harvesting.

5.0 Acknowledgements

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