NIWA
Taihoro Nukurangi

NIWA Project: WPL13501

25 February 2014

Westpower Ltd
PO Box 375
Greymouth

Attention: Sue Cotton

Dear Sue

Suspended sediment in the Waitaha River at Kiwi Flat

This letter adds to my report of July 2013 (Hicks 2013a) and letter of 13 December 2013 (Hicks 2013b) by assessing suspended sediment characteristics in the Waitaha River and also suggesting an approach to monitor fine sediment accumulation between Morgan Gorge and the power station discharge point during scheme operations.

Suspended sediment concentrations and loads in the Waitaha River

Objectives. As detailed in Hicks (2013a), the Waitaha sediment investigation included collecting one year of turbidity data from the upstream end of Kiwi Flat and calibrating this to suspended sediment concentration (SSC) with grab-samples collected on-site during a runoff event. This record would be analysed to understand the SSC dynamics during the recessions of floods and freshes, to learn how rapidly the river cleans up on recessions and what the SSC is likely to be in residual flows below the take point, and to estimate the suspended sediment load at Kiwi Flat.

Turbidity Data. A telemetered, solar-powered WTW turbidity sensor was installed by NIWA field staff at the upstream end of Kiwi Flat on 25 June 2013. The sensor ran properly for two weeks, collecting data from several runoff events, before losing power through lack of solar re-charging. Despite installing a larger solar panel, the WTW sensor and Neon telemetry system has returned unsatisfactory results. Given the remote location, we decided it was expedient to install a second sensor of a different type (a DTS-12, manufactured by Forest Technology Systems). This was installed on 12 November and has operated satisfactorily since. Matching flow records at the same location are provided by Martin Doyle. At the time of this analysis, Martin had not processed flow data beyond early November 2013, so concurrent records of flow and turbidity were only available for the short record from June-July 2013. For this reason, it was decided to also analyse the turbidity record collected from the same location by Martin Doyle between 14 March and 27 December 2010. While this sensor (manufactured by Greenspan, with a range of 0-2000 NTU) was installed above the baseflow water level (its purpose was to collect data during freshes and floods), and so provided no information on baseflow turbidity such as might relate to diurnal inputs of sediment from glacial melt, it was at least accompanied by a flow record.

SSC data for calibration. To date, no water samples have been collected from the Waitaha at Kiwi Flat during runoff events and analysed for SSC. In the interim, relationships between

SSC and turbidity from the nearby Amethyst catchment are considered (Hicks 2008). The Amethyst data showed two relationships: when the suspended load was dominated by silt-grade sediment, there was a 1:1 ratio between SSC (mg/l) and turbidity (NTU); however, with a sand-dominated suspended load the ratio was 6 mg/l sediment per 1 NTU. My experience at other sites shows that typically the SSC: turbidity ratio is in the range 1-2, due to a prevalence of silt and clay in the suspended load. For this assessment I have assumed a 1:1 ratio for the Waitaha. If anything, this will underestimate the true SSC, but it will be reasonably indicative of the concentration of silt which, based on my field observations, is the typical grade of sediment that collects in the littoral zone (e.g., Figure 2-5 of Hicks 2013a). When calculating suspended sediment load, a factor also needs to be applied to convert the bank-side point SSC at the turbidity sensor to the cross-section average concentration. This factor depends on the degree of mixing which relates to the sediment size grading, the flow rate, and channel characteristics. Typically, mixing is good (factor close to 1) at high flows but less-so at lower flows (factor greater than 1). A representative value for this factor is 1.3, based on data I have collected in the Motueka catchment.

Flow data. Martin Doyle has provided a 40 year record of the Waitaha flow into the top end of Kiwi Flat, spanning the period 1 April 1973 to 30 August 2013. Until 26 March 2006, this was derived from flow records in the nearby Hokitika and Whataroa Rivers (as detailed in Doyle 2013). Since then, the recorded Waitaha flow is used. Excluding gaps, the full record spans 39.97 years. As detailed below, this flow record was combined with suspended sediment rating functions to estimate annual average sediment loads into Kiwi Flat.

Turbidity dynamics at baseflows and during runoff events.

Diurnal variation. A time-series plot of the DTS-12 turbidity record collected between 12 November 2013 and 23 January 2014 was inspected for diurnal variation in turbidity during baseflow, which could indicate the effect of daytime glacial melt at the glaciers in the upper catchment. Periods of baseflow were difficult to isolate, given the frequency of runoff events. However, during the week of 14-19 November there was a weak diurnal signal (Figure 1), with a turbidity fluctuation of about ± 2 NTU around a daily average of 7-8 NTU, peaking in late afternoon – which is consistent with a melt signal allowing for travel time between the glaciers and Kiwi Flat. Higher frequency noise of about the same amplitude also occurs in the turbidity record, however, and appears to be an instrument sensitivity effect. No similar diurnal signal was observed during another week of low flow over 14-24 December. I conclude from this limited period of summertime observation that the Waitaha's turbidity at Kiwi Flat sometimes shows daily fluctuations that are probably due to daytime increase in melt of up-catchment glaciers, but often this effect is masked by higher turbidity values associated with runoff events and/or instrument noise. The amplitude of the diurnal signal suggests that a significant component of the baseflow turbidity stems from glacial melt (~ 25% for the observed week in November, although this is bound to vary depending on weather conditions and melt rates).

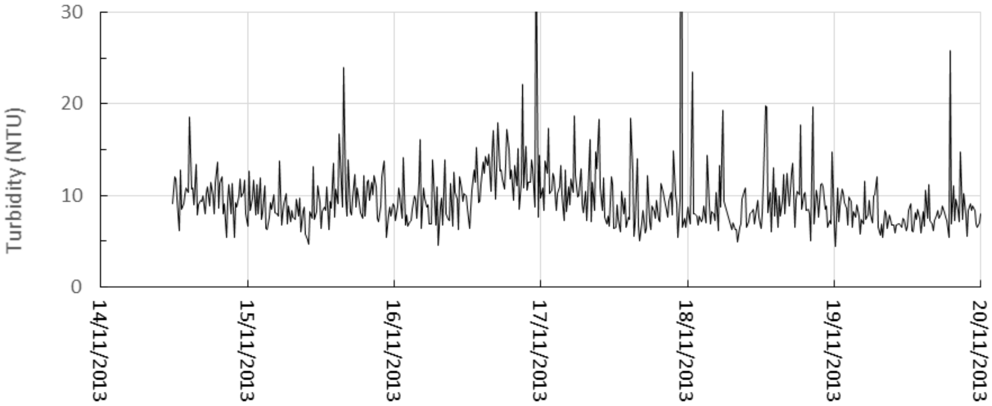

Figure 1: Diurnal variation underlying high-frequency 'noise' in baseflow turbidity at Kiwi Flat, mid November 2013.

Recession characteristics. The turbidity time-series plots also indicated the rate that turbidity (and SSC) declines on the recessions of runoff events. These showed that the durations of the turbidity event recessions were similar to those of the runoff recessions – that is, they typically fell rapidly to baseflow levels within about 24 hours of the last flow peak, thereafter were steady or declined much more slowly (Figure 2). For the events in June-July 2013 (from the WTW record), the turbidity recession could be approximated by the relation $T/T_o = e^{kt}$, where T is turbidity, T_o is a reference turbidity, t is time in days, and k = -4.6 days^{-1}. Thereafter, the decline rate is much lower (k ~ -0.4 days^{-1}). This indicates that the turbidity reduces by a factor of 100 over the first day until baseflow values are achieved, then declines by only a factor of 1/3 on subsequent days. Similar turbidity recession characteristics were observed in the turbidity record from November 2013 through January 2014 (DTS-12 sensor). Typical turbidity values during baseflows were in the range 20-35 NTU in January, while they were lower in June-July at ~ 8 NTU.

Thus, the Waitaha tends to clear-up quickly on event recessions but it maintains a small residual turbidity at baseflows that sometimes fluctuates on a daily basis, most likely due to fine suspended sediment sourced from glacial melt.

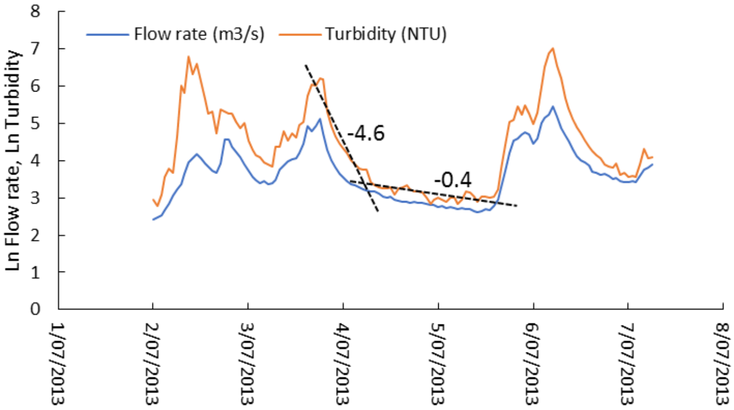

Figure 2: Turbidity and flow for June-July 2013. Note log-scale for vertical axis. Dashed lines indicate exponential decay trends.

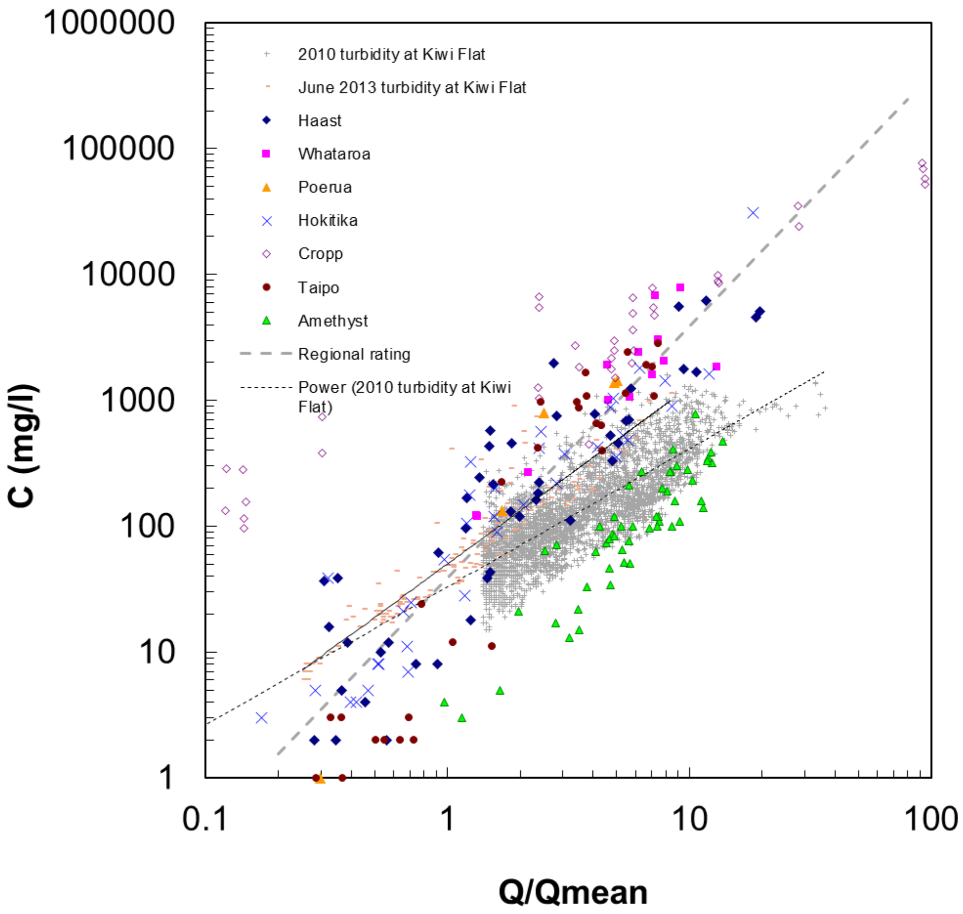

Figure 3: Relationship between SSC and normalised flow rate (flow rate divided by mean flow) for other Westland Rivers with 2010 and 2013 turbidity data from Waitaha River at Kiwi Flat superimposed (assuming 1:1 ratio of SSC to turbidity). Power-law regression models shown for (i) regional relationship using data from all other rivers except Amethyst and Cropp (dashed grey line); 2010 Kiwi Flat turbidity data (dotted black line); June-July 2013 Kiwi Flat turbidity data (solid black line).

Sediment rating relationships

Within-event and seasonal variation. The best indication of the Waitaha SSC vs flow rating relationship derives from the flow and turbidity records collected in 2010. This shows a very “noisy” relationship (Figure 3), with turbidity values at a given flow rate ranging over a factor of 10. While part of this scatter will be due to erroneous data (e.g., instrument noise, plant debris causing ‘spikes’ in the observed turbidity), a significant amount appears due to within-event hysteresis and a seasonal signal on sediment supply.

Event-scale hysteresis in the turbidity-flow relationship occurs both over individual runoff peaks and over multi-peak events. For example, Figure 4 shows a series of events during the first week in July 2013. The first event (3-4 July) shows a clockwise hysteresis loop (turbidity higher on rising stages). The subsequent event (4-5 July) shows an anti-clockwise hysteresis loop, while the third event (6-7 July) has no consistent hysteresis. Despite having larger peak flow rates, the latter events all plot lower than the first event - which suggests that there was more sediment available to the first event. Similar event-scale hysteresis patterns can be observed in the 2010 data. Overall, this indicates variability in SSC and suspended loads among events with similar flow rates, driven by space-time variability in sediment supply.

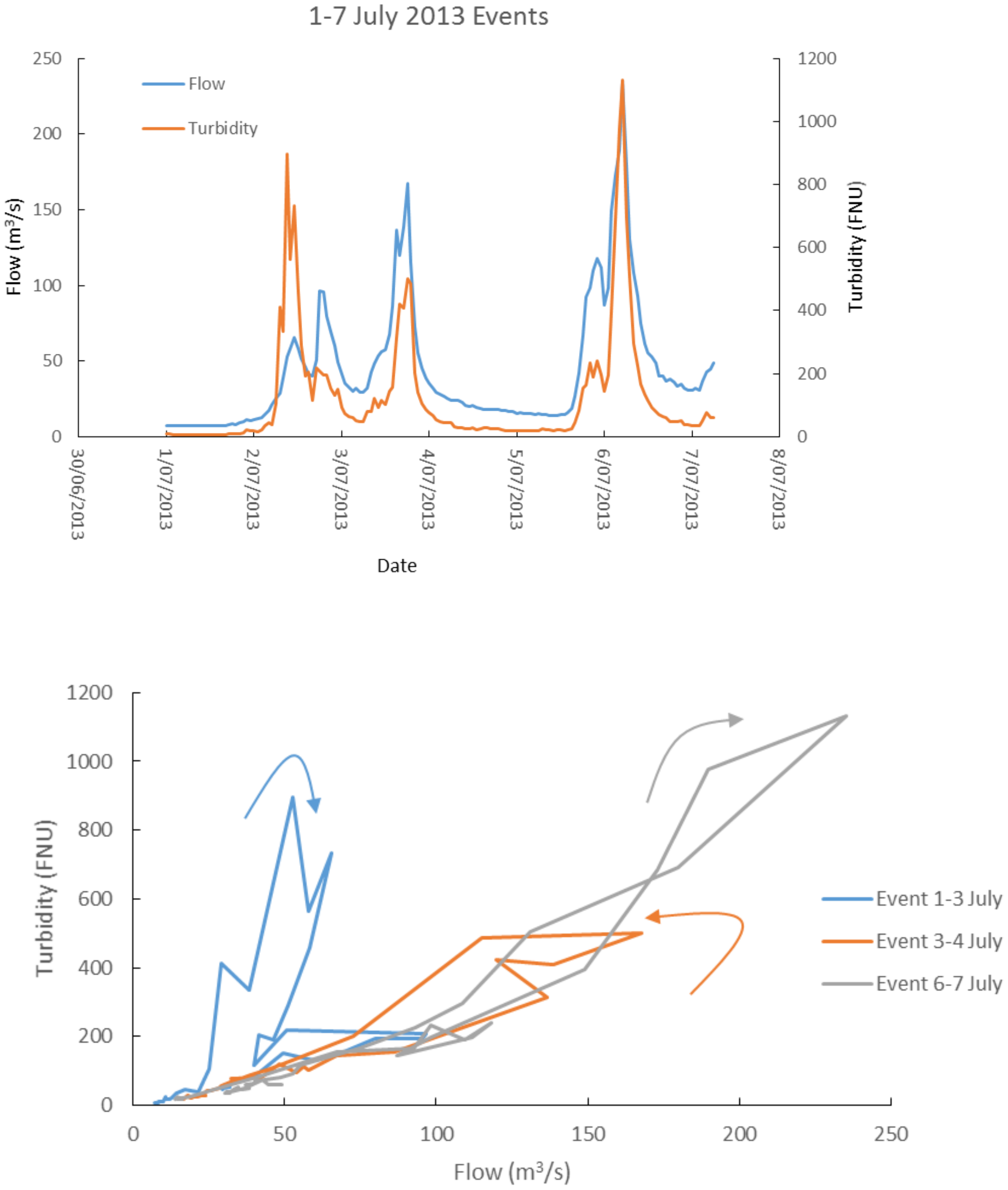

Figure 4: Relationship between turbidity and flow rate (lower plot) through a series of runoff events at Kiwi Flat during early July 2003 (upper plot). Arrows indicate time progression.

The 2010 data also show a significant seasonal shift in the turbidity vs flow rating (which I assume will translate to a seasonal shift in the SSC vs flow rating). This is demonstrated in Figure 5, where the December data plot generally higher than the April data, which plots above the August data. This likely relates to winter snow cover over high elevation sediment sources, which will usually be at its maximum in August. Power-model regression fits to these monthly datasets indicate that for a given flow rate, turbidity was on average three times higher in December than in August. This means that SSC vs flow sediment ratings should be derived from data representing all seasons – or else should be developed and applied on a seasonal basis.

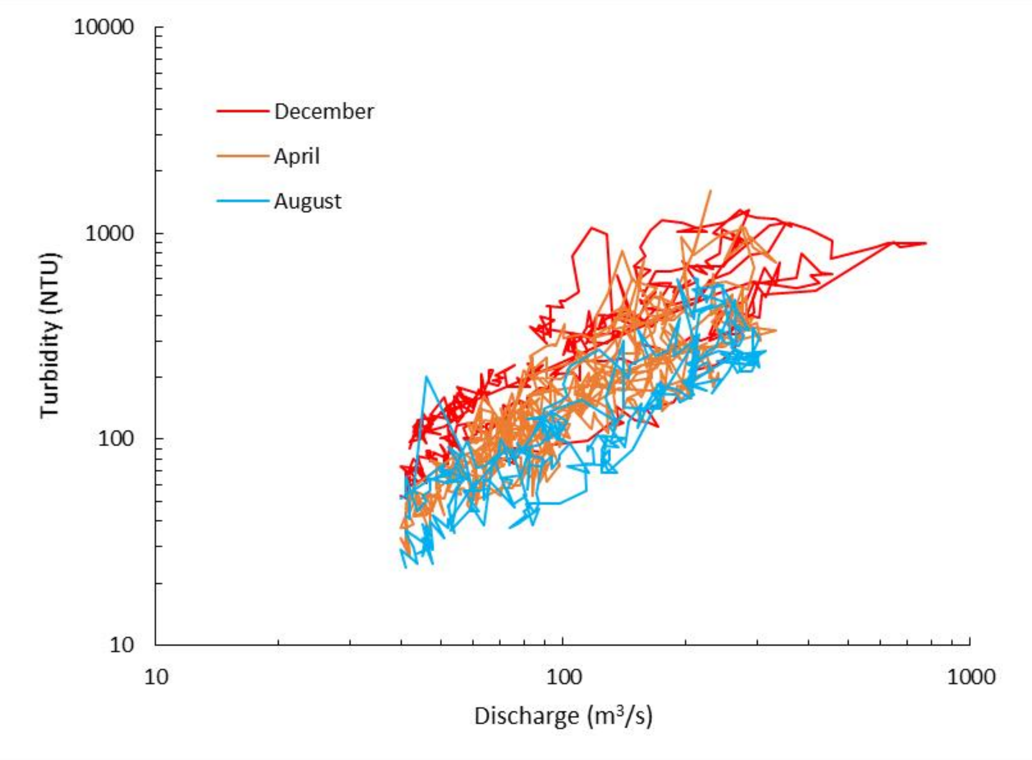

Figure 5: Turbidity vs flow rate relationship at Kiwi Flat for the months of April, August, and December 2010.

Average annual sediment loads. The mean annual suspended sediment load of the Waitaha at Kiwi Flat over the 40 years from 1973 to 2013 was calculated using three ratings (as plotted in Figure 2): a regional average rating (fitted to SSC data from the Whataroa, Haast, Hokitika, Poerua, and Taipo Rivers), a rating fitted to the 2010 Kiwi Flat turbidity data (assuming a 1:1 ratio between SSC and turbidity), and a rating fitted to the June-July 2013 Kiwi Flat turbidity data (again assuming a 1: 1 ratio). In the case of the turbidity based ratings, a 1:1 SSC to turbidity calibration is assumed, and a factor of 1.3 is assumed to convert to cross-section mean SSC. The derived mean annual loads are 1.15, 0.17, 0.47 Mt/yr, respectively. These equate to specific yields of 12800, 1830, and 5240 t/km^2/yr respectively (for a catchment area of 90 km^2). The range of these estimates is large, probably because of the assumed relationships between SSC and turbidity for the turbidity based ratings – thus it will be important to continue the effort to collect calibration data from Kiwi Flat. By comparison with the specific yields from nearby rivers (Hokitika, 5918 t/km^2/yr; Whataroa, 10136 t/km^2/yr; Haast, 4072 t/km^2/yr; Taipo 3637 t/km^2/yr – data from Hicks et al. 2011), the Kiwi Flat estimate based on the 2013 turbidity rating (5240 t/km^2/yr) is closest to the average of these rivers. Thus, I suggest using this figure as a working estimate but accepting that this may be in error by a factor of 2-3 until the turbidity records can be calibrated to SSC.

Monitoring fine sediment accumulation between the scheme weir and discharge point

In Hicks (2013a) I recommended that should the proposed HEP scheme proceed: (i) monitoring should include any fine sediment build-up in the channel between Morgan Gorge and the discharge point, and (ii) the intake design should include the facility to bypass the full baseflow if a flushing flow appears necessary from the sediment monitoring. Here, I expand on a recommended monitoring approach and what response this might trigger.

Any fine sediment build-up would be more likely to occur on channel margins (which is where turbulence fades), and would be similar to that observed during the low flow period of early 2013 (as illustrated in Figure 2-5 of Hicks 2013a). Generally, the frequent runoff events that typify the Westland climate will naturally inhibit such a build-up, but the risk will be higher during extended periods of baseflow. The suggested monitoring is simply visual inspection of the channel margins downstream from Morgan Gorge. Such inspections could be scheduled weekly during periods when more than, say, two weeks passes without a fresh in the river. If a build-up of sediment was noticed, then this could be flushed by temporarily returning the full river flow (minus any residual 'spinning' flow needed for the power station) to Morgan Gorge for several hours. It is assumed that the intake to the tunnel will be gated to enable this. The duration of the flush and the interval between flushes would best be established by trial and error. Given that the issue would develop during baseflow periods, the size of the flow available for flushing would not be large and could not be expected to be as effective as a natural fresh. Thus, this mitigation approach should be seen as an interim measure until subsequent freshes/floods arrive to do a more effective job.

Summary

- The Waitaha River at Kiwi Flat tends to clear-up quickly on event recessions but it maintains a small residual turbidity at baseflows that sometimes fluctuates on a daily basis, most likely due to fine suspended sediment sourced from glacial melt. This means that with the proposed power scheme operating, the steady residual flow in the river between Morgan Gorge and the point where the flow is returned will have typically low suspended sediment concentrations.

- Turbidity-flow relationships (and, by inference, SSC-flow relationships) in the Waitaha River at Kiwi Flat show considerable scatter within events, over series of events, and seasonally. This variability relates to sediment supply factors.

- Initial estimates of the mean annual suspended sediment load of the Waitaha River at Kiwi Flat range from 0.17 to 1.15 Mt/yr, depending on the source of data used for the sediment rating function. A working best estimate is 0.47 Mt/yr (5240 t/km^2/yr), but it should be accepted that this may be in error by a factor of 2-3 until the turbidity records can be calibrated to SSC.

- It is suggested that the channel margins downstream from Morgan Gorge and upstream from the return point are monitored visually for fine sediment build-up during extended periods of baseflow. If feasible from a design and operational viewpoint, any such build-ups could be flushed by passing most if not all of the full river flow through Morgan Gorge for several hours on an as-needed basis.

References

Doyle, M. (2013). The hydrology of the Waitaha Catchment. Report for Electronet Services Ltd, September 2013, 30 pp.

Hicks, D.M. (2008). Review and analysis of Amethyst River suspended sediment data. NIWA Client Report CHC2008-155 prepared for Mitton Electronet Ltd, November 2008, 15 pp.

Hicks, D. M. (2013a). Sediment investigations relating to a proposed HEP scheme on the Waitaha River. NIWA Client Report CHC2013-063 prepared for Westpower Ltd, June 2013, 25 pp.

Hicks, D. M. (2013b). Effects of proposed Waitaha HEP scheme on bed/channel stability. Letter from Hicks (NIWA) to Cotton (Westpower) dated 11 December 2013.

Hicks, D. M.; Shankar, U.; McKerchar, A.I.; Basher, L.; Jessen, M.; Lynn, I.; Page, M. (2011). Suspended sediment yields from New Zealand rivers. Journal of Hydrology New Zealand, 50(1): 81-142.

Yours sincerely

D M Hicks

D M Hicks
Principal Scientist
Sediment Processes
NIWA, Christchurch

+64-3-343 7872 (022 600 4831)
m.hicks@niwa.co.nz

Reviewed by

J Walsh