Hydro Tasmania

The power of natural thinking

Basslink Review Report 2006-12

Gordon River Basslink Monitoring Program

The Appendices

May 2013

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1. General conditions influencing the pattern of Tasmanian generation 2006-12

1.1 Summary of general influences

The commissioning of Basslink has given Hydro Tasmania greater flexibility in how the major storages are operated, however Basslink is just one of a number of variables that effects operation of storages such as Gordon. The increase in energy supply in Tasmania, with the addition of gas and wind along with the variability of the hydrological cycle, are significant influences on operations. Extended outages affect generating plant availability, and influence Hydro Tasmania's trading strategy and water storage policy.

Network constraints, energy demand, transmission outages, weather conditions and competitor behaviour across the NEM also influence the generation pattern in Tasmania. The majority of these influences are largely outside the control of Hydro Tasmania. Following are a number of conditions that have influenced the pattern of Tasmanian generation.

Across the National Electricity Market (NEM), a downward trend in peak and average electricity demand has become apparent over the last three years, resulting in a general decrease in price volatility (extreme price events). The introduction of the Carbon Tax in July 2012 has increased the marginal cost of base load coal generation, resulting in an increase in average electricity prices. Basslink effectively transfers these broader market influences into Tasmania. The Basslink Interconnector continued to assist management of run-of-river storages during high inflow periods and to capture arbitrage value during periods of market volatility.

High import capability on Basslink co-incident with average system yields permitted a strategy of filling discretionary (major) storages such as Great Lake and Gordon during 2010 and 2011 following the drought of prior years and leading into the carbon-priced period. Generation from Aurora Energy Tamar Valley's (AETV) Combined Cycle Gas Turbine has followed a base load profile over the last three years, which has assisted the storage build strategy.

Basslink has achieved the highest energy export since construction in the months since the Carbon Tax was introduced, primarily utilising increased Poatina generation.

Table 1.1: Summary of key energy statistics in Tasmania from 2006-12.

	HT Gen	System Yield	Basslink Export	Basslink Import	Basslink Net Flow	Wind Gen	AETV Gen
	GWh @Gen	% of LTA	GWh	GWh	GWh	GWh @ Gen	GWh @ Gen
2006 (from June)	5040	81 %	223	-1172	-949	145	17
2007	8229	90 %	594	-1879	-1285	159	26
2008	7017	84 %	67	-2722	-2655	441	28
2009	7952	113 %	530	-2111	-1581	487	616
2010	8900	110 %	1025	-1411	-386	463	1366
2011	8489	111 %	897	-1333	-436	470	1600
2012	9495	105 %	1806	-892	914	468	1601

Table 1.2: Electricity Demand statistics.

	Tasmania	NEM Total
	TWh	TWh
2006 (from June)	6.6	122
2007	10.7	208
2008	11.2	210
2009	10.9	208
2010	11.1	208
2011	11.0	205
2012	10.6	200

1.2 Annual influences

1.2.1 2006

Hydrology

The Hydro Tasmania system experienced an extreme low inflow year, and as a whole only received 70 % of its expected long-term average inflow. Inflows were the driest on record for Great Lake, Lake Echo and Mersey/Forth. Due to such a low inflow period, the major storages and associated power stations (Gordon and Poatina) were used more extensively to supplement the low yield.

Supply in Tasmania

In late April, Basslink was commissioned and until the end of 2006, there was over 900 GWh net of imported energy.

Bell Bay Power Station also generated over 500 GWh of energy during 2006.

Outages

The equivalent of at least one Gordon machine was out of service for 11 months of the year due to upgrade on number 1 and 2 machines in turn, and there was a complete Gordon Power Station outage for one week in October for intake inspection.

Tungatinah had a full station outage for 55 days starting in October.

Network constraints

This was the first year with a real physical connection to the NEM which provided Hydro Tasmania the opportunity of gathering real time experience regards Basslink operation and the impact of mainland network constraints on Tasmanian generation.

1.2.2 2007

Hydrology

This was a low inflow year, receiving only 78 % of long-term average inflow. Inflows during this period were so low, the major storages and associated power stations of Gordon and Poatina were again used more extensively to help maintain supply to the Tasmanian region of the NEM. Even with this low yield year there was a major flood event in early August, which impacted on small to medium storages, with nearly 300 mm of rain over three days.

In 2007 Lake Gordon started the year in a relatively higher position than Great Lake. This was for two reasons:

- for a large part of the previous year (2006), major refurbishment work was being carried out at Gordon Power Station which limited the output of the station during times it would normally be running three machines, and so allowed the storage to be greater relative to Great Lake; and
- the drought affected the Great Lake catchment more than others, resulting in Great Lake being forced down during 2007 to levels that raised serious environmental concerns. This limited the output from Great Lake to less than would normally be expected in a dry year. As a result, operation during 2007 was biased towards the use of Gordon Power Station to help achieve a better balance between the two lakes.

Lake Rowallan storage was drawn down towards the end of year in preparation for major outage work in the Mersey/Forth for the beginning of 2008.

Supply in Tasmania

Basslink was used extensively with a net import for the year of 1284 GWh.

Bell Bay Power Station also generated over 1049 GWh for the year – this directly translates to 2333 GWh of energy not supplied from hydro power.

Outages

Poatina Power Station was taken out of service for three weeks in July/August due to failure of an isolating valve on No. 3 machine. Poatina No. 3 machine remained out of service for the rest of the year (until March 2008).

Poatina No. 4 was taken out of service between July and December for an upgrade.

Gordon Power Station was taken out of service for intake work for over two weeks in October/November.

Tungatinah Power Station was out of service for four weeks in November/December for intake upgrade.

Trading strategy

Extensive use of Basslink import and gas generation used to supplement Hydro generation due to low storage position.

1.2.3 2008

Hydrology

In 2008, the Hydro Tasmania system experienced another low inflow year, receiving only about 74 % of long-term average inflow. With the storages already depleted from the previous two years, Hydro Tasmania was forced to adopt a very low generation strategy to allow storages to rebuild.

Supply in Tasmania

Basslink imported over 2647 GWh energy. The import capability of Basslink was gradually increased during the year to around 450 MW maximum (well over 100 MW more than originally expected and modelled).

- Bell Bay Power Station also generated 1069 GWh of energy during 2008;
- Wind farm output gradually increased from 60 MW to 125 MW by June 2008;
- Bell Bay No. 1 (120 MW) unit failed and was taken out of service in November 2008;
- Basslink outage unplanned from 1 to 8 January;
- Basslink outage unplanned from 8 to 10 June; and
- Basslink outage unplanned on 19 July.

Supply across the NEM

Kogan Creek commissioned 700 MW in Queensland early 2008.

Outages

- Rowallan and Lemonthyme Power Station outages from January to April cut off the water supply to Mersey/Forth cascade of stations for the period;
- one week outage at Tungatinah in January for intake commissioning; and

- Poatina No.1 out of service from August until February 2009 for an upgrade.

Network constraints

An additional transformer was added at Rowville substation in Victoria which relieved a network constraint between Victoria and NSW. This constraint would cause price volatility in Victoria for hot weather in NSW.

Trading strategy

Hydro Tasmania's operation has been guided by its 'Prudent Water Management' policies, which are aimed to provide adequate reliability of energy supply in Tasmania, in particular by ensuring that water storages do not fall too low. To help support storages, and to help maintain reliability of supply to the Tasmanian region of NEM due to the low inflows, the import capability of Basslink and gas generation was used extensively.

1.2.4 2009

Hydrology

This was an above average inflow year with Hydro Tasmania receiving 112.5 % of long-term average inflow.

Supply in Tasmania

- Bell Bay No. 2 unit was permanently taken out of service in April 2009 (120 MW).
- Energy supply in Tasmania increased with the staged completion of Aurora Energy Tamar Valley (AETV) gas-fired plant making available a total of 386 MW in October 2009.
- Total gas contribution (Bell Bay and AETV) was 854 GWh.
- Wind energy increased from 125 MW to 150 MW in May 2009.

Supply across the NEM

- Tullawarra commissioned in NSW (435 MW);
- Uranquinty commissioned in NSW (664 MW);
- wind energy has been progressively developed in South Australia, peaking at 600 MW this year; and
- there was 1537 GWh of imported energy across Basslink.

Outages

- Poatina No. 1 machine was returned to service after a long-term outage for modernisation in March 2009 and Poatina No. 5 machine was removed from service for a long outage for modernisation in August 2009;
- Wayatinah and Catagunya Power Stations were taken out of service from April to May 2009 for an extended period to enable repairs to be carried out in Wayatinah tail race;
- Tribute Power Station was taken out of service from January and February 2009 for an extended period for major maintenance;

- Tarraleah output was reduced significantly for an extended period in February and March 2009 to allow maintenance of No. 1 canal;
- John Butters had two one-week outages in August and November for wear ring repairs; and
- Gordon Power Station had a number of outages for downstream environmental studies and tuning of the No. 1 and 3 machine governors.

Network constraints

- Network constraints in Victoria due to bush fires 28–30 January;
- Basslink constraints due to high temperatures 28–30 January;
- Basslink constraints due to high temperatures 7 February;
- preventative network constraints across Tasmania due to lightning 23 February;
- preventative network constraints across Tasmania due to lightning 15 April; and
- preventative network constraints on Gordon–Chapel St line due to snow loading 25–26 August.

1.2.5 2010

Hydrology

- The first quarter was dry, continuing the trend of below-average yield from earlier years;
- By mid 2010, storages were receiving average yield;
- November and December were wet, receiving approximately double long-term average yield in each month.

Outages

- A six week outage of Mackintosh and Bastyan occurred in January for 6 Yearly Condition Assessment;
- A further outage occurred at Bastyan due to a transformer fault in October;
- A three week outage of Gordon station occurred in October for intake gate maintenance.

Trading strategy

- Gordon station used primarily as a hydro-peaking station, and to meet minimum environmental flow requirements. Average Gordon load was 55 MW for the whole year;
- Basslink used in hydro-peaking capacity, with full export capability required at all times and used during periods of market volatility;
- Storage build strategy commenced in anticipation of carbon arrival, with an additional 5 % of total energy stored over the calendar year;
- AETV ran their Combined Cycle Gas Turbine in a base load capacity, typically generating between 125 MW and 208 MW. This assisted the storage re-build strategy by offsetting hydro generation in the overnight import periods.

1.2.6 2011

Hydrology

- A very wet start to the year, with yield about double long-term-average for the first quarter;
- Dry conditions in May contributed to increased Gordon running;
- The remainder of the year brought average yield.

Supply across the NEM

- NEM wide total electricity demand began to trend downwards in annual terms;
- Reasons for the decline include: reduced major industrial load, rising uptake of residential roof top solar Photo Voltaic in all regions, and an increased focus on energy efficiency in households and industry.

Outages

- In April, Poatina Power Station came out of service for five months for penstock refurbishment;
- Canal works took Tarraleah station out of service for most of January; and
- Tungatinah unit 5 returned from a year long modernisation outage in November.

Trading strategy

- Gordon Station used as peaking capacity during the first quarter. Poatina Station and AETV's combined cycle gas turbine came out of service in May. These outages combined with lower monthly rainfall resulted in Gordon being used in baseload capacity from April to June;
- Gordon running was used to meet minimum environmental flow requirements from August to December;
- Average Gordon output for the year was 94 MW;
- Storage build continued in anticipation of carbon arrival, with an additional 8 % of total energy stored over the calendar year;

1.2.7 2012 (to November)

Hydrology

- August and September brought above average rainfall;
- Expecting to receive ~110 % of average yield by end of year.

Supply across the NEM

- Introduction of the Carbon tax in July 2012 resulted in increased electricity spot prices across the NEM;
- The carbon tax also caused a general shift in generation patterns, with owners of some coal plant choosing to reduce output during lower priced seasons.

Outages

- Canal works reduced Tarraleah output for most of January;
- John Butters came out of service in March for three months for Condition Assessment and to allow penstock painting.

Network constraints

- Basslink Pty Ltd has reduced their availability since July 2012. The export limit was reduced to 478 MW (instead of 594 MW);
- At times of high inflow, the restriction on Basslink and the need to manage run-of-river storages resulted in reduced generation from Gordon and Poatina in the second half of 2012;
- Transend experienced issues with their Network Control Special Protection Scheme (NCSPS), resulting additional transmission constraints on West Coast and Mersey Forth generation;
- To maintain system security, during the first half of 2012, significant load was placed on Gordon to facilitate West Coast generation.

Trading strategy

- Gordon running in the second half of 2012 has been affected by Basslink export limit reduction;
- Gordon average output January to November was 31 MW;
- Major storages continued filling until July 2012, at which point there was an additional 7 % in storage compared to the same time previous year;
- As a result of the Carbon Tax introduction, Hydro Tasmania's generation from Poatina increased to capture additional value in the Carbon environment;
- Political uncertainty and the possibility of a change in Government continue to affect the longer-term certainty of the carbon tax and Hydro Tasmania's generation strategy.

2. Gordon River conceptual model from Basslink Baseline Report (Hydro Tasmania 2005b)

The Basslink IIAS investigations (1999-2001) in the Gordon River involved a range of disciplines, including hydrology, geomorphology, vegetation, in-stream macroinvertebrates, river based mammals, karst and fish. The results of these investigations provided insights into how the Gordon River has responded, and continues to respond, to the present regulated flow regime of the river. Subsequent ongoing monitoring for the Basslink Monitoring Program (2001-05) has provided additional information about the processes acting on the river. These activities have led to the development of a conceptual model for the present conditions in the middle Gordon River.

The aim of the conceptual model is to provide an understanding of the processes presently operating in the middle Gordon River and assist in the interpretation of monitoring results, both pre- and post-Basslink. It is not intended as a predictive tool for forecasting changes due to Basslink, but rather a way of highlighting present relationships and linkages as a basis for understanding and interpreting future change. The conceptual model is based on the premise that the present characteristics of the middle Gordon are the result of the regulated and unregulated flow regimes interacting with the natural environment combined with the effects of the presence of the Gordon Dam.

The IIAS investigations and BMP monitoring have focussed on the middle Gordon River, between the power station and confluence of the Gordon and Franklin Rivers. The selection of this part of the Gordon River was based on hydrologic modelling which indicated that the flow regime between the power station and the Franklin confluence would be altered by Basslink operations. Downstream of the Franklin confluence, the water level in the Gordon River is controlled largely by tidal, rather than fluvial processes and power station releases. Although the middle Gordon is the focus of the investigations, it is recognised that processes and impacts in the middle Gordon are also linked to the upper and lower catchments (e.g. fish passage, sediment transport, seed dispersal).

In the 'Present' section (section 2.2), the present characteristics of the catchment are described, and linkages are made between components of the flow regime and these characteristics. This section contains considerable detail, as it forms the pre-Basslink understanding of the river, and serves as the model against which post-Basslink monitoring results will be interpreted. Although flow changes related to damming, combined with the influence of the dam itself, are linked to, and largely responsible for, the present condition of the river, it should be noted that the 'baseline' for post-Basslink monitoring is the present condition of the river. That is, although changes from the natural flow regime are useful for interpreting and understanding the present characteristics of the middle Gordon, it is the present condition of the river which constitutes the baseline against which Basslink changes will be measured.

In the conceptual model, components of the present hydrology (flow magnitude, duration, recession rates, etc.) are linked to specific processes for each discipline, and between disciplines. The conceptual model includes causal and potential linkages which have not been definitively established in the Gordon, but represent an expert view based on the literature and observations as well as results from other non-Gordon investigations. These include:

- the impact of regulated water temperatures or a reduction in the availability of organic matter on aquatic organisms;
- changes in flow or temperature on migration cues; and

- the effect of bank desiccation on bank stability and vegetation viability.

Many of these relationships are noted in the conceptual model, although the impact and relative importance of these theorised links is presently unquantifiable. The individual research chapters (chapters 6-11) should be consulted for a more detailed discussion of monitoring results and potential causal relationships.

The linkages between the hydrology and environmental processes in the middle Gordon River are also being used to statistically describe the present condition in the middle Gordon River, and will be used to assess post-Basslink changes. Therefore, the conceptual model is the basis for identifying which components of the hydrology need to be considered for pre- and post- Basslink comparisons, and assists in the identification of suitable statistical methods to identify Basslink-related changes compared to the existing variability within the system.

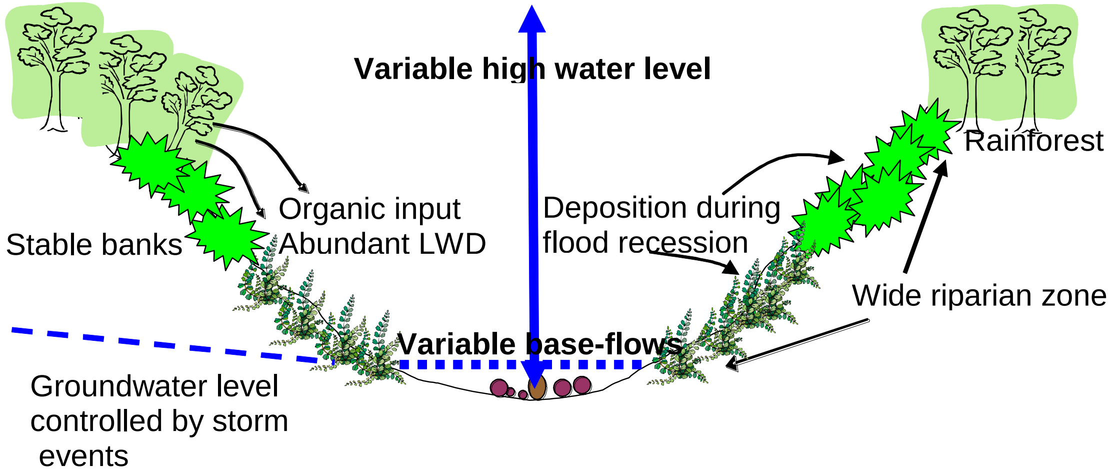
This chapter begins by briefly describing characteristics of the middle Gordon River prior to damming. These are largely based on inference and observations from unregulated tributaries in south-west Tasmania due to a lack of ‘pre-damming’ monitoring results.

The emphasis of this report is on the documentation of a pre-Basslink baseline and so a conceptual model for post-Basslink conditions is not presented. Post-Basslink predictions were made for each discipline and presented in the IIAS (Locher 2001) and its appendices.

2.1 Pre-dam conceptual model

As discussed in ‘Regional setting’ (section 2.1.1), the Gordon River catchment is underlain by Precambrian basement rocks, and Palaeozoic rocks including Ordovician limestones and sandstones, and Devonian-Silurian limestone-siltstone-shale sequences. The east-west trending reach of the river, postulated to be derived from a pre-Tertiary land surface, has cut narrow gorges through the Precambrian ranges, which have exerted a strong control on the evolution of the river. The catchment was shaped by glaciation during the Quaternary resulting in rugged ranges and extensive sand and gravel deposits in valleys (Roberts and Naqvi, 1978, J. Bradbury, pers.com.). Periglacial processes on mountain slopes gave rise to talus deposits. Tributaries have formed broad valleys in less resistant strata, and in the north-south trending Olga-Gordon-Franklin valley, the carbonate substrate has been modified by dissolution processes to produce cave and karst systems (Roberts and Naqvi, 1978).

Prior to damming, the Gordon catchment was largely undisturbed except for some small scale forestry activity in the catchment and along the banks (Huon pining), and minor mining operations. The characteristics of the Gordon River were similar to the present large dynamic unregulated tributaries in the region, with stable channels primarily due to the presences of abundant riparian vegetation, low physical weathering rates in the catchment, and organic-acid rich, low ionic strength waters. Pre-dam flow in the Gordon and its tributaries was controlled by rainfall patterns in the catchment and groundwater inputs. Large rainfall events occurred throughout the year, but were more common in winter months. As depicted in Figure B.1, water levels in the river were highly variable, with low (<0.2 m h^{-1}) rates of water level change. Water temperature varied seasonally from ~5 to ~20 °C, with a ~1-3°C diurnal variation.



Characteristics

* Highly variable flows
* Permanent water cover
* Mobile bed with organic matter
* Diverse benthic macroinvertebrates
* Seasonal flow triggers
* Seasonal water temp changes
* <0.2 m s^{-1} of water level change
* Deposition of organic matter
* Deposition of sediments
* Correlation of flows in tributaries and Gordon

Figure 2.1: Generalised conceptual model of pre-dam Gordon River showing cross-section of river.

River banks had low rates of change due to the high proportion of bedrock control and presence of a wide, dense riparian vegetation zone which extended from low summer baseflow level to high flood level (Figure B.2). Episodic disturbance resulted in localised erosion of banks and bars, with replenishment occurring through the deposition of sediment and organic matter during the recession stage of storm events. Rainforest occupied the valley above the flood disturbance zone. Within the riparian zone there was a high level of diversity, with vegetation distributions determined by flood disturbance patterns.

Figure 2.2: Photo of river bank in the Franklin River during low river flow.

Within the river channel, the sediment was mobile and composed of sediment and organic matter, with episodic reworking and throughput of material during flood events. The riparian zone of the Gordon and its tributaries contributed organic matter and large woody debris (LWD) to the river which provided habitat for a diverse range of benthic macroinvertebrates.

Benthic macroinvertebrates were highly diverse, with a number of regionally endemic species, a wide range of functional feeding groups, dominated by both grazers and organic detritus feeders. Benthic macroinvertebrates within the Gordon would have shown little longitudinal trend in diversity, abundance and community composition. These factors were more strongly influenced by local site features (substrate, hydraulic conditions, tributary influences).

Benthic filamentous algae were generally low in density due to the high optical attenuation of the dark river water, and frequent flood disturbance of the dominant substrate elements (cobble). Shallow water and bank-associated algal production was also limited by rain-event driven variation in water levels. Locally higher densities of moss were often associated with stable substrate elements (bedrock, boulders), and filter feeding macroinvertebrates. Pre-dam, there would have been no marked longitudinal trend in algal or moss diversity or abundance within the middle Gordon, with local site and micro-habitat features dictating their distribution.

Native fish were naturally highly diverse and abundant in the reaches upstream of the tidal limit, with recruitment from whitebait migrations varying annually, depending on coastal and oceanic conditions. Native fish decreased in abundance and diversity with distance upstream due to life-history factors and natural barriers, but there was good habitat available, and seasonal migratory cues occurred through flow events and temperature changes within the river. Native fish were restricted to *Galaxias brevipinnis* and *Anguilla australis* in the upper reaches and tributaries, and were probably absent or only maintained occasional incursions within the main river reaches between the First Splits and the upper Serpentine due to substantial barriers combined with distances from sources of recruitment.

Exotic fish were absent until stocking of the upper Franklin and of Macquarie Harbour in the 1960's, and probably only reached moderate abundance in the lower Gordon by the early 1970's. Some supplementation of exotic fish probably occurred due to intense stocking of the Gordon and Pedder impoundments with brown trout in the 1970's, and the subsequent establishment of redfin perch in Lake Gordon.

2.2 Present characteristics of the middle Gordon River

The middle Gordon River extends 39 km from the power station to the Franklin River. The present characteristics of the middle Gordon River vary with distance from the power station due to changes in hydrology, sediment input, river width and depth, and slope of channel. A large step-change occurs downstream of the confluence of the Gordon and Denison Rivers (~15 km downstream of the power station) due to the unregulated inflow of the relatively large Denison-Maxwell catchment (see Map 2.4).

The middle Gordon River has been divided into five geomorphic zones, separated by major hydraulic features (Figure B.3). The key characteristics of the five zones are discussed in this section, with subsequent sections discussing the important processes operating in each zone, and identifying linkages between ecosystem components.

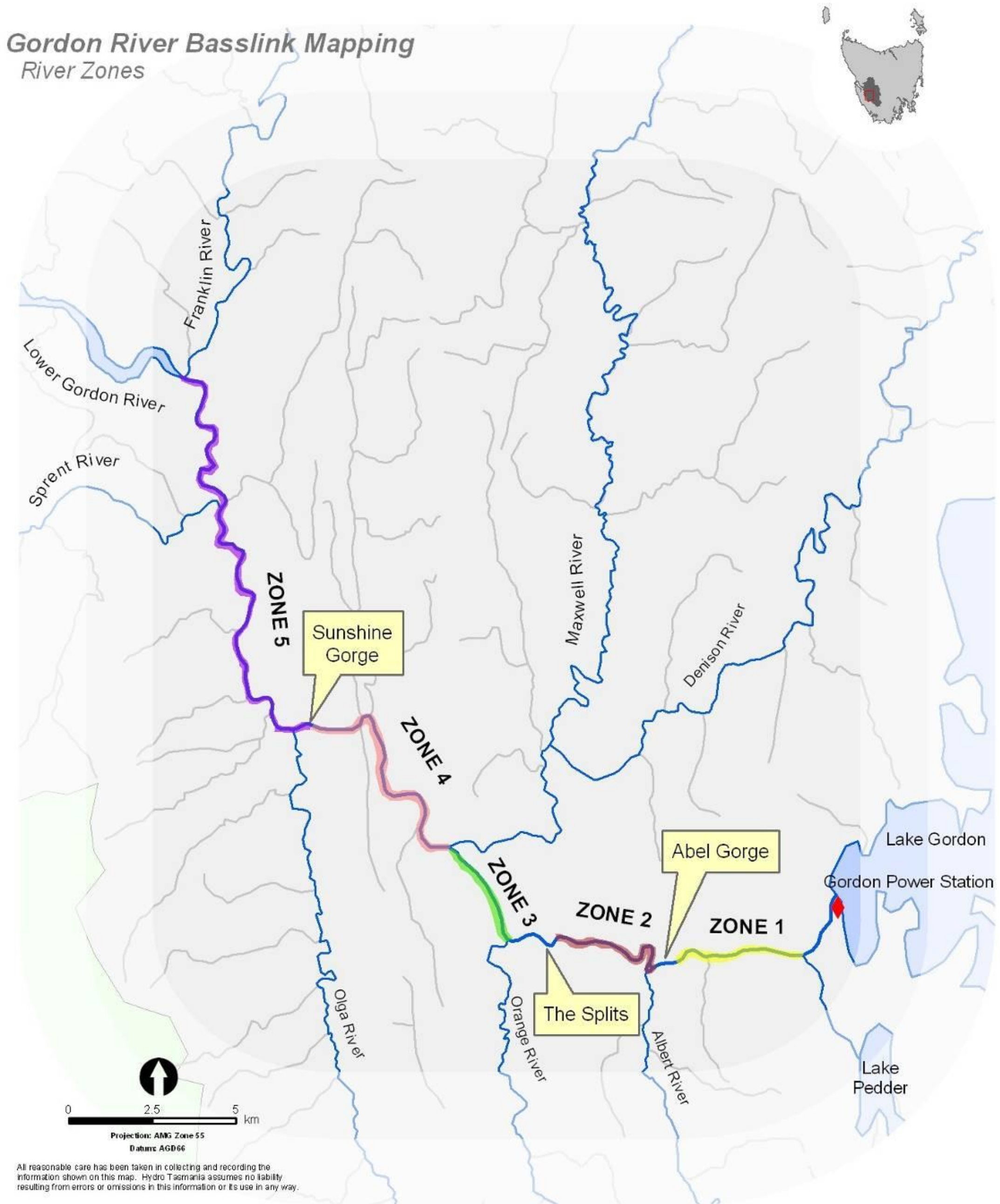


Figure 2.3: The middle Gordon River, showing the location of the five geomorphic zones.

The banks in the middle Gordon River can be broadly classified as bedrock, cobbles and sandy alluvium, or a combination of bedrock overlain by cobbles or sandy alluvium, or cobbles overlain by sandy alluvium. Representative photos of these bank types are shown in Figure B.4 to Figure B.6, with the distribution of the banks presented in Figure B.7. Additional background information about the composition and distribution of bank types as determined during the IIAS is contained in Koehnken *et al.* (2001).

Figure 2.4: Example of alluvial bank from zone 2.

Figure 2.5: Example of cobble bank in zone 1.

Figure 2.6: Example of bedrock bank in zone 1.

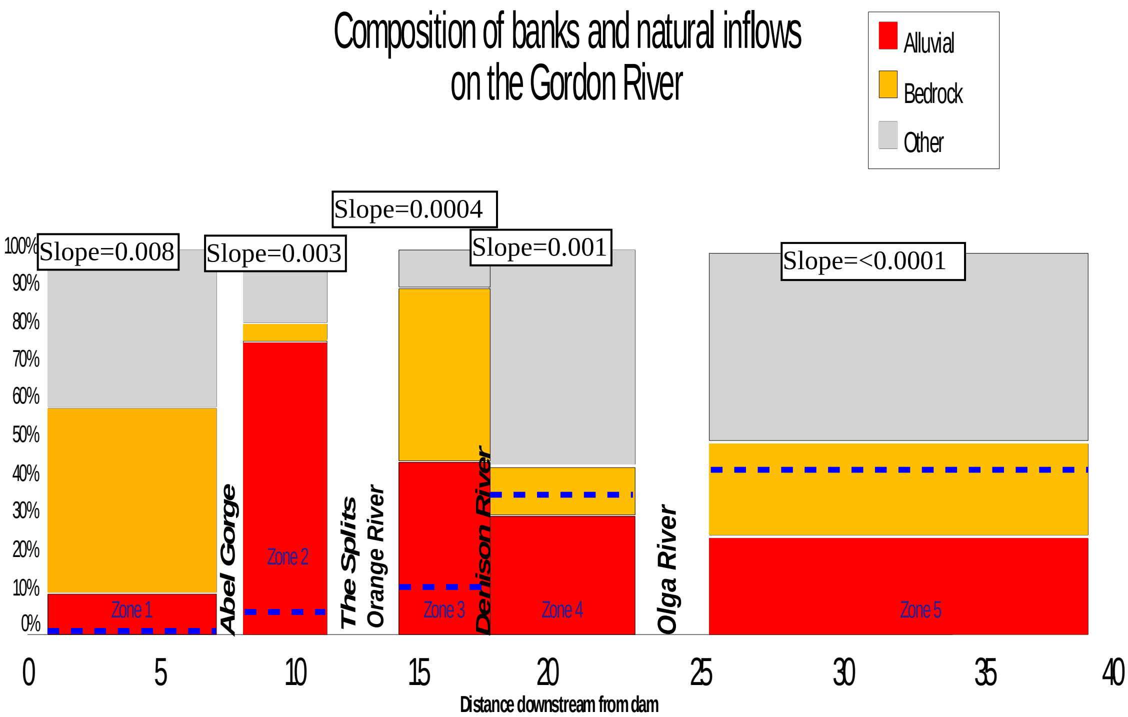


Figure 2.7: Summary of the composition of banks in the middle Gordon River and the level of natural inflows in each geomorphic zone. 'Other' banks include consolidated vertical cobble banks and combinations of bedrock overlain by cobbles or alluvium, or cobbles overlain by alluvium. The percentage of natural inflow entering the zone on an annual basis is shown by the blue dashed line. The average channel slope of the zone is displayed in the boxes at the top of the diagram.

2.2.1 Zones 1 and 2: Gordon Power Station to the Splits

The Gordon River between the power station and the Splits (zones 1 and 2, ~8 km) is comprised of bedrock reaches and gorges (downstream of power station, Abel Gorge, the Splits) interspersed with sandy alluvial banks and cemented vertical cobble banks, contributing to a stable river channel. In these zones, the hydrology of the middle Gordon is dominated by the operation of the power station throughout the year. It is characterised by large (2.5-4.5 m) water level fluctuations associated with power station discharge. Water level fluctuations occur rapidly, with water level rising and falling at rates in excess of 3 m h^{-1} during power station start-up or shut-down. In these zones, flow events in excess of power station releases are rare due to the small catchment area. Sediment and organic matter/seed input is greatly restricted due to trapping by the Gordon Dam.

The river is narrow (~40-70 m wide) in these zones, with a steep channel slope dropping 40 m in zone 1 (slope = 0.008), and 10 m in zone 2 (slope = 0.003). The only significant tributary stream is the Albert River (Figure B.3) which provides about 5 % of the total flow in zone 2. Characteristics of these zones are shown schematically in Figure B.8.

Water levels are low in these zones when the power station is shut-down, with water depths generally ≤1 m in runs and riffles. Deeper pools, to 4 m depths, are present at low flows. The low flows expose 2-4 m of vertical banks which de-water during shut-down events. The regulated flow regime of alternating high (+ 4 m) and low (≤1 m) water levels has led to a biological zonation of the banks.

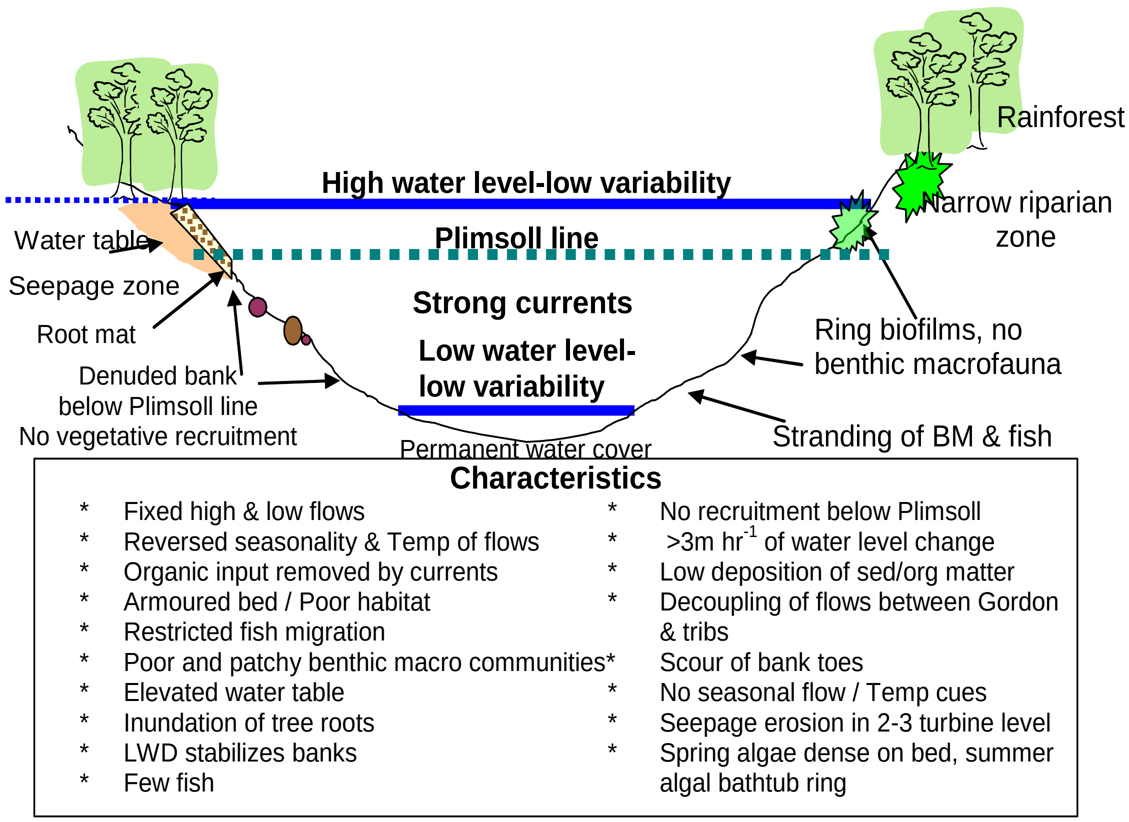
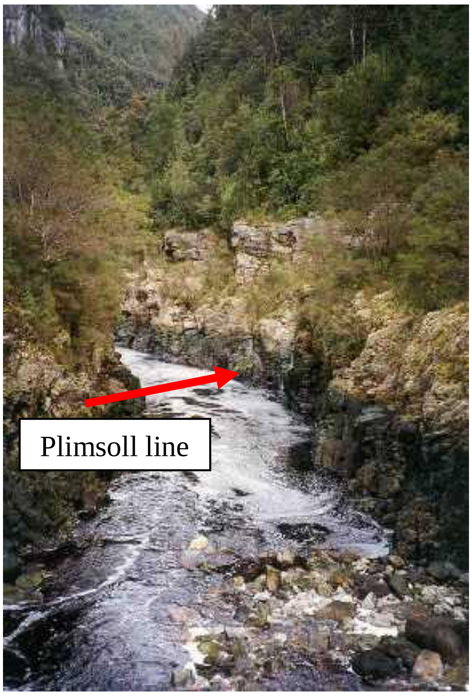


Figure 2.8: Characteristics of zones 1-3 of the middle Gordon River (downstream of the power station and upstream of the Denison confluence). LWD=large woody debris, BM = benthic macroinvertebrates.

Above power station-controlled high water levels, flood-induced erosion and disturbance to vegetation has been reduced compared to pre-dam conditions. This has led to a narrowing of the riparian zone with encroachment of rainforest species downslope towards the high-water level. Vegetation above the power station-controlled high water level is exposed to prolonged periods of elevated groundwater (equivalent to the height of the river flow) due to prolonged power station operation, which may affect the root depth and viability of trees over long time periods.

The 3-turbine operating level (1-1.5 m below high water level) is characterised by a decrease in vegetation cover. There is low species richness in the riparian zone compared to those of tributaries in the catchment, with tea tree the most widespread riparian species. The extent of vegetation on the banks is sharply defined by a ‘Plimsoll line’, which generally falls between the level of 2-turbine and 3-turbine power station operation. Between the Plimsoll line and the power station-controlled high water level, de-vegetated alluvial banks are prone to collapse following rapid bank de-watering. Figure B.9 shows examples of the vertical zonation produced by the regulated flows.



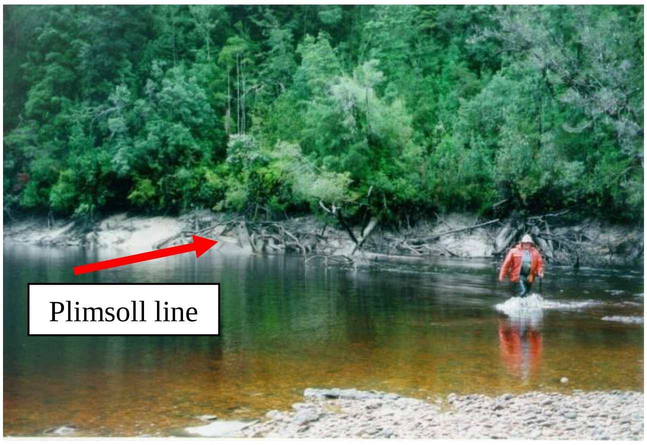


Figure 2.9: (Left) bedrock controlled reach downstream of power station showing the ‘Plimsoll line’ and encroachment of vegetation down to the Plimsoll line. (Right) Alluvial reach upstream of the Splits showing the distinct ‘Plimsoll line’. (L. Koehnken photos).

From below the ‘Plimsoll line’ to approximately 1 m above the power station ‘off’ low-water level (~1-2- turbine level), the banks are devoid of vegetation and, where present, alluvial banks are subject to scour from the regulated flow, and deposition from upslope seepage erosion. The strong power station discharge also removes organic matter deposited on the banks from the riparian zone during power station outages. This region of the bank is mainly devoid of aquatic fauna, though prolonged high water levels can result in periods of temporary colonisation. In summer-autumn, dense filamentous algal growth occurs over a band (in a ‘bath tub ring’) within 1-2 m downslope of average water levels, especially on stable substrate and logs. Algal growth is limited by the penetration depth of photosynthetically active radiation (PAR) in the coloured water.

In the 1 m above low-water level, the banks are also devoid of vegetation, and subject to scour associated with increased water surface slopes accompanying the initiation of power station operation. This area of the bank is prone to fish and benthic macroinvertebrate stranding following power station shut-down. Moss growth is observed in this zone on stable substrates.

Below the regulated low-water level, the high power station-induced velocities combined with the lack of sediment and organic matter input has resulted in an armoured bed which is low in stored fine sediments and organic matter. The lack of woody debris input from upstream, or from the riparian zone, limits the variability of in-stream habitat present in these zones. In winter-spring (or during any period of extended power station shut-down), extensive filamentous algal growth can occur across the channel, as extended periods of low flows allow light penetration to the channel bed. Depths > 1 m of water are believed to preclude algal growth, due to high colour, leading to a reduction in algal occurrence during summer-autumn. This is consistent with research by Bowling et al. (1986) on euphotic depths in humic Tasmanian waters.

A stable benthic macroinvertebrate community is observed in this permanently wetted zone but is low in abundance, diversity and growth/productivity compared to unregulated west coast rivers.

Zones 1 and 2 also display longitudinal changes in fish community structure. The presence of natural hydraulic control features (the Splits and Abel Gorge) naturally restricts the upstream migration of native fish into zones 1 and 2. Fish populations are low in abundance and limited to eels, lampreys, locally recruiting brown trout, redfin and an isolated tributary population of climbing galaxias. The naturally expected decrease in native species diversity with distance upstream has been exacerbated by flow regulation from the Gordon Power Station.

Dissolved oxygen levels in zones 1 and 2 can fluctuate from very low, if the water intake at the power station is below the Lake Gordon oxycline, to very high, if initial dissolved oxygen levels at the intake are high and air injection is in use at the power station. Neither of these oxygen conditions persist downstream due to turbulent flow in the steep gorge downstream of the tailrace, allowing the de-gassing or re-aeration of the water.

Zones 1 and 2 are also characterised by the presence of relatively high biomass and substrate cover of filamentous algae and mosses on the stream bed. Abundance of both declines downstream from zone 1 but algae have been observed to increase markedly during power station outages.

Zone 2 (5-8 km downstream of the power station) has the highest incidence of bank collapse in the middle Gordon River due to extensive seepage erosion of the banks. This process is driven by the large range of water level changes associated with power station operation (up to 4.5 m), the predominance of sandy alluvial banks (~75 %) in the zone, and low catchment inputs. This is in contrast to zone 1 where, due to steeper bed channel slopes water velocities are higher, water level fluctuations are limited to ~2.5 m, and only about 10 % of the banks are composed of sandy alluvial material. Zone 2 is also a karst-rich area, and the fine grained alluvial banks contain a higher proportion of silts (<63 μm) than in other zones. This may inhibit bank draining following river level decrease and promote seepage erosion.

2.2.2 Zone 3: the Splits to the Denison River:

For the 5 km downstream of the Splits and upstream of the confluence of the Gordon and Denison Rivers the width of the Gordon river is similar to zones 1 and 2, but the slope decreases considerably (slope ≈ 0.0004) with less than ~2 m drop between the top of the zone (downstream of Snake Rapids) and the Denison confluence. The proportion of alluvial banks decreases relative to zone 2, with alluvium limited to the area downstream of Snake Rapids (top of zone) and upstream of the Denison confluence. Flow in the Gordon is augmented by the Orange River and catchment inputs downstream of the power station, increasing unregulated flow inputs to about 10 % of the total flow on an annual basis.

The characteristics of zone 3 are similar to those of the upstream zones (Figure B.8), however the range of power station-induced water level fluctuations in zone 3 is lower (~2.5 m) compared to zone 2. The 'Plimsoll line' on the banks is lower, seepage erosion is less common and less active, and there is a slightly greater diversity and abundance of benthic macroinvertebrates in the permanently wetted portion of the channel compared to zones 1 and 2.

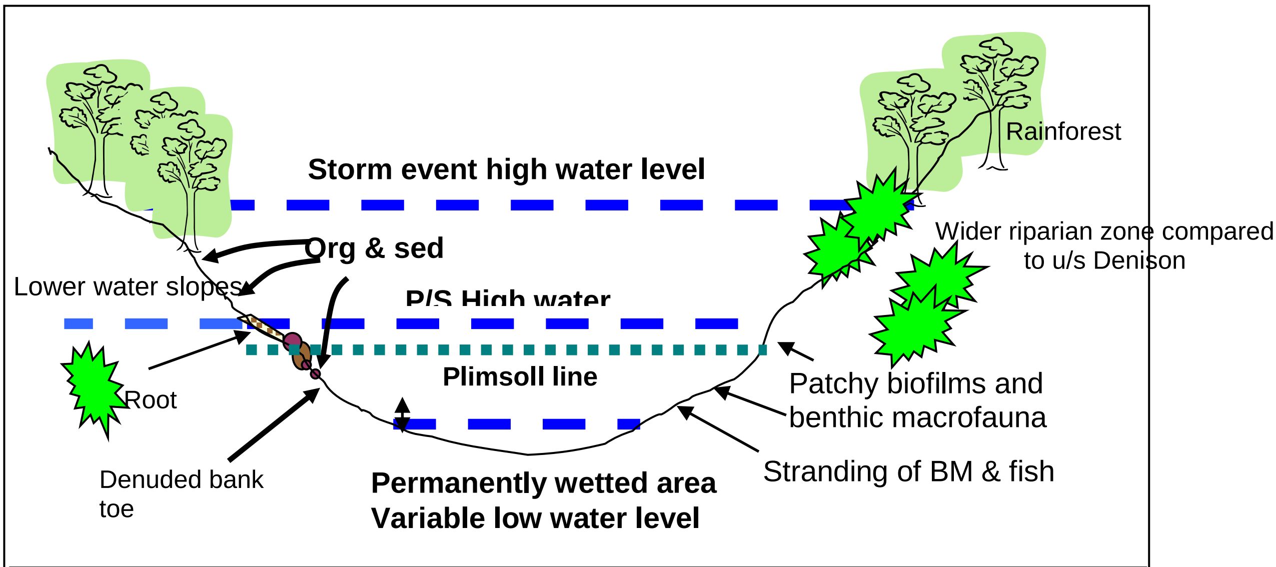
The diversity of fish species increases downstream of the Splits, although abundance remains low. Eels (*Anguilla australis)*, brown trout (*Salmo trutta)*, and lamprey (*Geotria australis)* are present in zone 3. In the tributaries, these species have been found along with spotted galaxias (*Galaxias truttaceus*).

Benthic macroinvertebrate abundance and diversity increases in this zone relative to zones 1 and 2, though still low. This increase is accompanied by increases in supply of coarse particulate organic matter (CPOM) with catchment inflows, trapped as a food resource within the channel substrate.

The low slope of the zone results in backwater effects from the Denison River occurring as far upstream as Snake Rapids when flow in the Denison River is high, and discharge from the power station is low. This leads to episodic deposition of sands in the upstream end of the zone when flood flows from the Orange River meet the Denison backwater. It also causes this reach to have a macroinvertebrate community more similar to that of zone 4, due to enhanced organic inputs from the Denison. Overall, this zone shows some reduction in effects associated with the regulated flow regime and an increase in flow variability and sediment input due to unregulated inflows.

2.2.3 Zones 4 and 5: the Denison River to the Franklin River

Zones 4 and 5 extend 23 km from the Denison confluence to the Franklin confluence. Bedrock control of the channel is extensive in these zones, as the river cuts through the Ordovician limestone of the Olga and Franklin valleys. The Denison is a large tributary, contributing ~30 % of the flow to the downstream river on an annual basis. Because much of the flow enters during the winter months when power station operation is generally reduced, the Denison provides a large unregulated flow and sediment input to the lower river. There is a notable step-change in the appearance and riverine processes occurring in the Gordon River downstream of this confluence. Characteristics of these zones are shown in Figure B.10.



Characteristics-Compared to Upstream Denison

- More variable high and low flows
- Reduced seasonality and Temp of flows
- More organic input and deposition
- More mobile bed/improved habitat
- More fish migration
- Higher benthic. macro abund. and diversity
- Lower in-bank water slopes
- Sediment deposition above P/S flow
- LWD stabilizes banks
- No recruitment below Plimsoll
- Lower rates of water level change
- More diffuse Plimsoll line
- Higher proportion of unregulated in-flow
- Scour of bank toes
- Reduced seasonal flow/Temp cues
- Reduced seepage erosion
- Little filamentous algae

Figure 2.10: Characteristics of the middle Gordon River downstream of the Denison River.

The unregulated flow of the Denison River results in a more variable flow regime in zones 4 and 5. Natural inflows following high rainfall events produce water levels well in excess of the 2-3 m regulated water level fluctuations. Similarly, during low or no power station discharge, natural inflows maintain relatively higher and more variable baseflow, so there is a reduced occurrence of dewatering of the lower banks and bars. In spite of greater variability, flow in these zones has a strong seasonal signal, with summer flows dominated by power station discharges, and winter flows dominated by natural, short-duration storm events. The unregulated inflow transports sediment, organic matter and seed, which can be deposited on banks above power station operating levels, or within the power station-controlled level during periods of shut-down.

Riparian vegetation in these zones extends further up the bank, and has greater species richness compared to zones 1 and 2. The Plimsoll line is lower and less distinct compared to upstream of the Denison confluence, and there is a greater occurrence of muds and organic material deposited on the banks, especially above power station-controlled water levels. The biological zonation of the banks is similar to upstream, although it is condensed into a smaller vertical distance due to the lower water level fluctuations associated with power station operation.

Figure 2.11: Zone 5 alluvial bank showing less defined Plimsoll line and greater occurrence of vegetation compared to zones upstream of the Denison confluence.

The bed of the river has a higher sand and organic matter component, and is more mobile compared to upstream. The benthic macroinvertebrates have a higher density of simuliids and hydropsychid caddis larvae as well as predatory macroinvertebrates and fish, compared to upstream of the Denison confluence. An unusually large peak in abundance of organic particle ‘filter’ feeding macroinvertebrates, especially hydropsychid caddis and simuliids, occurs in zone 4 between the Denison confluence and Sunshine Gorge, taking advantage of the organic material input. These decrease toward the Franklin confluence to levels similar to natural rivers. Filamentous algae maintain very low abundances downstream of the Denison confluence. The magnitude and rate of water level change in these zones is reduced, which reduces the risk of fish and benthic macroinvertebrate stranding and seepage erosion.

The Bill Nielson Cave is located downstream of the Denison confluence, and is subject to inundation due to power station and natural flow events, but is not inundated by the Gordon River during power station shut-downs. The cave contains a stream which begins as a surface drainage upstream of the cave, and enters Bill Nielson Cave via one of several holes in the partially collapsed roof. The cave contains more sediment than commonly occurs due to this hydrologic connection with the surface. The cave is characterised by sediment banks near the downstream entrance to the cave, and where the cave stream descends to power station-controlled water levels. The cave also contains a zoned biological community, with species such as glow worms present above the regulated high water levels.

The diversity and abundance of fish increases downstream of Sunshine Gorge (zone 5). This is primarily dictated by a natural gradient of increasing native fish diversity and abundance toward the coast, observed by Davies (1994) and Gherke and Harris (2000) for Tasmanian river systems. This pattern is a result of the migratory life histories of local native fish species, coupled with the presence of natural barriers to upstream fish movement which interacts with the effects of the regulated flow regime on fish passage at barriers like Sunshine Gorge.

2.3 Model drivers and linkages

The conceptual model of the middle Gordon River is based on the premise that the damming, reduced sediment delivery, and present regulated flow regimes are the main drivers behind the processes currently affecting the river. The main changes associated with the damming and regulation of the flow commenced 30 years ago and, over the years, the flow regime of the river has varied according to the number of turbines available for use, large-scale weather patterns in Tasmania, and electricity demand. Although the flow regime has varied with time, there are some consistent characteristics of the present flow regime which are driving the major processes in the river channel. These include:

- alteration of sediment and water flow;
- restricted range of flow regime (loss of large floods);
- prolonged duration of ‘high’ discharge events;
- decoupling of water flow and sediment delivery;
- high rates of water level and flow velocity change; and
- reversed seasonality of discharge, a regulated water temperature regime and variable dissolved oxygen levels.

The following sections describe how each of these flow components has contributed to the present ecosystem characteristics of the middle Gordon River.

2.3.1 Alteration of sediment and water flow at a catchment scale

At the broadest scale, construction of the Gordon Dam divided the catchment and altered the water and sediment delivery processes to the middle Gordon. The dam restricts sediment, organic matter, and biota (fauna and seed) transport downstream. It eliminates access to habitat upstream of the dam for organisms in the lower catchment. The loss of the major sediment, seed and organic material source to the river downstream of the dam and upstream of the Denison River has resulted in a reduction in habitat variability. The bed and banks are largely devoid of fine sediments, fine organic material, and small woody debris. The lack of bed load has created an armoured bed downstream of the dam site, which also reduces habitat variability and provides a stable substrate for filamentous algae and mosses which further reduce benthic macroinvertebrate habitat and food resources.

The power scheme has increased overall water flow to the lower catchment by ~15 % on an annual basis, increasing median monthly flows by up to 50 $m^3 s^{-1}$ (Figure 2.6). At the same time the dam also greatly diminishes sediment supply to the river severely reducing fluvial deposition on banks and in the bed. These flow and sediment changes would be expected to promote channel enlargement downstream of the dam, as the channel adjusts to carrying the additional flow, and has a sediment load significantly lower than its carrying capacity. The predominance of bedrock and cobble-boulder controlled reaches within the river, the reduction in bed load, and flows insufficient for incising the bed (discussed next section) limits the areas susceptible to channel widening to the ~35 % of the middle Gordon River channel composed of sandy alluvial banks. The greatest impact occurs on the 50 % of alluvial banks situated upstream of the Denison confluence where water level fluctuations are greatest, channel gradients are high, and unregulated inflows comprise a minor amount of the total flow. Zone 2 is especially susceptible to channel widening processes due to the high proportion (~75 % of zone) of alluvial banks. The strong bedrock control of the channel limits the potential for changes to the planform of the river, and channel widening is confined to alluvial ‘pockets’ delimited by bedrock controls.

Actively eroding banks are no longer suitable habitat for macroinvertebrates or fish. Armouring of the bed has also reduced habitat suitability for benthic macroinvertebrates in the channel. Starvation of organic material supply to the reach upstream of the Denison confluence limits food resources for the majority of macroinvertebrate species. Re-introduction of a substantial portion of that supply from the Denison River results in a peak in abundance of filter feeders (simuliids, *Asmicridea* caddis) downstream.

2.3.2 Restricted range of the regulated discharge regime

The operation of the power station has altered the range of flow levels in the river, especially between the power station and the Denison River (zones 1, 2 and 3), capping high flows at maximum power station discharge levels, and resulting in very low baseflows during power station shut-downs. Intermediate discharge levels are also governed by the number of turbines in operation.

The elimination of very high flow events has led to an increase in vegetation cover in many areas of the river no longer periodically disturbed by high energy floods. This includes the crests of cobble bars and banks situated above levels affected by power station discharges. The narrow gorge immediately downstream of the power station (zone 1) is a good example of where vegetation in general, and the occurrence of rainforest species in particular, has expanded since damming (Figure B.11 and Figure B.12).

Figure 2.12: Increase in vegetation above power station-controlled operating level in zone 1. Vegetation above the Plimsoll line has grown since the power station began operating.

The encroachment of rainforest species from upslope has led to a reduction in the vertical extent of the riparian zone, and a reduction in the riparian species mix, in part due to the lack of flood-induced disturbance creating new open spaces which certain species require. Low flows associated with power station shut-downs affect vegetation in the riparian zone through the desiccation of banks which can disadvantage seedlings. Low flows also create conditions of instability after rapid draw-downs, which indirectly affect vegetation, where present, through erosion and bank collapse.

In the Bill Nielson Cave, the reduction in high flows has led to the desiccation of sediment deposits located at higher elevations (above maximum power station operating level) within the cave, and colonisation of species, such as glow worms, at lower levels due to a reduction in flood events. During very low flows, desiccation of sediment banks may increase instability.

The limit on high flows, especially in the Gordon River upstream of the Denison confluence, has reduced the capacity for bed disturbance, leading to an armoured bed with reduced habitat variability for in-stream biota. The lack of very high flow events (coupled with a lack of temperature cues) is hypothesised to affect the spawning or migration triggers for native fishes. The lack of bed-disturbing high flow events combined with the introduction of fine particulate organic matter (FPOM) from the Denison River favours the development of an exceptionally large and sustained peak in abundance of filter feeding macroinvertebrates (simuliids, *Asmicridea* caddis) between the Denison confluence and Sunshine Gorge.

During power station shut-downs, the permanently wetted area in the river is reduced compared to pre-dam low flow conditions, limiting the habitat available for aquatic organisms and benthic feeding habitat for aquatic mammals. The reduction in wetted area may slightly increase the mortality of juvenile aquatic mammals through raptor predation during low water levels.

Abnormally low water levels during shut-downs promote growth of filamentous algae and mosses in bed sections with water depths < 1m due to increased light availability (normally limited at depth due to dark water colour). This occurs predominantly in the steeper sections of zones 1 and 2, on bar-riffle features, and is dependent on duration of low flows and season.

2.3.3 Prolonged high flow events

The prolonged, relatively constant high flow associated with power station base-load operation drives a number of processes operating in the river. The long-duration (days to weeks) high flow events have resulted in the inundation and water logging of riparian vegetation, leading to a loss of vegetation from the banks within the power station-controlled water level range. The level to which vegetation has been removed varies throughout the river, and generally decreases with distance from the power station, due to widening of the river and greater variability of flow. The timing of the long-duration discharge events, which generally occur in summer, has also exacerbated the impact on the vegetation, as the dark water of the Gordon River restricts light penetration, reducing photosynthesis and possibly impacting seed production.

Where banks consist of bedrock-cobbles-boulders, this process has led to the exposure of the underlying rock substrate and the establishment of a distinct Plimsoll line below which there is no vegetation (Figure B.2). The impact of vegetation removal on sandy alluvial banks has resulted in an increased susceptibility of the underlying bank to both scour and seepage erosion processes. The impact of vegetation removal on bank stability in the Gordon River cannot be overstated, as vegetation is a primary bank stabilising mechanism.

The removal of bank vegetation is an ongoing process which is strongly linked to the regulated water levels. At the initiation of the Basslink investigations, the 'Plimsoll line' which marks the transition between the denuded bank toe and vegetation generally corresponded to the two turbine power station operating level. This is consistent with the operational history of the power station, where between implementation of the scheme and 1999, 2-turbines were in use ~35 % of the time, compared to ~7 % for 3-turbines, based on daily power generating data (which is likely to under-estimate three turbine usage). Since 1999, three turbines have been in use for a greater percentage of the time (up to ~40 % during some years). Although the direct loss of vegetation through inundation and waterlogging is not a major process at this time, ongoing seepage erosion and bank collapse continue to remove vegetation from banks upstream of the

Denison confluence between the 2- and 3- turbine operating levels. This is strong evidence that the river is continuing to adjust to 3-turbine operation, and is not yet in geomorphic equilibrium.

2.3.4 Impact of vegetation removal on banks

In the absence of riparian vegetation, buttressing of the bank toe or bank face by large woody debris (LWD), cobbles or boulders has become the main bank stabilising process in the middle Gordon. LWD is common throughout both the regulated Gordon River and unregulated tributaries and its role in bank accretion is discussed in the next section.

Below the 1-2 turbine water level, low angle bank faces, at or near the theoretical equilibrium angles are common, and these banks are more stable with respect to seepage erosion processes. However, the exposed bank toes are subjected to scour during the rapid increase in water level associated with power station start-up or natural inflows downstream of the Denison confluence.

The impact of vegetation removal on the banks is greatest upstream of the Denison confluence, where power station-controlled water levels are highest (up to 4.5 m), catchment inflows are low, and there is a high prevalence of sandy alluvial banks. The rapid reduction in river levels accompanying power station shut-down results in high in-bank water surface slopes. Because the banks are not stabilised by vegetation, water draining from the sandy banks may have sufficient energy to entrain and transport sand. This results in seepage erosion, leading to the creation of cavities at the site of sediment entrainment, and deposition of sediment flows downslope of the cavity. Figure B.13 illustrates this process. The progressive enlargement of bank cavities further increases bank instability, and eventually the overlying vegetation and bank collapse. Through this process, riparian vegetation not directly lost to inundation or waterlogging continues to be lost, which further destabilises the upper bank.

Seepage-induced erosion occurs episodically, generally following prolonged periods of three-turbine power station usage and appears to be exacerbated by extended high rainfall following power station shut-down. Spatially, the process occurs discontinuously on sandy alluvial banks, with large variations over distances of only several metres. The removal of tea tree and other vegetation from the riparian zone through scour is believed to be a significant trigger for the initiation of seepage processes. Zone 2 is particularly susceptible to this process due to the prevalence of sandy alluvial banks and large water level fluctuations.

Figure 2.13: Active seepage erosion (water and sediment exiting bank) following power station shut-down (left) leads to sediment flows (right) on alluvial banks in zone 2.

Impact of vegetation removal on aquatic habitats

With respect to aquatic habitats, the removal of riparian vegetation and bank erosion has altered habitat availability and quality in a number of ways. The loss of vegetation has led to a decrease in-bank roughness where LWD is not deposited, resulting in higher energy environments compared to pre-dam conditions, and contributing to a reduction in macroinvertebrate community diversity and abundance. The removal of bank vegetation has also reduced the local input of organic material and organisms from the riparian zone to the river, which has reduced habitat variability (i.e. fewer snags), food availability (as coarse organic particulate material (CPOM) and habitat suitability for fish and aquatic mammals. Bank disturbance and understorey removal also decreases potential burrow site suitability for platypus.

Sustained high flow levels during summer-autumn also reduce diatom and algal production due to reduction of light penetration to the stream bed, especially downstream of the Denison River. This reduces the food source for benthic grazing invertebrates. As a result, the community is dominated by species which feed on the limited coarse and fine organic material (filter feeder, collector and shredder feeding guilds) which is derived from riparian vegetation along the river and from tributaries.

In zones 1 and 2 where the bed is armoured and stable, prolonged high water levels result in a 'bath tub ring' of filamentous algae, dominated by *Mougetia*, especially on stable bank and bed features such as logs, bedrock, etc. This spans from average high water level to *ca.* 2 m lower in elevation, reflecting the extent of light penetration, and is most noticeable in summer-autumn.

2.3.5 Decoupling of flow and sediment delivery

The delivery of sediment to the Gordon River from tributaries naturally coincides with flood events. Prior to damming, this episodic sediment input fed into the synchronized rise and fall of the mainstem Gordon. The timing of sediment and flow inputs from the tributaries drives a number of important processes which have been altered in the middle Gordon River due to damming and flow regulation.

In addition to a decrease in sediment delivery to the middle Gordon River, the decoupling of flow and sediment delivery from the tributaries has also decreased the deposition of organic matter and sediment on the banks and bed of the river. Because a power station shut-down rarely coincides with the falling limb of natural storm events in the catchment, the middle Gordon has largely become a sediment throughput zone for tributary derived fine-grained material (Figure B.14).

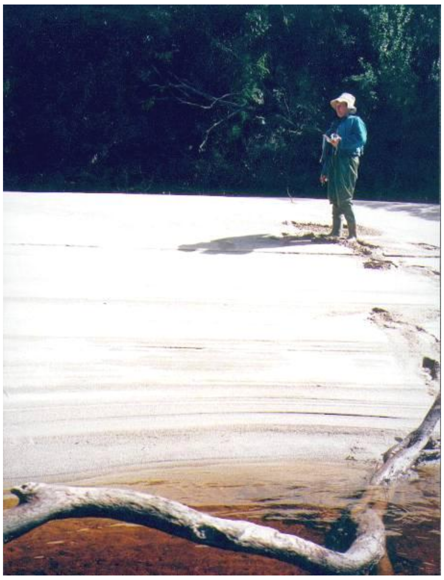


Figure 2.14: Comparison of alluvial banks immediately following power station shut-down (left) with no mud or organic matter on bank toe, and following an extended shut-down (right) when muds have accumulated due to unregulated flow events originating in tributary streams.

The high velocity flow associated with power station operation, and especially scour associated with rising water levels, also removes any organic material derived from over-hanging vegetation that accumulates on the bank faces between power station operating events. Combined, these processes prevent the accumulation of organic rich, fine grained material on banks, preventing the re-establishment or recruitment of vegetation on the denuded banks, and decreasing habitat variability and food supply.

Widespread deposition of fine-sands and muds and accumulation of organic material from overhanging trees on bank faces is observed during extended power station outages (zero discharge). This provides evidence that the general absence of these materials can be attributed to high velocity discharges associated with power station operations.

Downstream of the Denison confluence, sediment deposition increases due to the contribution of the unregulated flow and sediment supply from this large tributary. Although much of this material is transported through the system by the power station-controlled discharge, a proportion is deposited on the river banks, generally above the power station-controlled high water levels. These deposits are the result of the receding limb of unregulated high flow events from the Denison and other tributaries operating on top of the power station discharge. When high natural flows occur during power station shut-downs, deposition takes place within the power station-controlled range of the bank. These deposits can be short-lived due to remobilisation during subsequent periods of high power station discharge.

The lack of deposition on the banks also removes the potential for one of the major bank accretion processes in west coast rivers. The natural riparian zone of west coast rivers, including the Gordon, contains abundant Huon pines which are long-lived and slow-decaying. These trees tend to grow out over the river, and eventually collapse, creating depositional zones where fine sediment and organic rich material collects. The fallen tree is stable over time-scales of hundreds to thousands of years, providing a base for the next generation of bank stabilising trees. Because fine material is not accumulating in most of the middle Gordon River, fallen trees remain exposed, and although they provide bank stability through buttressing and increasing bank roughness, are generally not sites of bank aggradation.

The decoupling of flow and sediment supply in the Gordon River compared to the tributaries also affects the lower reaches of tributaries, especially upstream of the Denison confluence. During periods of low natural flow and high power station discharge, water from the Gordon River inundates the mouths of tributaries up to the power station-controlled high water level. This has led to seepage erosion occurring in the lower reaches of creeks and tributaries, causing channel widening. Additionally, tributary floods combined with power station shut-downs create large water surface slopes with great erosive energy. The mouth of the Albert River is a prime example of this, widening by up to 30 m near the confluence with the Gordon since the establishment of the power scheme. Widening in alluvial reaches near the mouth of the Orange River and small creeks in zone 2 has been estimated at 10-20 m based on aerial photo analysis. Figure B.15 shows the conditions at the mouth of the Albert River.

The decoupling of flow and sediment delivery has also affected sedimentation processes in the Bill Nielson Cave and Kayak Kavern, located downstream of the Denison confluence. Sediment deposition has increased due to the very low velocity currents in the cave environment which allow the settling of fine material from the water column under any flow level sufficient to inundate the cave (~2 m above summer baseflow), whether derived from the Gordon Power Station or unregulated inflows. Additionally, in the Bill Nielson Cave, there is a creek which drains into the Gordon River. If periods of high natural flow and sediment transport in the creek correspond to power station ‘on’ conditions, then deposition of sediments occurs when the creek meets the power station-controlled water level in the cave due to the formation of a backwater. Prior to the establishment of the Gordon Power Scheme, this process would have occurred during flow events where the local water depth was in excess of 2 m when the cave was inundated. Since flow regulation, this backwater deposition is likely to occur any time the power station is operating with two or three turbines.

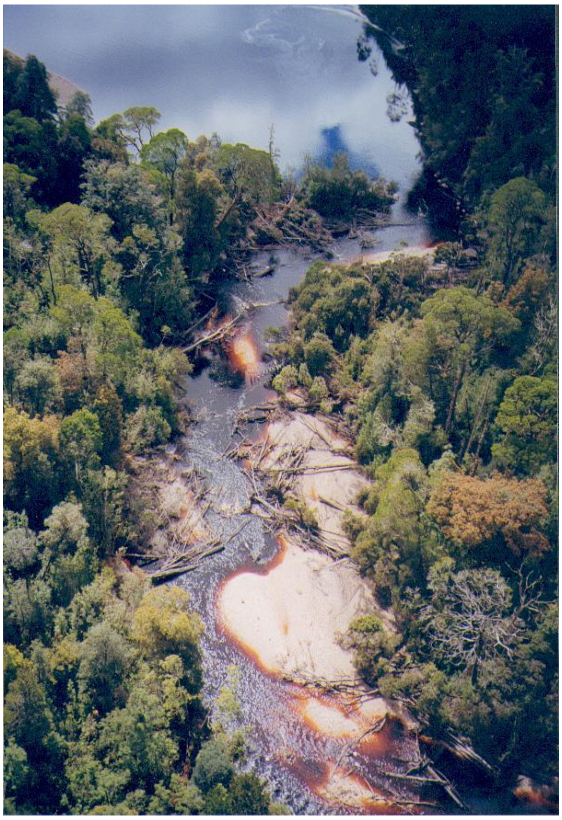


Figure 2.15: Aerial view of mouth of Albert River showing channel widening. The confluence of the Albert and Gordon Rivers is towards top of the photo. Tree fall is associated with seepage erosion and scour.

Biologically, the supply of food and organic matter to the middle Gordon River has been altered through the decoupling of flow and sediment inputs. Enhanced transportation of FPOM due to sustained high water velocities, coupled with reduced delivery from upstream (of the dam) has reduced the availability of the FPOM food resource to benthic macroinvertebrates, especially upstream of the Denison confluence. In addition, storage of FPOM and finer coarse particulate organic matter (CPOM: leaf, twig fragments, etc.) in the stream bed is reduced downstream of the dam, only increasing significantly downstream of the Denison confluence. These represent key food resources for several macroinvertebrate feeding groups.

2.3.6 High rates of water level and velocity change

During operation of the power station, water levels fluctuate rapidly immediately downstream, with rates of response decreasing with distance downstream (see chapter 2). Rapid water level rise leads to bank scouring, including removal of organic or inorganic material which may have accumulated during the power station shut-down, and the disturbance and downstream displacement of macroinvertebrates and fish.

Rapid reductions in water level can promote seepage erosion if banks are saturated, leading to bank instability, collapse and loss of overlying vegetation in the sandy alluvial banks upstream of the Denison. For seepage erosion to occur, in-bank water levels relative to river level must be sufficiently high to result in slopes of 0.1 over the first ~10 m of the bank. In general, this level of saturation is achieved following 1-2 days of continuous power station usage, depending on the initial groundwater conditions in the bank (see Koehnken *et al.* 2001 for discussion of seepage processes).

Rapid reduction of flows to very low levels also leads to rapid 'dewatering' of channel substrates, especially in run reaches upstream of the Denison and on bars. Stranding of macroinvertebrates, and to an extent, fish, occurs on each dewatering event. It is estimated that up to 15 % of the benthic macroinvertebrate population upstream of the Denison can be stranded with each event, making this a significant source of mortality. Rapid declines in flow also prevent predictable occupation of key shelter and refuge habitats for fish in pool and channel margins.

Highly variable velocities decrease the suitability of habitat for flow-obligate macroinvertebrates e.g. filter feeders and collector-gatherers. Highly variable velocities also reduce habitat suitability for fish. This, coupled with loss of access to habitat features along channel margins and reduced macroinvertebrate food production, further reduce fish growth, survival and population viability.

2.3.7 Reversed seasonality of flows, regulated water temperatures, variable oxygen levels

The role of the Gordon Power Station in providing base-load power during dry summer periods results in a reversed seasonality of discharge in the middle Gordon River, with prolonged-duration high flows (3-turbine) occurring in summer, and short-duration lower flows (1- or 2-turbine) in winter.

This reversed seasonality affects riparian vegetation by reducing recruitment due to the inability of seedlings to establish on the inundated banks, and potentially reducing photosynthetic ability due to inundation and decreased light penetration. The same effect is applied to benthic diatomaceous algae, an important food resource for macroinvertebrates. The flow pattern also affects benthic macroinvertebrates by eliminating normal seasonal life history cues, especially upstream of the Denison confluence. A similar response is associated with cave fauna, where high summer flows can affect life-cycle triggers. In the case of fish, there is a reduction in the frequency of spawning and migration trigger events, and the feeding success of aquatic mammals is decreased during the summer months due to the high flows. The reversed seasonality of the flow in the river causes a reduction in the magnitude of seasonal migration cues, as does the regulated water temperature.

Because the intake for the Gordon Power Station is located deep in Lake Gordon, the temperature of discharged water has little variability over timeframes of days to weeks. During the warmer months the regulated water temperature is reduced compared to unregulated rivers, and during the cooler months it is generally warmer. The regulated temperature is believed to contribute to delayed or reduced growth and development of benthic macroinvertebrates and fish, and may increase the metabolic demands of aquatic mammals, especially juveniles, during the summer months.

Dissolved oxygen concentrations in the middle Gordon River immediately downstream of the power station are controlled by the relative depth of the oxycline (depth at which dissolved oxygen decreases rapidly) in Lake Gordon relative to the power station intake, as well as the operating conditions at the power station. The dissolved oxygen levels of discharges are low if the intake level is below the oxycline, and no air injection is in use in the power station. Dissolved oxygen levels may be elevated if the intake level is above the oxycline, and air injection is in use. Downstream of the power station, the highly turbulent flow caused by the confined channel and steep slope leads to rapid re-oxygenation of low-oxygen water, and de-gassing of oxygen-rich water. These fluctuations in dissolved oxygen level would contribute to the reduction in habitat suitability in the gorge reach immediately downstream of the power station for benthic macroinvertebrates and fish.

2.3.8 Limitations of the model

The conceptual model for the present Gordon River links the present flow regime to the current condition of the river, and processes operating in the system. The conceptual model of the present system is not intended as a predictive tool for identifying Basslink change, but rather one that highlights existing relationships between the flow regime and the condition of the river, which can be used to assist in the interpretation of post-Basslink monitoring results.

As post-Basslink monitoring progresses, changes to the flow regime and condition of the river will be incorporated to develop a post-Basslink conceptual model, which will be used as a tool for interpreting results over time, and for investigating conditions which are outside of the trigger values of indicator variables identified in this report.

2.4 Longitudinal trends

As discussed in section 2.2.3, the input of the Denison River results in a large step change with respect to the degree of regulation of the flow and sediment inputs, and the magnitude of FPOM and CPOM loads. Downstream of this confluence, during periods of high catchment input, there is a large increase in flow variability and sediment input to the river, and a relative decrease in the role the regulated flow plays in ecological processes in the middle Gordon River. How flow, sediment input and important biological indicators vary with distance downstream of the power station is shown schematically in Figure B.16. In each diagram, relative changes with distance from the power station are shown, along with an indication of the relative range of each parameter in unregulated reference streams. For all parameters, there is a shift towards the reference condition with increased distance downstream.

Natural inflows increase, relative to total flow, with distance from the power station, leading to a decrease in short-term flow variability and an increase in long-term variability. The rate of water level changes and the height of power station-controlled water levels also decrease. Downstream of the Denison, the range of water level fluctuations due to power station operations is lower than those associated with large winter storm events. The inflows from the Denison River reflect the natural seasonality and water temperature of the catchment, as do the rates of water level rise and fall of the inflows which moderate the power station-derived flow regime.

Downstream of the Denison River, the greater variability of the flow regime and sediment input results in the river responding to different flow patterns through the year. At a very general level, during the summer months, flow is dominated by power station releases, and long-duration constant high flows are typical. During the winter the power station is in use much less frequently, and the river experiences high natural water and sediment inflows. These flow trends are not present upstream of the Denison, where the hydrology is dominated by power station releases throughout the year.

The Denison River and other tributaries also deliver a sediment and organic matter supply to the Gordon which increases deposition on banks, bed load and provides a seed source, resulting in an increase in the variability of in-stream and riparian habitats.

Benthic macroinvertebrate abundance and diversity therefore is low downstream of the power station compared to unregulated rivers due to the interaction of the unnaturally variable flow regime, mortality through stranding, low food supply (FPOM and diatoms), reduced recruitment and displacement due to rapid velocity increases. Diversity and abundance increase downstream through zone 1-2 as inputs of FPOM and recruits increase slightly from tributary input, and baseflow increases which limits filamentous algal growth.

Fish abundance and diversity is also lower than expected in the main channel due to variable flows coupled with limited food supply form the benthos and the riparian zone. Fish have been observed feeding on chaoborid (ghost midge) larvae, which are sourced from Lake Gordon and which probably constitute the majority of the invertebrate drift in reaches upstream of the Denison. Variable flow conditions in the river may preclude successful spawning by brown trout, which are locally abundant in some tributaries.

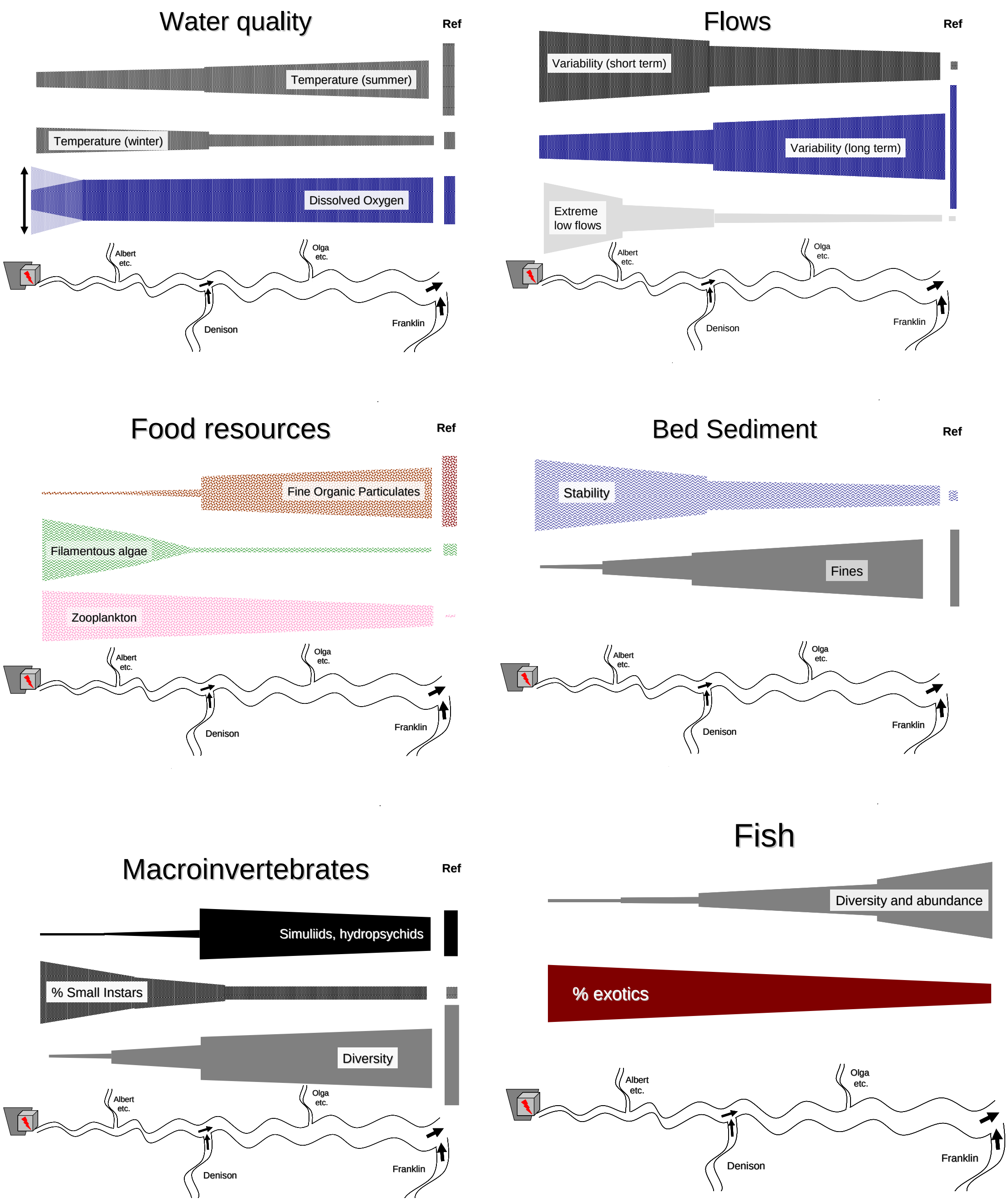


Figure 2.16: Schematic diagrams showing changes in important environmental characteristics and ecological components in relation to distance from the dam and power station. Note arrow indicates variable dissolved oxygen conditions in power station discharge. Variation in fish diversity is naturally dictated by distance from the sea and is also affected by the presence of barriers, especially at Sunshine Gorge and the Splits.

The inflow of the Denison River leads to an increased and more sustained food source and increases the quality and quantity of suitable habitat for macroinvertebrates and fish downstream of the Denison confluence. A greater flux of FPOM and CPOM contributes to a significantly greater food supply for filter feeding, gathering and shredding benthic macroinvertebrates, which respond by having locally very high densities of simuliids and hydropsychid caddis larvae. This enhanced secondary productivity is reflected in higher densities of predatory macroinvertebrate (e.g. hydrobiosid caddis, eusthenid stoneflies) and of fish. Higher growth rates are reflected in greater abundances of larger instars of aquatic insects, and adult recruitment from adult insect reproduction and egg survival becomes more likely, though still restricted. Most macroinvertebrate recruitment is still from tributary inflows by drift.

Downstream of the Denison confluence, the reduced severity of water level changes associated with power station operation and slower recession rates reduce the incidence and extent of seepage erosion sites. However, scouring due to natural inflows increases, especially during the winter months when tributary inflows are high, and banks are exposed. Biologically, these factors led to a more secure food source and increase the quality and quantity of suitable habitat for macroinvertebrates and fish downstream of the Denison River. With respect to bank stability, the lower water level changes associated with power station operation and lower recession rates reduce the incidence and extent of seepage erosion sites on the banks. There is also a higher rate of recruitment of vegetation on the banks due to a supply of organic matter and seed, which contributes to bank stability.

The Basslink investigations and monitoring have been confined to the Gordon River upstream of the confluence with the Franklin River as the hydrology in this reach is most affected by flow regulation associated with the power station. It is recognised that although river flow variations are greatly reduced by this point in the river, the processes and impacts documented during the pre-Basslink monitoring are also linked to the downstream environment. For example, fish passage in the middle Gordon River is ultimately associated with passage through the lower river, sediments eroded from the banks in the middle Gordon River are most likely being deposited in the tidal reaches of the lower Gordon River, and seed dispersal to the lower river is affected by the processes occurring in upstream reaches. These linkages are recognised in a conceptual sense, but have not been investigated.

2.5 Stability of present characteristics of the middle Gordon River

The conceptual model for the middle Gordon River incorporates a wide range of processes which operate over variable timescales. Response of the river over long timescales reflects adjustment to the present flow regime at a catchment scale, while short-term responses tend to be localised and linked to the immediate flow and sediment conditions in the river.

With the exception of bank stability, most components of the river's ecosystem have adjusted to the large-scale changes in the catchment associated with damming and flow regulation. The status of benthic invertebrates, fish and vegetation are considered to be broadly static over timescales of the order of about five years (with a degree of natural interannual variability), which is the extent of observations in the middle Gordon River. This indicates that the adjustment of these components to regulated flow has occurred over periods considerably shorter than the 30 years since damming, even though the regulated flow regime has been variable over that time (1-3-turbines). That these processes are considered broadly stable over the pre-Basslink monitoring period, which coincides with a period of increased 3-turbine power station discharge, suggests that adjustment occurred relatively rapidly, and that the incremental and ongoing changes to flow over the past five years have not had a further substantive impact on benthic invertebrates, fish or vegetation.

The ongoing erosion of sandy alluvial river banks is not static, and continues as a response to damming and flow regulation in the Gordon River, with some of the activity documented during this pre-Basslink monitoring period likely to be associated with adjustment of the river to the increased 3-turbine power station discharge regime. The increased 3-turbine usage has increased median monthly flows (Figure 2.6) upstream of the Denison by up to 50 $m^3 s^{-1}$ relative to pre-dam conditions. The correlation between the recent increase in 3-turbine operation of the power station (~40 % in 2000-05 vs. <10 % in 1989-99) and the prevalence of seepage induced erosion on the banks immediately below the 3-turbine operating water level in zones upstream of the Denison is the basis for this linkage. The vegetation monitoring shows that the main process currently removing vegetation from banks is collapse of the underlying bank, rather than inundation or waterlogging. This supports the hypothesis that flow-induced effects, rather than loss of stability due to loss of overlying vegetation is the main driver of bank modification. This ongoing erosion of banks leads to ongoing local changes in riparian and in-stream habitat suitability.

Localised responses of the vegetation and aquatic organisms occur following short-term (hourly-daily) to medium-term (weekly-monthly) events, such as bank erosion, seasonal storm events, or extended power station shut-down. The localised responses may be long-term, such as the removal of vegetation from banks, or short-term, such as the response of invertebrates to a long power station shut-down, which is rapidly modified following the re-initiation of power station operations.

Intermediate-term variability (seasonal to yearly) also occurs in algae, macroinvertebrate and fish populations and assemblage composition, some of which is in response to power station operations, and some of which in response to natural and catchment-wide phenomena. Seasonal changes in light availability from both natural light fluctuations and altered seasonal patterns of low flows due to power station operations control the relative abundances of filamentous algae, moss and diatoms. Responses by fish to changes in power station discharge are likely to take place over several years, as fish age classes respond over periods of two to five years.

Seasonal to yearly responses to changes in flow patterns, and severe low or high flow events, are observed in macroinvertebrates due to their annual to two-yearly life cycles and recruitment patterns, as well as to seasonal fluctuations in flow and food resources. Overall, the current pattern in in-stream biota is a result of the change in conditions in the Gordon River resulting from the building of the dam and operating the power station. The in-stream biota is in a ‘quasi-equilibrial’ state, with a fairly consistent longitudinal pattern, combined with occasional short-term responses to flow events at the site and reach-scale, dictated by power station operations and lower catchment inputs. However, these variations are not highly auto-correlated.

2.6 References

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Gherke, PC and Harris, JH (2000) Large-scale patterns in species richness and composition of temperate riverine fish communities, south-eastern Australia. *Marine and Freshwater Research* **51**: 165-182.

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Locher H (2001) *Summary Report. Basslink Integrated Impact Assessment Statement – Potential Effects of Changes to Hydro Power Generation*; Hydro Tasmania, Hobart.

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3. Tailrace water quality graphs

This appendix presents graphs of Lake Gordon water level plotted against water temperature at site 75, and Gorgon Power Station discharge plotted against dissolved oxygen concentration at site 77.

These data are plotted month by month to indicate the variation in the strength of the correlation at different times of the year, and to remove any variation as a result of seasonal influences. Pre- and post-Basslink measurements are differentiated by different colours in the graph.

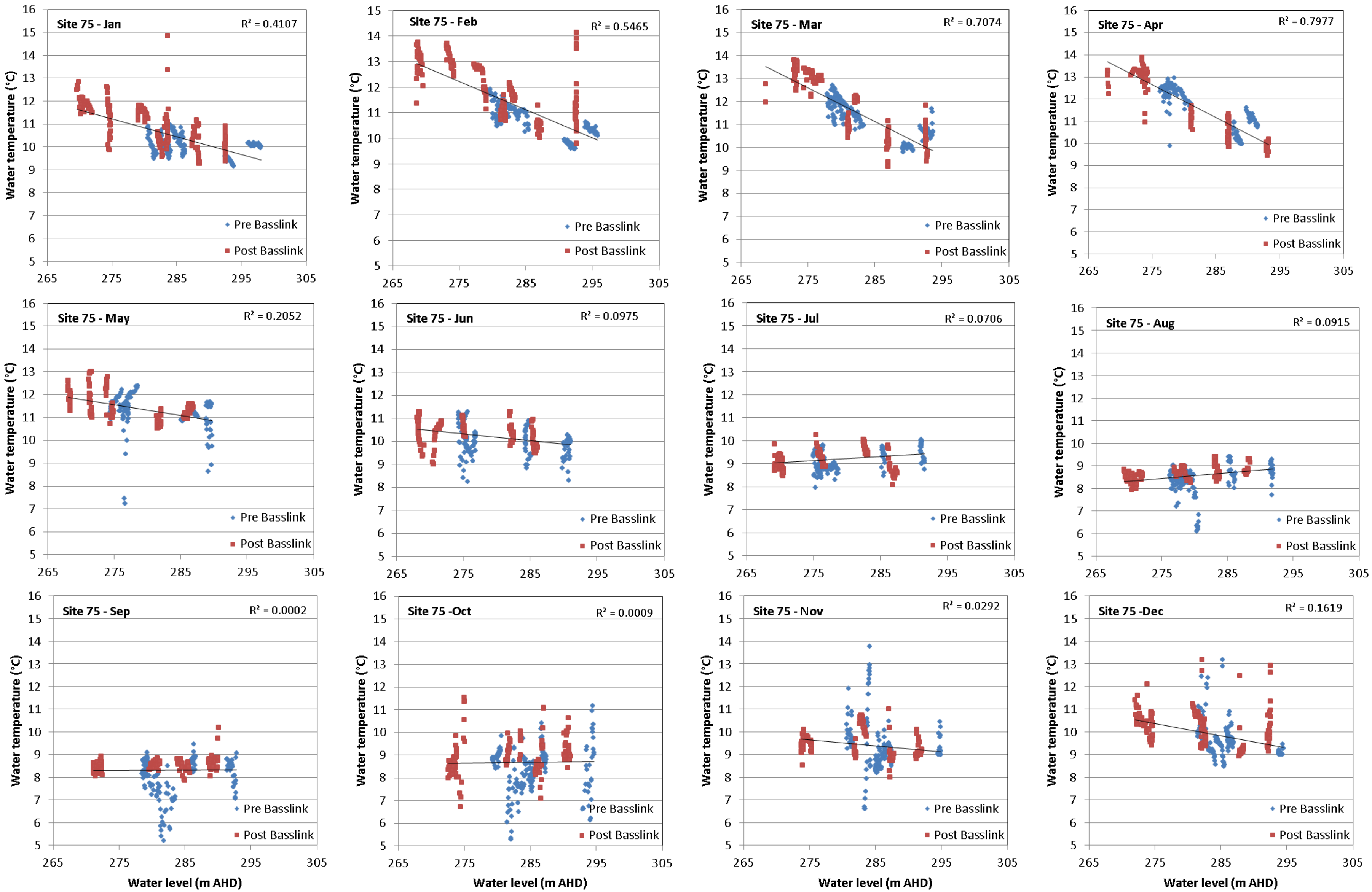

Figure 3.1: Water level in Lake Gordon plotted against water temperature at site 75 for individual months.

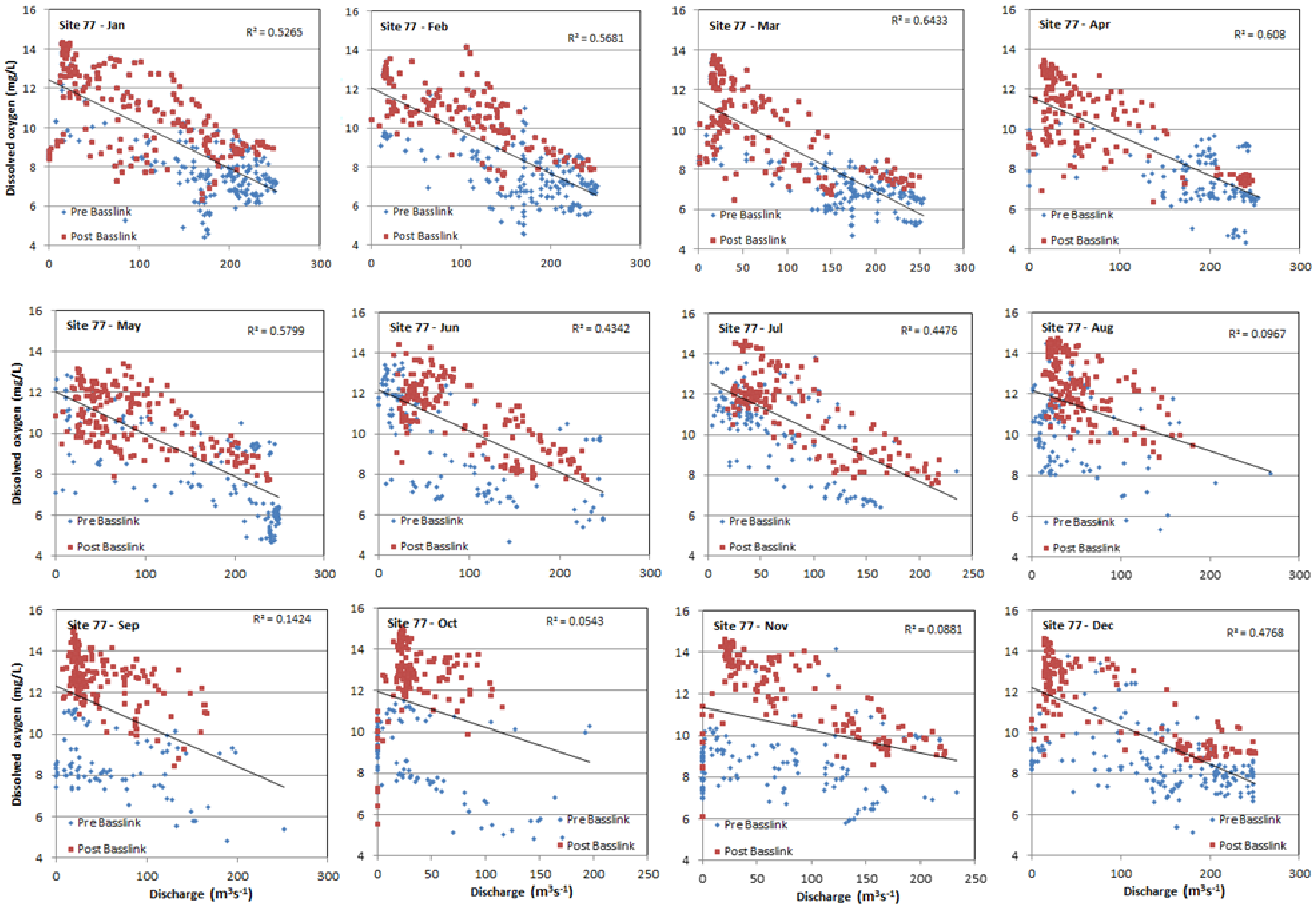

Figure 3.2: Discharge from Gordon Power Station plotted against dissolved oxygen at site 77 (tailrace) for individual months with r-squared values for correlations.

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4. Summary of individual geomorphic monitoring sites

4.1 Zone 1

Zone 1 extends from the power station tailrace to Abel Gorge. The first several kilometres of the zone are in a narrow bedrock gorge. The most upstream erosion pin site, 1A, is located at the first break in slope, below which the river flows through another gorge. In this zone, several of the erosion pin sites are in colluvial banks overlying bedrock. The downstream end of the zone is delimited by Abel Gorge.

Figure 4.1: Satellite imagery of zone 1.

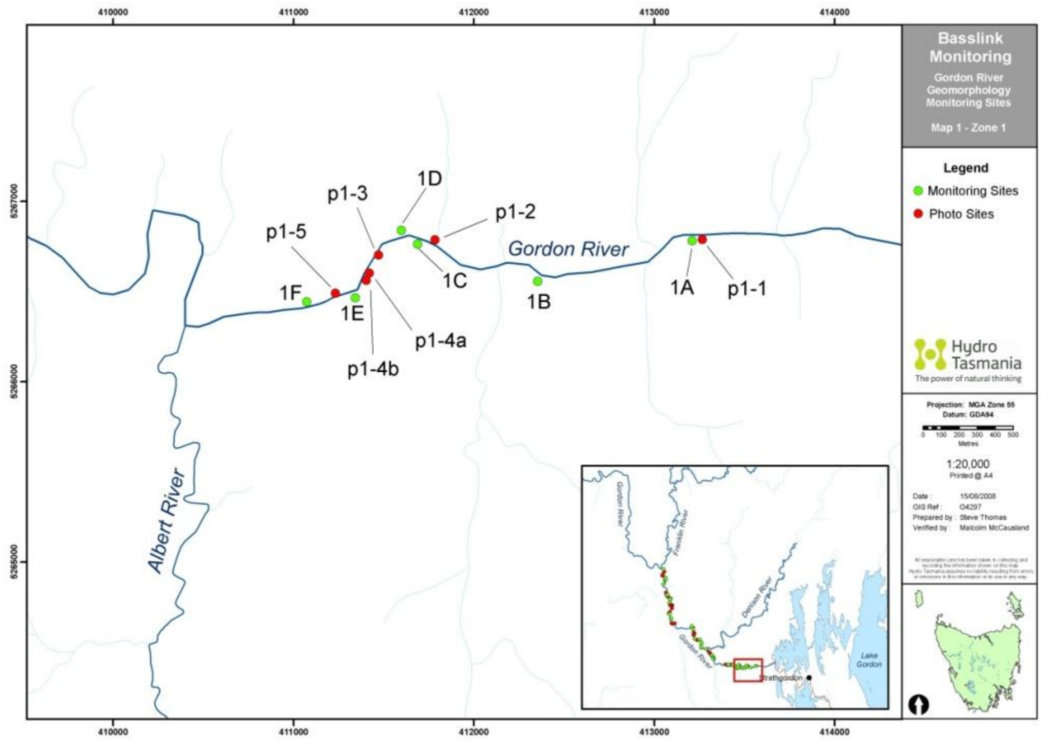

Figure 4.2: Location of monitoring and photo sites within zone 1.

4.1.1 Site 1A

Description: Site 1A is located on the left bank, on an inside bend in short break between two gorges. This is the most upstream site of middle Gordon River investigations. The site is located on a steep colluvial bank behind a cobble bar (photo monitoring site 1A). Erosion pins are installed horizontally along the bank behind the cobble bar over a length of ~50 m.

Erosional processes: Scour is the dominant process observed on the bank face, but erosion pin site appears to be protected from main flow due to position and presence of cobble bar. The right bank of the river has been scoured to bedrock. Pins and scour chains installed near base of bank have recorded scour over Basslink monitoring and vegetation and degraded root-mat have crept downslope. No evidence of seepage erosion has been observed at the site. A large Huon pine tree has progressively ‘rolled’ downslope over the duration of monitoring and branches are now on the ground. In March 2013, a large tree ‘break’ was observed on site, with the trunk snapping in the 1 to 2 turbine bank level – probably due to prolonged saturation.

Pins in general have recorded no / little change or erosion. This is consistent with lack of seepage processes observed at site. The pin (pipe) 1A/3b has shown the largest erosional change. The sudden increase in erosion in October 2006 and February 2011 is associated with rupture, slumping and erosion of the local root-mat.

Erosion pin results

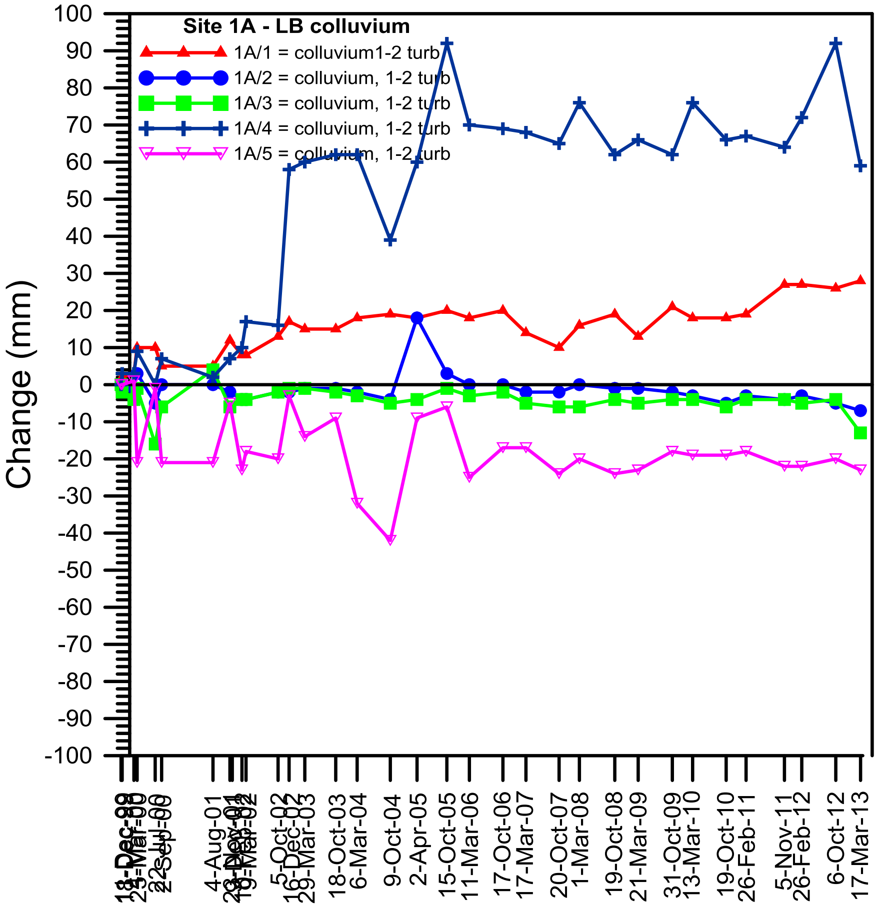

Figure 4.3: Erosion pin results from site 1A (pins 1-5).

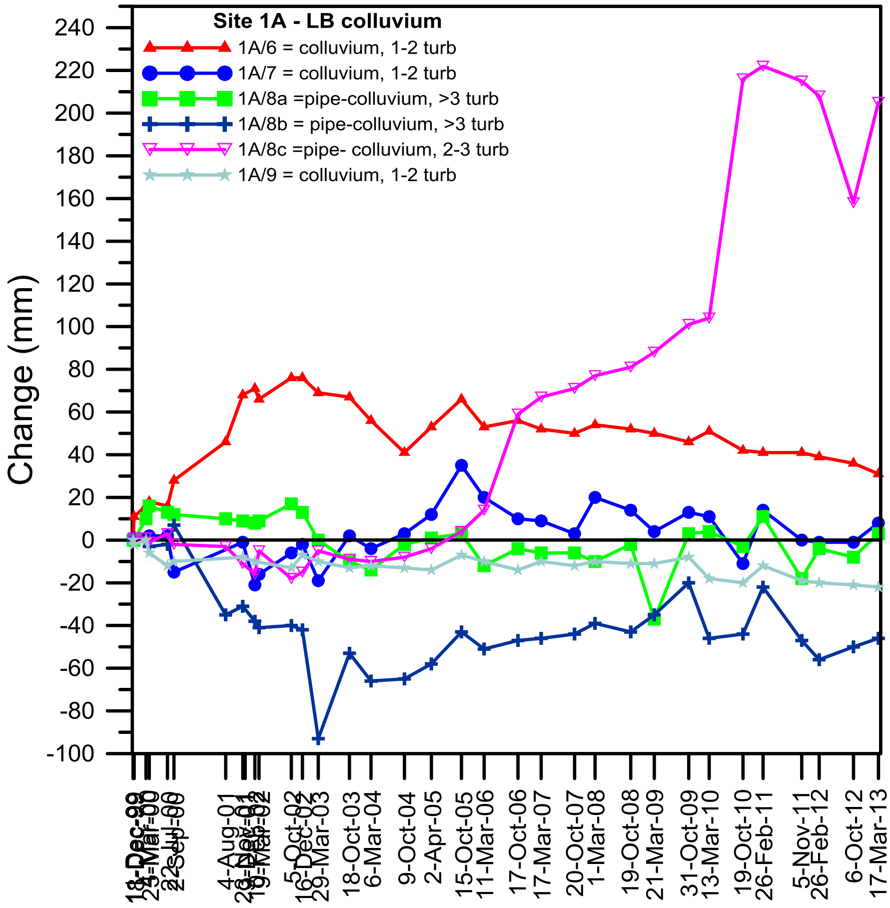

Figure 4.4: Erosion pin results from site 1A (pins 6-9).

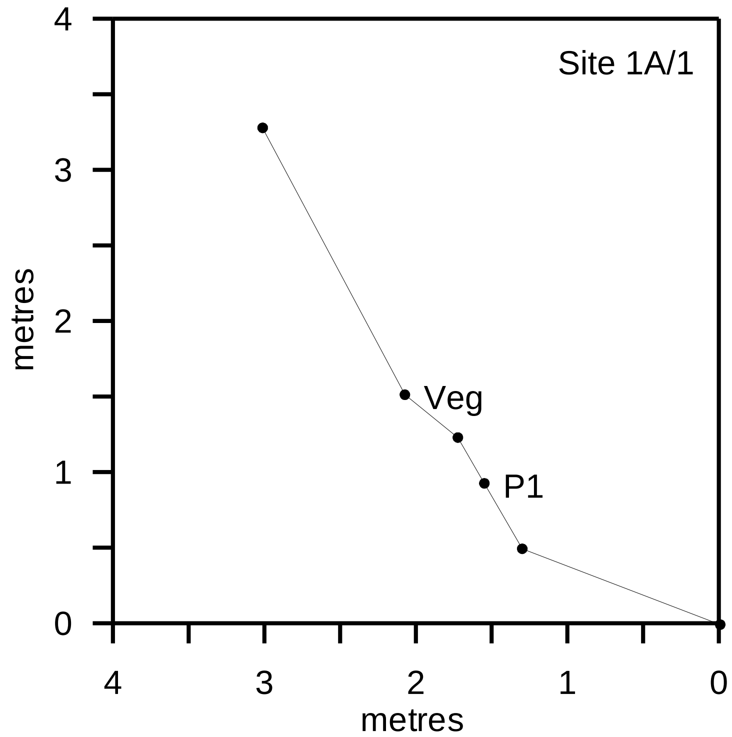

Figure 4.5: Bank profile at pin 1A/1 in 2004. 'Veg' is the most downslope extend of vegetation. P1 is pin 1.

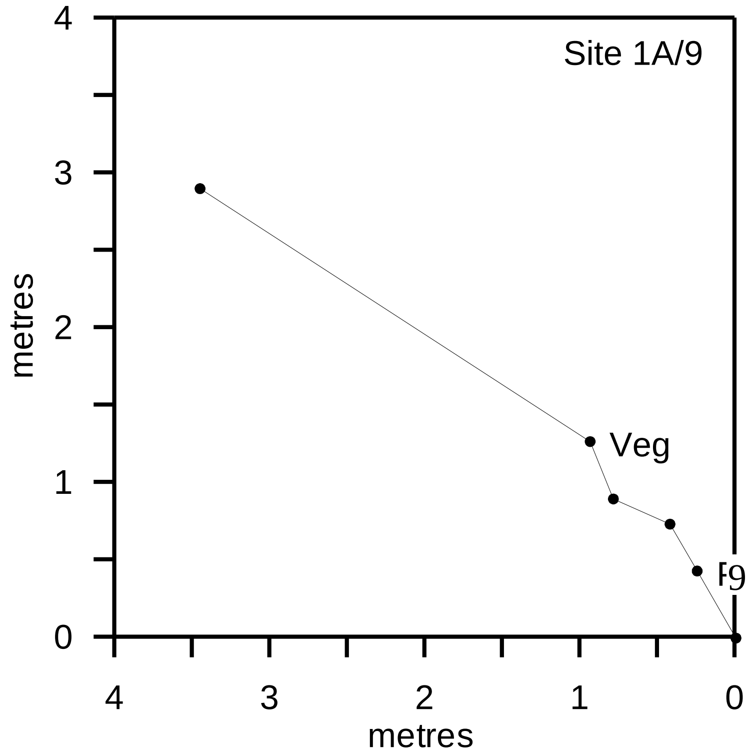

Figure 4.6: Bank profile at pin A1/9 in 2004. 'Veg' is the most downslope extend of vegetation. P9 is pin 9.

Photos

Figure 4.7: View looking upstream of erosion pin site 1A, on left bank (right of picture) behind cobble bar.

Figure 4.8: Site 1A Feb 2013 - view facing downstream of cobble bar in front of site 1A which is on left bank behind the bar.

Figure 4.9: Site 1A February 2013 – Section of colluvial bank showing recent tree break. Photo is typical of site with vegetation overhanging colluvium.

4.1.2 Site 1B

Description: Site 1B is located on the left bank, in small cove / backwater at the downstream end of a straight bedrock gorge that cuts through a steep ridge. The site is immediately downstream of the 'construction' bar (the only new bar formed in the middle Gordon River following construction of the dam). The site consists of colluvium over bedrock on steep bank. Erosion pins were installed horizontally in cavities and vertically in the sandy bank toe along the bank over a distance of ~30m. A drainage line enters the Gordon through site between pins 1B/1 and 1B/4.

Erosional processes: In the first years of monitoring the bank was affected by seepage near pins 1B/1 and 1B/2 (the upstream end of the site), with cycles of erosion and deposition recorded by pin 1B/1 pre-Basslink. The collapsed or the root-mat led to deposition recorded at pin 2, which was ultimately buried and lost. Subsequent removal of the vegetation mat and scour at the site has re-exposed pin. Sandy deposits are limited to upstream end of site suggesting it may be a backwater during high flow with limited scour (leading to preservation of sandy deposits).

Comments: This site is difficult to access and measurements are frequently made at end of long field day with chopper waiting on bar.

Erosion pin results

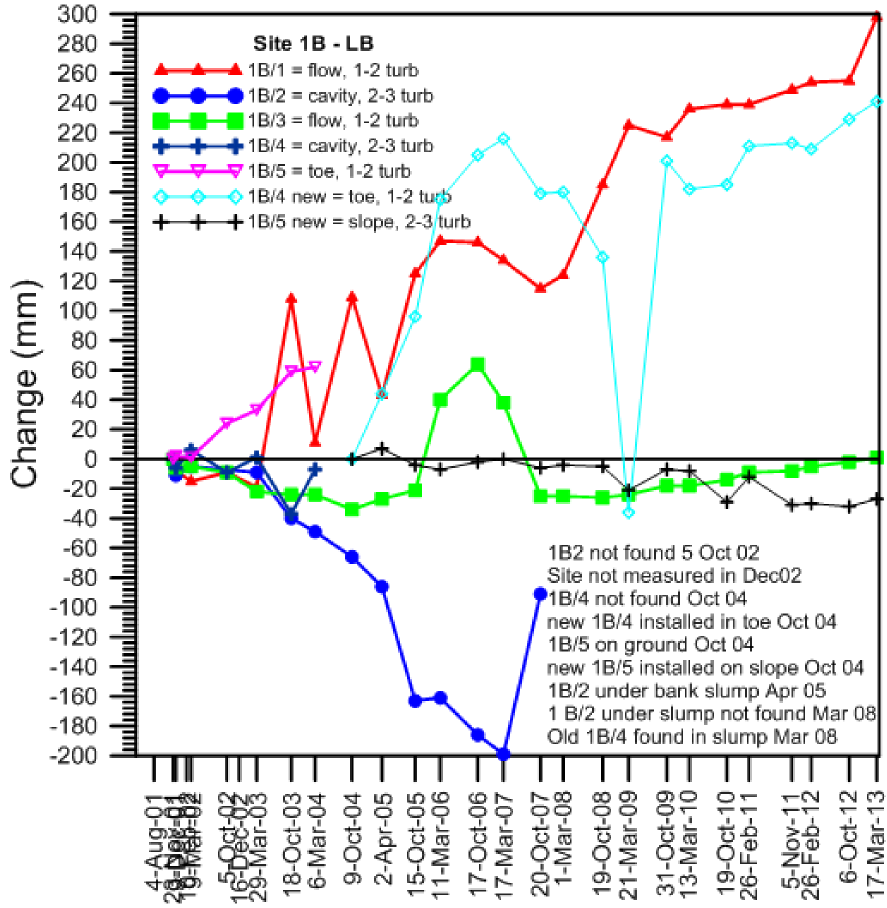

Figure 4.10: Erosion pin results from site 1B.

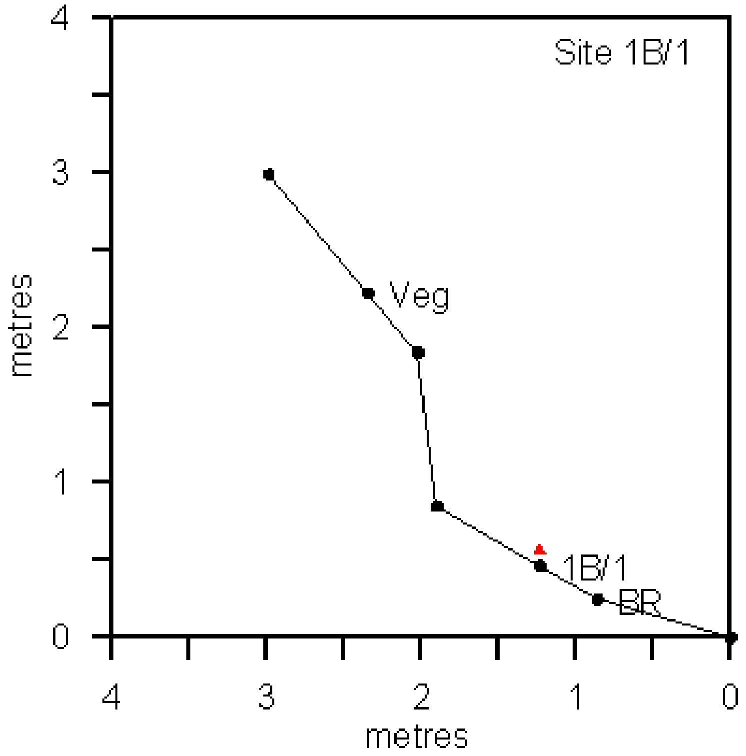

Figure 4.11: 1B bank profiles from 2004. 'Veg' is the most downslope extend of vegetation, BR is bedrock and red triangle shows location of pin 1B/1.

Photos

Figure 4.12: Upstream end of site 1B, 2001.

Figure 4.13: Site 1B March 2008 upstream end.

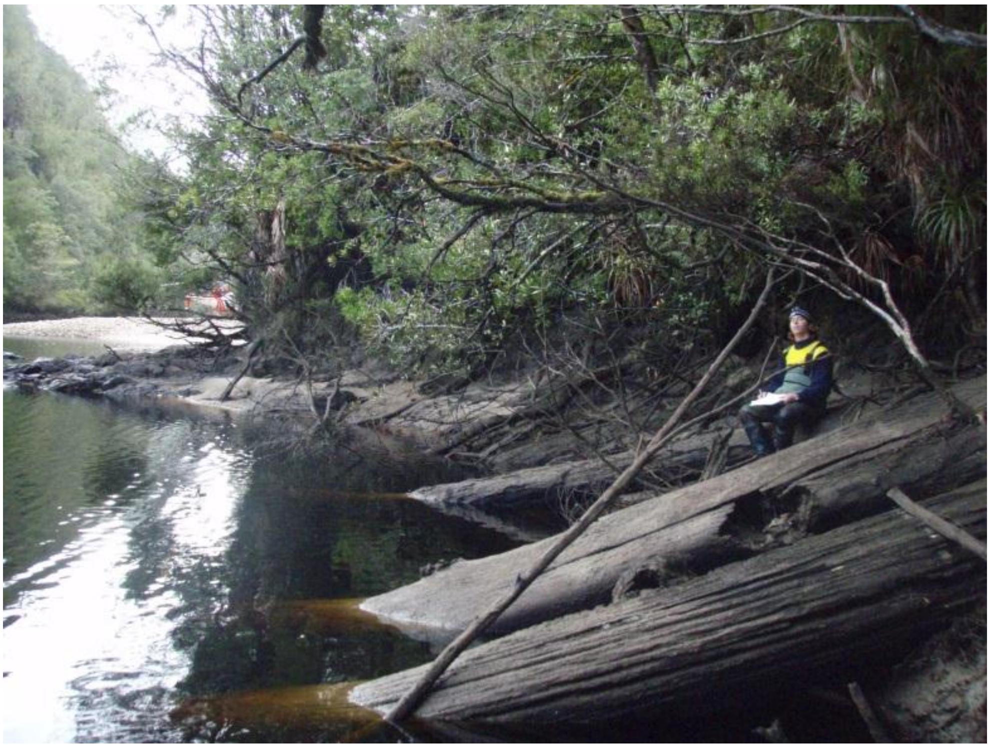

Figure 4.14: Site 1B October 2008 view from downstream end.

Figure 4.15: Site 1B October 2008 upstream end of site.

4.1.3 Site 1C

Description: Site 1C is located on the left bank of the river on a shallow inside bend at upstream of a rapid. The site consists of 4 erosion pins installed vertically into sands overlying cobbles at the base of a tea tree stand. Woody debris is common on the bank.

Erosional Processes: Scour is the dominant erosional process at the site. The bank appears to have a dynamic equilibrium with the regulated flow-regime prior to the commencement of Basslink monitoring, as there has been little change recorded at the site over the 10-year monitoring period.

Erosion pin results

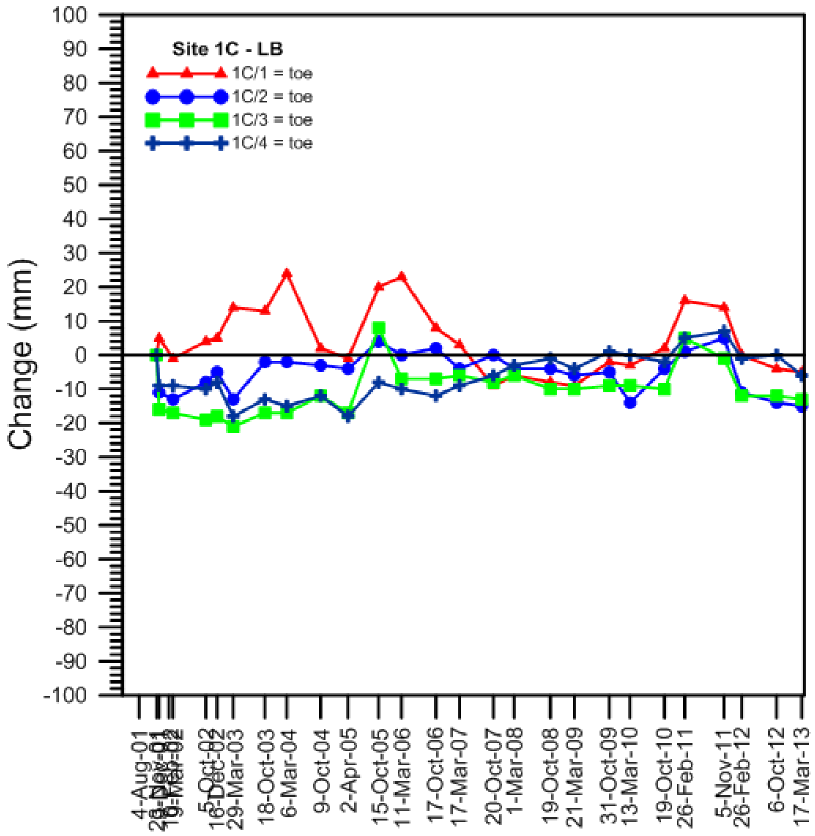

Figure 4.16: Erosion pin results from site 1C.

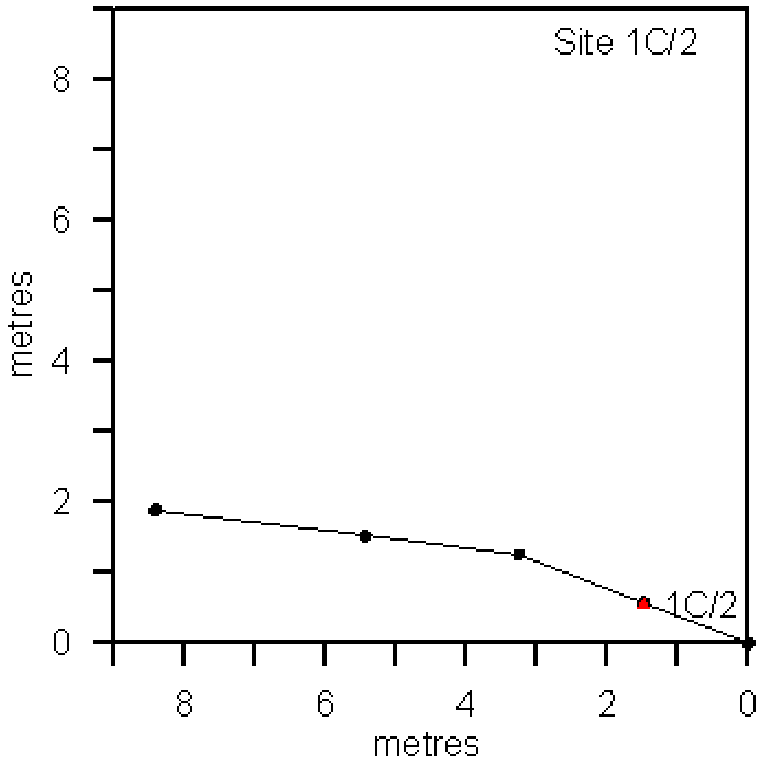

Figure 4.17: Bank profile of site 1C in 2004. Red triangle shows location of pin 1C/2.

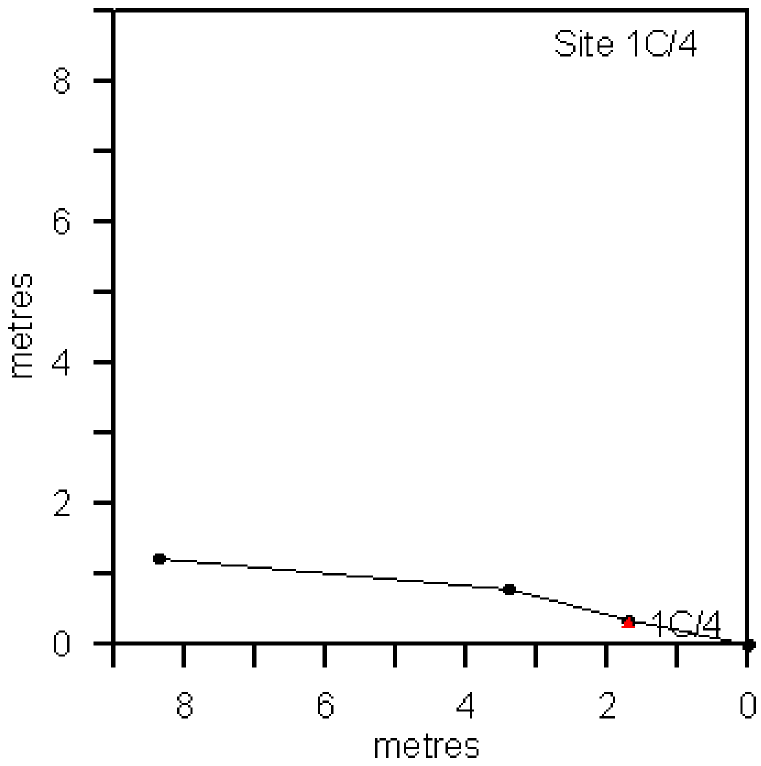

Figure 4.18: Bank profile of site 1C in 2004. Red triangle shows location of pin 1C/4.

Photos

Figure 4.19: Site 1C erosion pin at base of tea tree in 2001.

Figure 4.20: March 2013 - erosion pins are located within tea tree.

4.1.4 Site 1D

Description: Site 1D is on the right bank of the Gordon, at a bedrock controlled riffle. The bank materials consist of colluvium and degraded root-mat over cobbles. Pins were installed in cavities in the 2-3 turbine bank level, and on the bank slope below each cavity.

Erosional processes: The cavities initially recorded scour, but have shown little change over the last 5 years. The bank slopes have recorded variable changes. Field observations include slumping of the overlying root-mat, similar to that observed at the sites 1A and 1B.

Erosion pin results

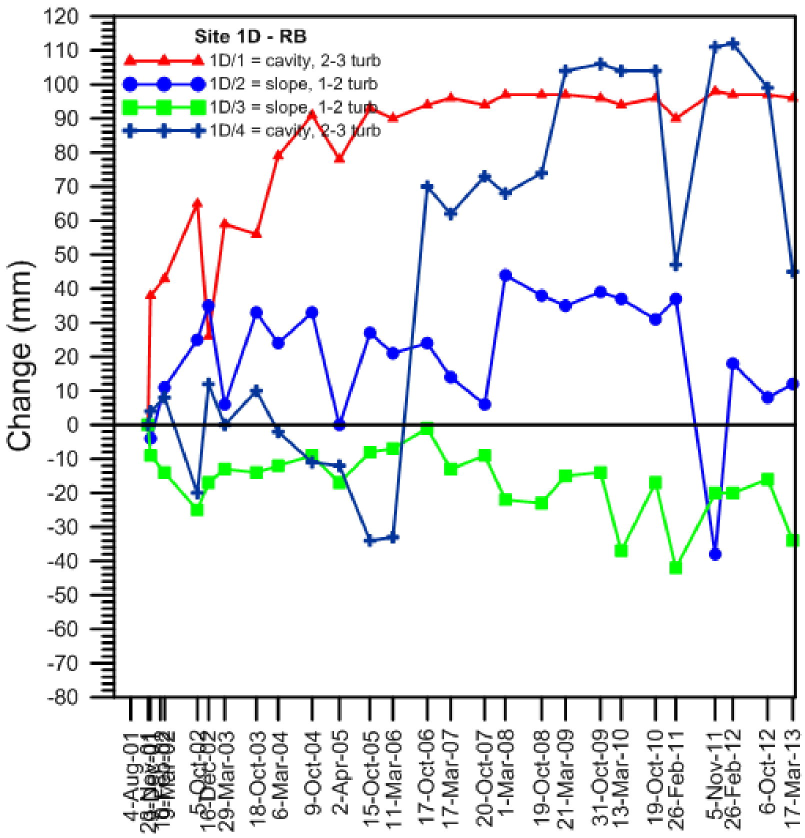

Figure 4.21: Erosion pin results.

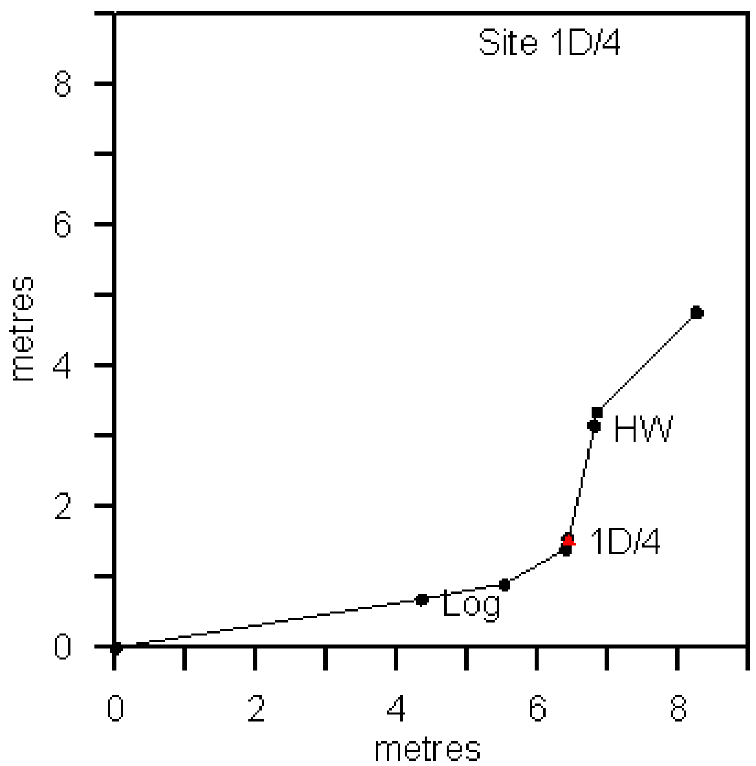

Figure 4.22: Bank profile from site 1D in 2004. 'HW' is high water level, red triangle shows location of pin 1D/4 and 'Log' shows location of a log.

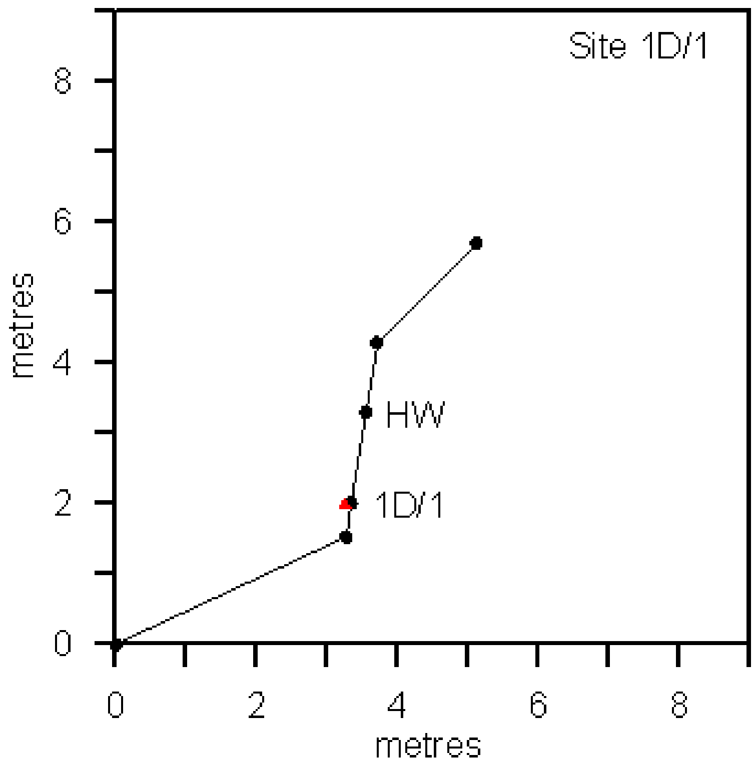

Figure 4.23: Bank profile from site 1D in 2004. 'HW' is high water level and red triangle shows location of pin 1D/1.

Photos

Figure 4.24: Site 1D March 2001.

Figure 4.25: Site 1D March 2010.

Figure 4.26: Site 1D February 2013.

4.1.5 Site 1E

Description: Site 1E is located on the left back, in an alluvial reach on an outside bend. Erosion pins are installed in a profile along the bank. The site is located in tea tree, and when monitoring began, the site showed clear breaks in slope at the 1-turbine and 2-turbine power station operating levels. Post-Basslink, the greater variation in power station operating levels has removed these slope-breaks.

Between March 2009 and October 2009, a large tree fell directly over the line of the erosion pin profile, but landed on a large branch so remained supported above the erosion pins. A duplicate profile was established on the bank upstream of the original profile, but the original pins remain intact and have continued to be measured.

Erosional Processes: The dominant erosional processes on this bank are scour of the tea tree root-mat, followed by seepage processes leading to a reduction in slope of the exposed sands. Some of this flattening may be attributed to the introduction of the environmental flow which results in the original ‘bank toe’ being continuously inundated (except during Basslink monitoring). No sediment flows have been observed on the bank.

Comment: This bank is a good example of tea tree banks in an area affected by high flow level fluctuation and considered a key site for these processes (along with site 2L).

Erosion pin results

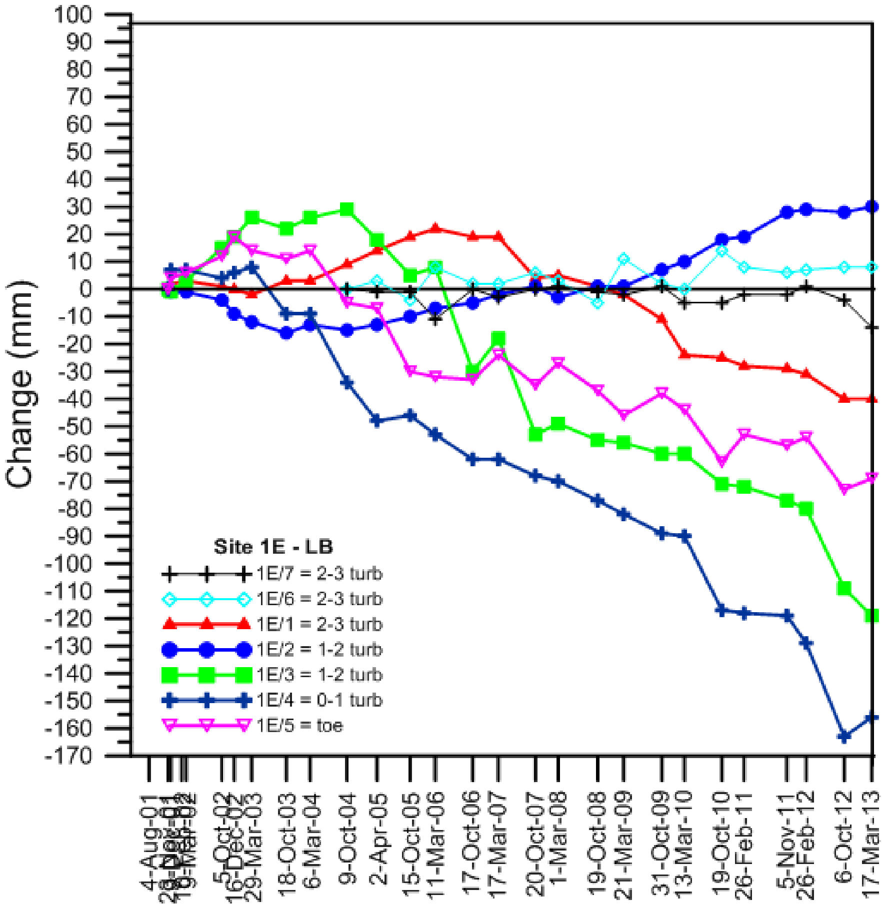

Figure 4.27: Erosion pin results from site 1E.

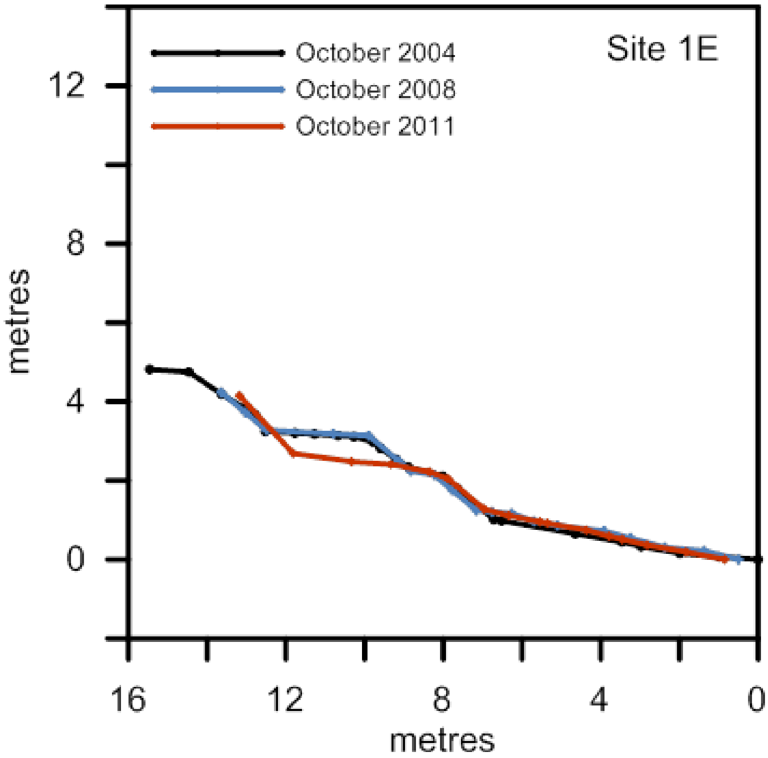

Figure 4.28: Bank profiles of site 1E. Erosion pins do not record scour, suggesting 2011 profile is not in exact same location.

Photos

Figure 4.29: Site 1E December 2004.

Figure 4.30: Site 1E December 2004.

Figure 4.31: Site 1E March 2008.

Figure 4.32: Site 1E October 2008.

Figure 4.33: Site 1E October 2009.

Figure 4.34: Site 1E February 2013 - Erosion pin profile is directly below tree-fall in centre-right of photo. New profile has been installed upstream (left in photo).

4.1.6 Site 1F

Description: Site 1F consists of 4 erosion pins installed horizontally in cavities on the right bank immediately upstream of Abel Gorge in colluvium overlying bedrock. Measurement of the erosion pin in cavity 1F/1 is difficult due to the presence of many tree roots, and the measurements are highly variable and are unlikely to accurately reflect the length of the erosion pin. The other pins have shown variability associated with the slumping of the overlying root-mat.

Erosional Processes: Similar to the other colluvial sites, the predominant process is the slumping and erosion of the overlying root mat. Little sand and no sediment flows have been observed at the site for the past few years.

Erosion pin results

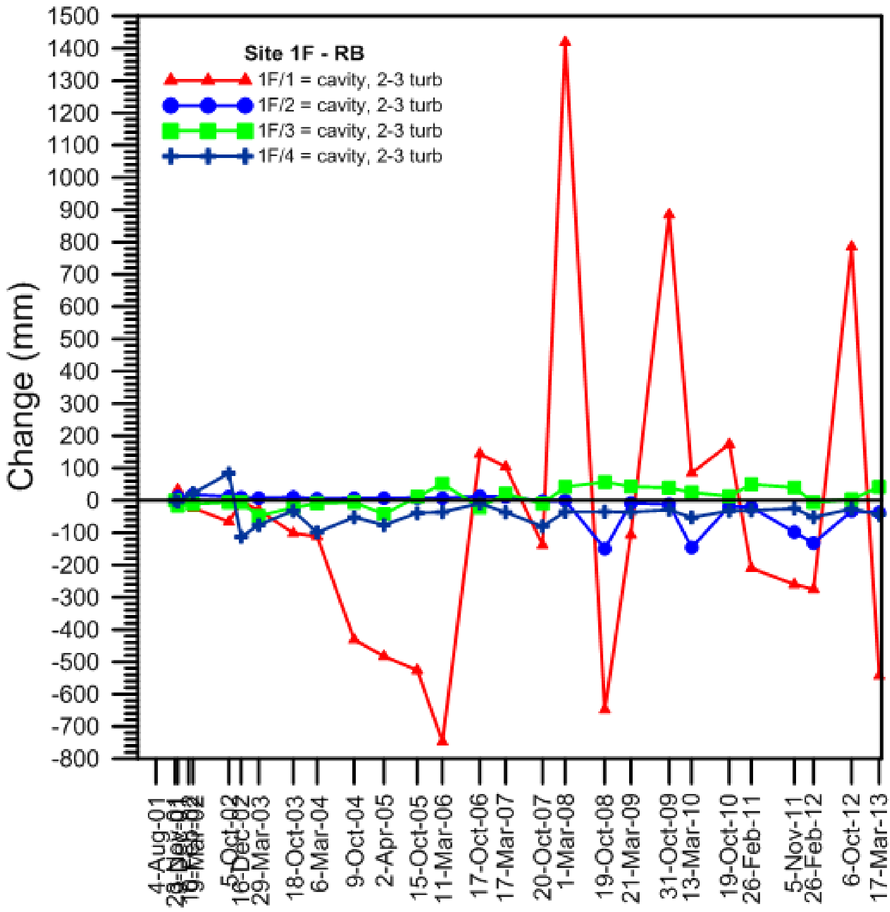

Figure 4.35: Erosion pin results from site 1F (pins 1-4).

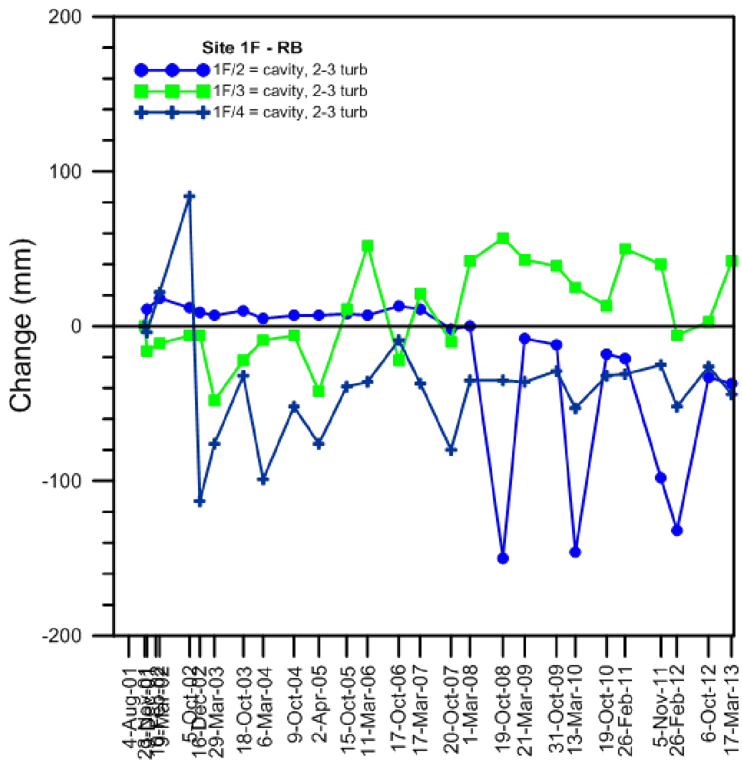

Figure 4.36: Erosion pin results from site 1F (pins 2-4).

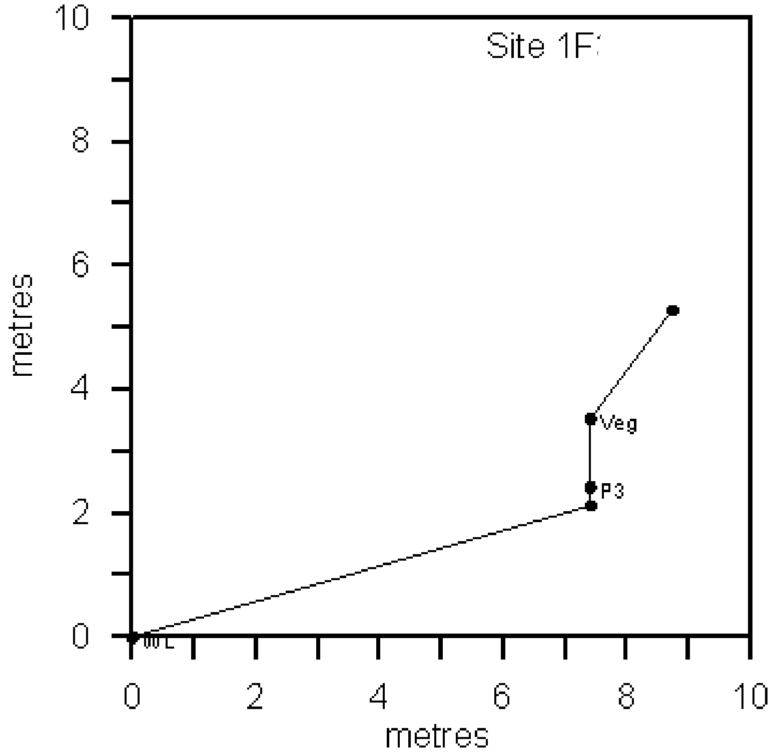

Figure 4.37: Bank profile at pin 1F/3 in 2004. ‘Veg’ is the most downslope extend of vegetation and ‘WL’ is water level.

Photos

Figure 4.38: Site 1F March 2001.

Figure 4.39: Site 1F March 2001.

Figure 4.40: Site 1F October 2007.

Figure 4.41: Site 1F March 2008.

Figure 4.42: Site 1F October 2008.

Zone 1 erosion pin results – turbine comparison

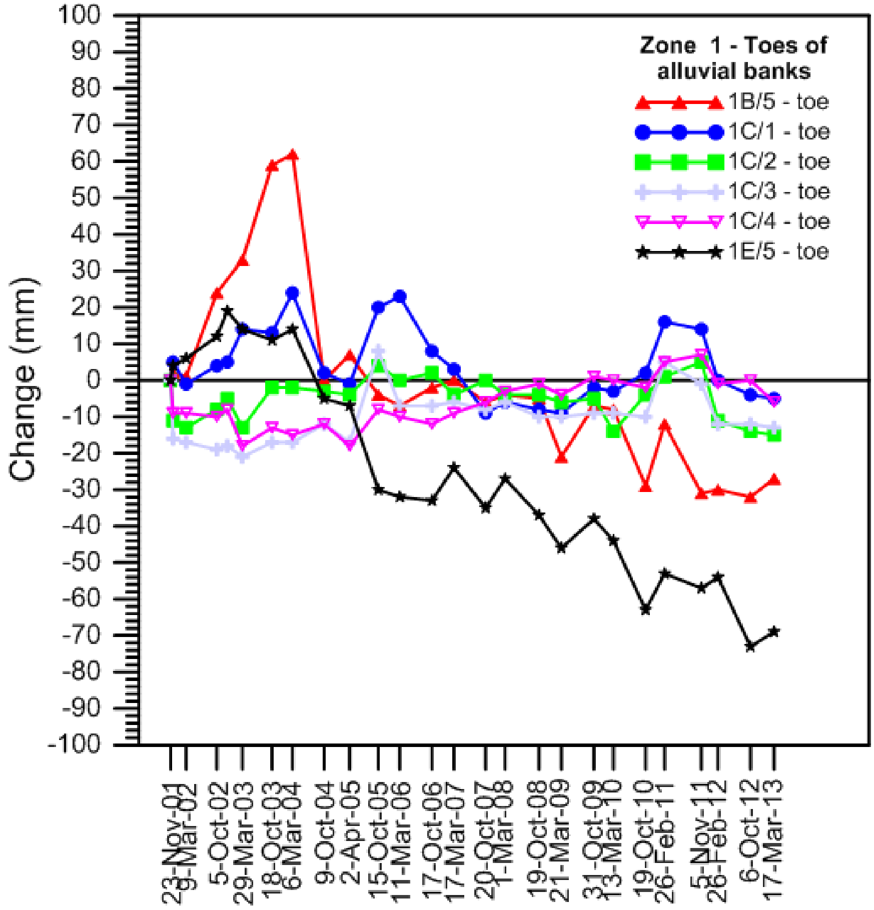

Figure 4.43: Erosion pin results from bank toes in zone 1.

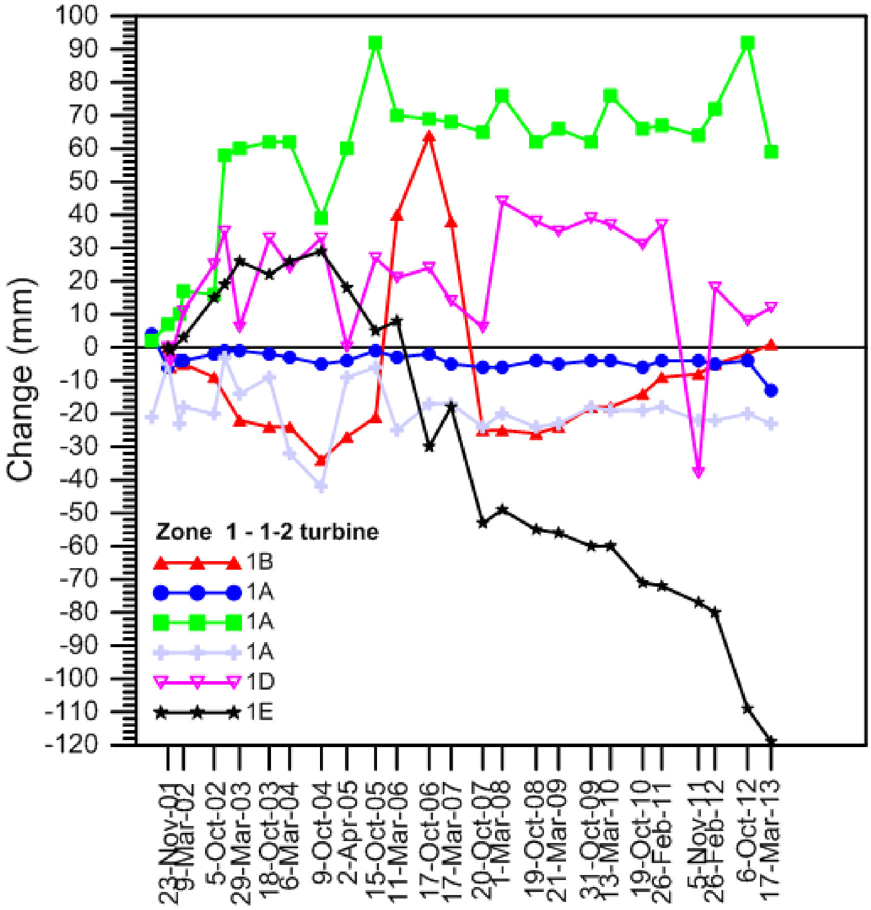

Figure 4.44: Erosion pin results from pins in 1-2 turbine bank level in zone 1.

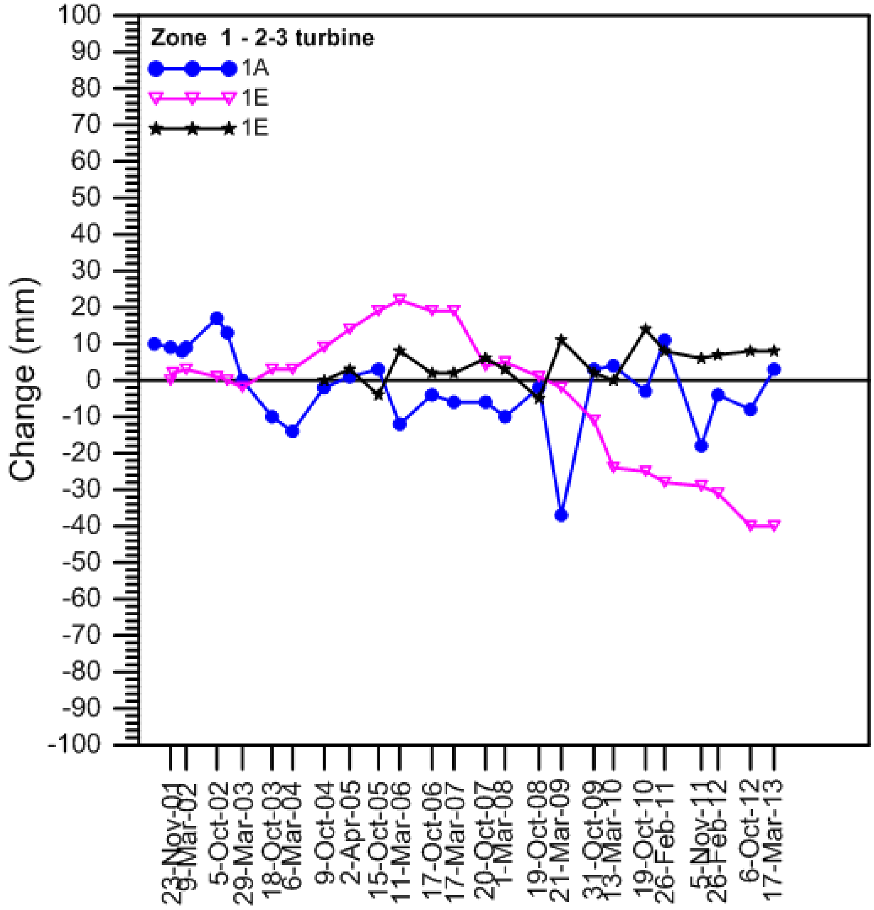

Figure 4.45: Erosion pin results from pins in 2-3 turbine bank level in zone 1.

4.2 Zone 2

Zone 2 extends from Abel Gorge to the Splits, with the Albert River entering the Gordon at the upstream end of the zone. The planform of the river includes a large tight bend. Vertical alluvial banks composed of cobbles overlain by sands are exposed on the inside of the bend, with the outside bank being largely bedrock controlled with alluvial pockets. The bend occupies a relatively broad valley. Downstream of this, the river has a straight course and cuts through several ridges before entering the Splits.

Figure 4.46: Satellite imagery of zone 2.

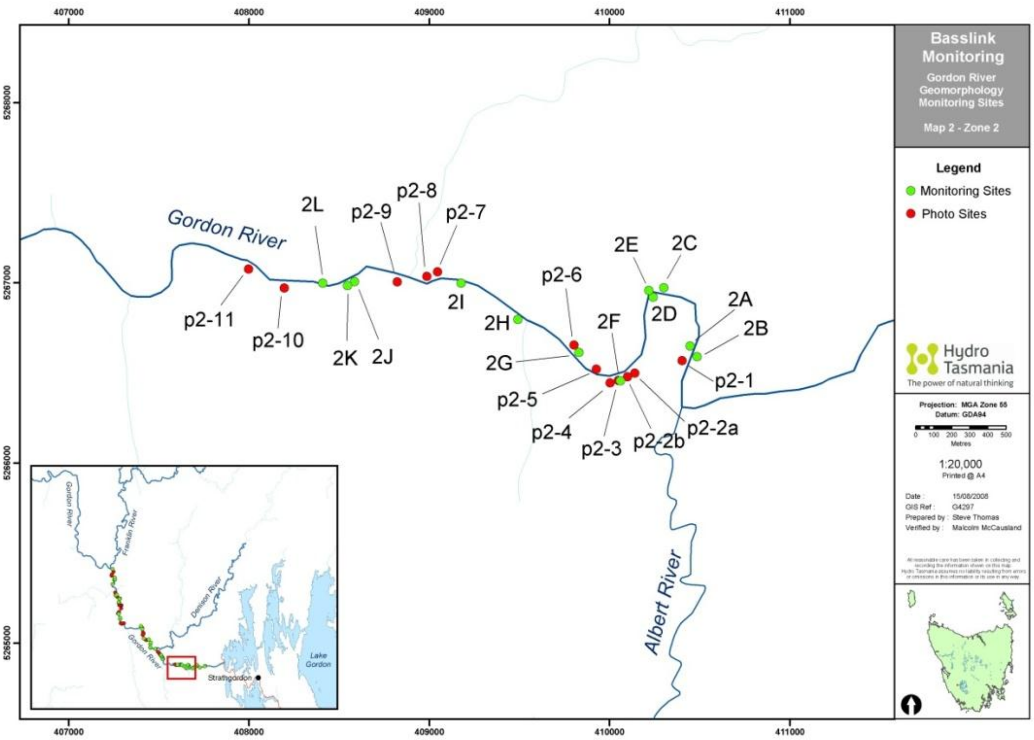

Figure 4.47: Location of monitoring and photo sites within zone 2.

4.2.1 Site 2A

Description: Site 2A is located on a mid-stream bar, separated from the left bank of the river by a channel which becomes active in the 1-2 turbine flow range. The site is on a sandy berm overlying cobbles, and the erosion pins are installed in a transect from the river side over the berm to the backwater channel. The top of the berm is just above the 3 turbine power station discharge level. The site is located within tea tree.

Erosional processes: The river-side of the bank has shown little change in the 1-2 turbine level. The 2-3 turbine level has shown flattening (deposition through seepage) on both sides of the crest. The pin in the bed of the back channel has shown the largest changes due to a scour hole forming at the base of the pin, and then subsequently refilling. The vegetation in the back water has varied from almost non-existent at the start of the monitoring program to abundant following the several years of low power station usage. The left bank of the back channel is prone to seepage erosion.

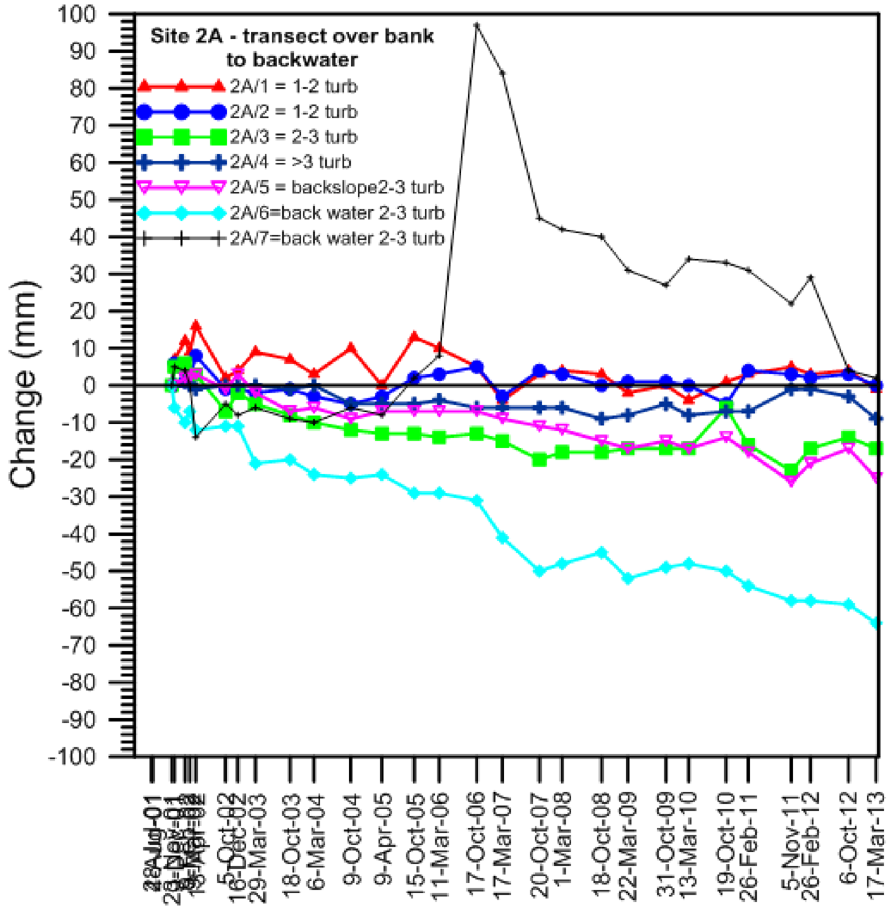

Figure 4.48: Erosion pin results from site 2A.

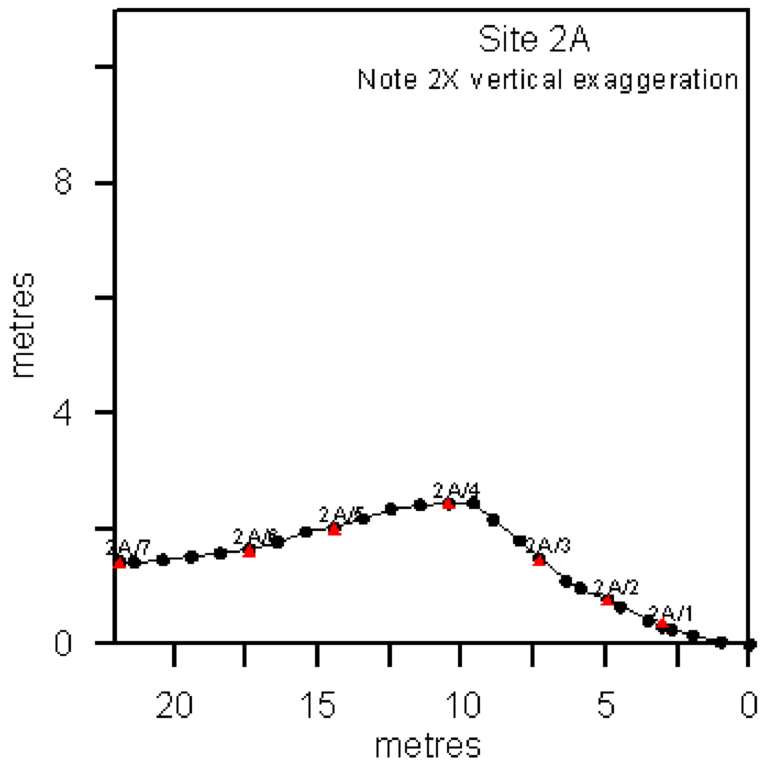

Figure 4.49: Bank profile of site 2A from 2005. Red triangles show location of pins.

Photos

Figure 4.50: Site 2A is on the left bank in the tea tree stand behind the cobble bar. Photo from ~2000.

Figure 4.51: Site 2A March 2001.

Figure 4.52: Site 2A October 2010.

Figure 4.53: Site 2A December 2010.

Figure 4.54: Site 2A March 2013.

Figure 4.55: Site 2A backwater March 2006.

Figure 4.56: Site 2A backwater October 2006. Scour hole at base of pin 2A/7.

Figure 4.57: Site 2A Backwater December 2007. Left bank of back channel showing tree fall.

Figure 4.58: Site 2A backwater March 2010. View is downriver.

Figure 4.59: Site 2A backwater March 2013. View is upriver, with tea tree bank on left of photo.

4.2.2 Site 2B

Description: Site 2B is on the right bank across from the cobble bar where 2A is located, adjacent to a riffle. The site is composed of alluvium containing angular pebbles, cobbles and sand overlain by a thick root-mat. Erosion pins were initially placed in a cavity and in the sandy deposits at the base of the bank. A large block of material fell from the bank between March and October 2008 which contained an erosion pin and fell onto another pin.

Erosional Processes: Initially the site showed evidence of seepage erosion, but over the period of monitoring erosion has been the dominant process. One cavity has shown little change over time, while the second cavity has collapsed. No sediment flows were observed following the collapse, possibly due to scour removing the material.

Erosion pin results

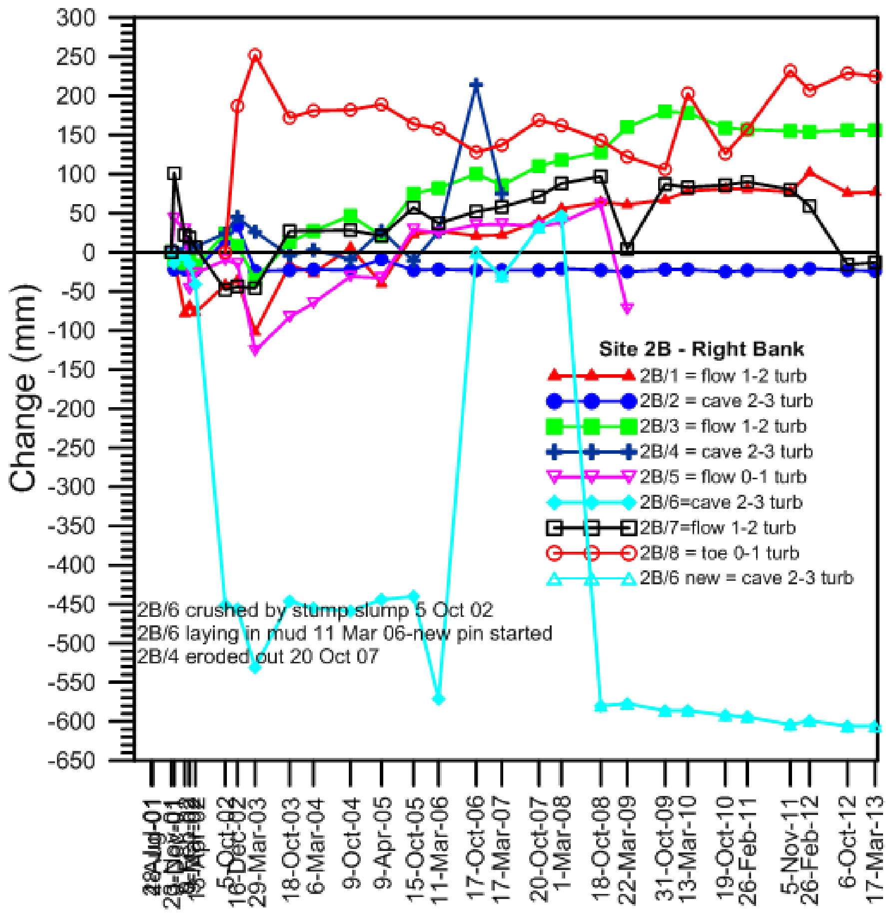

Figure 4.60: Erosion in results from site 2B.

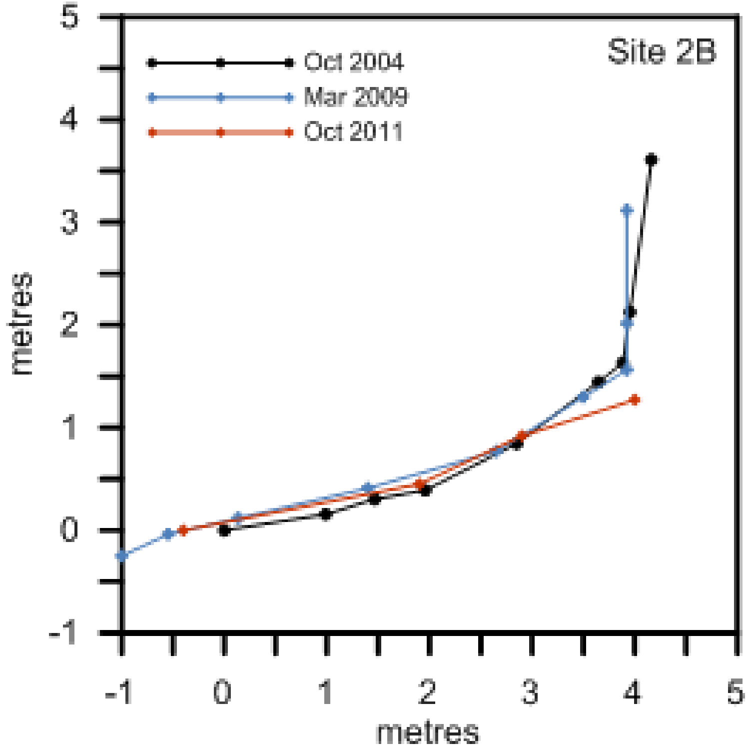

Figure 4.61: Bank profile from site 2B in 2004, 2009 and 2011.

Photos

Figure 4.62: Site 2B November 2001.

Figure 4.63: Site 2B November 2001.

Figure 4.64: Site 2B October 2002.

Figure 4.65: 2B October 2006.

Figure 4.66: 2B October 2009.

Figure 4.67: 2B October 2009.

Figure 4.68: 2B October 2010.

Figure 4.69: 2B March 2013.

4.2.3 Site 2C

Description: Site 2 C is located on the right back at the outside and upstream end of a sharp bedrock controlled bend. The site is composed of sands overlain by a thick vegetation mat. The hydraulics of this area are complex at high flows, and include numerous eddies. The bank tends to be saturated, and early in the monitoring was observed to 'flow' downslope after being disturbed by the field team. A pipe that was initially installed in the lower bank (shown in 2000 photo) was lost and presumed to have moved with the bank downslope. The erosion pins at the site were installed in two cavities, at the base of one of the cavities, and on the bank toe. One of the cavities has collapsed over the period of monitoring. The pin in the 1-2 turbine zone is a pipe which appears to be supporting the bank.

Erosion Processes: This site is one of the 'wettest' sites in the river. During the initial IIAS investigations, seepage flows were observed at the base of the root-mat, and the bank itself was prone to seepage processes. The collapse of the root-mat and relatively low level of activity at the site suggests that there was a period of rapid change which coincided with the IIAS and initiation of extended 3-turbine power station operation. The bank profile has changed from convex to concave over the monitoring period, suggesting that there is less material being transported from under the root-mat onto the bank.

Comment: This bank drains slowly compared to other banks and has likely been substantially altered due to field personnel stepping on the bank when very wet.

Erosion pin results

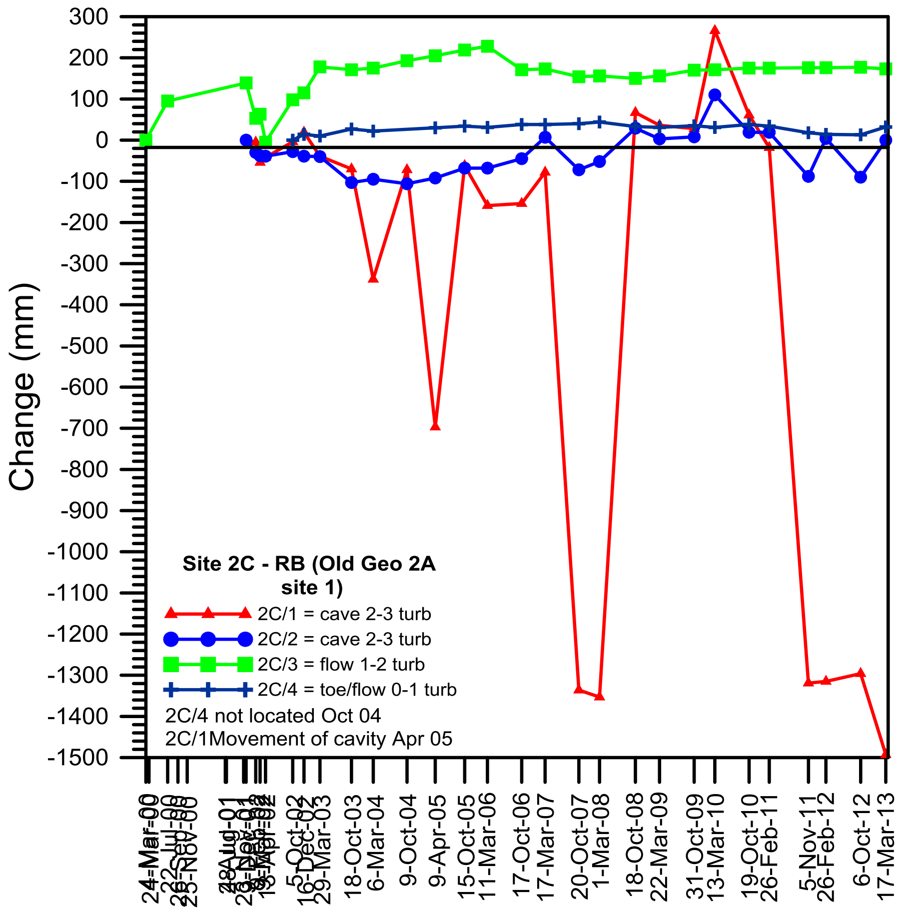

Figure 4.70: Erosion pin results from site 2C.

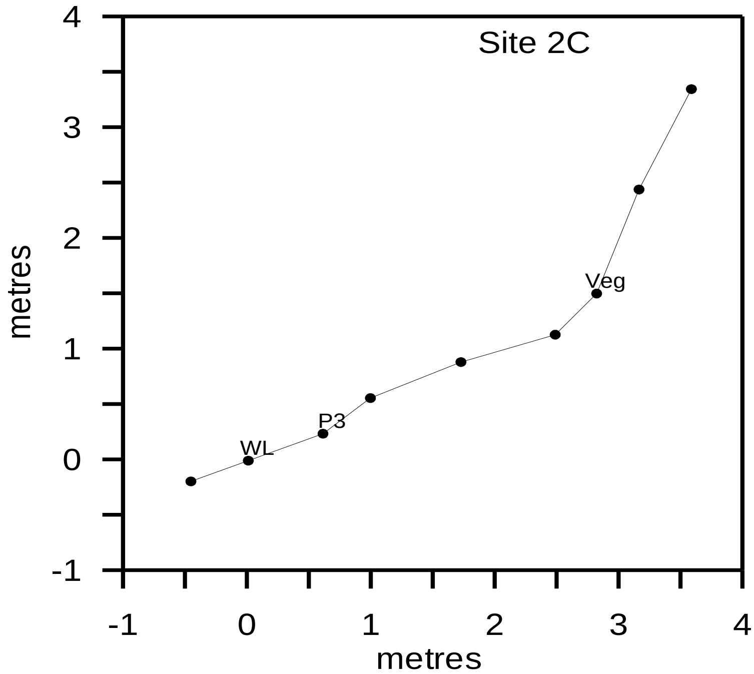

Figure 4.71: Bank profile from site 2C in 2004. ‘Veg’ is most downslope extent of vegetation and ‘WL’ is water level.

Photos

Figure 4.72: Site 2C 2000.

Figure 4.73: Site 2C 2000.

Figure 4.74: Site 2C October 2007.

Figure 4.75: Site 2C October 2007.

Figure 4.76: Site 2C December 2007.

Figure 4.77: Site 2C March 2010.

Figure 4.78: Site 2C March 2010.

Figure 4.79: Site 2C Oct 2010.

Figure 4.80: Site 2C March 2013.

4.2.4 Site 2D

Description: Site 2D is located on the left bank on the inside of a sharp bend across from sites 2C and 2E. The local hydraulics are complicated at high flow with several eddies and backwaters present in the tight bend. The site is composed of sands overlain by a root-mat, with a prominent sandy toe and abundant woody debris. Large trees and associated roots contribute to the morphology and stability of the banks. The erosion pins were installed as a profile up the bank face.

Erosional Processes: When established, there was a remnant root-mat which extended into the 1-2 turbine level. The mat was progressively scoured, and once gone, the erosion pins recorded deposition, associated with local seepage processes flattening the banks. Some scour of the root-mat continues in the 2-3 turbine zone. The bank toe has shown highly variable behaviour, some of which may be associated with the introduction of the environmental flow.

Comment: it is likely the toe of this bank is subjected to very different hydraulic conditions under different flow rates, ranging from scour to fluvial deposition as part of a back-water eddy.

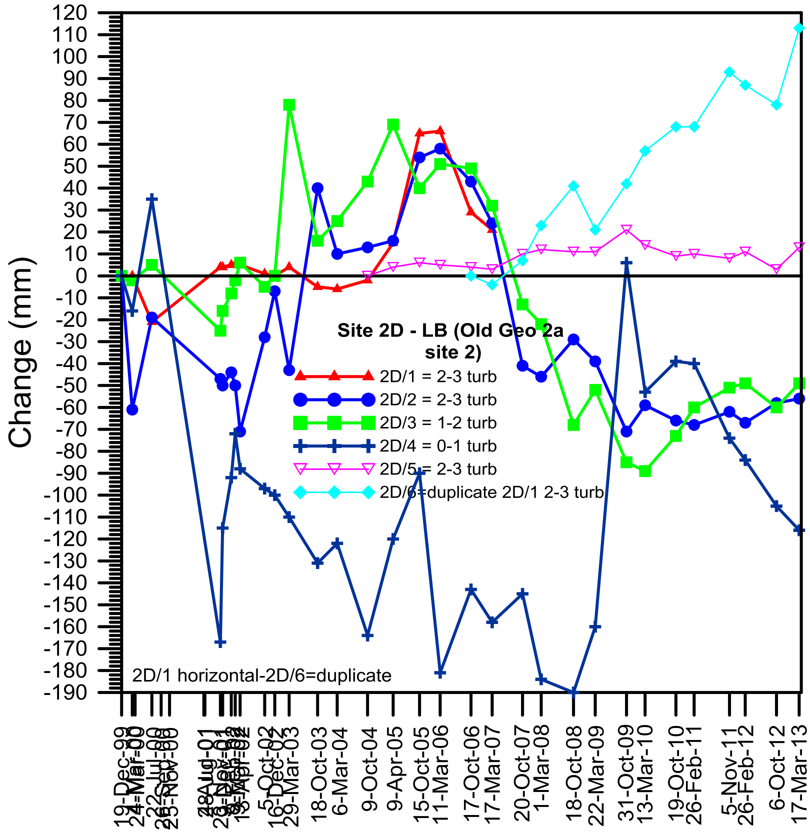

Figure 4.81: Erosion pin results from site 2D.

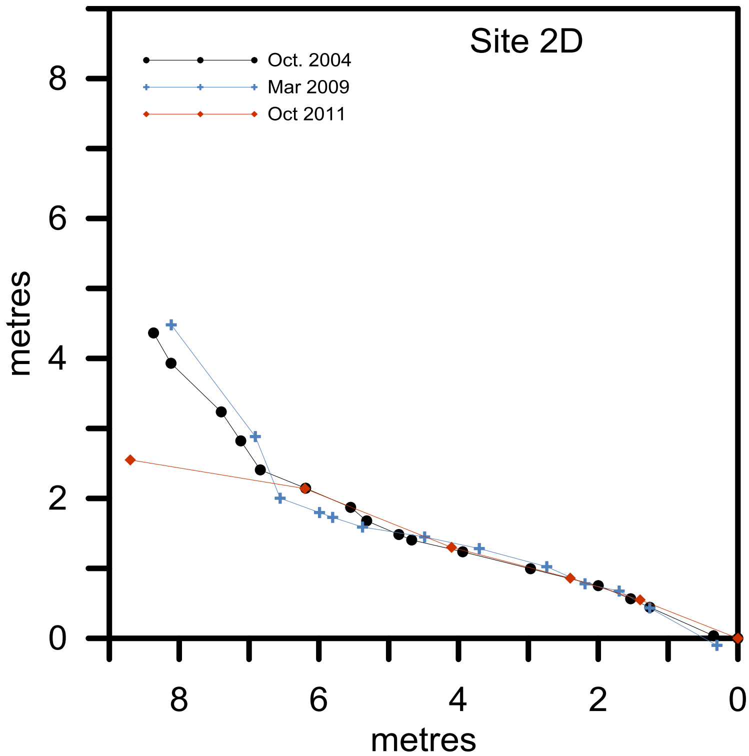

Figure 4.82: Bank profiles differ due to 2013 profile collected along different transect on bank face during combined vegetation and geomorphology monitoring.

Photos

Figure 4.83: Site 2D 2000.

Figure 4.84: Site 2D December 2004.

Figure 4.85: Site 2D October 2007.

Figure 4.86: Site 2D December 2007.

Figure 4.87: Site 2D December 2007.

Figure 4.88: Site 2D March 2010.

Figure 4.89: Site 2D Oct 2010.

Figure 4.90: Site 2D March 2013.

4.2.5 Site 2E

Description: Site 2E is located on the right bank, on the outside of a very sharp bend just downstream from site 2C and across from 2D. The site is in an alluvial 'pocket' upstream of a large bedrock outcrop. Similar to site 2C, there is thick vegetation and root-mat overlying sands. There is abundant woody debris on the site and in the river in front of the site. Erosion pins were installed in a cavity and in a profile up the bank.

Erosional Processes: Scour is the predominant process affecting the 1-2 and 2-3 turbine levels. The toe of the bank is flattening through local seepage process. During the initial IIAS investigations sediment flows were observed at this site, but have not been observed for many years.

Comment: Erosion pin 2E is a pipe which is contributing to bank stability by supporting the bank.

Erosion pin results

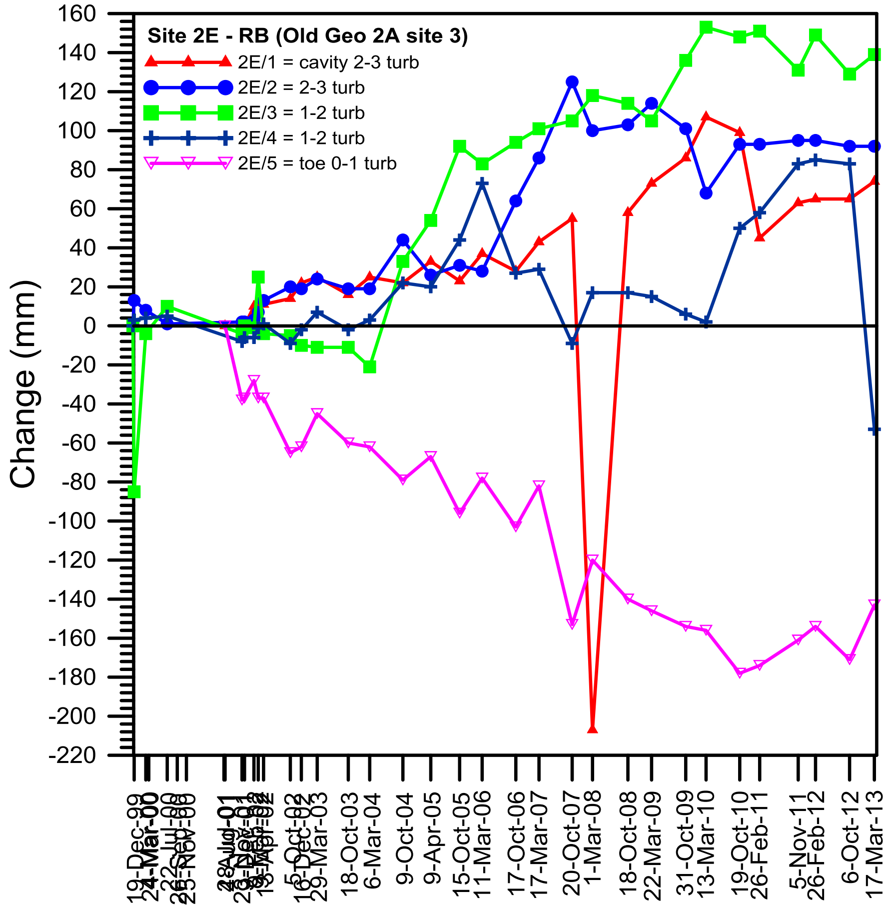

Figure 4.91: Site 2E Erosion pin results.

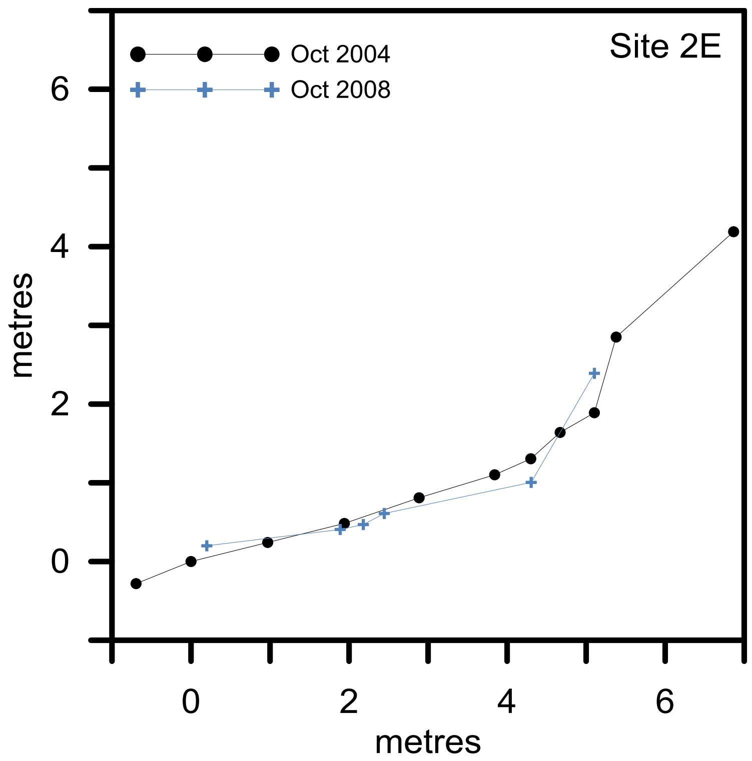

Figure 4.92: Site 2E bank profiles.

Photos

Figure 4.93: Site 2E 2000.

Figure 4.94: Site 2E Oct 2010.

Figure 4.95: Site 2E October 2007.

Figure 4.96: Site 2E December 2007.

Figure 4.97: Site 2E Dec 2007.

Figure 4.98: Site 2E March 2013.

4.2.6 Site 2G

Description: Site 2G is located on the right bank, at the head of a small rapid. The right bank is steep and supports a very large tree, with a sandy bank toe. The site is adjacent to and upstream of the zone 2 piezometer site. Erosion pins were installed in large cavities in the steep bank, in the sediment flows at the base of the cavities, and on the bank toe.

Erosional Processes: Characteristics of this site include large rills and tension cracks in the sandy lower bank and toe, reflecting local seepage processes. However, the erosion pins tend to record variable results, with net erosion recorded at most pins over the duration of monitoring period. The vegetation mat is slowly being scoured away, revealing a low angle bank under the mat. It is likely that the root system associated with the very large tree is providing bank stability.

Comment: If/when the large tree collapses, the site is likely to become similar to photo monitoring site 2-5 which is situated just upstream on the same bank, and is characterised by a long, relatively flat sandy toe with abundant woody debris grading back to a steep break in slope. A photo of this site is shown at the end of the site 2G photos.

Erosion pin results

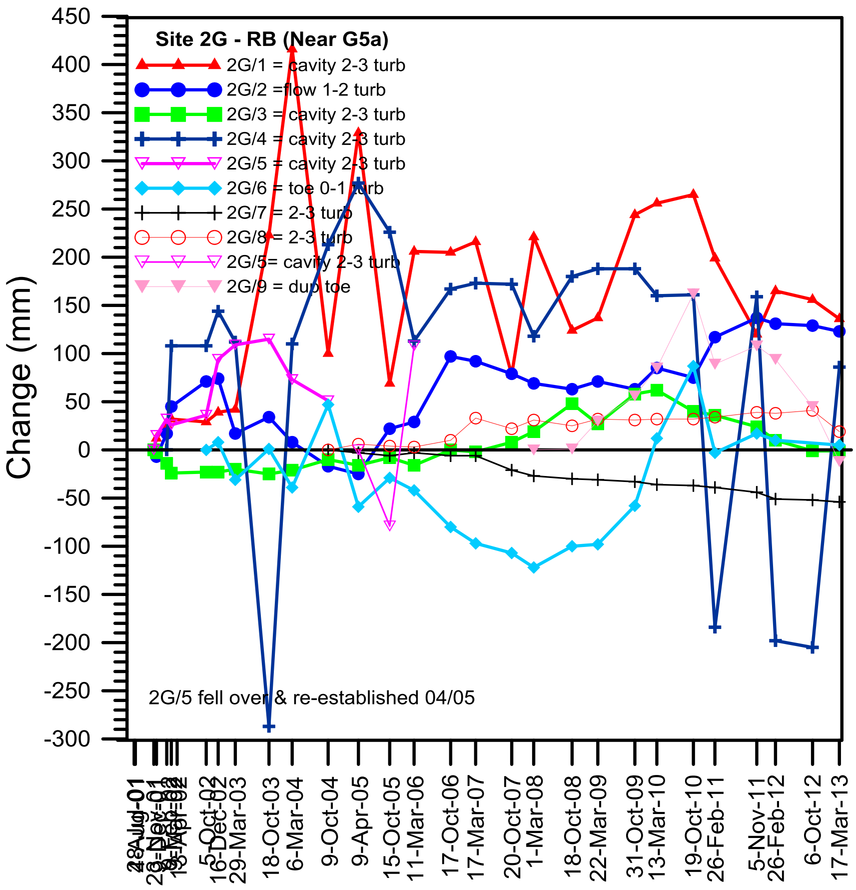

Figure 4.99: Erosion pin results from site 2G.

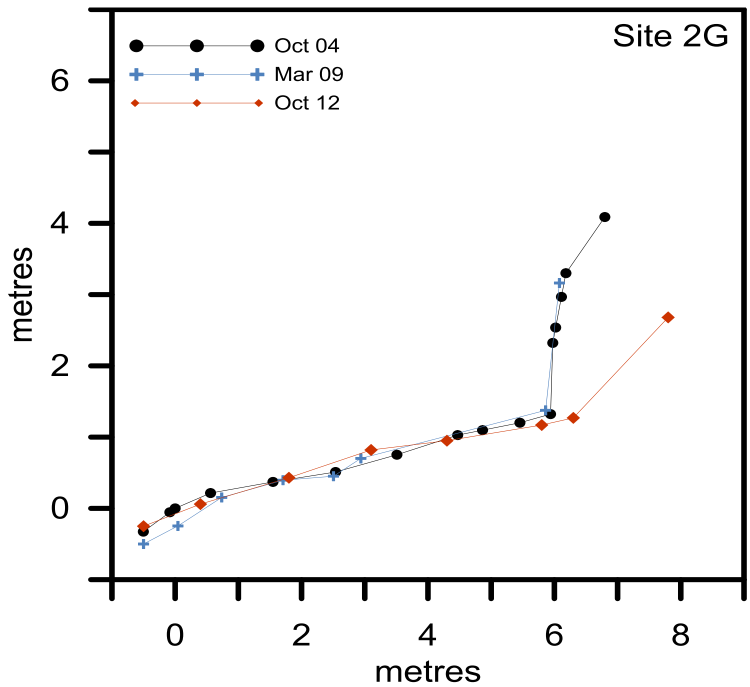

Figure 4.100: Bank profiles form site 2G. 2004 and 2009 profile shows surface of vegetation mat, 2012 profile measures into cavity as root-mat has scoured.

Photos

Figure 4.101: Site 2G March 2002.

Figure 4.102: Site 2G March 2004.

Figure 4.103: Site 2G December 2004.

Figure 4.104: Site 2G October 2003.

Figure 4.105: Site 2G October 2006.

Figure 4.106: Site 2G December 2007.

Figure 4.107: Site 2G March 2010.

Figure 4.108: Site 2G Oct 2010.

Figure 4.109: Site 2G March 2013.

Figure 4.110: Photo monitoring site 2-5.

4.2.7 Site 2H

Description: Site 2H is located on the left bank of the river in a straight reach. The site consists of two profiles of erosion pins. One profile is located where tea tree and the associated root-mat is present, and the other just downstream in an area where tea tree is absent and seepage erosion features are common.

Erosional Processes: This site has it all. The area that supports tea tree is dominated by scour, with the root-mat slowly disappearing. In the past ~3 years, small sand deposits have been present at the base of the degraded root-mat during monitoring, suggesting that sand is being transported under the root mat. The erosion pins in the tea tree profile in the 1-2 and 2-3 turbine levels recorded net deposition during the first two years of monitoring, and little change since. The toe pin of this profile, which is below the level of the root-mat has recorded slow deposition reflecting the 'flattening' of the toe over time. The deposition of the pins on the upper bank is probably also reflecting seepage related flattening associated with periods when the bank was saturated.

The pins in the profile associated with the seepage features have shown higher levels of deposition associated with active seepage processes. Pin 2H/4 was lost due to a large Huon pine tree moving downslope over the pin. At present, only flagging tape is visible extending from under the tree. Between April 2005 and October 2008 the tree moved ~380 mm downslope, or about 185 mm/year.

Erosion pin results

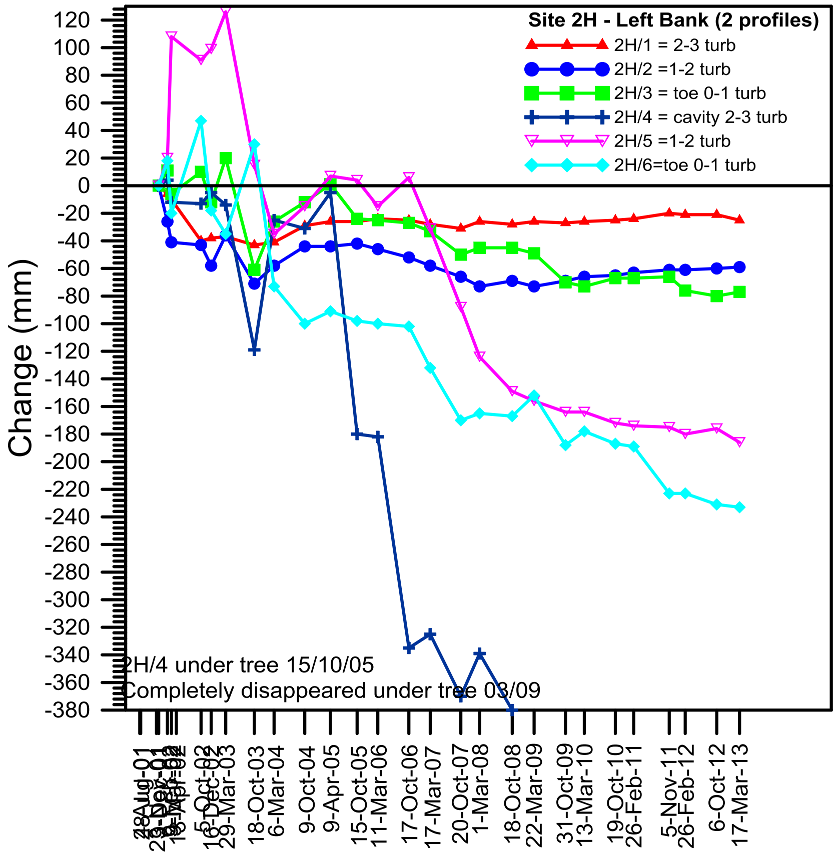

Figure 4.111: Site 2H erosion pin results.

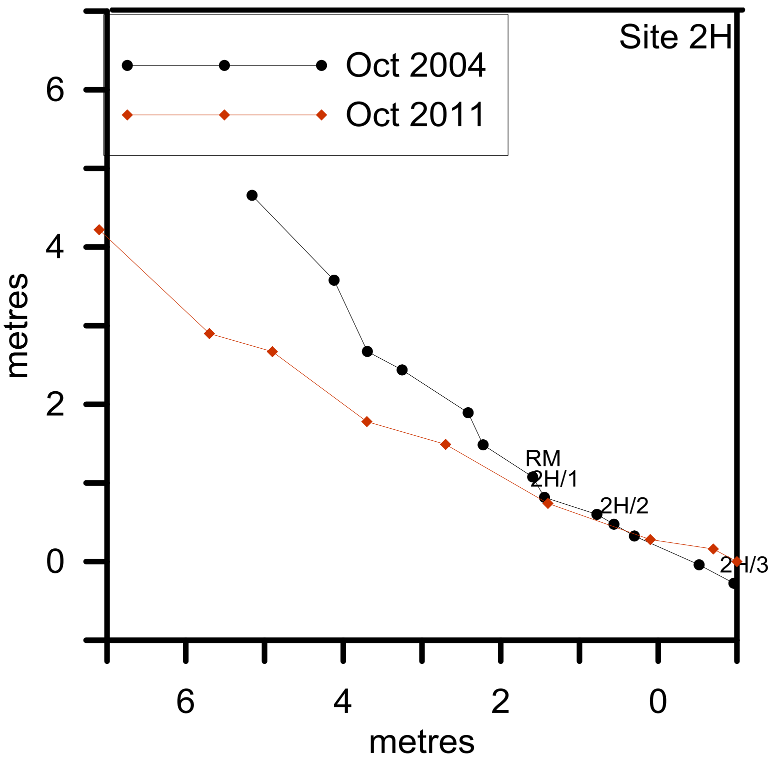

Figure 4.112: Approximate bank profiles for site 2H. 'RM' is location of root-mat. Profiles not collected at exact location in 2011 which accounts for change in upper bank. The flattening of the bank toe is consistent with the erosion pin results.

Photos

Figure 4.113: Site 2H October 2010.

Figure 4.114: Site 2H October 2010.

Figure 4.115: Site 2H October 2010.

Figure 4.116: Site 2H Nov 2011.

Figure 4.117: Site 2H December 2007.

4.2.8 Site 2I

Description: Site 2I is located on the left bank along a straight reach behind a low cobble bar. The sand bank is low and supports tea tree and divides the main river from an inflowing creek. The pins are installed in a profile down the bank.

Erosional processes: The toe of the bank is stabilised by a degraded root-mat. The mat and bank toe are being scoured. The surface of the bank, where the erosion pins are located, shows little change. The deposition recorded by the pins is likely associated with the accumulation of organic matter and fine sediments during periods of low power station usage, and sands being washed down slope from under the root-mat.

Comment: It is likely the toe of this bank will continue to scour, revealing the underlying cobbles.

Erosion pin results

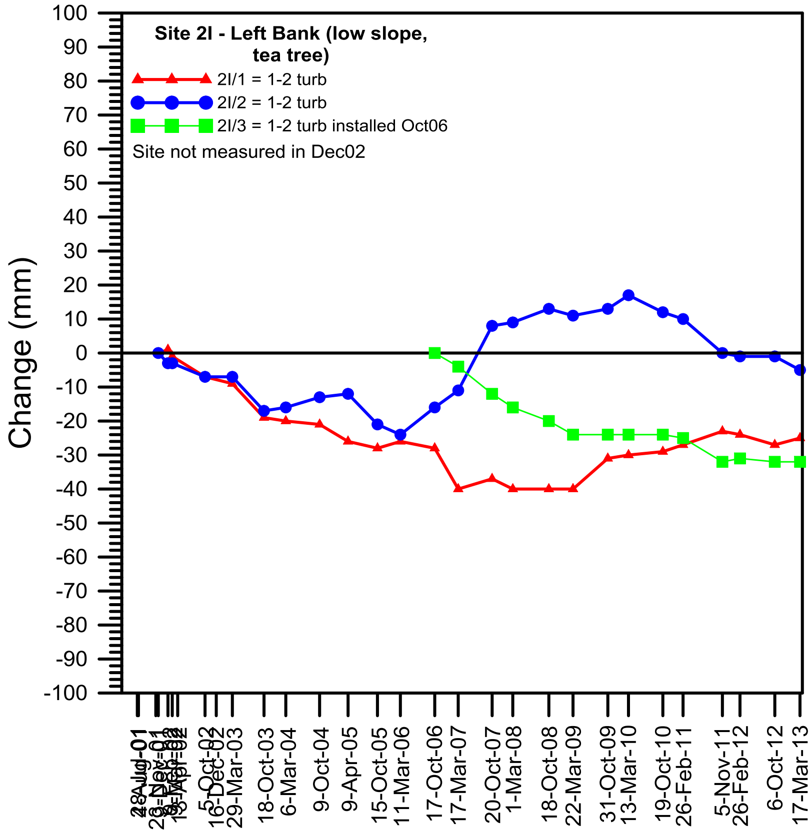

Figure 4.118: Erosion pin results for site 2l. Pin 1 is highest on the bank, pin 3 is lowest.

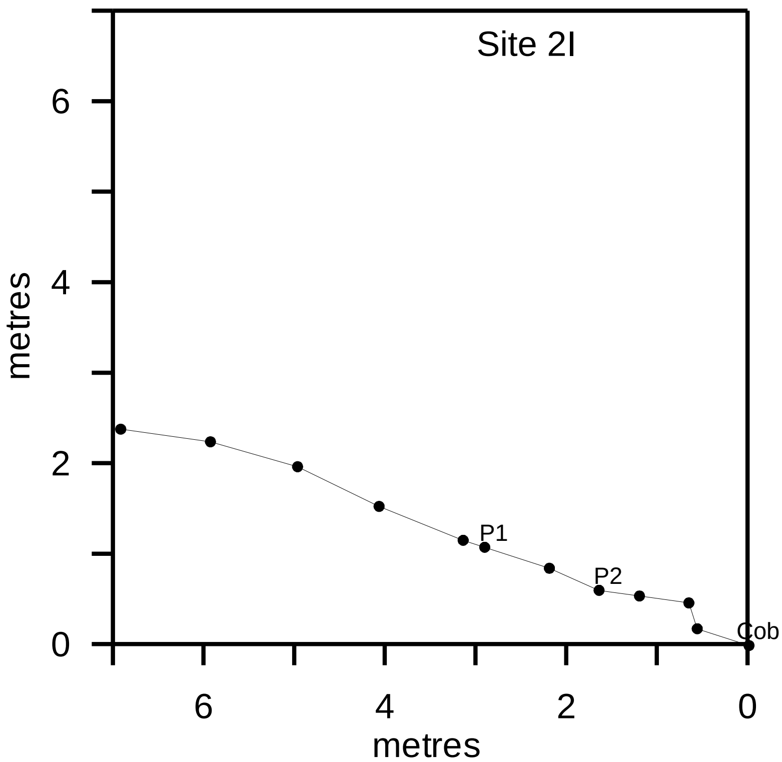

Figure 4.119: Bank profile from 2004.

Photos

Figure 4.120: Site 2I October 2005.

Figure 4.121: Site 2I October 2006.

Figure 4.122: Site 2I October 2007.

Figure 4.123: Site 2I December 2007.

Figure 4.124: Site 2I October 2010.

Figure 4.125: Site 2I October 2012.

Figure 4.126: Site 2I March 2013.

4.2.9 Site 2J

Description: Site 2J is located on the left bank, upstream of the Gordon Splits, on a steep, sandy bank overlain by a thick vegetation mat. The site is in a shallow outside bend. The bank has a lot of woody debris deposited, which appears to be locally derived. Initially pipes were installed in a profile down the site to house piezometers, but the site was converted to an erosion pin site only (piezometers were installed on opposite bank near site 2L). The pipes and pins were installed in a profile down the bank. The site is subjected to very high water level fluctuations due to back water effects from the Splits.

Erosional processes: This site is one of the few which has only recorded erosion. This is inconsistent with the field observations that show seepage processes are active on the site, and the net erosion suggests that scour is removing sand at a rate higher than it is being supplied by seepage processes. This is consistent with the highly variable results. Since October 2007, following a very high flow event, the toe of the bank has been recording reduced scour (increased deposition) suggesting the bank toe has flattened. The pin in the 2-3 turbine zone has also recorded decreased erosion since that monitoring period.

Comment: This bank, along with the adjacent site 2K always appear very active, and erosion pins which were installed vertically end up pointing towards the river reflecting the movement of the bank.

Erosion pin results

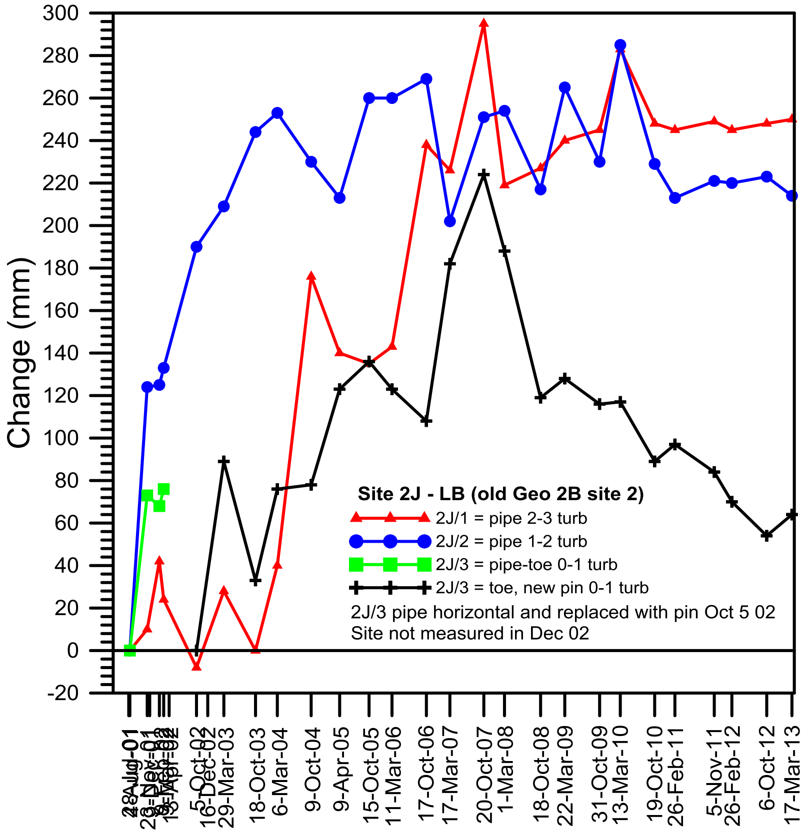

Figure 4.127: Erosion pin results from site 2J.

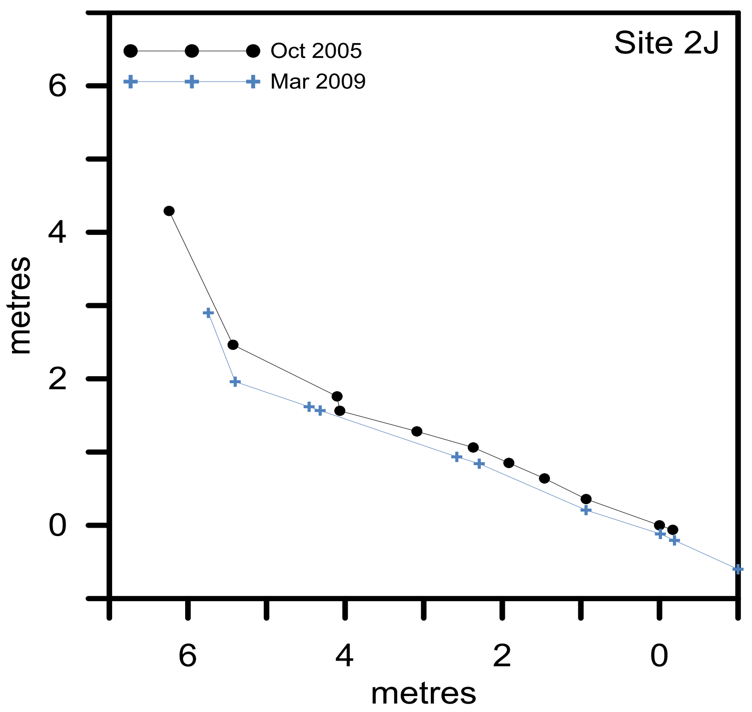

Figure 4.128: Bank profiles from site 2J.

Photos

Figure 4.129: Site 2J December 1999.

Figure 4.130: Site 2J December 2007.

Figure 4.131: Site 2J October 2010.

Figure 4.132: Site 2J March 2013.

Figure 4.133: Site 2J March 2013.

4.2.10 Site 2K

Description: Site 2K is located on the left bank about 20 m downstream of site 2J. Similar to site 2J it is a steep sandy bank, with a thick vegetation mat present in the 2-3 turbine level. There is an active seepage vent on the downstream side of the site, and material which appears to be derived from a landslip behind the site has been transported through this vent. Pins have been installed in a profile down the site, but many erosion pins have been lost at this site. It is likely that some have been knocked down, and / or buried by seepage processes. A large tree fall occurred just upstream of the site between March and October 2007, possibly associated with the high rainfall and flood in August 2007. Since approximately 2008 the pins have shown reduced activity and the toe pin has recorded decreased erosion (e.g. relative deposition) similar to site 2J.

Erosional processes: Seepage is very active at this site, likely attributable to the large range of water level fluctuation (>4 m). Seepage processes are occurring under and behind the remnant root / vegetation mat. The toe is affected by scour and seepage deposition from upslope.

Comment: Similar to site 2J this is a highly active site. The bank toe appears to see-saw depending on the relative contributions from scour and the deposition of seepage derived material.

Erosion pin results

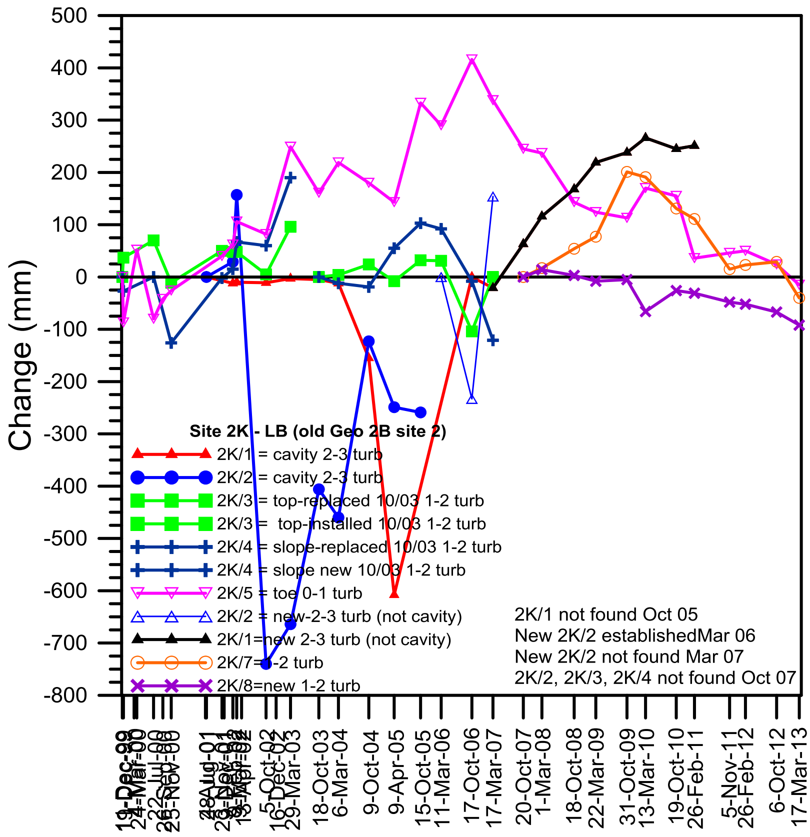

Figure 4.134: Erosion pin results form site 2K.

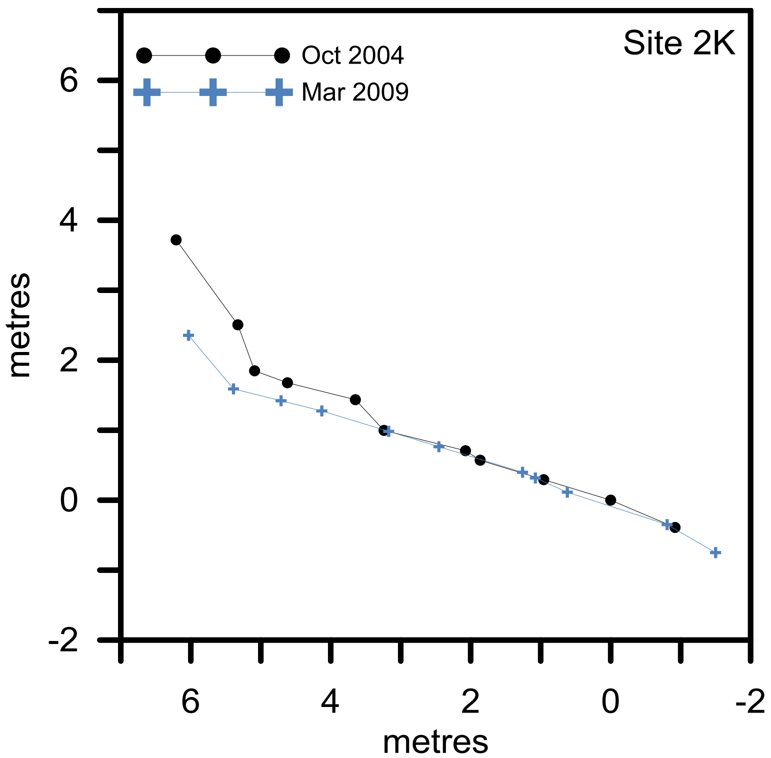

Figure 4.135: Bank profiles from site 2K for October 2004 and March 2009. Removal of material at back of site is associated with the erosion of the vegetation mat.

Photos

Figure 4.136: Site 2K December 1999.

Figure 4.137: Site 2K March 2000.

Figure 4.138: Site 2K Oct 2003.

Figure 4.139: Site 2K Dec 2004.

Figure 4.140: Site 2K October 2007.

Figure 4.141: Site 2K December 2007.

4.2.11 Site 2L

Description: Site 2L is located on the right bank at the downstream end of a cobble bar upstream of the Splits. The bank has a flat sandy toe, and supports tea tree in the 2-3 turbine bank level. Erosion pins are installed in a profile up the bank face, and in one cavity located about 40 m upstream.

Erosional processes: This site is dominated by scour. Erosion pins have recorded the removal of the muddy root-mat and underlying sands at successive pins in the profile. The toe pin experienced rapid erosion following installation, and then little was recorded until scouring of the muddy root-mat began to affect pin 2L/3, followed by 2L/4. The original 2L/3 pin was removed through scour, and a deeper pin was installed at the same site which continues to record scour.

Comment: This site could show some interesting changes over the next few decades.

Erosion pin results

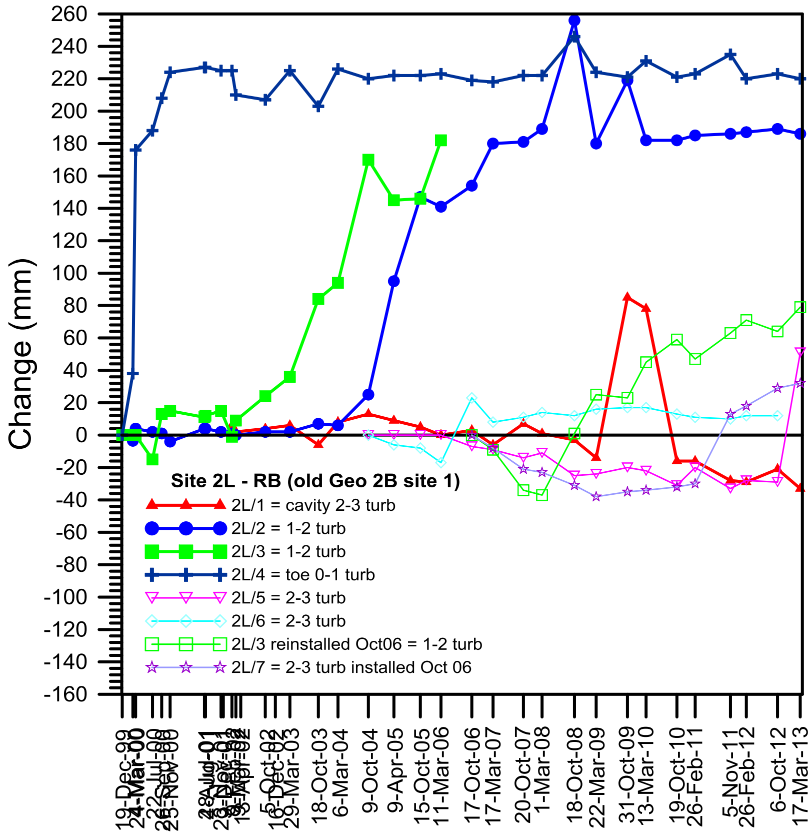

Figure 4.142: Erosion pin results for site 2L.

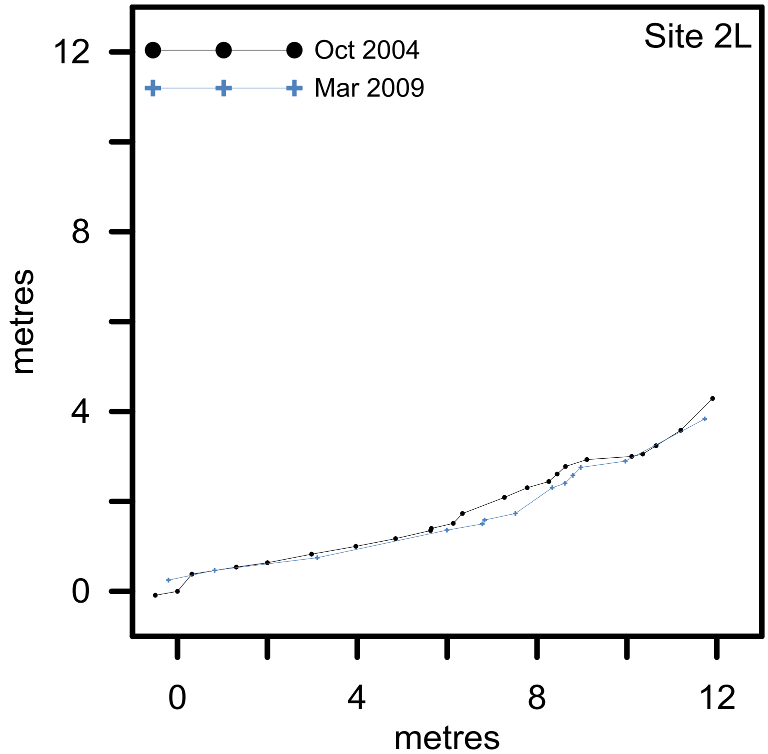

Figure 4.143: Bank profiles for site 2L from 2004 and 2009 showing erosion in 1 – 2 turbine bank level.

Photos

Figure 4.144: Site 2L December 1999.

Figure 4.145: Site 2L July 2001.

Figure 4.146: Site 2L October 2004.

Figure 4.147: Site 2L March 2006.

Figure 4.148: Site 2L October 2006.

Figure 4.149: Site 2L October 2007.

Figure 4.150: Site 2L October 2007.

Figure 4.151: Site 2L December 2007.

Figure 4.152: Site 2L October 2010.

Figure 4.153: Site 2L March 2013.

Zone 2 Erosion Pin Comparisons

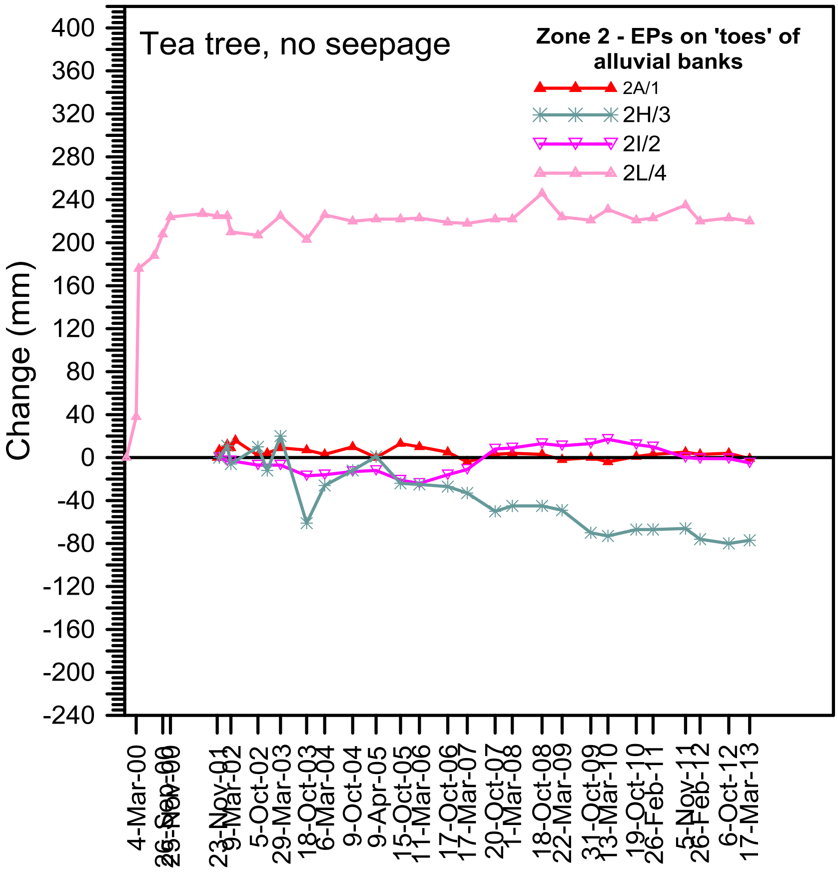

Figure 4.154: Zone 2 toes at sites with tea tree on banks.

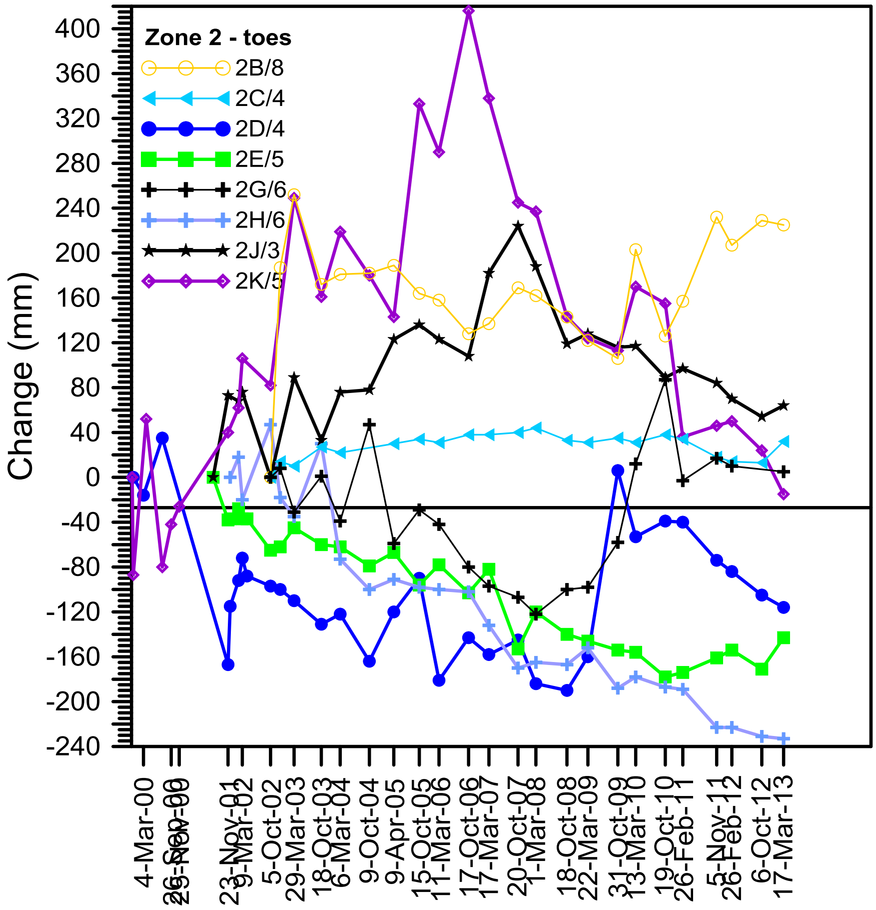

Figure 4.155: Zone 2 toes at sites with seepage processes on bank.

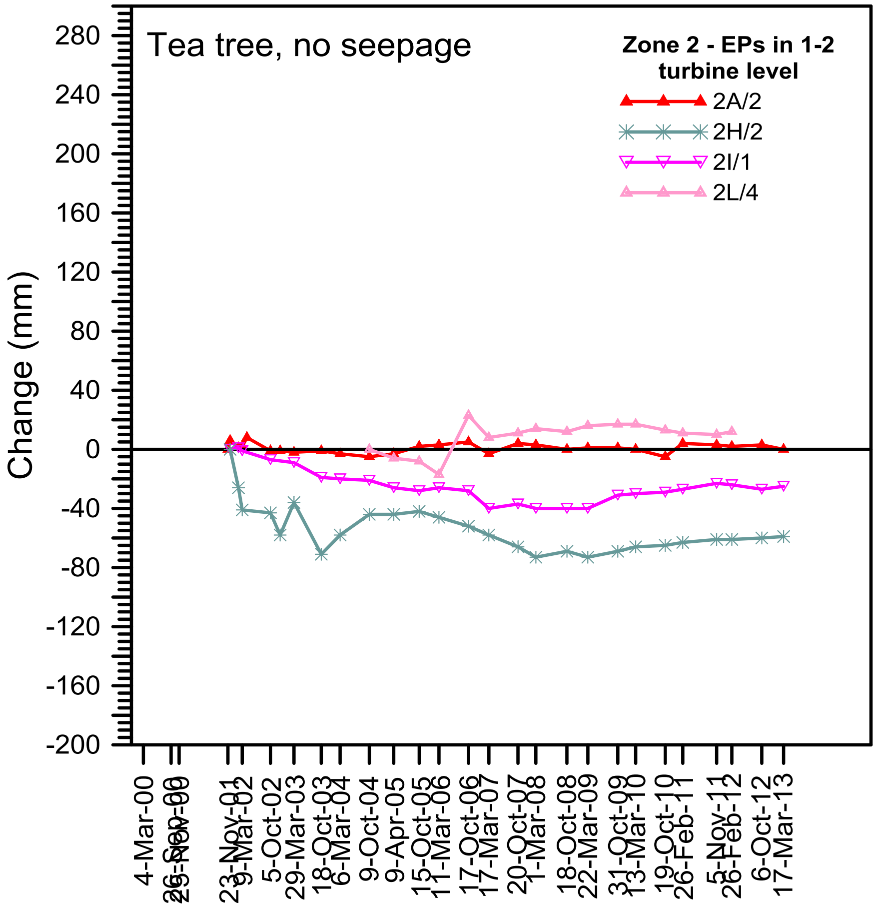

Figure 4.156: Zone 2, 1-2 turbine level for banks with tea tree.

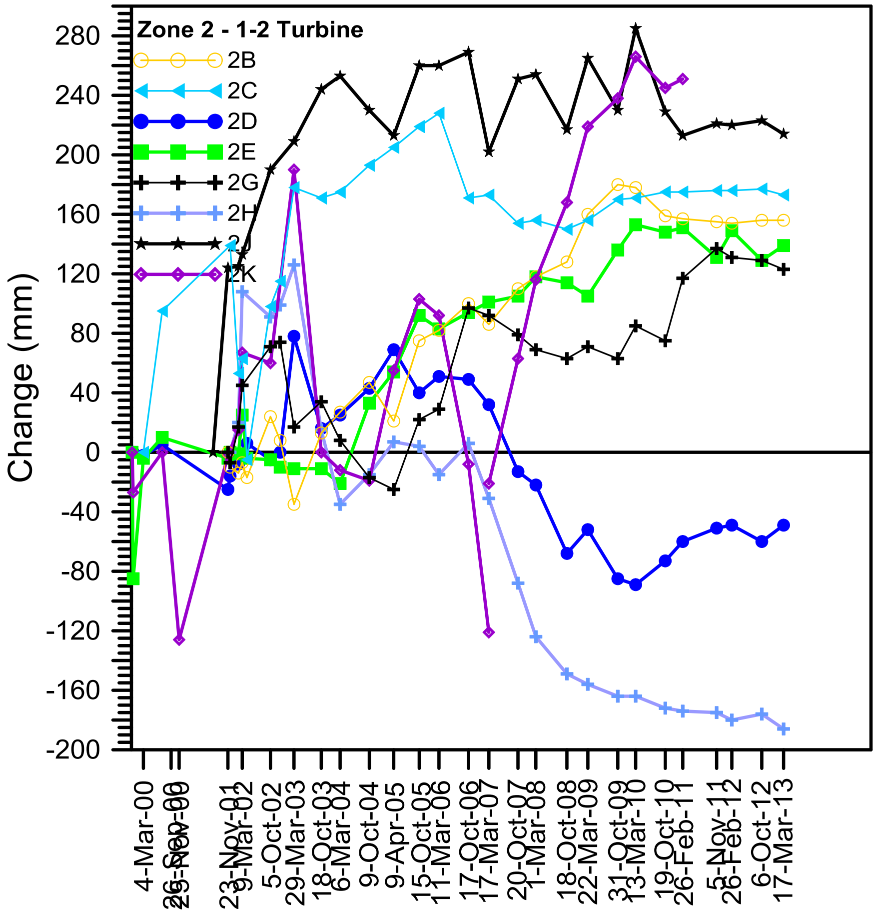

Figure 4.157: Zone 2, 1-2 turbine level at sites with seepage processes on bank.

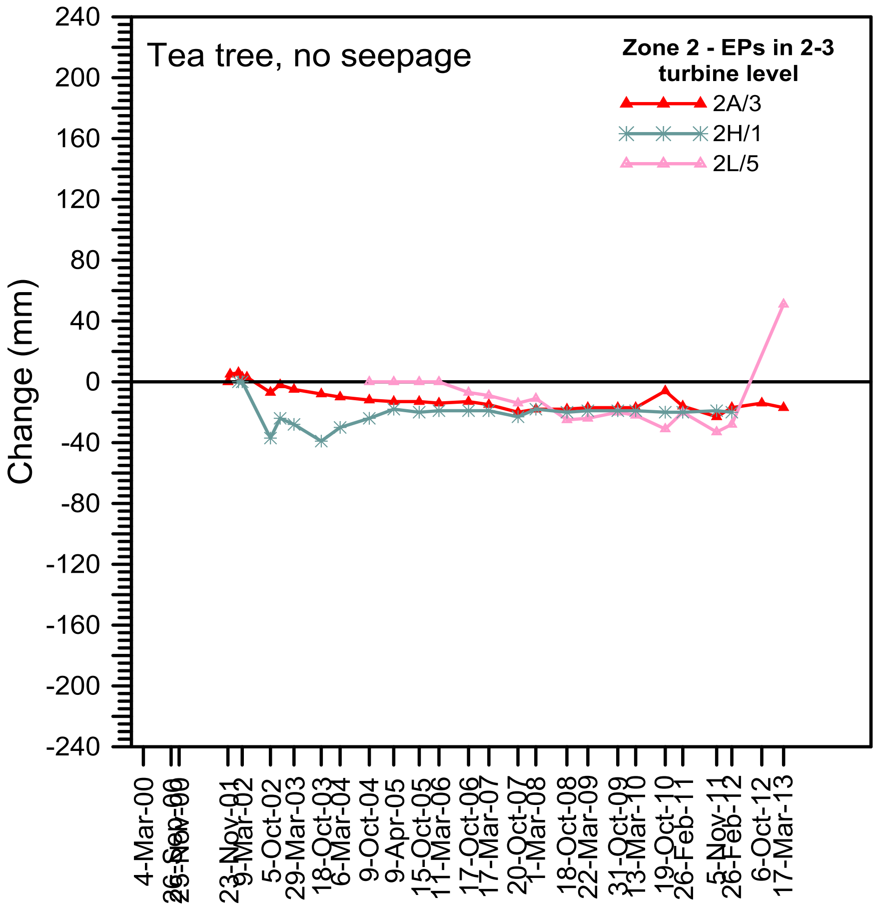

Figure 4.158: Zone 2, 2-3 turbine level at sites with tea tree on banks.

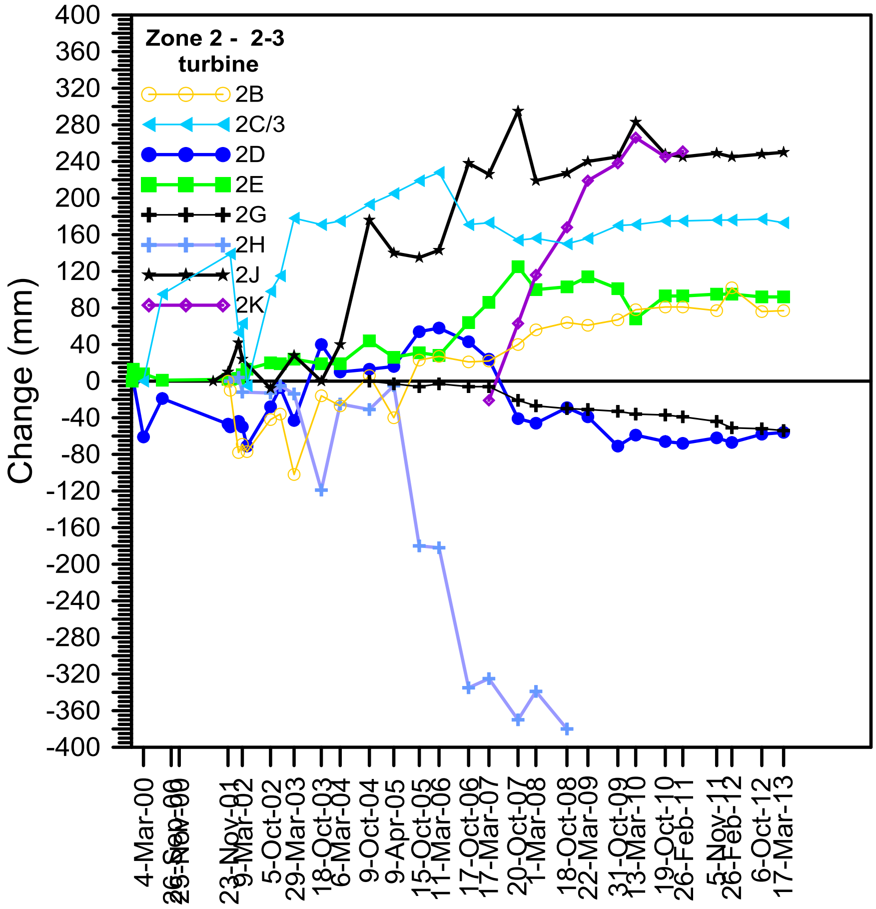

Figure 4.159: Zone 2, 2-3 turbine level at sites with seepage processes on banks.

4.3 Zone 3

The reach between the Splits and the Denison River confluence is designated as Zone 3. The top of the section includes Snake Rapids which is a steep bedrock reach. From the base of Snake Rapids to the confluence of the Denison the course of the river is relatively straight, and confined in a single valley without cutting through any ridges. The most upstream erosion pin monitoring site is located at a break in slope at the base of Snake Rapids, and the last erosion pin site is located immediately upstream of the confluence of the Denison.

Figure 4.160: Satellite imagery of zone 3.

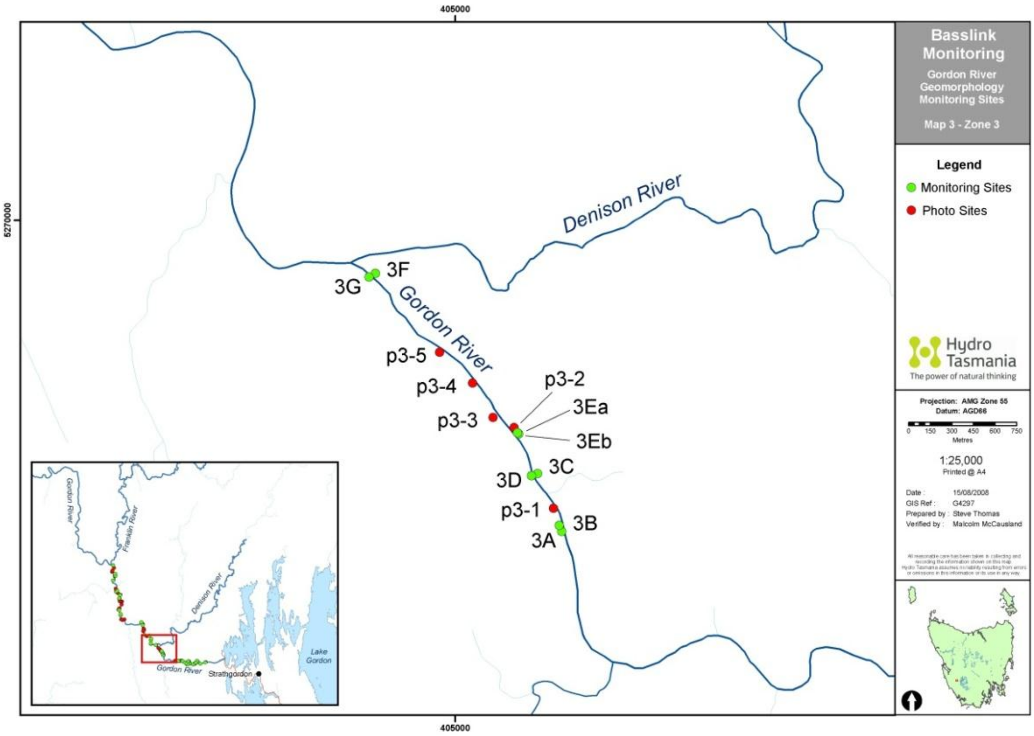

Figure 4.161: Location of monitoring and photo sites within zone 3.

4.3.1 Site 3A

Description: Site 3A is located on the left bank downstream of the confluence of the Orange and Gordon Rivers, and Snake Rapids. The site is located just below the base of the rapids and behind a small low-lying cobble bar composed of angular cobbles. Site 3A is at the upstream end of the bar, and site 3B is at the downstream end of the bar.

All of zone 3 can be a backwater if flow in the Denison River is high, and flow in the Gordon is low (power station off). Following these conditions, fluvial deposition of sands has been observed at site 3A, presumably due to the deposition of sands derived from the Orange River and from the Gordon below power station catchment, as the site is at a major break in slope in the river.

The toe of site 3A is buttressed by a large log, and the site has a large sandy toe, that grades up into a bank supporting tea tree. The erosion pins are in a profile down the length of the bank.

Erosion processes: Site 3A is one of the few sites where fluvial deposition is commonly observed. At this site, the toe is affected by scour and deposition, with the toe results showing variable changes over the period of monitoring of ±175 mm. The 1-2 turbine bank level has also shown large fluctuations, whereas the 2-3 turbine level, which is located in the tea tree bank behind the sandy toe, has recorded erosion, consistent with other tea tree bearing banks in the middle Gordon.

Comment: The deposition of mud veneers on bank toes is common throughout zone 3, and is presumably also related to the reduction in flow velocity due to the Denison River inflow.

Erosion pin results

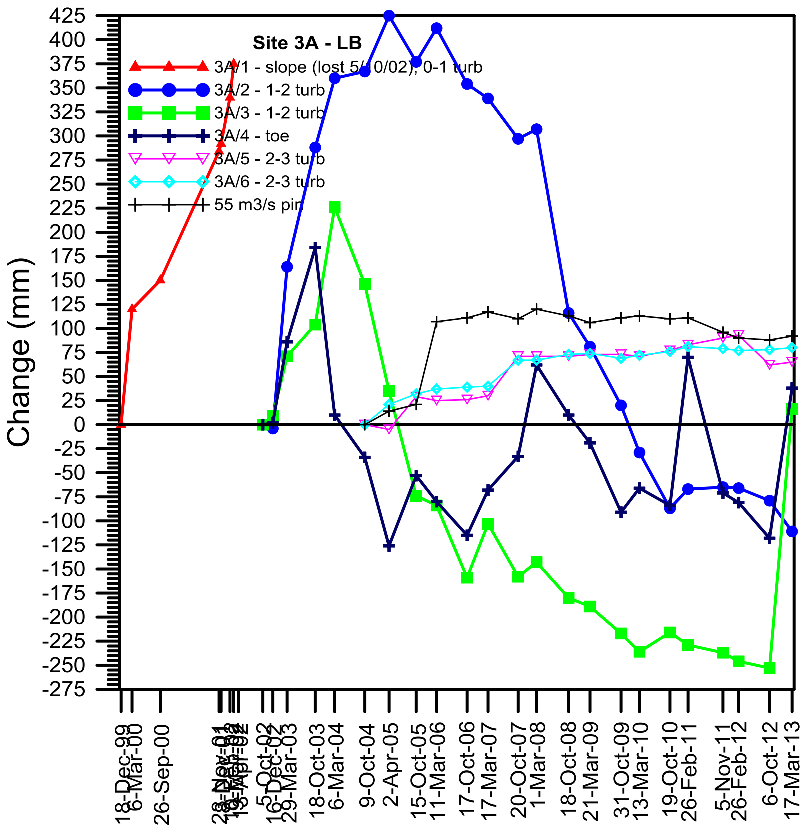

Figure 4.162: Erosion pin results from site 3A.

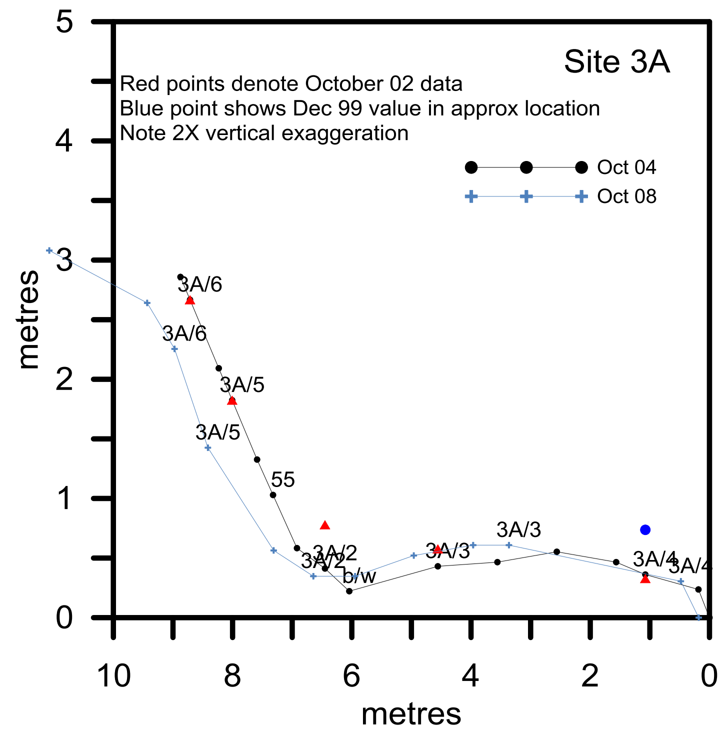

Figure 4.163: Bank profiles from 2004 and 2008. Changes to pins 3A/5 and 3A/6 are ~75 mm showing the profiles are off set.

Photos

Figure 4.164: Site 3A October 2002.

Figure 4.165: Site 3A Oct 2003.

Figure 4.166: Site 3A October 2004.

Figure 4.167: Site 3A October 2006.

Figure 4.168: Site 3A October 2007.

Figure 4.169: Site 3A March 2008.

Figure 4.170: Site 3A March 2010.

Figure 4.171: Site 3A March 2013.

4.3.2 Site 3B

Description: Site 3B is located at the downstream end of the same cobble bar as site 3A (see description of site 3A for general location information). The site is located behind the cobble bar in a break in the tea tree root mat between two stands of tea trees. The site consists of sands overlain by a vegetation mat. The site has cavities located at the base of the vegetation mat, and abundant woody debris. Sediment flows were observed at the site during the IIAS investigation.

Erosional processes: One of the two cavities at this site has collapsed due to vegetation slumping (as evident in the bank profiles). One erosion pin was lost during monitoring, possibly due to rilling eroding around the base of the pin. The site has not shown evidence of seepage flows for many years. The toe has 'flattened' over the monitoring period, and scour has been recorded with little change been recorded in the 2-3 turbine bank level.

Erosion pin results

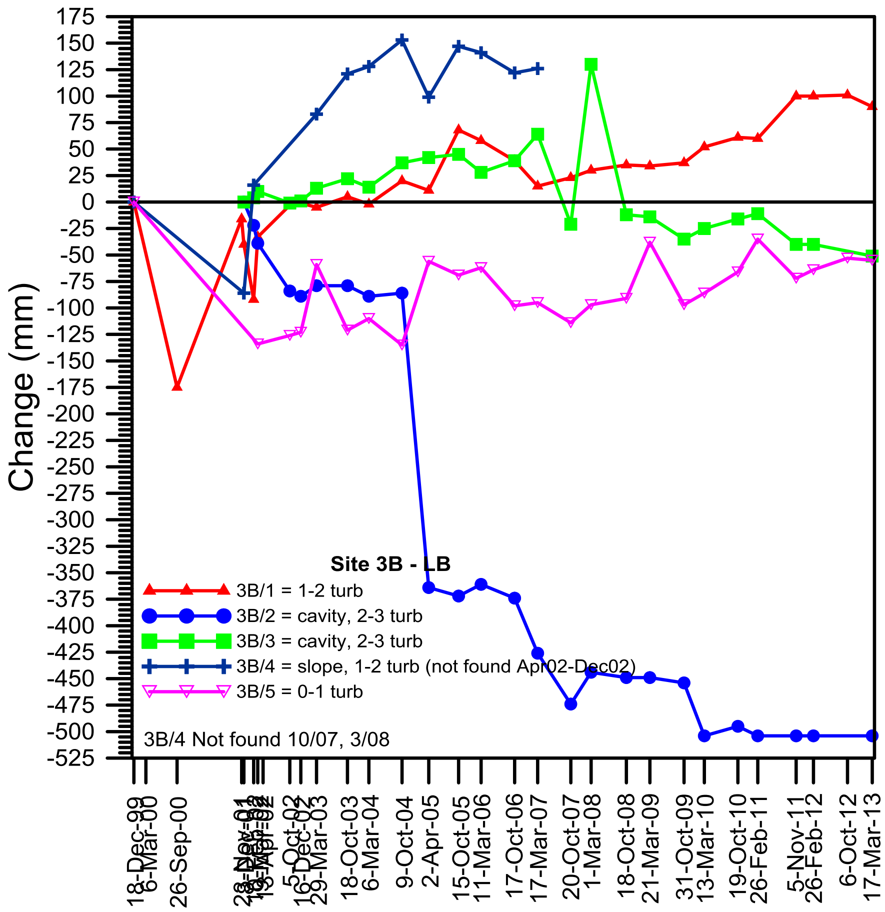

Figure 4.172: Erosion pin results for site 3B.

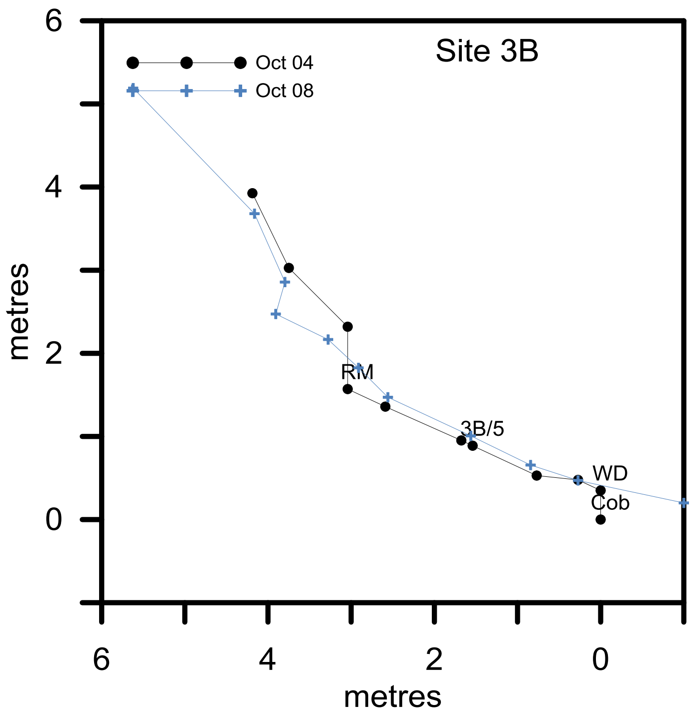

Figure 4.173: Bank profiles from site 3B from 2004 and 2008. ‘RM’ is root-mat, ‘WD’ is woody debris and ‘Cob’ is cobble.

Photos

Figure 4.174: Site 3B December 1999.

Figure 4.175: Site 3B October 2006.

Figure 4.176: Site 3B October 2009.

Figure 4.177: Site 3B March 2010.

Figure 4.178: Site 3B March 2013.

4.3.3 Site 3C

Description: Site 3C is on the right bank along a straight reach. The sandy bank toe has a medium slope, and is overlain by a remnant muddy root mat. Higher on the bank tea tree are present. There is a deep cavity at the top of the site formed by the vegetation / root-mat layer overlying the sands. Over the monitoring period this mat has ruptured and 'daylight' is now visible at the back of the deep cavity. The erosion pins are installed in a profile down the bank, with another pin in the deep cavity.

Erosional processes: The muddy root mat which initially extended into the 1-2 turbine bank level has been eroded through scour, resulting in erosion recorded in the 1-2 turbine level. The toe has recorded deposition, associated with local seepage deposition and processes. Muddy veneers on the lower bank are common at this site, indicating fluvial deposition does occur, although the lack of mud layers at depth suggests that the mud is scoured during high flows.

Erosion pin results

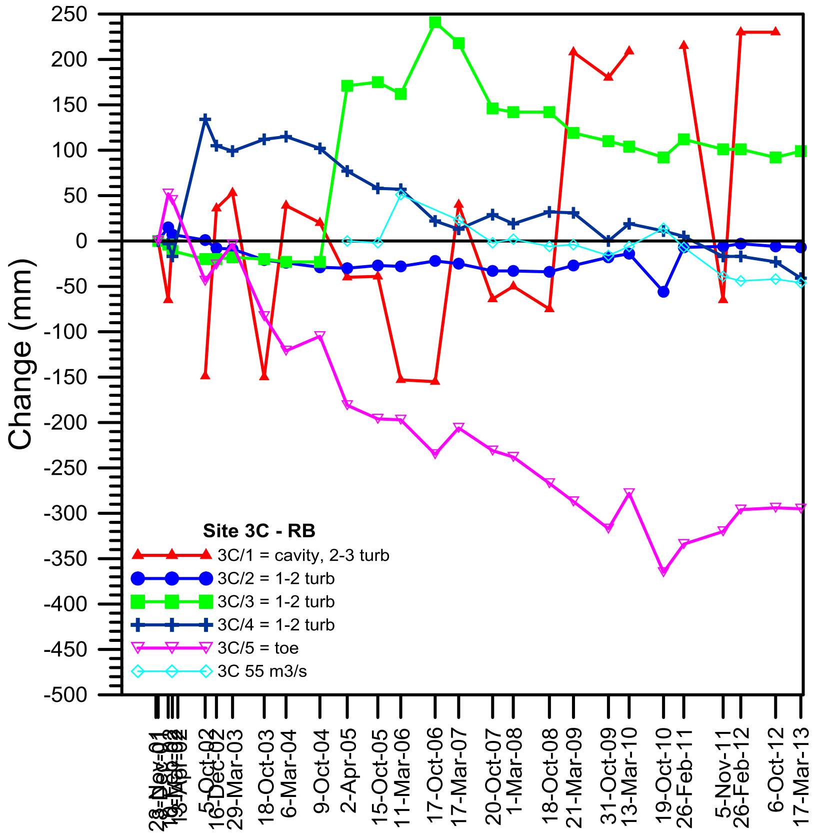

Figure 4.179: Erosion pin results for site 3C.

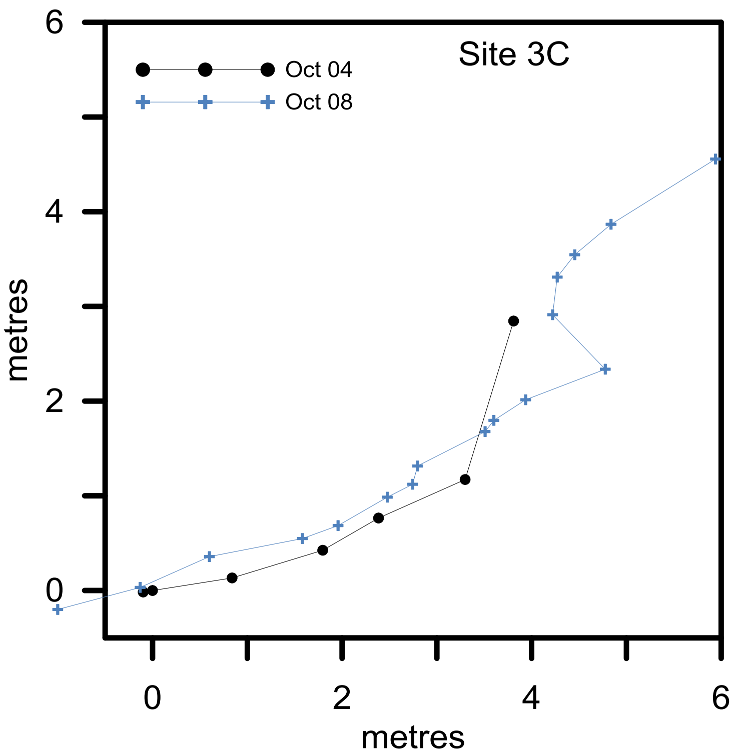

Figure 4.180: Bank profiles for site 3C from 2004 and 2008. The 2004 profile shows the surface of the vegetation mat, the 2008 profile shows the surface of the underlying bank as the vegetation was removed through scour.

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Photos

Figure 4.181: Site 3C December 2001.

Figure 4.182: Site 3C October 2006.

Figure 4.183: Site 3C March 2008.

Figure 4.184: Site 3C March 2013.

4.3.4 Site 3D

Description: Site 3D is located on the left bank in a straight reach across from site 3C. The bank is steep, supports tea tree and a degraded vegetation mat and has a short steep sandy toe.

Erosional processes: The site is predominantly affected by scour, with the cavity showing little activity during the monitoring period. The 1-2 turbine bank level has recorded the highest level of erosion, and this is likely associated with the higher flow variability in this range post-Basslink. After initially recording scour, the toe has shown variability but little net change since 2007, which coincided with increase erosion at the 55 m^3s^{-1} pin, and in the 1-2 turbine bank level. The 2-3 turbine bank level has shown very little change over the monitoring duration, and may actually be located above the 2-3 turbine bank level. It is also common at this bank to have mud veneers on the bank toes during monitoring.

Erosion pin results

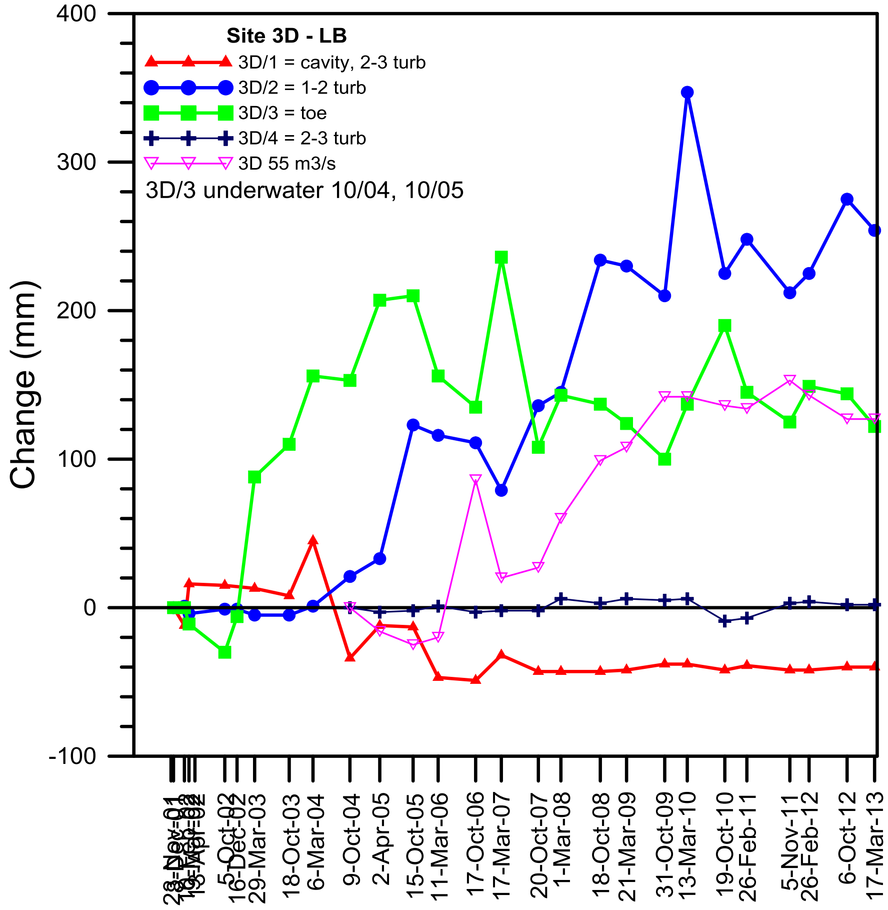


Figure 4.185: Erosion pin results from site 3D.

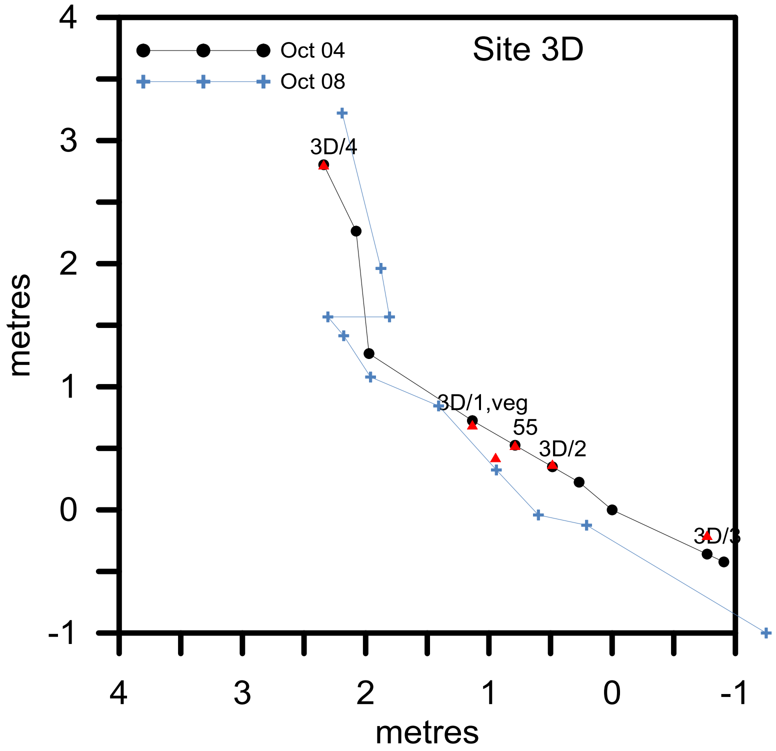


Figure 4.186: Bank profiles from 2004 and 2008. 'Veg' is the most downslope extent of vegetation.

Photos

Figure 4.187: Site 3D December 2001.

Figure 4.188: Site 3D December 2004.

Figure 4.189: Site 3D October 2006.

Figure 4.190: Site 3D March 2008.

Figure 4.191: Site 3D October 2009.

Figure 4.192: Site 3D March 2010.

Figure 4.193: Site 3D November 2011.

Figure 4.194: Site 3D March 2013.

Figure 4.195: Site 3D March 2013.

4.3.5 Site 3Ea

Description: Site 3Ea is located on a gully / drainage line on the right bank of the river at the upstream end of the sandy bank where site 3Eb is located. The bank is composed of sand overlain by vegetation mat and degraded root mat.

Erosion processes: The gully has flattened over the duration of monitoring, with erosion occurring in the 2-3 turbine bank level. The lower bank levels have shown variability – this is consistent with field observations that have noted episodic sediment deposition in the drainage line. The deposits are subsequently scoured, as evident in the photos.

Erosion pin results

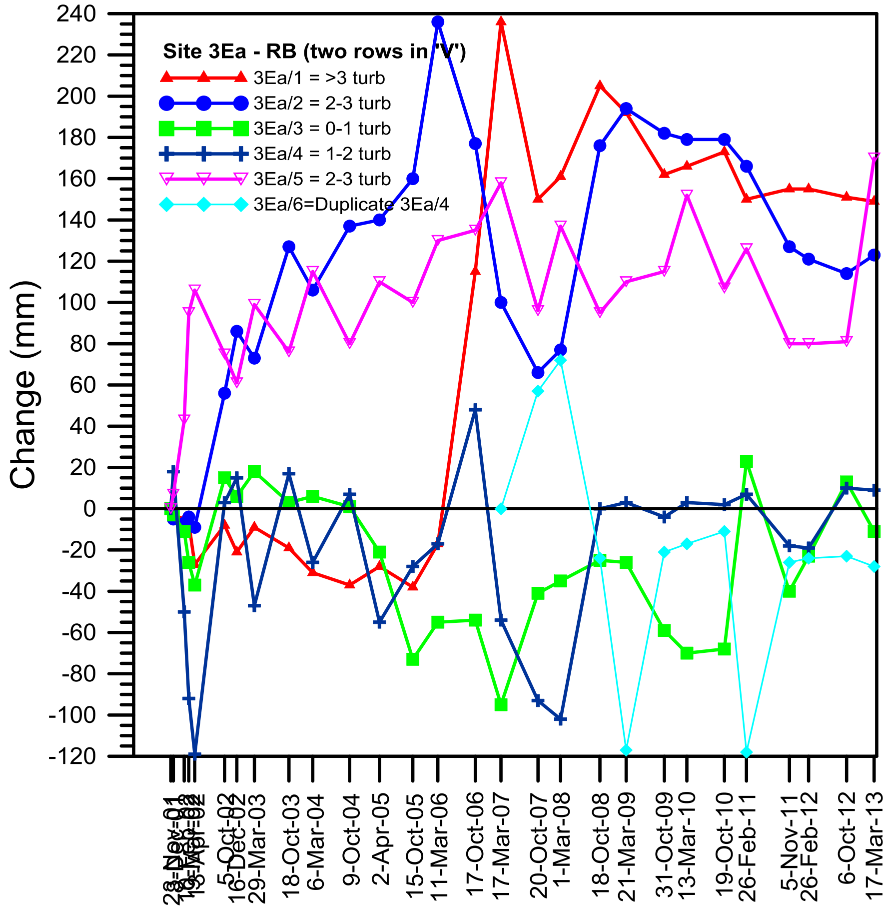


Figure 4.196: Erosion pin results from site 3Ea.

Photos

Figure 4.197: Site 3Ea December 2001.

Figure 4.198: Site 3Ea October 2003.

Figure 4.199: Site 3Ea October 2006.

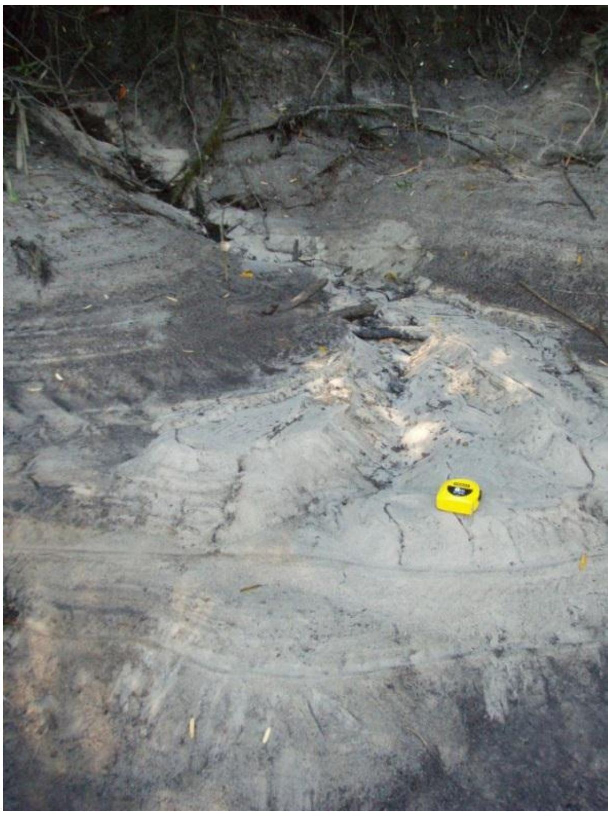


Figure 4.200: Site 3Ea March 2009.

Figure 4.201: Site 3Ea March 2013.

4.3.6 Site 3Eb

Description: Site 3Eb is located on a prominent bank with a sandy toe on the right side of the river on a straight reach. The ripple marks on the bank have continually indicated that flow at the site is upstream suggesting the site is an eddy during high flow. These local hydraulics can also account for the sandy bank extending upstream (in front of site 3Ea). The top of the sandy bank is overlain by vegetation and degraded root-mat.

Erosion processes: Net scour in the 1-2 turbine bank level is the dominant change recorded at the site. Similar to other sites, this is associated with the erosion of benches which were hypothesised to be related to the 1 or 2 turbine efficient load water levels. Post-Basslink the power station discharge is more variable which has translated into less pronounced breaks in slope on the bank. Some of this change also reflects the continued scour of the remnant root-mat in the 2-3 turbine bank level.

Erosion pin results

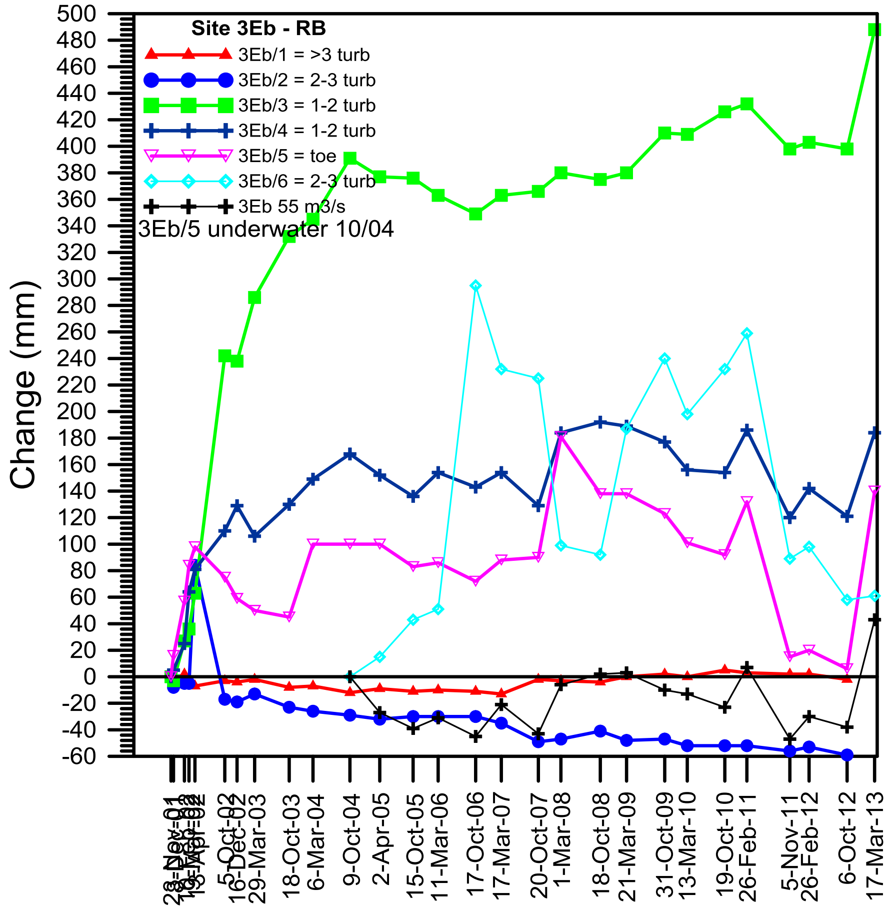


Figure 4.202: Erosion pin results for site 3Eb.

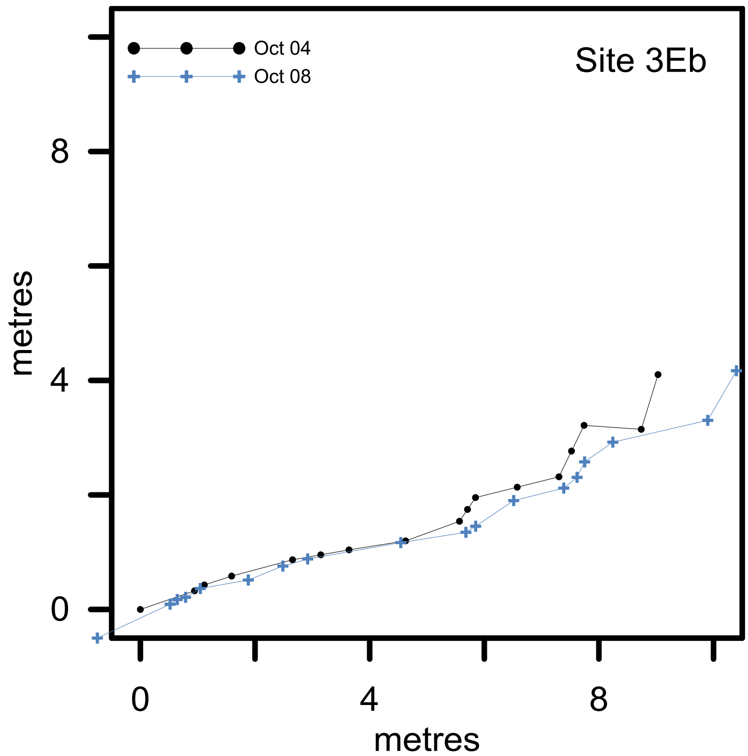


Figure 4.203: Bank profiles from 2004 and 2008.

Photos

Figure 4.204: Site 3Eb December 2001.

Figure 4.205: Site 3Eb December 2004.

Figure 4.206: Site 3Eb October 2007.

Figure 4.207: Site 3Eb March 2008.

Figure 4.208: Site 3Eb March 2009.

Figure 4.209: Site 3Eb March 2010.

Figure 4.210: Site 3Eb March 2013.

4.3.7 Site 3F

Description: Site 3F is located on the right bank, approximately 200 m upstream of the confluence of the Gordon and Denison Rivers. The site is at the downstream end of a riffle and is composed of sands over cobbles and boulders, with tea tree in the 2-3 turbine bank level. There is abundant woody debris at the site. There is also a large Huon pine tree immediately downstream of the pins, which probably contributes to the stability of the site. This site is undoubtedly affected by backwater effects from the Denison River, but unlike site 3G, does not show evidence of deposition.

Erosional processes: The tea tree bank has shown some scour over the monitoring period, but overall the site appears very stable. The cavity located in the 2-3 turbine bank level is very deep and difficult to measure. Small sediment flows (evident as lighter coloured sand in the photos) are associated with this feature. The combination of the cobbles, bedrock, tree buttressing and Huon pine combine to make this a stable site.

Erosion pin results

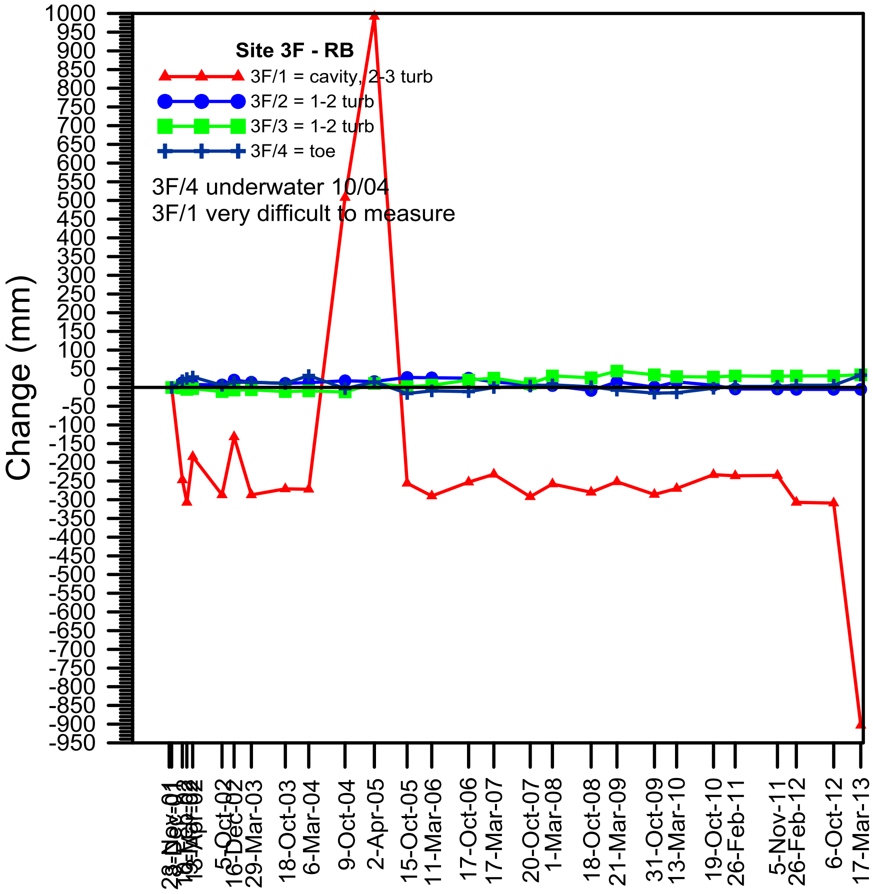


Figure 4.211: Erosion pin results from site 3F.

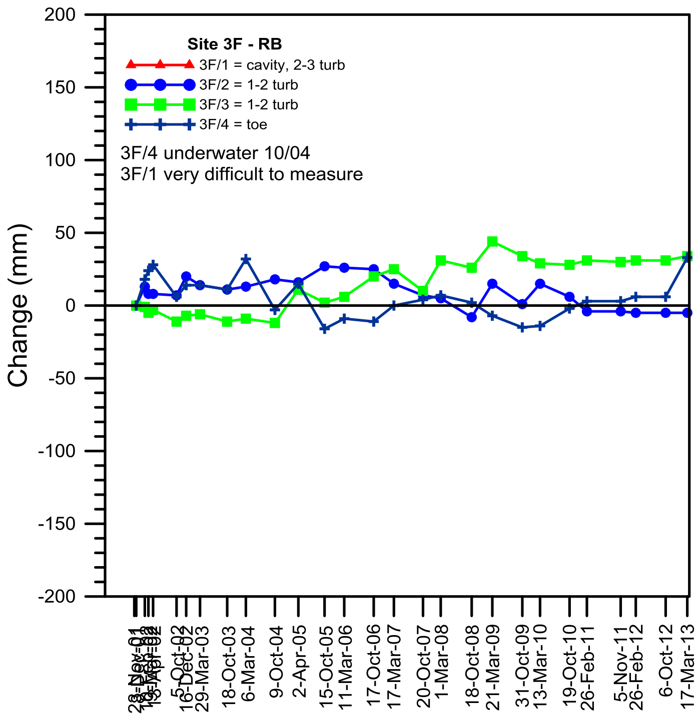


Figure 4.212: Erosion pin results from site 3F excluding results from pin in difficult to measure cavity.

Photos

Figure 4.213: Site 3F December 2001.

Figure 4.214: Site 3F October 2009.

Figure 4.215: Site 3F February 2011.

Figure 4.216: Site 3F March 2013.

4.3.8 Site 3G

Description: Site 3G is located on the left bank, across from site 3F just upstream of the confluence with the Denison River. The bank is composed of a flat lying toe, extending up to a steeper sandy bank, which is overlain by a degraded root mat and vegetation. This site is frequently affected by backwater from the Denison, and the toe pin at this site has been submerged when other toe pins in the zone have been exposed.

Erosional processes: It is likely that site 3G is a backwater when flow in the Denison River are higher than in the Gordon, which could account for the organic matter and muds frequently deposited on the bank toe. Digging into the toe reveals layers of organic matter, and when the submerged toe is stepped on, gas bubbles are released. In spite of this depositional evidence on the toe, the erosion pins show the 1-2 turbine bank level has scoured, and the 2-3 turbine bank level shows local deposition associated with collapse of the root-mat. The toe of the bank has recorded highly variable changes with no clear trend.

Erosion pin results

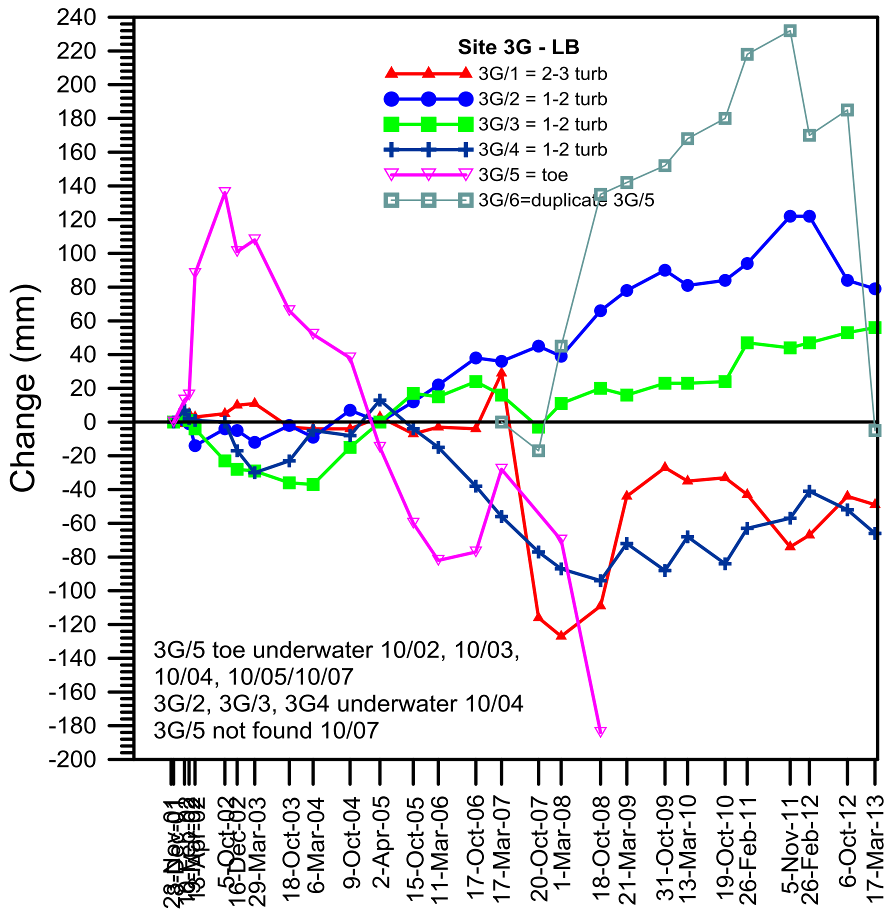


Figure 4.217: Erosion pin results from site 3G.

Photos

Figure 4.218: Site 3G December 2001.

Figure 4.219: Site 3G December 2004.

Figure 4.220: Site 3G October 2009.

Figure 4.221: Site 3G March 2010.

Figure 4.222: Site 3G March 2013.

Comparison of erosion pin results in zone 3

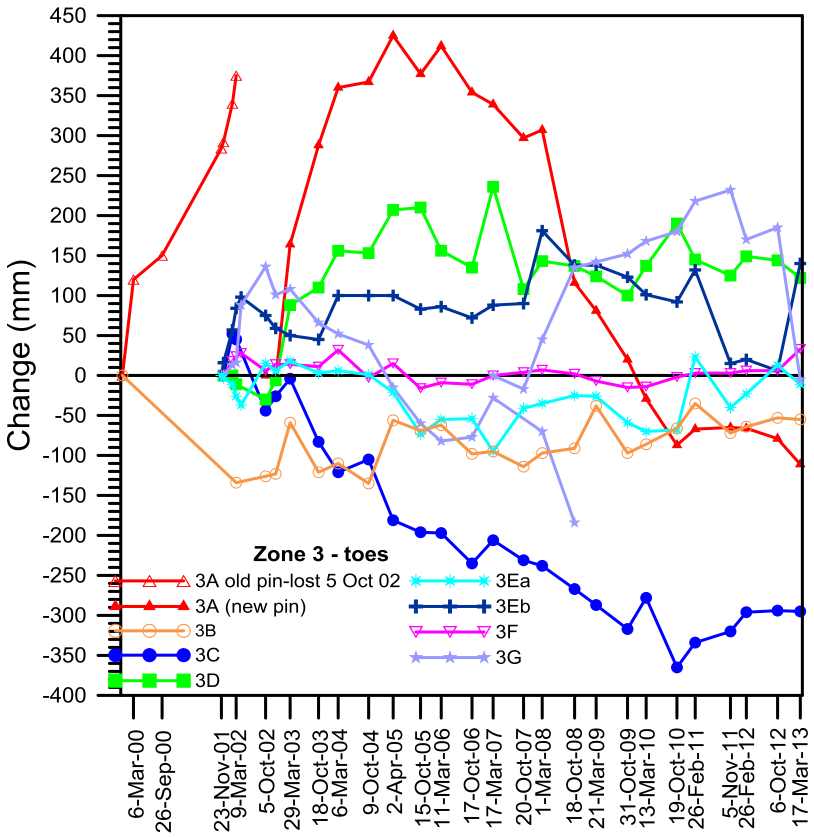


Figure 4.223: Erosion pin results from bank toes in zone 3.

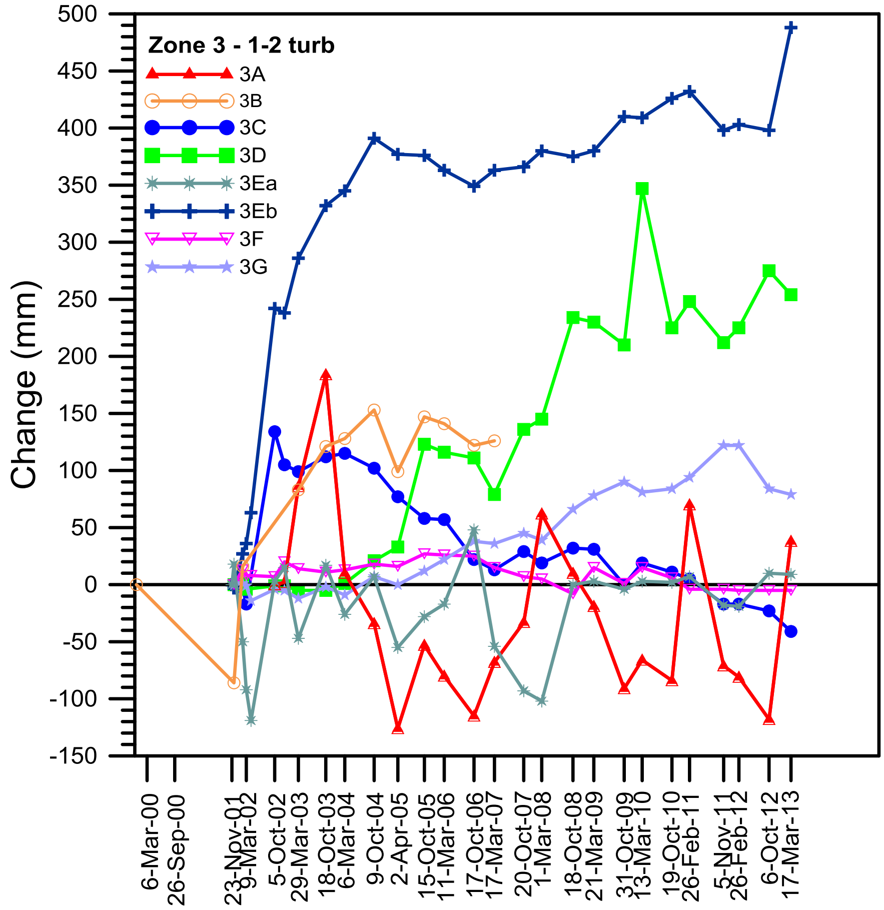


Figure 4.224: Erosion pin results from 1-2 turbine level in zone 3.

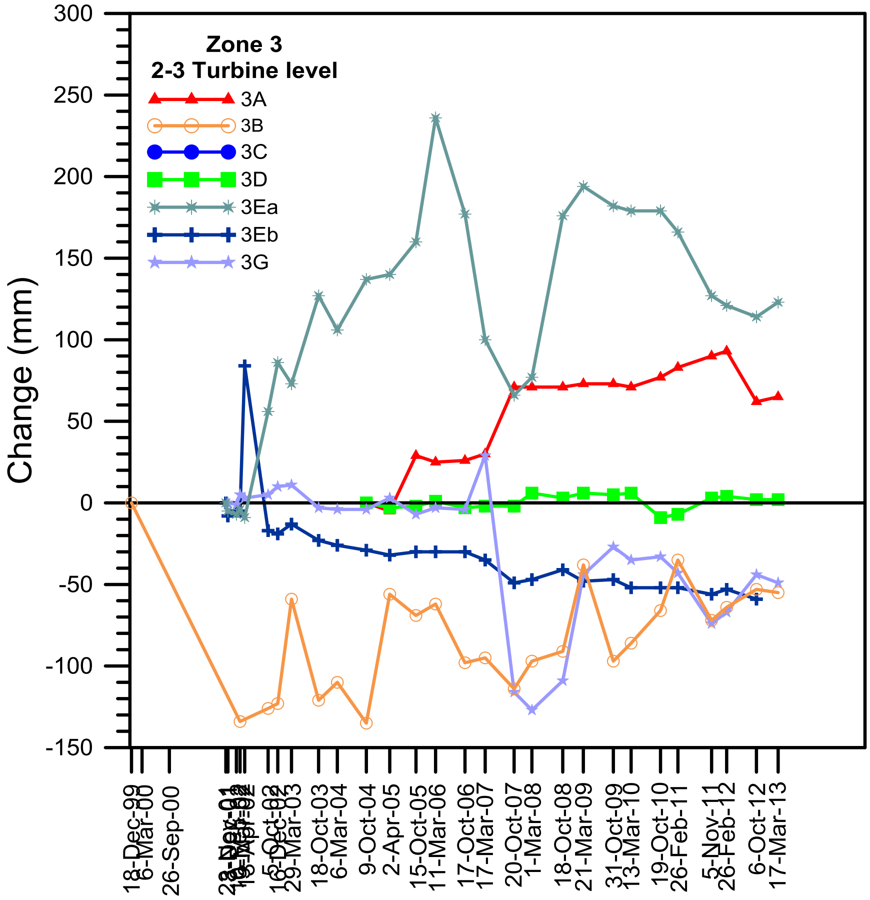


Figure 4.225: Erosion pin results from 2-3 turbine in zone 3.

4.4 Zone 4

Zone 4 extends from the confluence of the Denison River to Sunshine Falls (Gorge). The river in the upstream half of the zone forms broad bends through a limestone terrain, in a relatively flat broad valley. Downstream of this reach the river cuts through a more resistant ridge, and flows northward in a steep and confined valley setting. Water level fluctuation associated with power station operation are lower in this zone as compared to upstream of the Denison RIver due to the wider channel, and higher percentage of flow derived from unregulated tributaries.

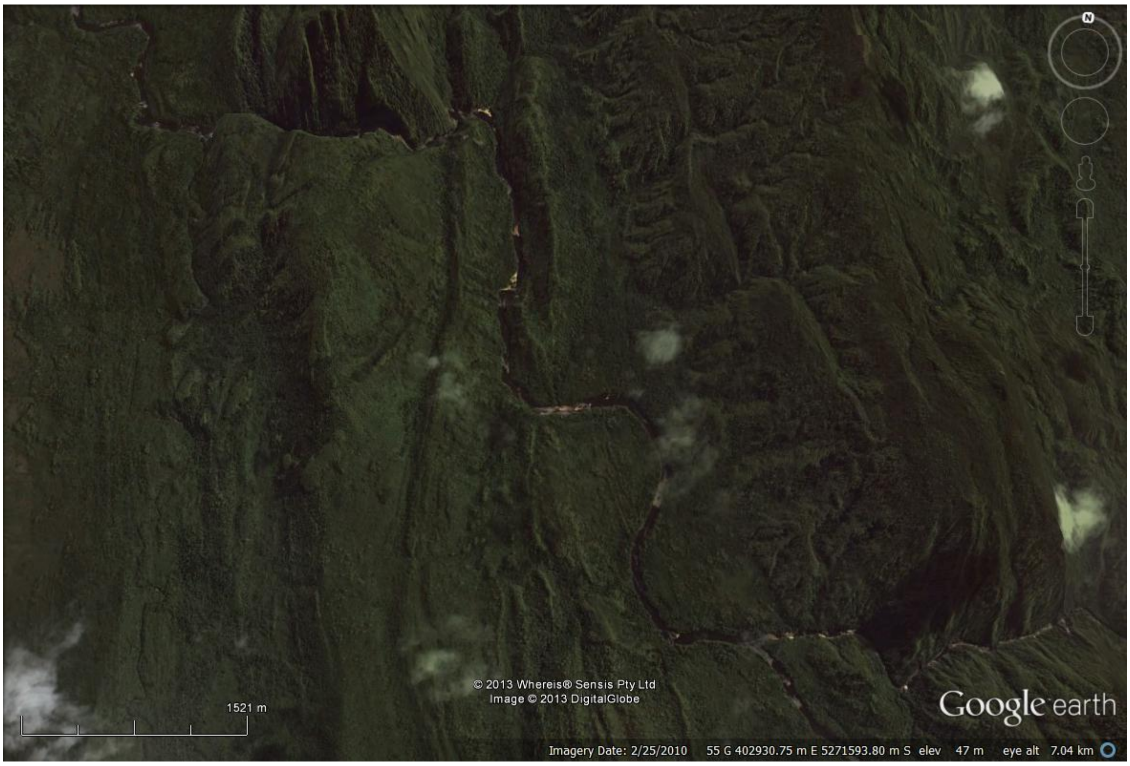


Figure 4.226: Satellite imagery of zone 4.

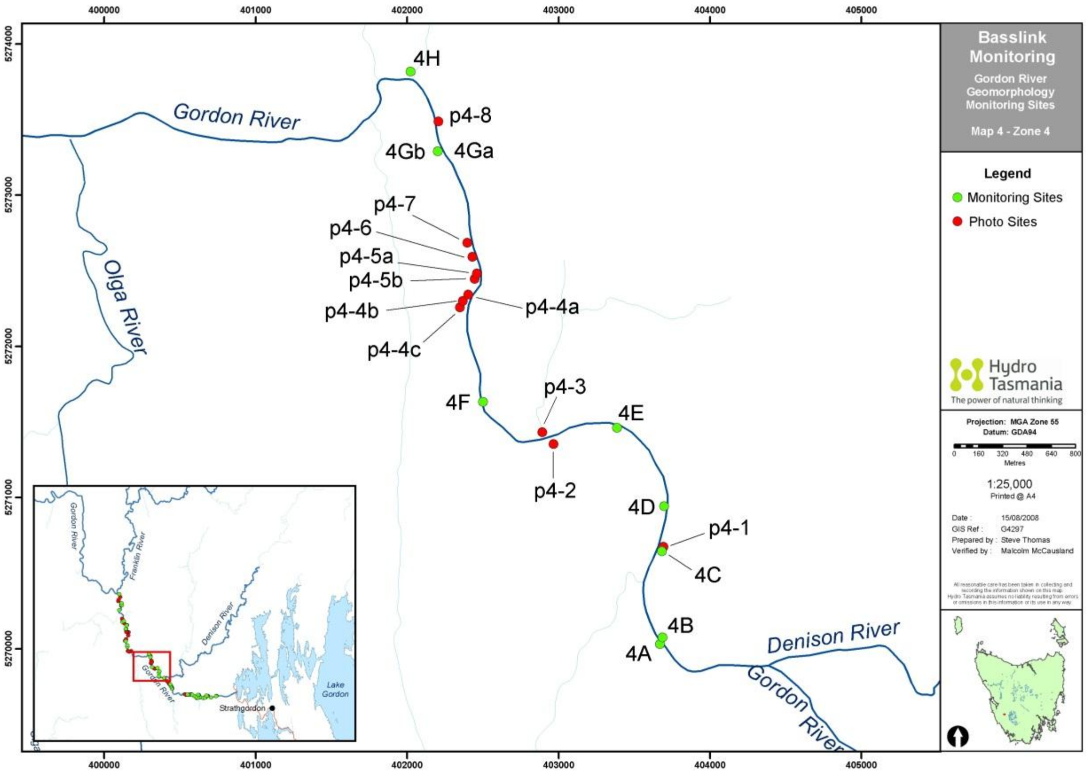


Figure 4.227: Location of monitoring and photo sites within zone 4.

4.4.1 Site 4A

Description: Site 4A is located on the left bank of the river, on an outside bend in a reach with limestone bedrock exposed along the banks and in the channel. The site is located in an alluvial pocket and has a moderately sloping sandy toe extending up below a vegetation / degraded root-mat layer. Erosion pins are installed in a profile down the bank.

Erosional processes: In general, seepage processes in zone 4 are reduced and fluvial deposition is increased relative to the upstream zones. The toe of site 4A has undergone scour, while the 2-3 turbine zone has recorded deposition. A large depositional event in the 2-3 turbine bank level occurred at this site between March and October 2007, and was likely related to the very large flood in August 2007. The same period recorded scour in the 1-2 turbine level and deposition on the toe. The root-mat is progressively being removed from the 2-3 turbine zone, with the underlying sands slumping once exposed.

Erosion pin results

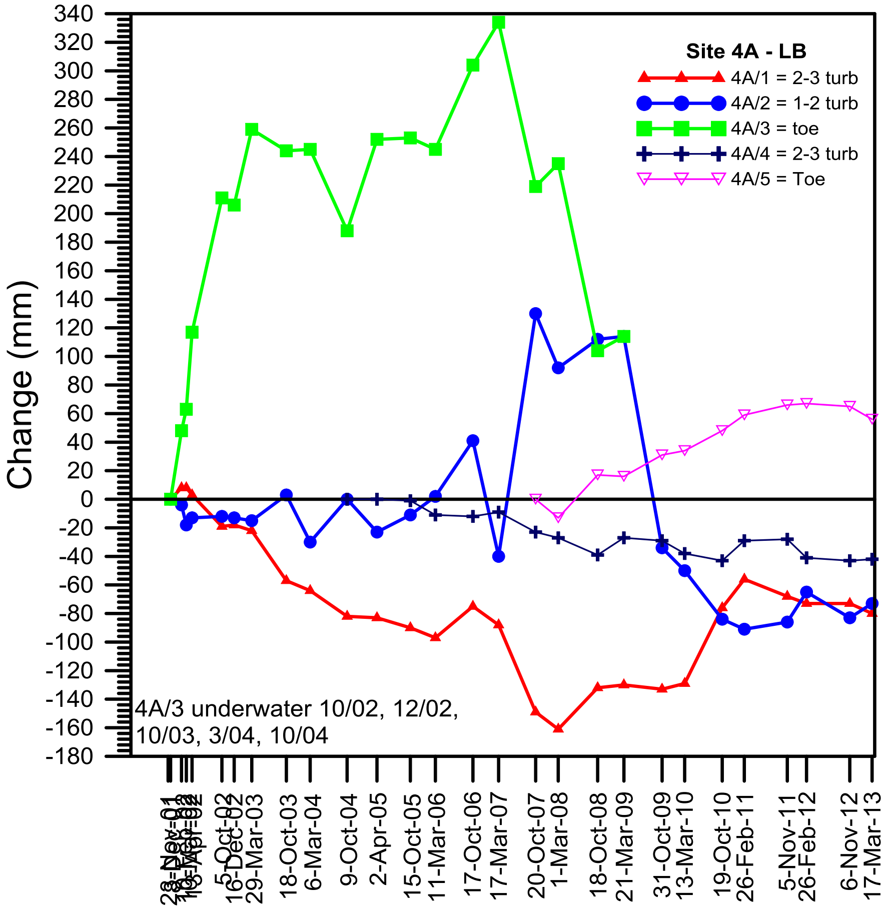


Figure 4.228: Erosion pin results from site 4A.

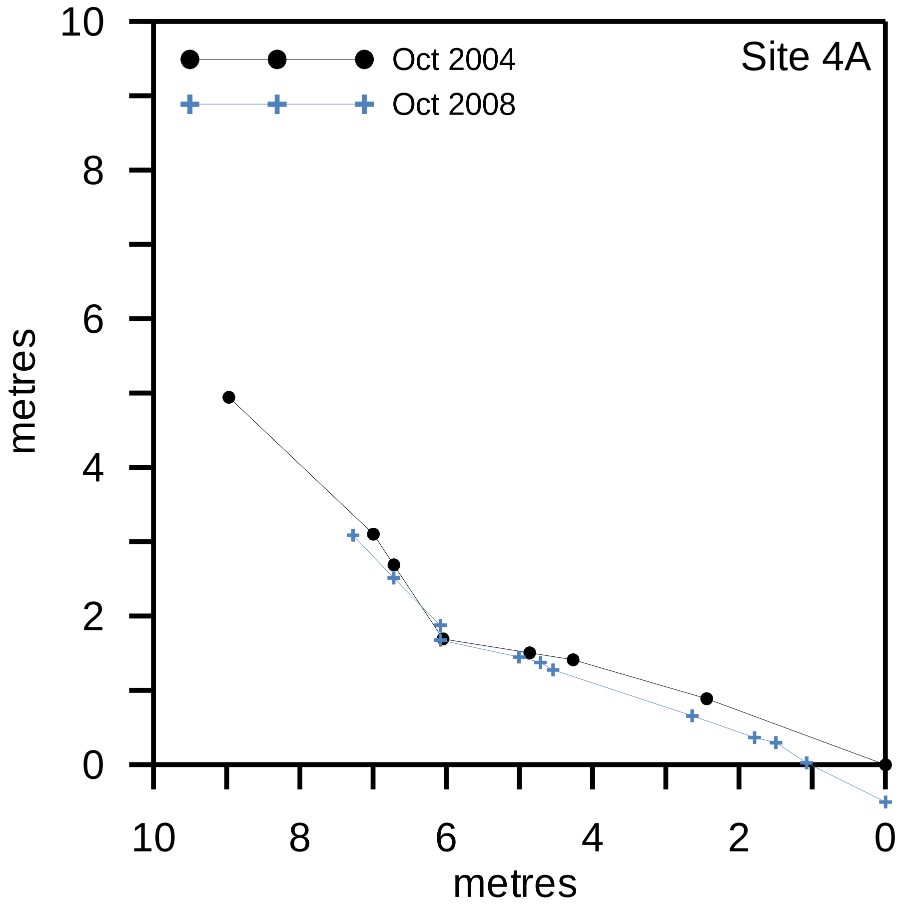


Figure 4.229: Bank profiles from 2004 and 2008.

Photos

Figure 4.230: Site 4A December 2001.

Figure 4.231: Site 4A October 2009.

Figure 4.232: Site 4A March 2010.

Figure 4.233: Site 4A December 2010.

Figure 4.234: Site 4A October 2012.

Figure 4.235: Site 4A March 2013.

4.4.2 Site 4B

Description: Site 4B is located on the right bank across from site 4A on an inside bend, and is composed of vegetation and degraded root-mat overlying sands. There are outcrops of bedrock in the channel and upstream and downstream of this site.

Erosional processes: This site is similar to site 2C in that it tends to be more saturated than other banks and frequently shows signs of seepage processes (rilling, tension cracks). The original toe pin installed at the site moved down slope as the saturated bank 'seeped' into the river. Post-Basslink, when the power station usage was reduced saturation of the bank was also reduced. The root-mat in the 2-3 turbine zone and underlying sands are being scoured, whilst the toe is flattening through local seepage processes.

Erosion pin results

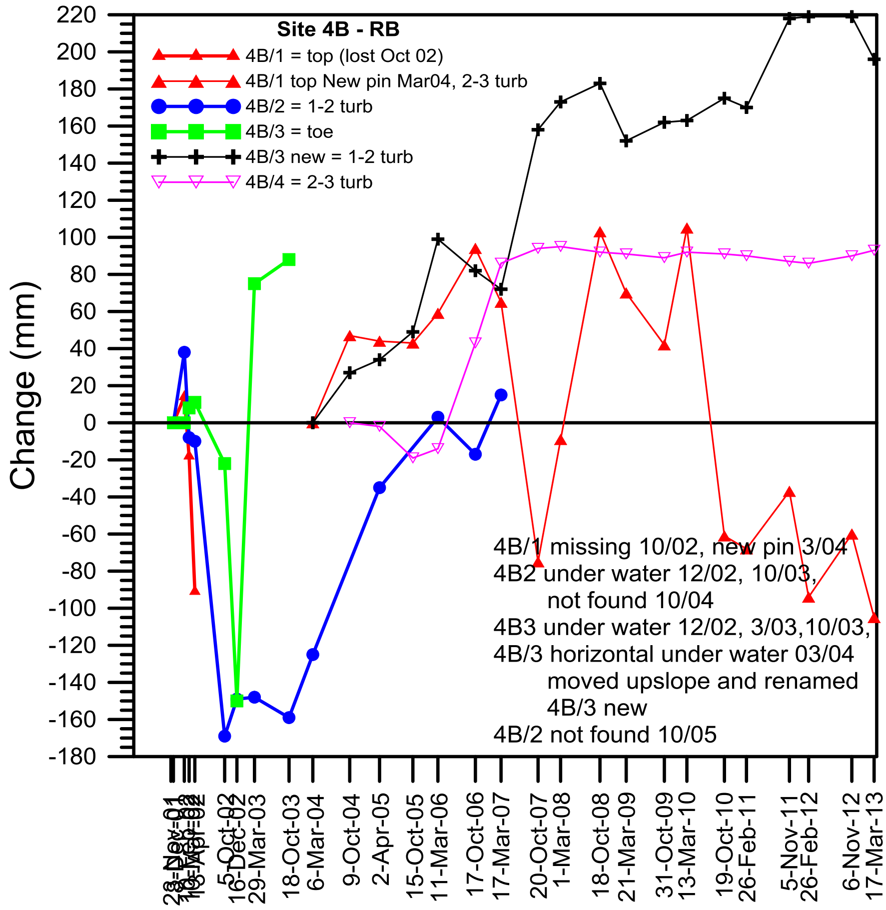


Figure 4.236: Erosion pin results from site 4B.

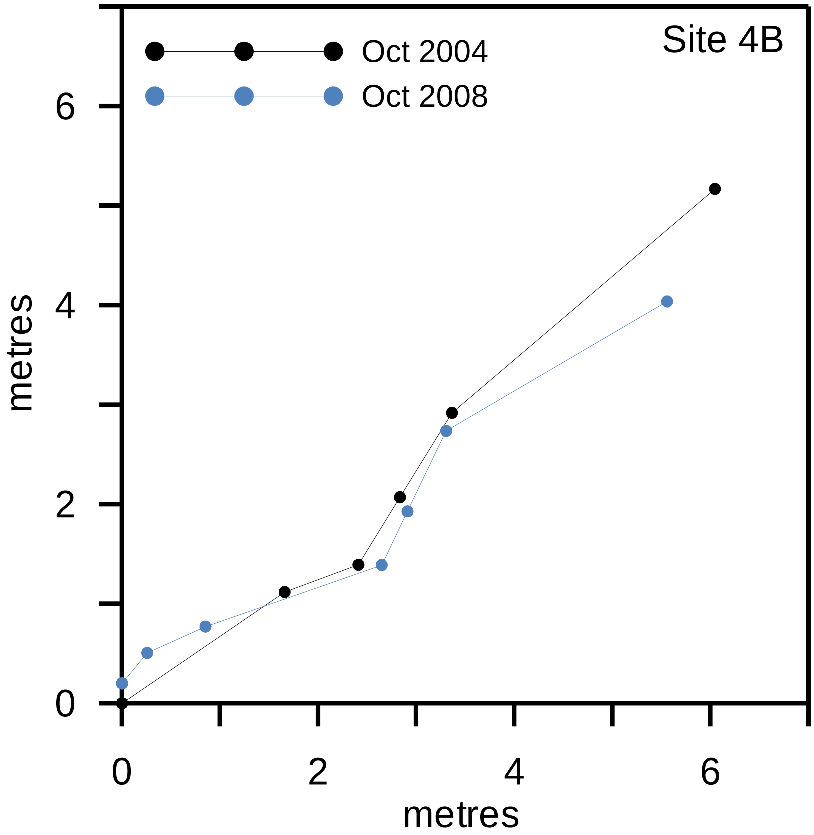


Figure 4.237: Bank profiles at site 4B from 2004 and 2008.

Photos

Figure 4.238: Site 4B December 2001.

Figure 4.239: Site 4B March 2004.

Figure 4.240: Site 4B December 2004.

Figure 4.241: Site 4B October 2006.

Figure 4.242: Site 4B Dec 2007.

Figure 4.243: Site 4B November 2011.

Figure 4.244: Site 4B March 2013.

(Note: Site 4C was in a cobble bank and discontinued early in the monitoring program due to safety concerns associated with overhanging vegetation.)

4.4.3 Site 4D

Description: Site 4D is located on the left bank of the river on an inside bend at the downstream end of a cobble bar. The site has a large log buttressing the toe of the bank, and supports tea tree. Originally piezometers were also installed at this site, but they were removed prior to the implementation of Basslink.

Erosional processes: The erosion pin in the lower 2-3 turbine bank level has recorded deposition, reflecting the slumping of sands from under the degraded root-mat. The rest of the pins on the site have shown variability over the monitoring period but little net change. When the site was established in 2001, a clump of dead tea tree was present in the 1-2 turbine bank level. In 2013, the root ball and some of the branches remain, suggesting that the erosion of tea tree can be slow. In this case the buttressing of the bank by the large tree undoubtedly has contributed to the stability of the site.

Erosion pin results

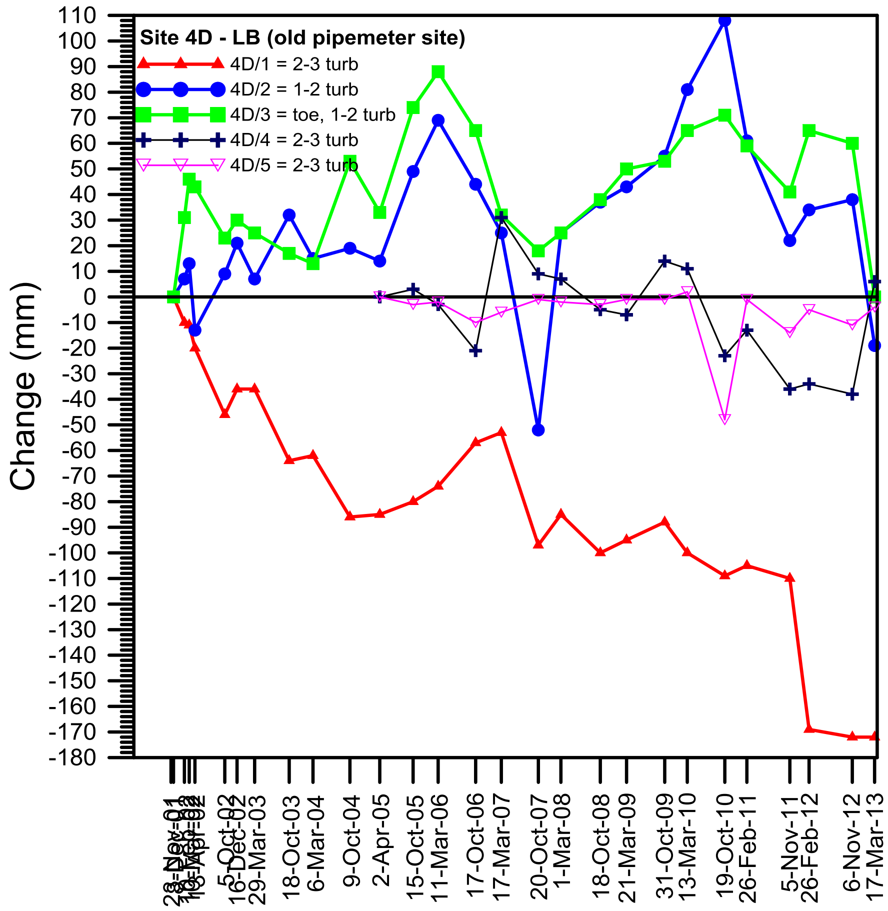


Figure 4.245: Erosion pin results from site 4D.

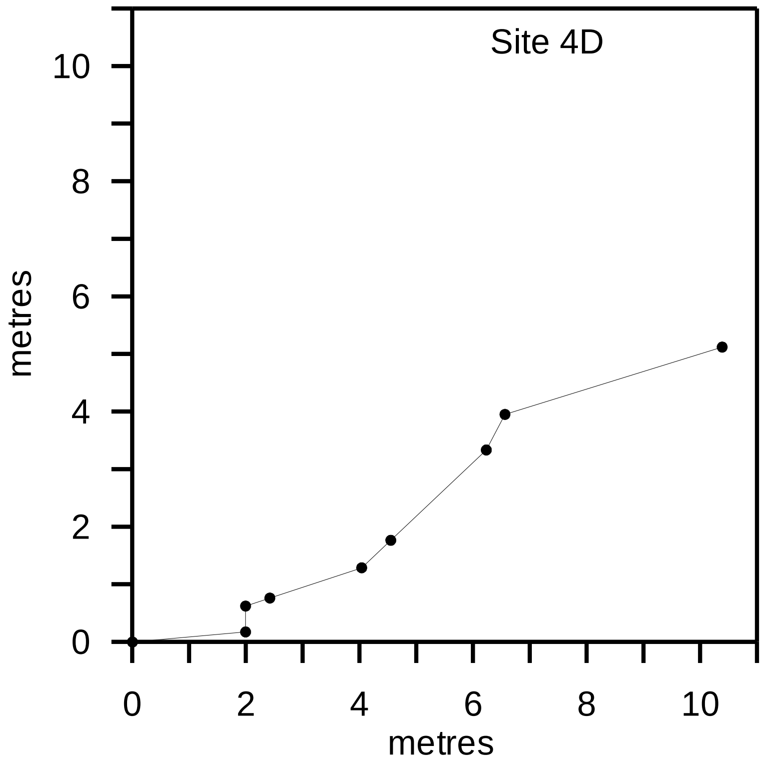


Figure 4.246: Bank profile at site 4D in 2004.

Photos

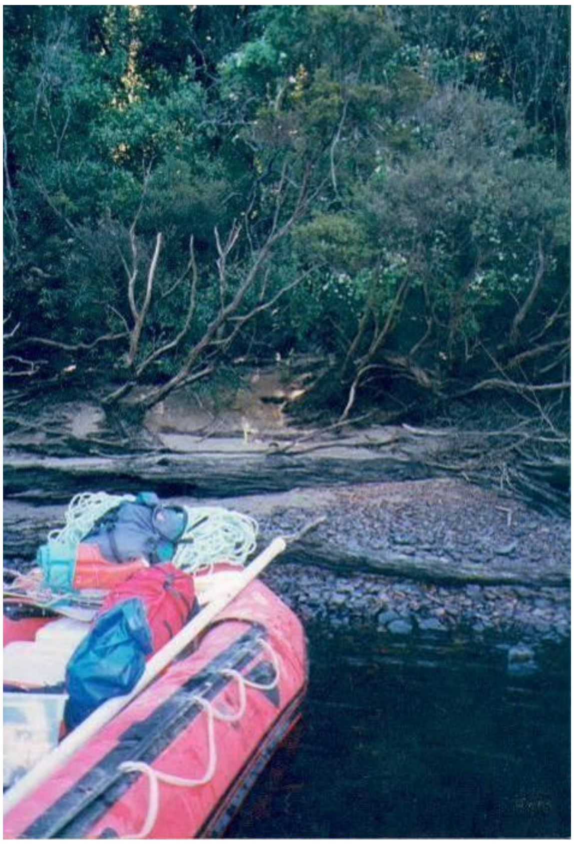


Figure 4.247: Site 4D December 2001.

Figure 4.248: Site 4D March 2004.

Figure 4.249: Site 4D March 2010.

Figure 4.250: Site 4D November 2011.

Figure 4.251: Site 4D March 2013.

4.4.4 Site 4E

Description: Site 4F is on the left bank on the downstream end of an outside bend below the eagles nest across from the Bill Nielson Cave. The bank is composed of a short steep sandy toe extending under a vegetation and degraded root mat layer. There is abundant woody debris on the site.

Erosional processes: This bank is highly variable, with evidence of scour, slumping and fluvial deposition observed at various times. In general, the bank appears to scour in the summer, when power station operations dominate the flow pattern, with deposition recorded in the winter, when unregulated inflows contribute a large proportion of the flow. The net impact of these processes on the bank has been erosion and steepening of the 2-3 turbine bank level, which has resulted in the exposure of an oxidised scour chain see Figure 4.255.

Erosion pin results

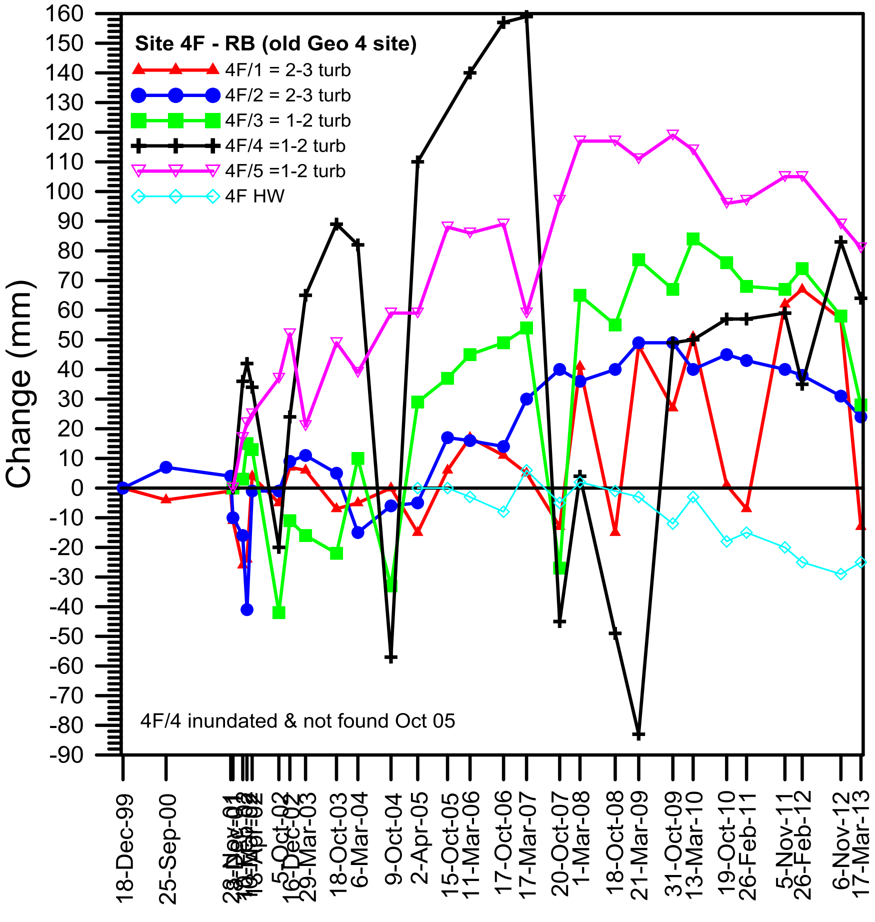


Figure 4.252: Erosion pin results from site 4E.

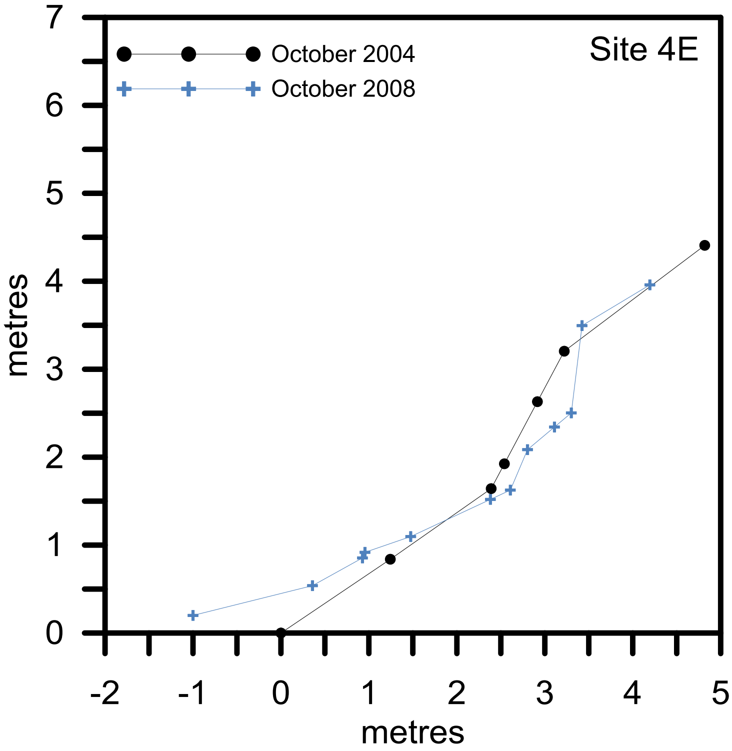


Figure 4.253: Bank profiles from 2004 and 2008.

Photos

Figure 4.254: Site 4E December 2001.

Figure 4.255: Site 4E February 2011.

Figure 4.256: Site 4E November 2011.

Figure 4.257: Site 4E March 2013.

4.4.5 Site 4F

Description: Site 4 F is located on the right side of the river at a bedrock constriction just upstream of a short but steep rapid. The site consists of 5 erosion pins and a high water star picket installed on sands overlying the bedrock downslope of a stand of tea tree. Pins 4 and 5 are located ~15 m downstream in a sandy bank which contains abundant woody debris.

Erosional processes: Similar to site 4E, this site has shown seasonal fluctuations, with net erosion the general trend. An exception to this is pin 4F/4 which has shown very large fluctuations. This pin is located in an area of the banks which receives fluvial deposition as well as being subjected to scour. A large tree fall probably associated with the August 2007 flood also affected this pin, resulting in increased deposition.

Erosion pin results

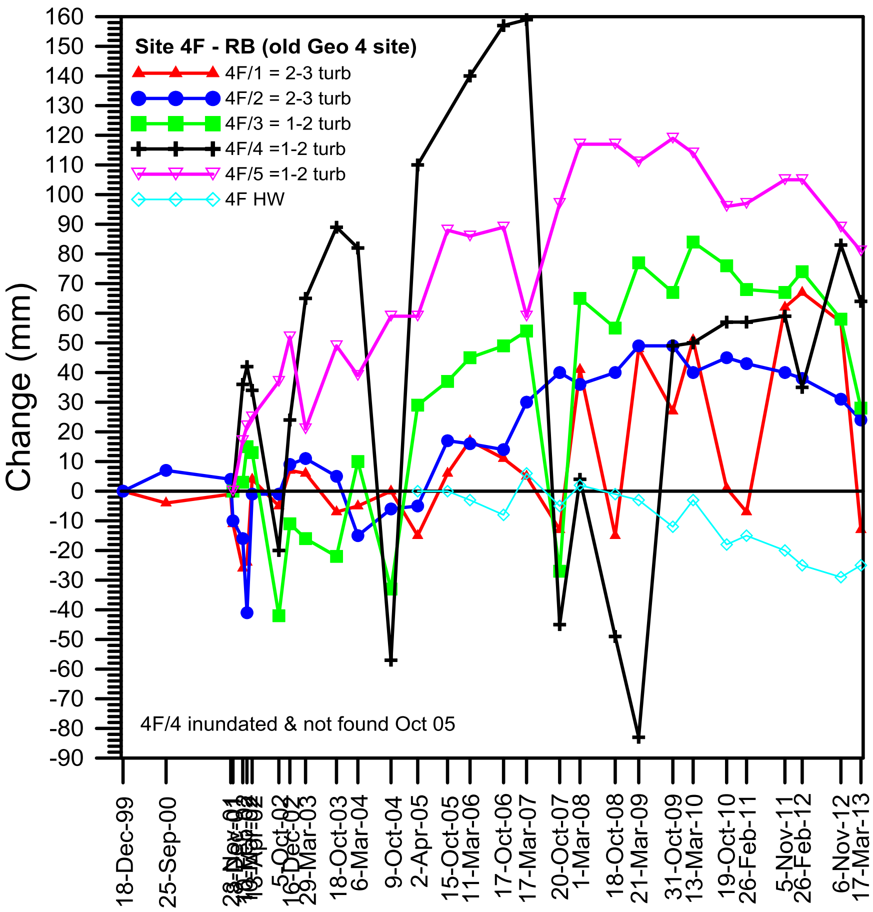


Figure 4.258: Erosion pin results from site 4F.

Photos

Figure 4.259: Site 4F March 2001.

Figure 4.260: Site 4F October 2009.

Figure 4.261: Site 4F October 2009 – sandy bank downstream of bedrock.

Figure 4.262: Site 4F November 2013.

Figure 4.263: Site 4F March 2013.

4.4.6 Site 4Ga

Description: Site 4Ga is on the right bank of the river, in a straight reach upstream of Sunshine Gorge at the base of a very steep slope (Just downstream of the track leading to the Olga Camp). The site is composed of an extended sandy bank toe extending up under degraded vegetation and tea tree. There is abundant woody debris at the site, and over the course of monitoring several tree falls occurred at the site, with the largest falls observed after the 2007 flood event. The erosion pins are installed in a profile down the bank.

Erosional processes: This bank always appears very dynamic, with sand and woody debris moving around. The local hydraulics of the site are greatly affected by the woody debris on the bank and in the river off of the toe. The large flood event in 2007 resulted in deposition on the toe and in the 1-2 turbine bank level, but scour in the 2-3 turbine level. Similar to other sites it appears that the tea tree stabilised bank is slowly scouring, with the underlying sands being washed down slope, which contributes to the flattening of the bank toe.

Erosion pin results

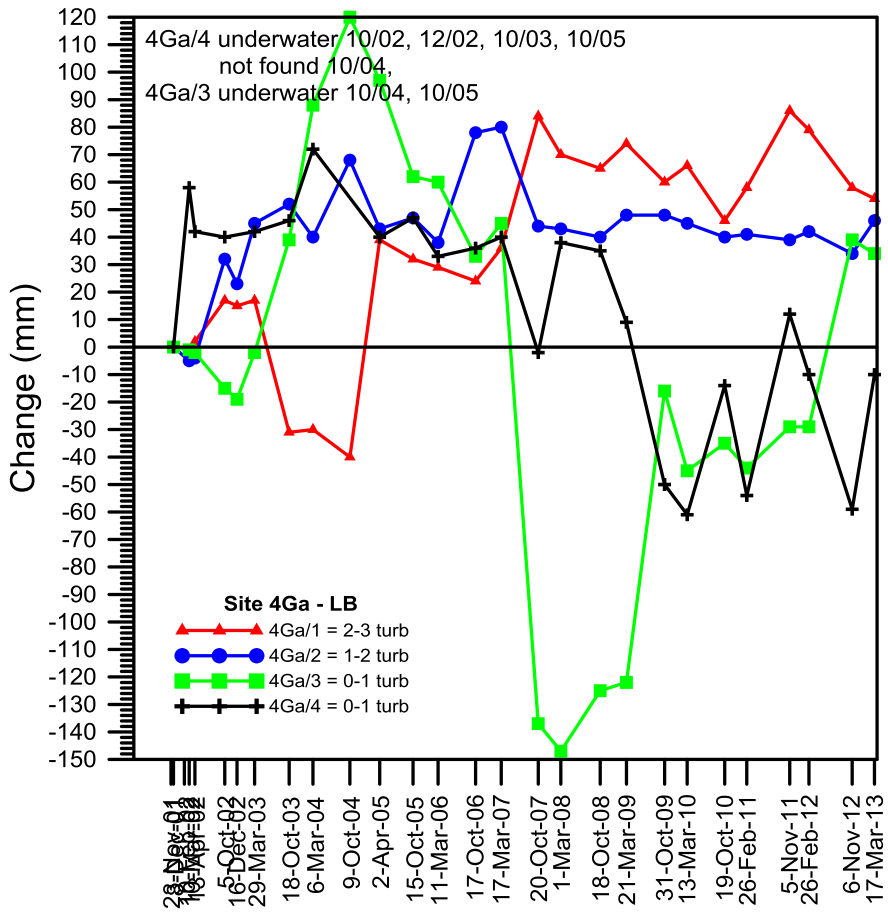


Figure 4.264: Erosion pin results from site 4Ga.

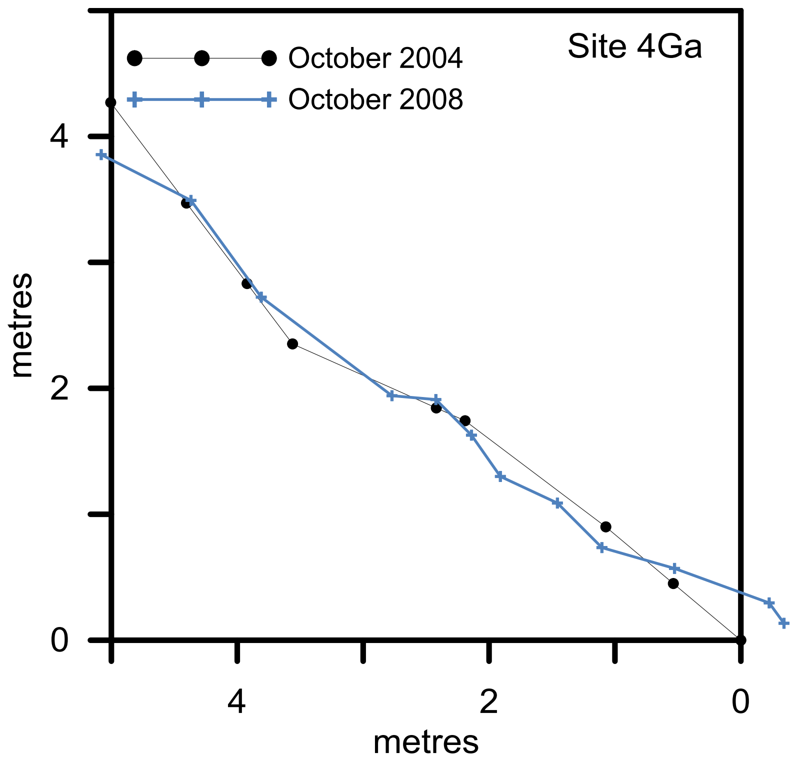


Figure 4.265: Bank profiles from site 4Ga from 2004 and 2008.

Photos

Figure 4.266: Site 4Ga December 2001.

Figure 4.267: Site 4Ga March 2006.

Figure 4.268: Site 4Ga March 2007.

Figure 4.269: Site 4Ga March 2009.

Figure 4.270: Site 4Ga December 2010.

Figure 4.271: Site 4Ga October 2012.

Figure 4.272: Site 4Ga March 2013.

4.4.7 Site 4Gb

Description: Site 4Gb is located approximately 20 m downstream from site 4Ga on the same bank. It is also characterised by a sandy toe extending upslope under tea-tree and a degraded root mat, and woody debris. The erosion pins are installed in a profile down the bank.

Erosional processes: This site has not been affected by tree falls, and has appeared less dynamic as compared to site 4Ga although it is on the same bank. The tea tree root mat in the 2-3 turbine bank level is slowly scouring, and the erosion pin on the toe of the bank has shown variability. The 0-1 turbine bank level has shown the greatest changes during monitoring, see-sawing between extended periods of erosion and deposition.

Erosion pin results

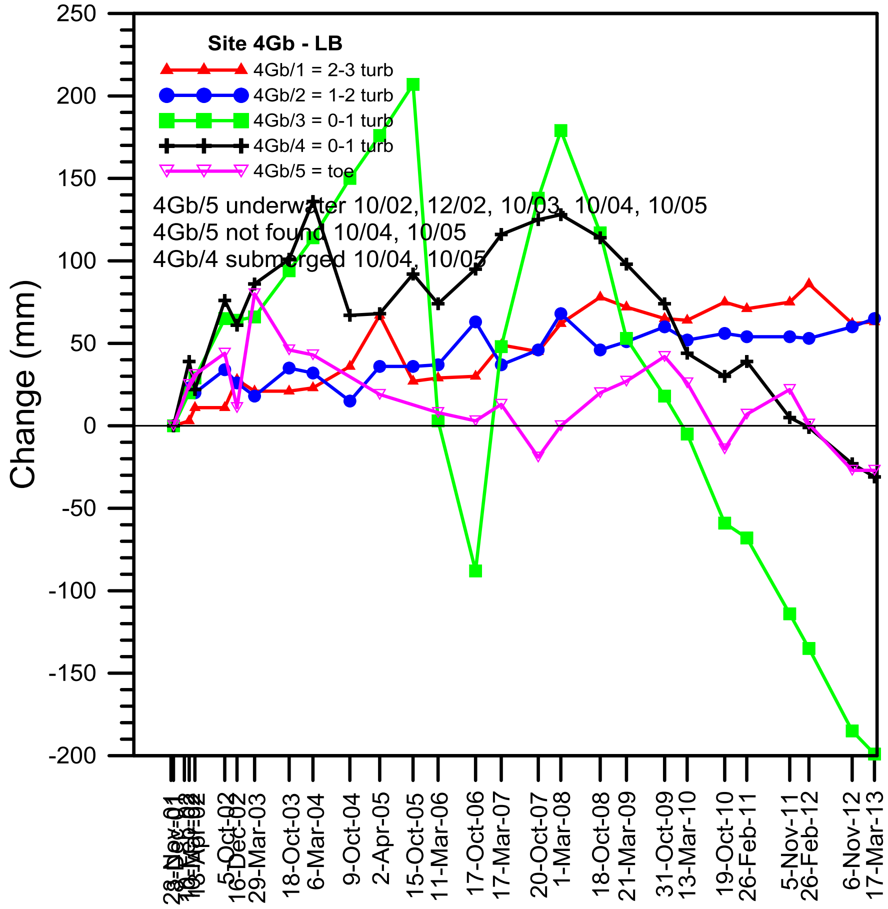


Figure 4.273: Erosion pin results from site 4Gb.

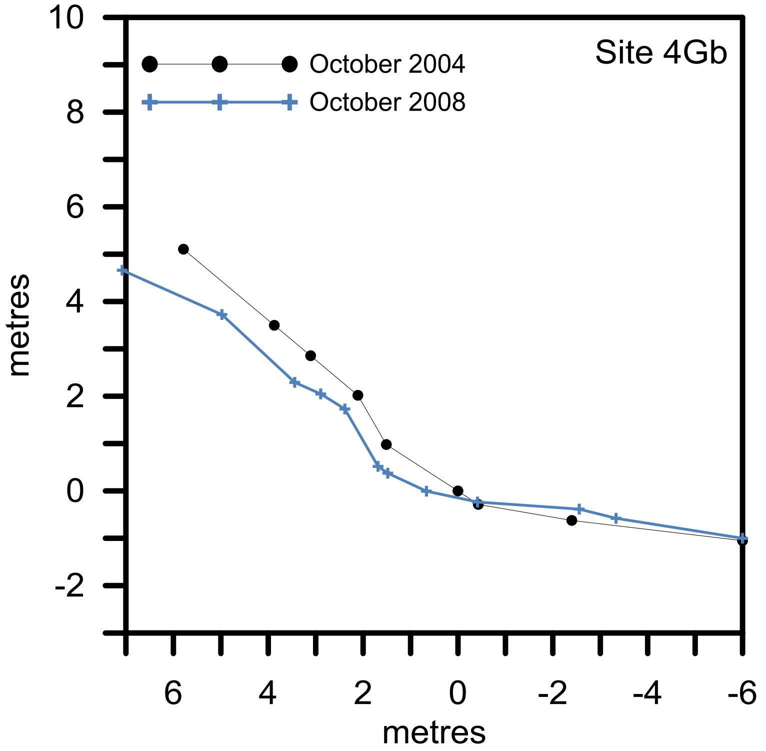


Figure 4.274: Bank profiles from 2004 and 2008.

Photos

Figure 4.275: Site 4Gb December 2001.

Figure 4.276: Site 4Gb October 2009.

Figure 4.277: Site 4Gb March 2013.

4.4.8 Site 4H

Description: Site 3H is located on a sandy bank at the downstream end of zone 4, on the right bank of the sharp bend entering Sunshine Gorge, between Smith and Harrison Creeks. Similar to the other sites in zone 4, the site consists of an extended sandy toe with tee tree in the 2-3 turbine bank level. When the erosion pin site was installed, the bank had distinct breaks in slope which were interpreted as corresponding to discrete turbine levels.

Erosional processes: The trend on the bank has been one of deposition, with the distinct breaks in slope no longer present. Fluvial deposition is active on this bank, presumably due to backwater effects from the gorge. The bank recorded scour over the August winter period, probably associated with the large flood event, with the lowest pin recording the largest change.

Comment: There are surprisingly few photos of this site. This is probably because it is the last site of the day and time is often a constraint.

Erosion pin results

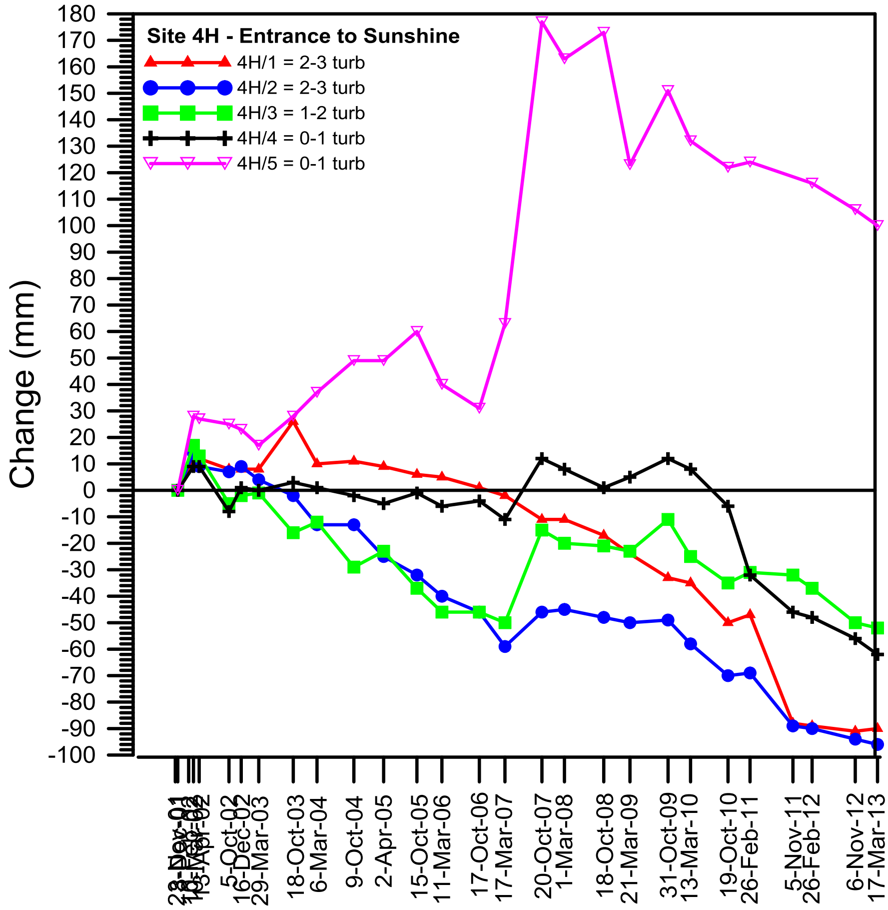


Figure 4.278: Erosion pin results from site 4H.

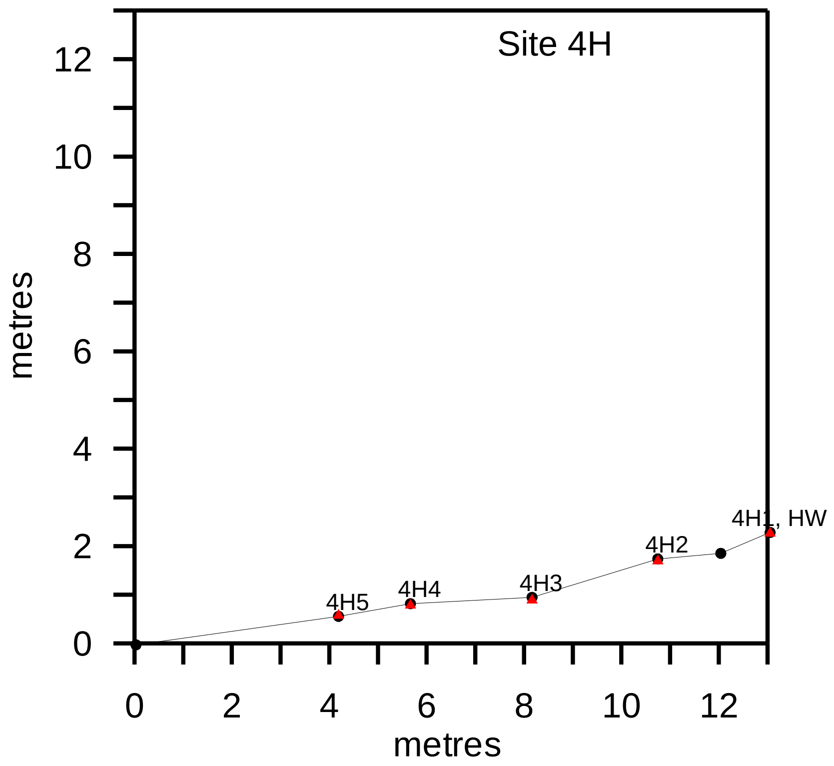


Figure 4.279: Bank profile of site 4H from 2004.

Photos

Figure 4.280: Site 4H October 2009.

Figure 4.281: Site 4H November 2011.

Figure 4.282: Site 4H October 2012.

Figure 4.283: Site 4H March 2013.

Comparison of erosion pin results in zone 4

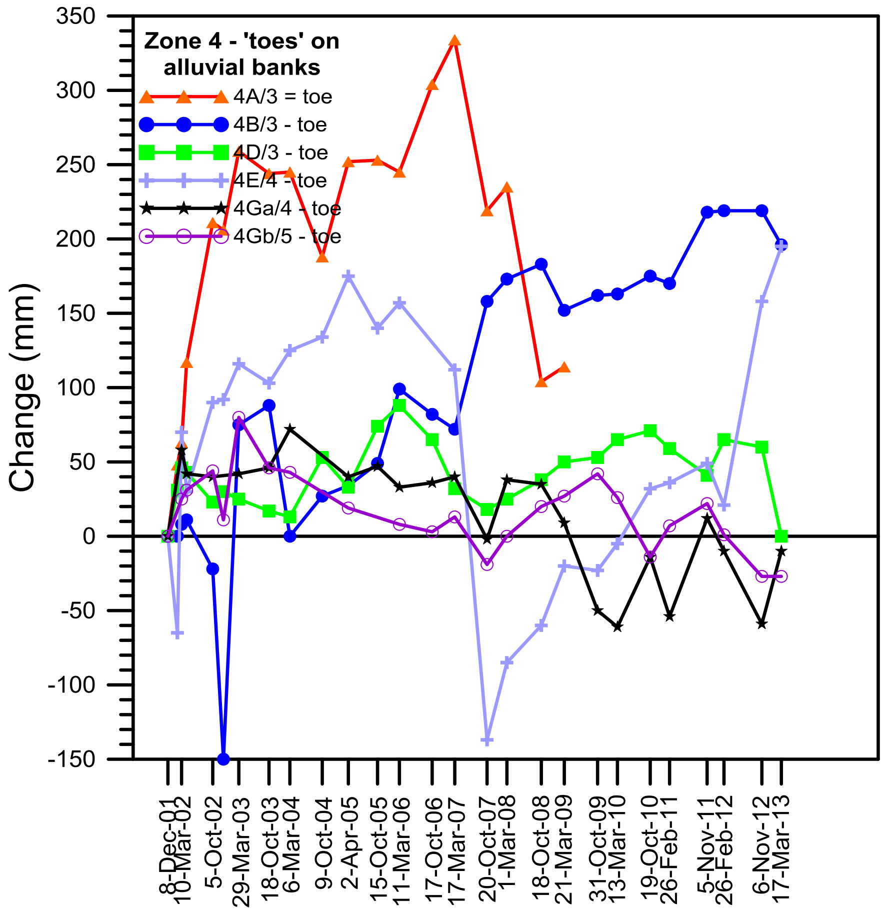


Figure 4.284: Erosion pin results for bank toes in zone 4.

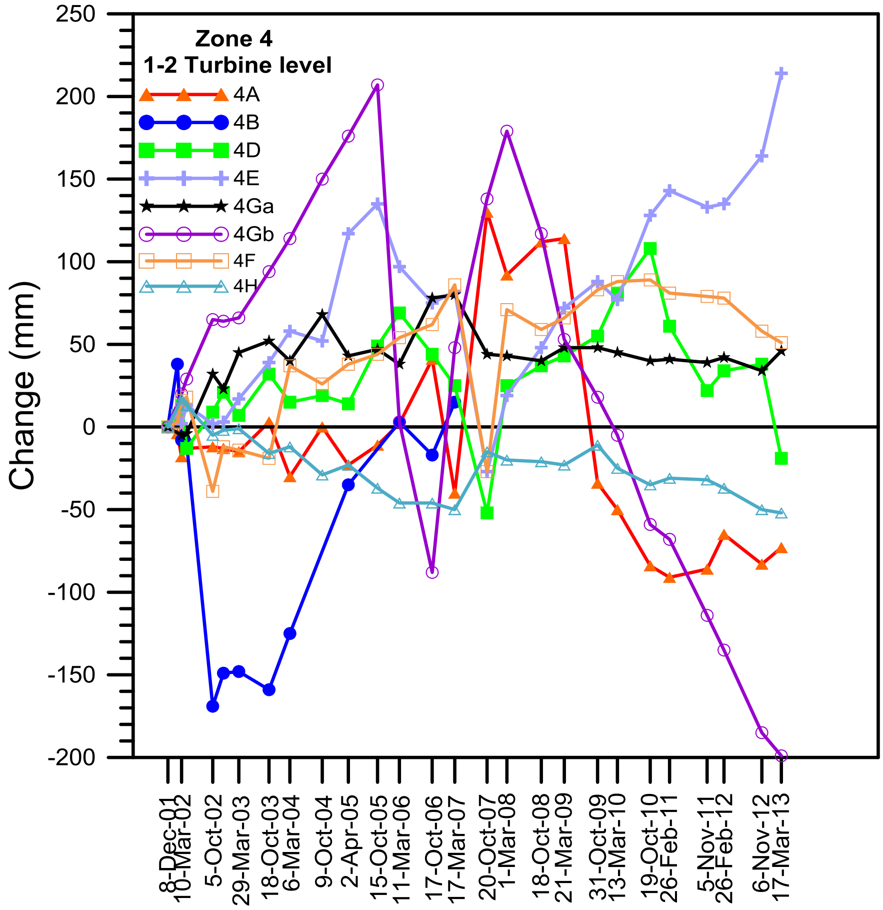


Figure 4.285: Erosion pin results for pins in the 1-2 turbine bank level in zone 4.

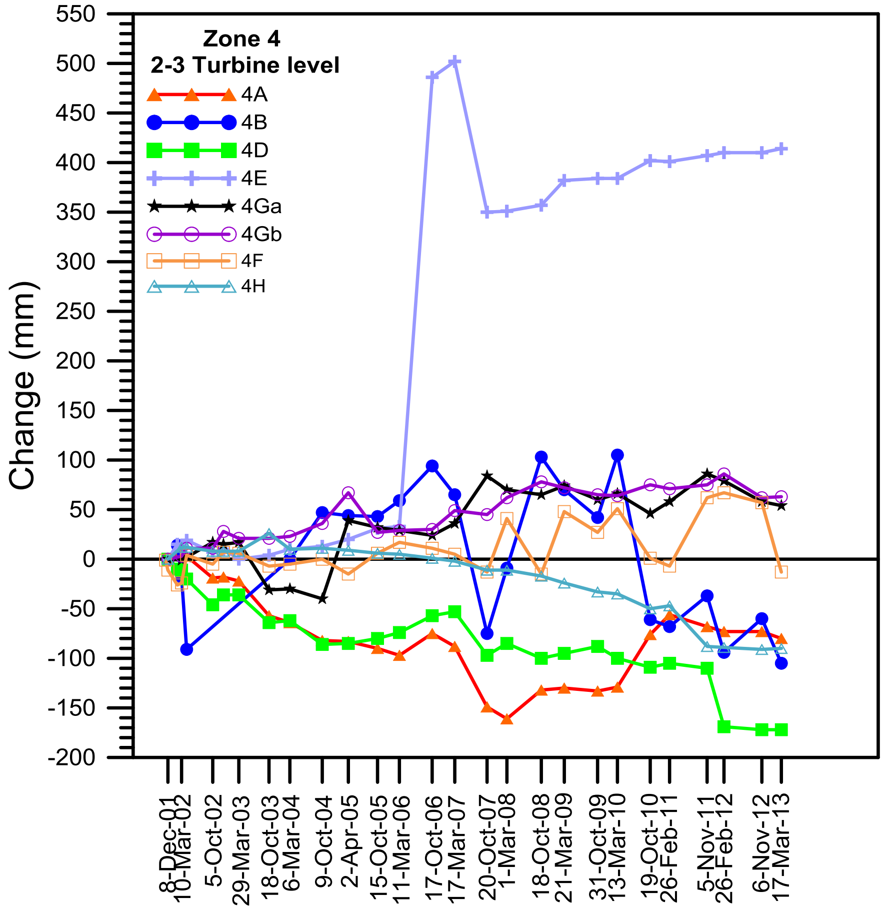


Figure 4.286: Erosion pin results for pins in the 2-3 turbine bank level in zone 4.

4.5 Zone 5

Zone 5 is delimited by Sunshine Falls at the upstream end and the confluence of the Gordon and Franklin Rivers at the downstream end. The Olga River enters the zone downstream of Sunshine Falls and upstream of Sharks Mouth Rapid. Zone 5 is the longest geomorphic zone in the Basslink monitoring program, comprising about half of the overall river length of the study area. Zone 5 is also the most distal zone from the power station and has the largest proportion of unregulated tributary inflows. In this zone the Gordon is largely confined to a broad valley developed on limestone and sandstone / siltstones, which is an extension of the same valley occupied by the Olga River. Outside bends of the river tend to be bedrock controlled.

Figure 4.287: Satellite imagery of zone 5.

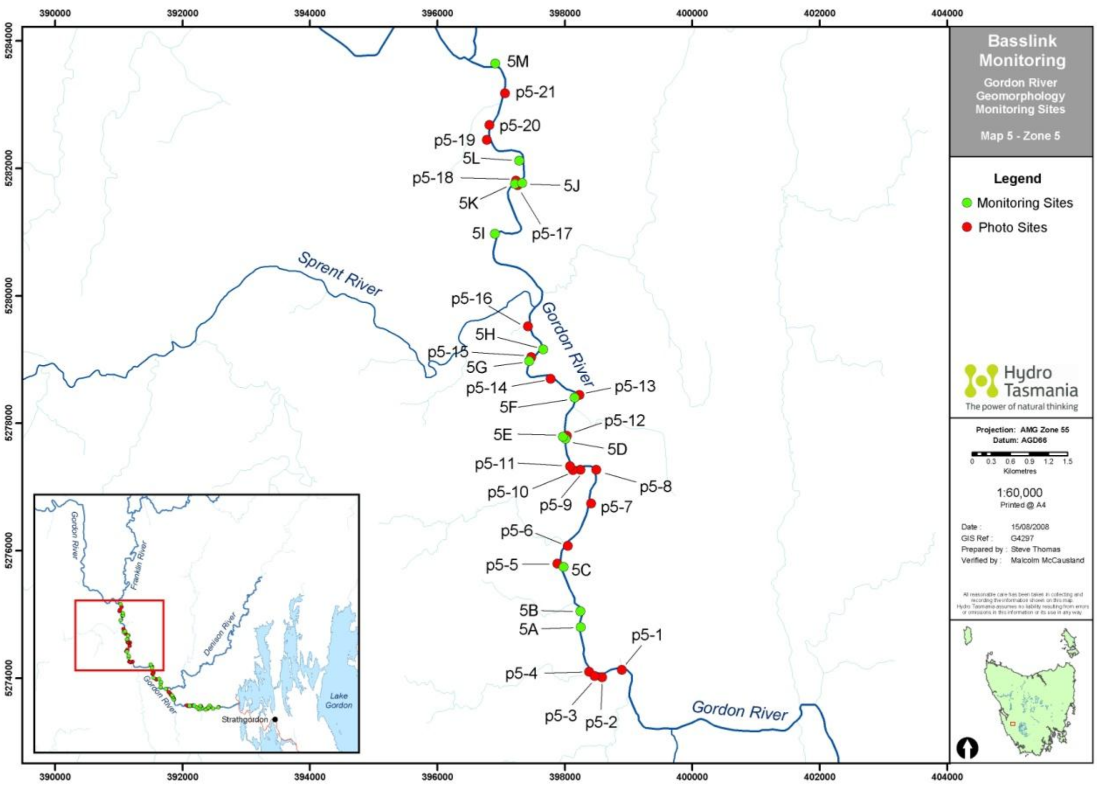


Figure 4.288: Location of monitoring and photo sites within zone 5.

4.5.1 Site 5A

Description: Site 5a is located on the right bank at the downstream end of a straight reach. The site consists of a shallowly sloping sandy bank to extending upslope under a degraded root-mat and vegetation consisting of tea tree, prickly moses, restio and eucalypts (higher on the bank). This is a very typical assemblage of vegetation on the alluvial banks of zone 5.

Erosional processes: During the pre-Basslink period, the erosion pin results from the lower bank tended to show erosion during summer when power station operations dominated the flow regime, and deposition in winter associated with unregulated tributary inflows. Since October 2007, following the high flow event in August 2007, the site was highly altered due to a large rotational slump which occurred on the bank at a distance of about 15 m from the river's edge, disturbing the bank and overlying vegetation. Since this disturbance the bank toe has recorded deposition, associated with seepage related processes with sands derived from higher on the bank. Discrete sediment flows have not been observed, but rather a more general downslope movement of sands exposed due to the slump and scour of the root-mat, and eroded from the 1-2 turbine bank level. The 1-2 turbine bank level has been eroded through scour, likely associated with the more variable flow levels since the introduction of Basslink.

Erosion pin results

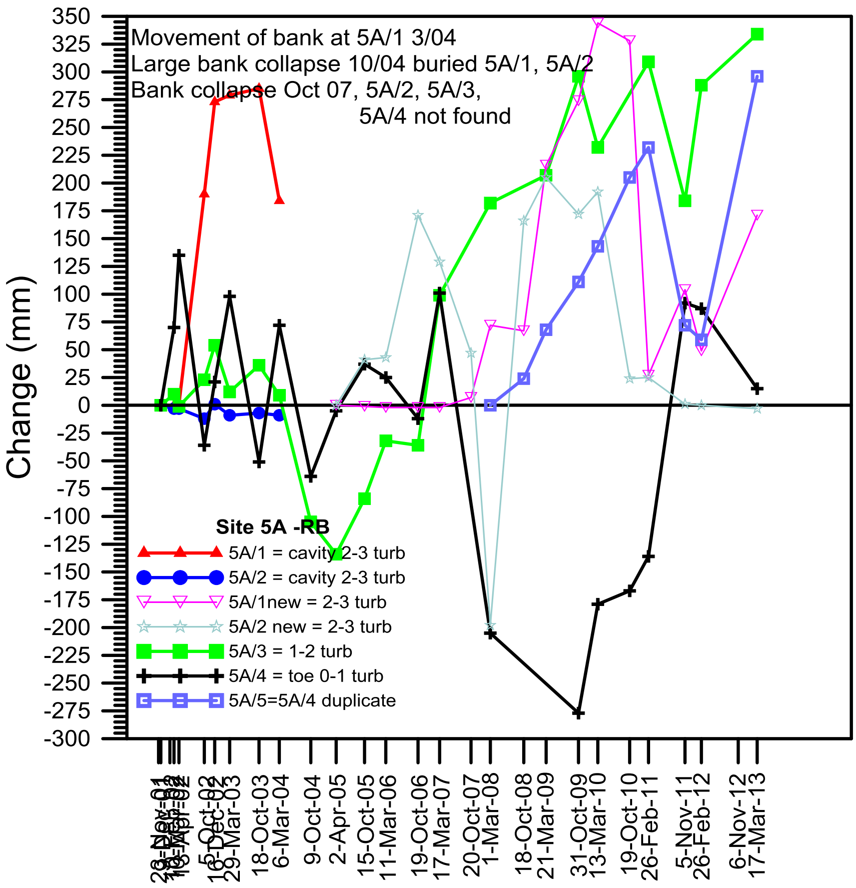


Figure 4.289: Erosion pin results from site 5A.

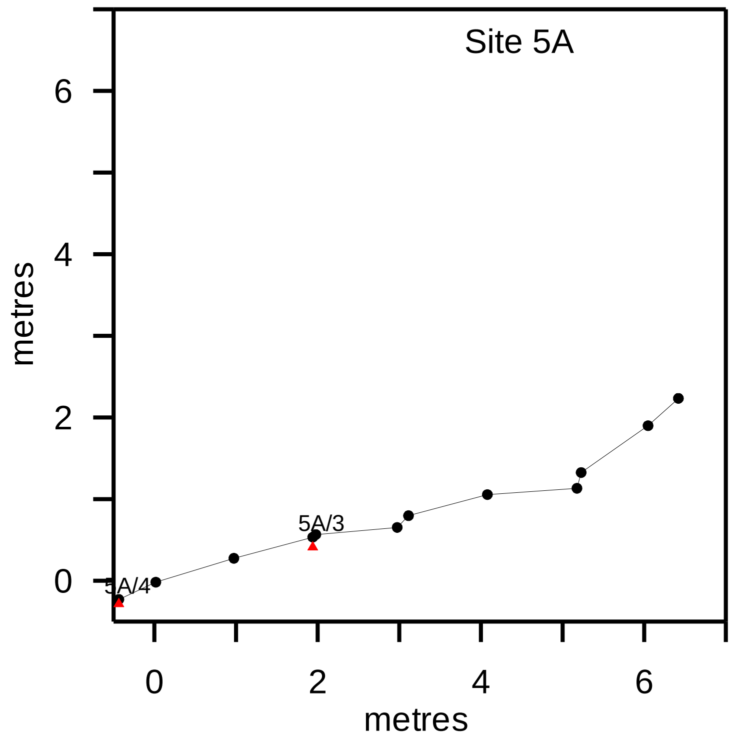


Figure 4.290: Bank profile in 2004 from site 5A.

Photos

Figure 4.291: Site 5A December 2001.

Figure 4.292: Site 5A March 2007.

Figure 4.293: Site 5A March 2007.

Figure 4.294: Site 5A October 2007 after flood.

Figure 4.295: Site 5A February 2011.

Figure 4.296: Site 5A March 2013.

4.5.2 Site 5B

Description: Site 5B is located on the left bank on an inside bend. The bank is composed of shallowly sloping toe composed of sands and silts extending upslope beneath a degraded root-mat and overlying vegetation. Solitary tea tree remain on the bank on the river side of the continuous root-mat. The site is a back eddy during high flows which has promoted the deposition of woody debris on the bank, as well as silts and muds which are commonly observed as veneers on the bank.

Erosional processes: The flat-lying bank appears to be 'maintained' by grey-silt that is washed out from beneath the root-mat. The bank tends to be more saturated than other banks, probably due to the higher proportion of clays and silts deposited in the back water. The sands on the bank are subject to movement when the woody debris is disturbed. Scour was recorded at the site following the August 2007 high flow event, but overall the trend is for 'flattening' of the bank, consistent with a back water environment.

Erosion pin results

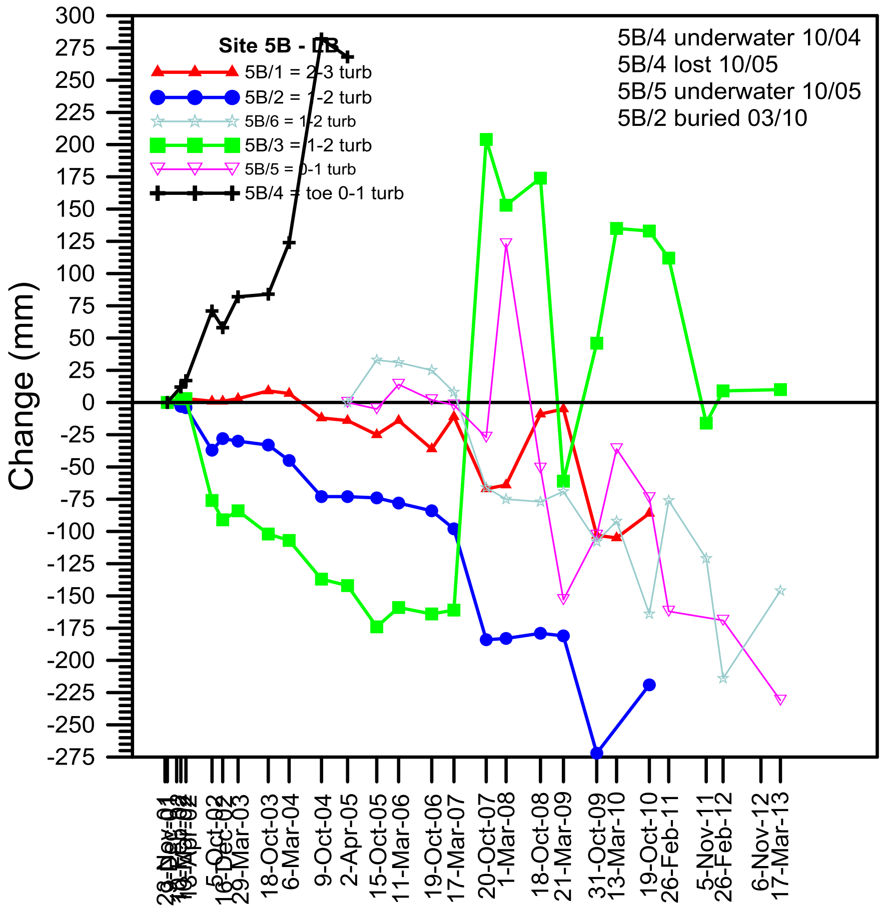


Figure 4.297: Erosion pin results from site 5B.

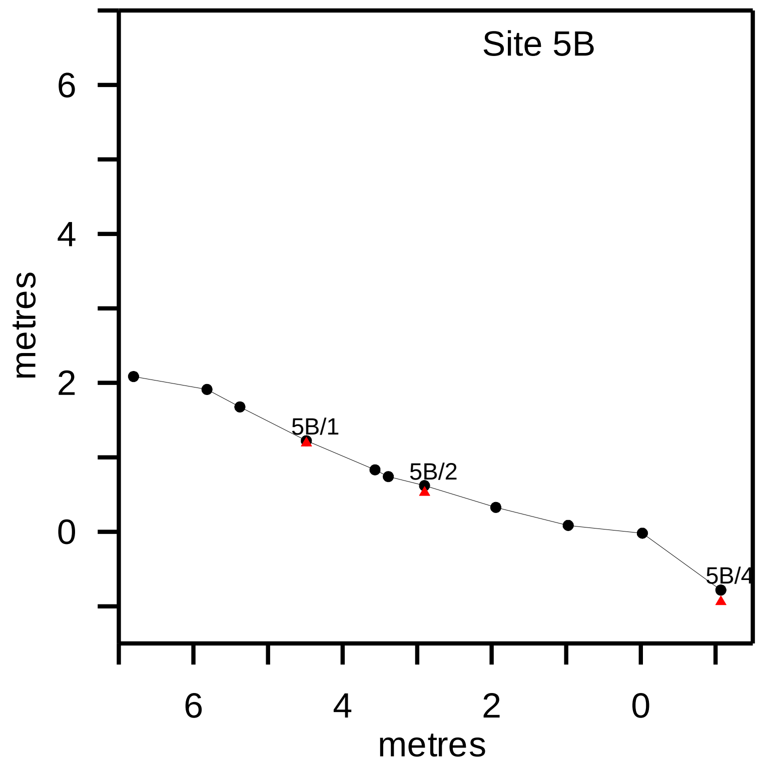


Figure 4.298: Bank profile in 2004 from site 5B.

Photos

Figure 4.299: Site 5B December 2001.

Figure 4.300: Site 5BMarch 2007.

Figure 4.301: Site 5B March 2007.

Figure 4.302: Site 5B October 2008.

Figure 4.303: Site 5B March 2010.

Figure 4.304: Site 5B February 2011.

Figure 4.305: Site 5B March 2013.

4.5.3 Site 5C

Description: Site 5C is located on the right bank on an inside of a broad bend. The site is downstream of 'Log Pile Island' in a wide shallow section of the river. Cobbles are visible at the base of the site during periods of very low water. The site consists of steeply sloping white sands extending upslope under a degraded root-mat and vegetation (tea tree, Huon pine).

Erosional processes: Similar to other sites on straight uniform reaches, scour is the dominant erosional process which maintains the steepness of the bank, with the water velocity sufficient to create ripples on the bank. Erosion is generally higher in the summer period, and reduced during the winter when unregulated inflows generally predominate. Deposition on the bank is derived from fluvial deposition combined with the re-working of sands derived from under the degraded root-mat.

Erosion pin results

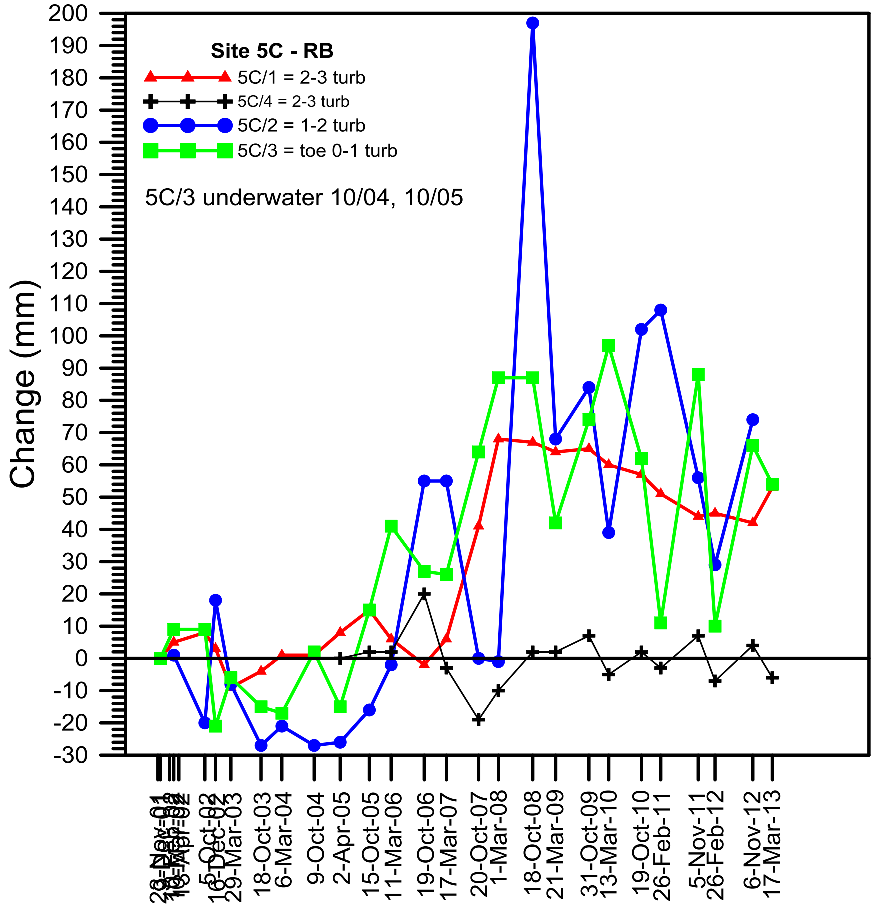


Figure 4.306: Erosion pin results from site 5C.

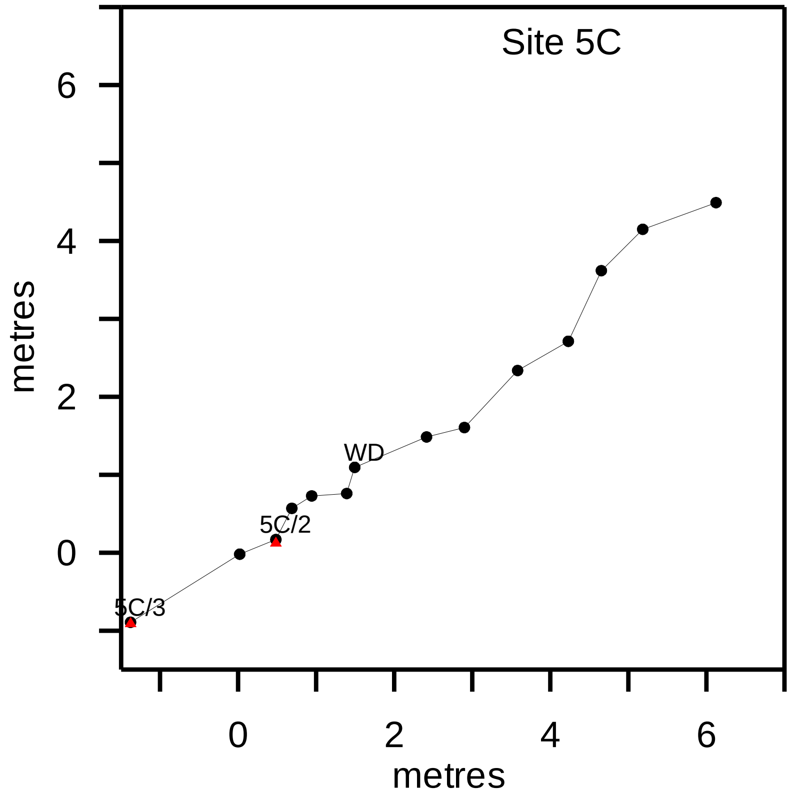


Figure 4.307: Bank profile in 2004 from site 5C. ‘WD’ is woody debris. Red triangles show pin locations.

Figure 4.308: Site 5C December 2001.

Figure 4.309: Site 5C March 2007.

4.5.4 Site 5D

Description: Site 5D is located on the right bank of a straight reach. Similar to site 5C, it consists of a relatively steep toe and bank extending upslope under a degraded root-mat and tea tree in the 2-3 turbine bank level.

Erosional processes: The bank has recorded scour in the 1-2 turbine bank level, and deposition in the other bank levels. This suggests that the sand being deposited by the river, and derived from under the root-mat is leading to more deposition than erosion associated with scour along the straight reach.

Erosion pin results

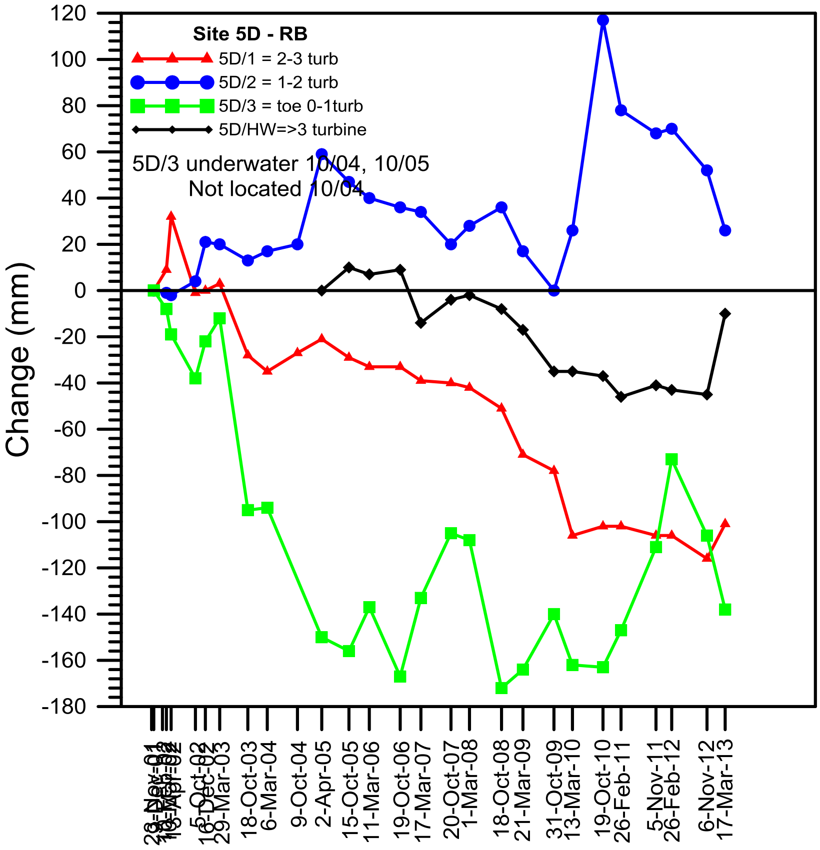


Figure 4.310: Erosion pin results from site 5D.

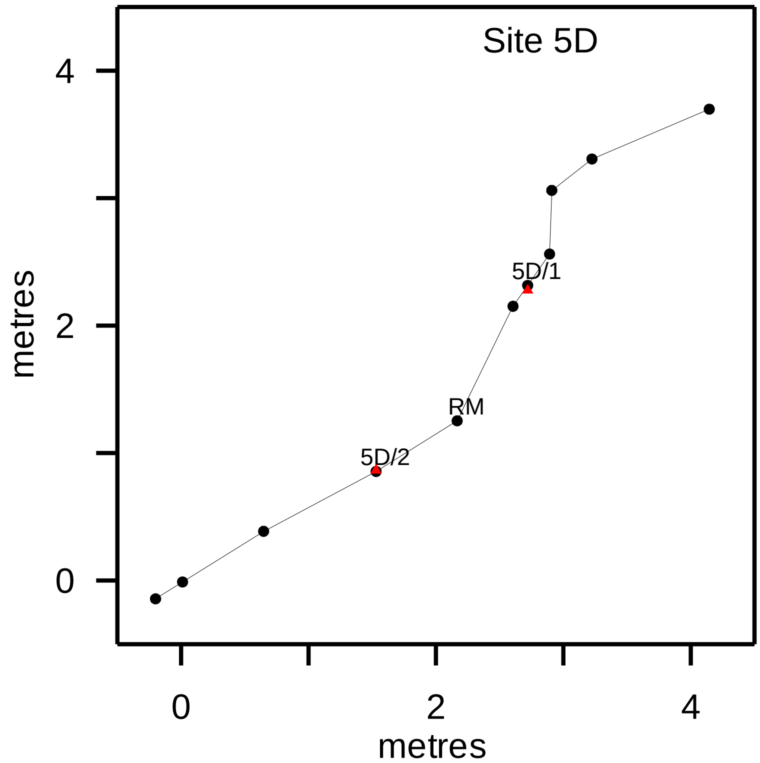


Figure 4.311: Bank profile in 2004 from site 5DA. 'RM' is root mat.

Photos

Figure 4.312: Site 5D December 2001.

Figure 4.313: Site 5D March 2007.

Figure 4.314: Site 5D October 2008.

4.5.5 Site 5E

Description: Site 5E is located on the left bank opposite of and just downstream of site 5D. The site is characterised by a relatively flat-laying sandy, silty and organic rich bank toe extending up slope under the ubiquitous degraded root-mat and tea tree assemblage. There is a cavity at the back of the bank. This bank frequently has filamentous algae growing on the bank face and a moderate amount of woody debris. The site is downstream of a bedrock outcrop that juts into the river, and appears to create a backwater environment at site 5E.

Erosional processes: The cavity at the back of the bank collapsed following the large flood event in August 2007. The flat laying sands are likely the result of sand delivery from the upper bank original via the cavity and ore recently washing out from under the degraded root-mat, combined with the fluvial deposition of material in a backwater environment. The filamentous algae provide stability for the bank face. The erosion pins suggest the bank is flattening, consistent with the ongoing adjustment to power station operations.

Erosion pin results

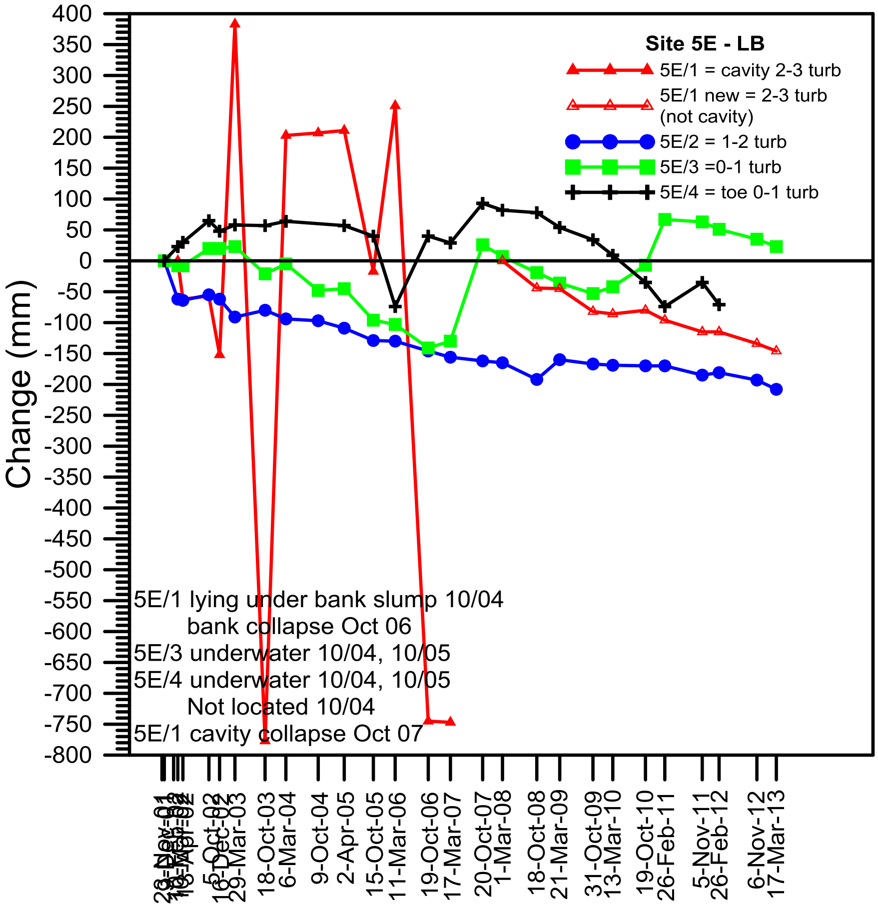


Figure 4.315: Erosion pin results from site 5E.

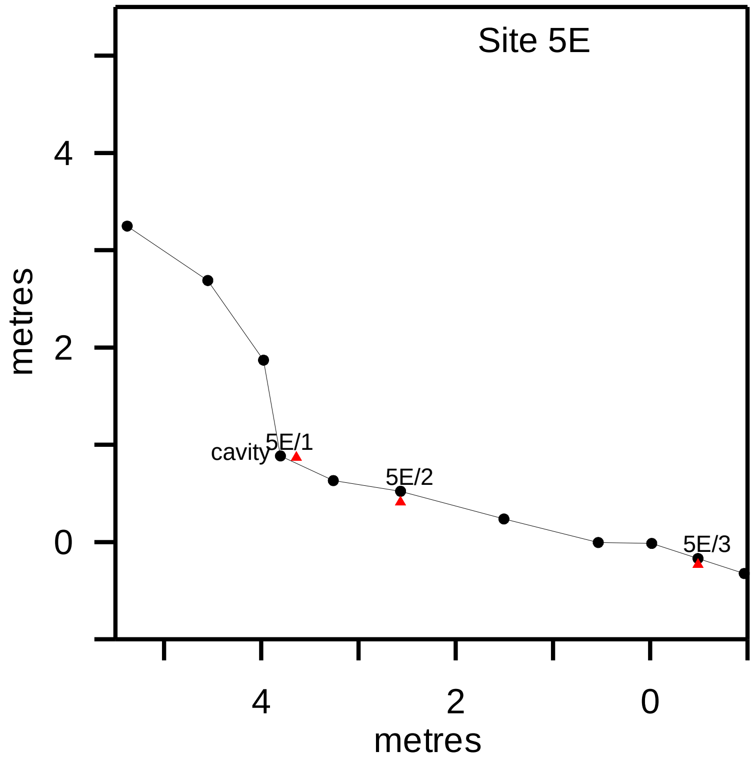


Figure 4.316: Bank profile in 2004 from site 5E.

Photos

Figure 4.317: Site 5E December 2001.

Figure 4.318: Site 5E March 2007.

Figure 4.319: Site 5E October 2008. Vegetation decreased erosion on bank.

4.5.6 Site 5F

Description: Site 5F is situated on the left bank of an inside bend in sands overlying limestone bedrock. The site has a relatively flat bank toe extending upslope beneath a degraded root-mat and tea tree vegetation.

Erosional processes: This site is showing a similar pattern of flattening, with erosion in the 1-2 turbine level and deposition on the lower bank. The large flood event eroded the 0-1 turbine level, but since that time deposition has been recorded by the toe.

Erosion pin results

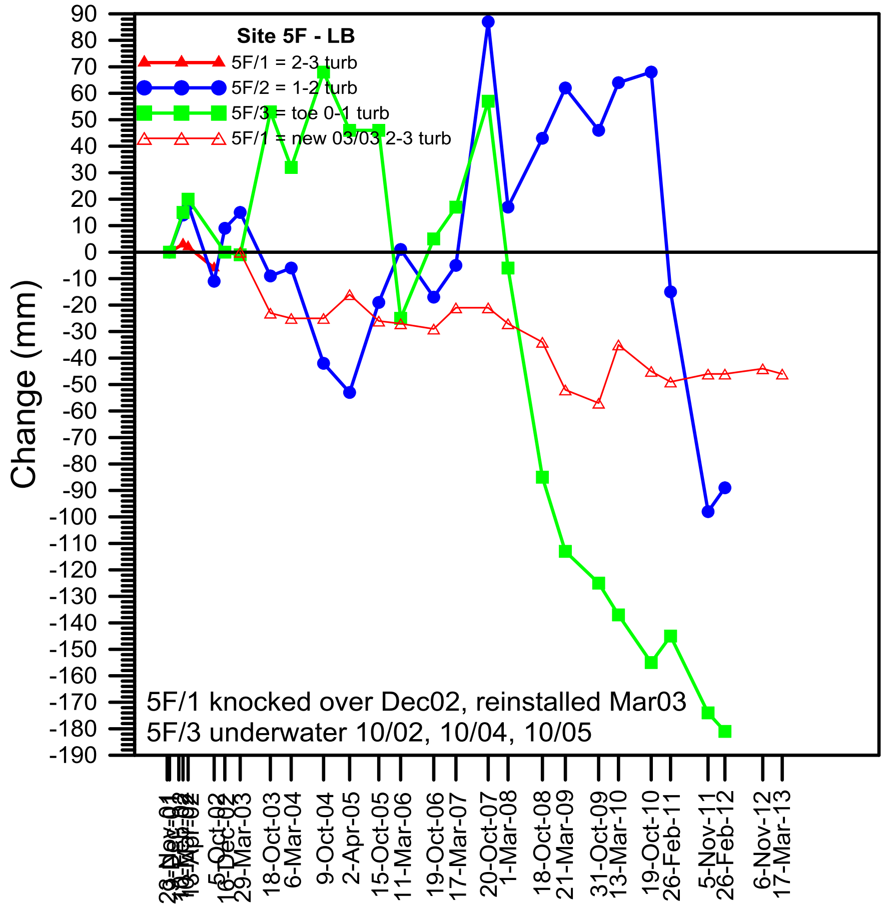


Figure 4.320: Erosion pin results from site 5F.

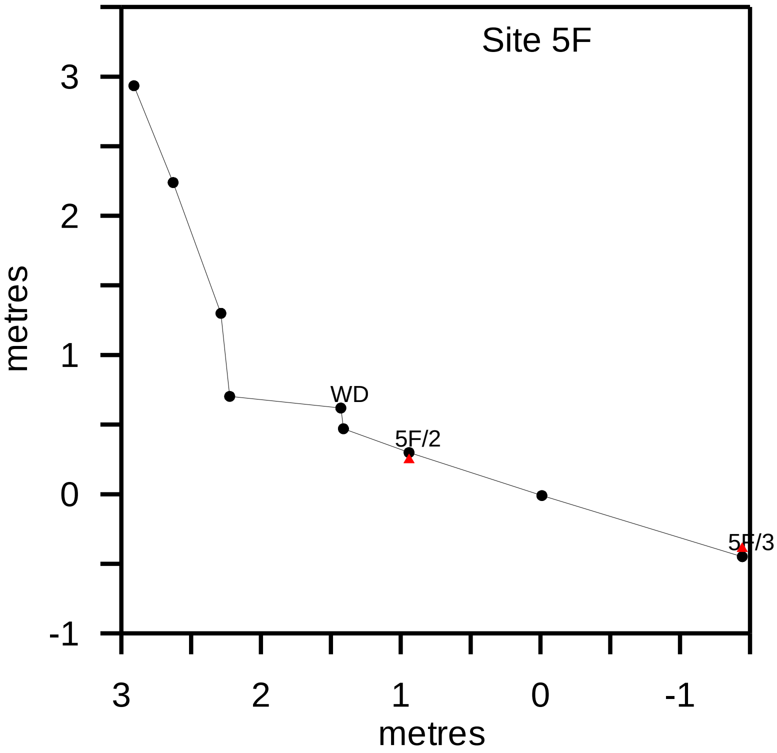


Figure 4.321: Bank profile in 2004 from site 5F. 'WD' is woody debris.

Photos

Figure 4.322: Site 5F December 2001.

Figure 4.323: Site 5F 2007.

4.5.7 Site 5G

Description: Site 5G is located on the left bank behind a cobble bar on a wide straight river reach. There is a small but perennial pool at the toe of the bank on the cobble bar. A large Huon pine buttresses the bank, and there is a cavity located at the back of the site. The bank is somewhat protected in high flows by the presence of an upstream tea tree island and cobble bar.

Erosional processes: Scour appears to be the dominant process affecting the bank, with stability provided by the Huon pine, cobble bar. The cavity at the back of the site is not active, and the vertical bank at the back of the cavity is eroding. The erosion pin results and bank profile suggests the low-angle toe extending back through scour of the steep bank face in the 2-3 turbine bank level.

Erosion pin results

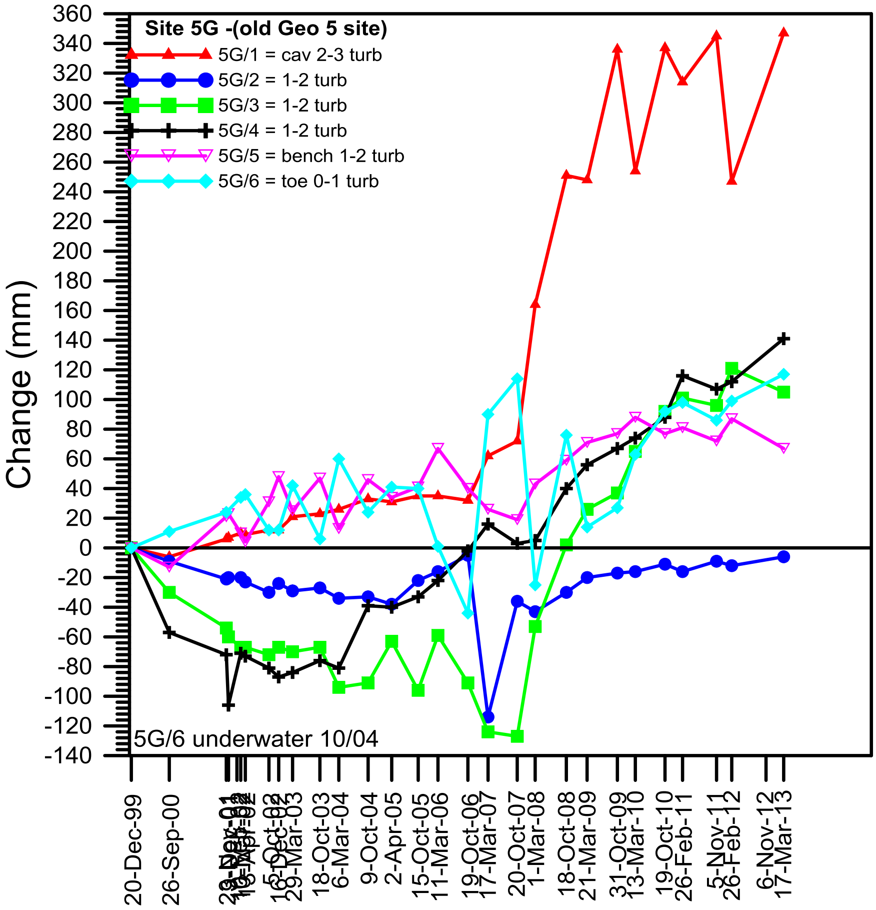


Figure 4.324: Erosion pin results from site 5G.

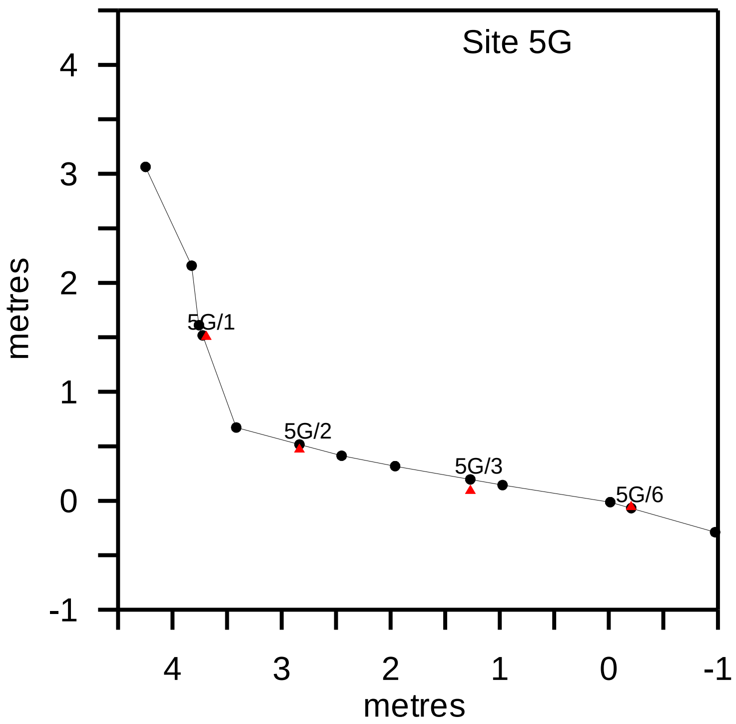


Figure 4.325: Bank profile in 2004 from site 5G. Red triangles show position of pins.

Photos

Figure 4.326: Site 5G December 2001.

Figure 4.327: Site 5G March 2007.

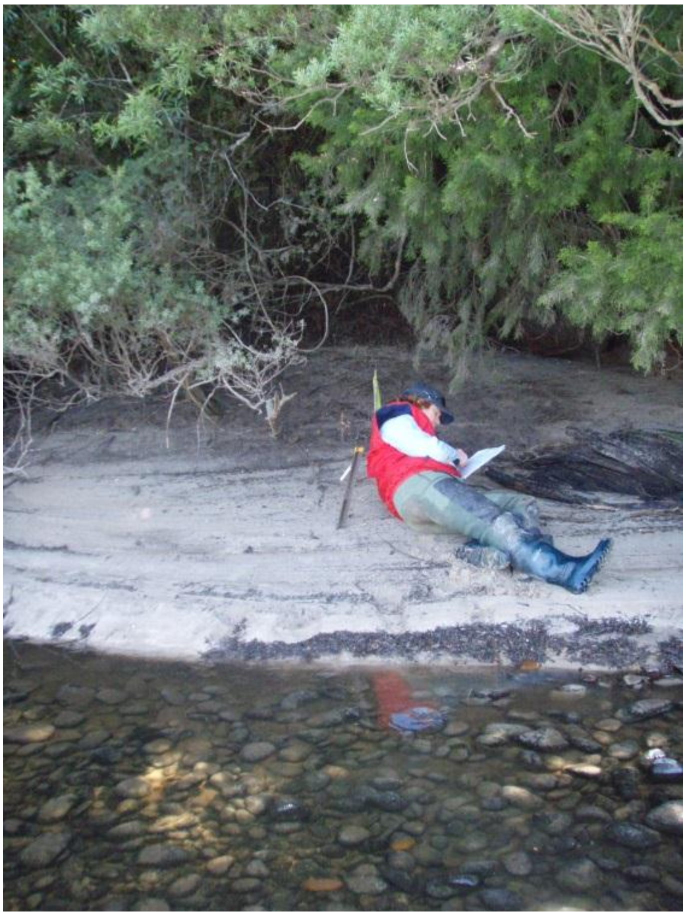


Figure 4.328: Site 5G October 2008.

Figure 4.329: Site 5G March 2010.

4.5.8 Site 5H

Description: Site 5H is on the right bank, at the downstream end of a straight reach heading into an outside bend. The site is relatively steep with abundant woody debris. The alluvial materials include sands, brown silt and muds. It is likely the site is a back eddy at high flow. Similar to the other sites in zone 5, the toe extends upslope under a degraded root-mat with tea tree.

Erosional processes: Toe has shown episodic steepening through scour, although little net change over the monitoring period. The 1-2 turbine level is aggrading as the bank flattens through fluvial deposition and the movement of locally derived material from the upper bank. Tension cracks have been repeatedly observed on the upper bank following extended periods of low power station usage, indicating slumping of the saturated sands.

Erosion pin results

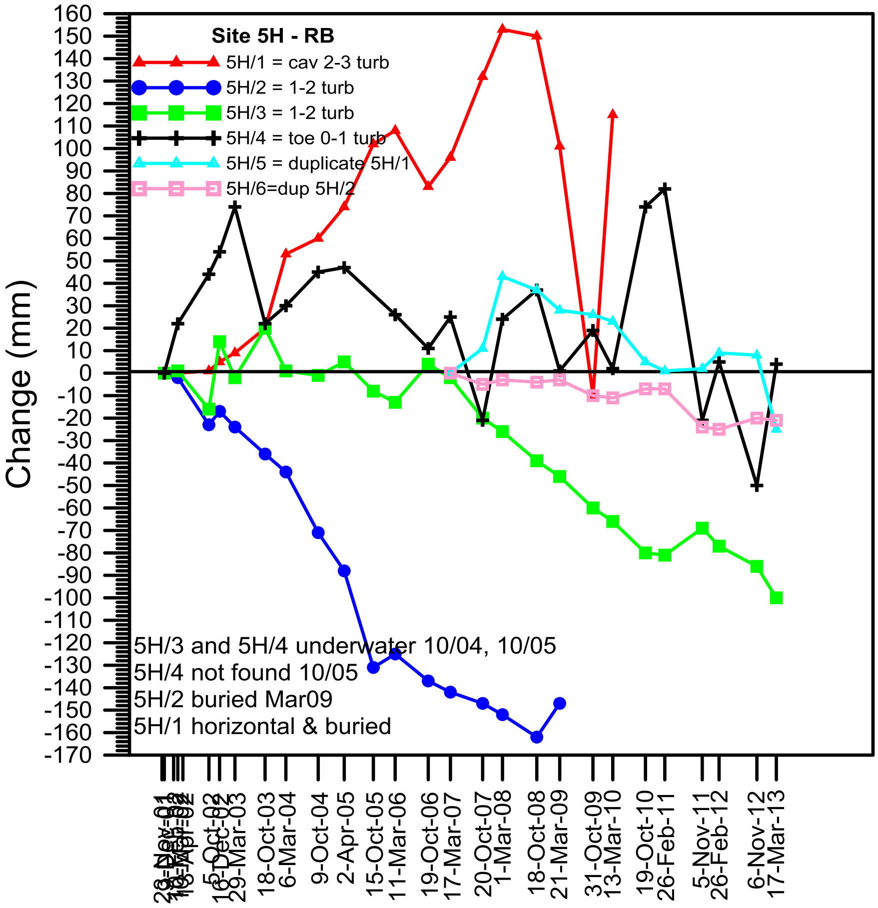


Figure 4.330: Erosion pin results from site 5H.

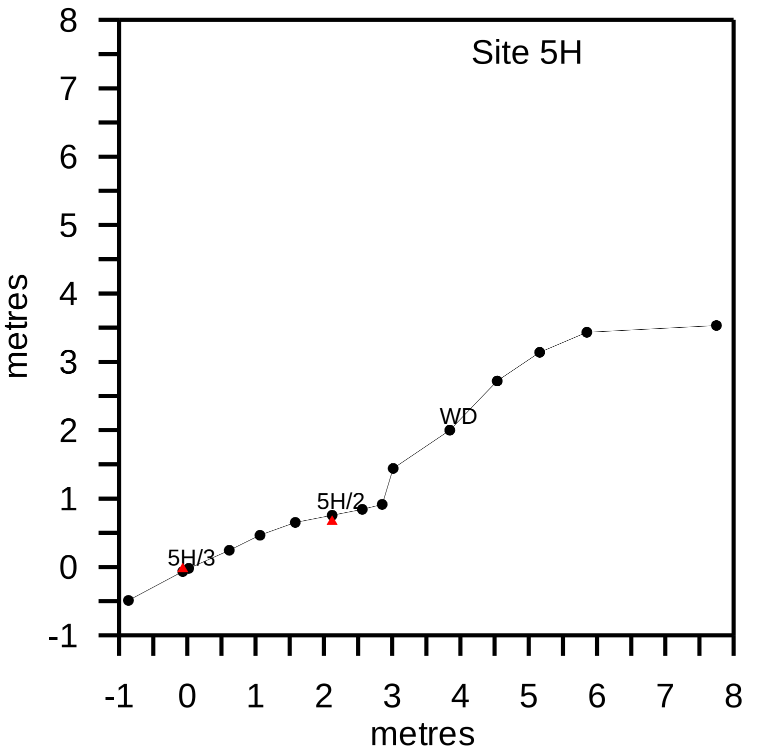


Figure 4.331: Bank profile in 2004 from site 5H. 'WD' is woody debris.

Photos

Figure 4.332: Site 5H December 2001.

Figure 4.333: Site 5H 2007.

Figure 4.334: Site 5H October 2008.

4.5.9 Site 5I

Description: Site 5I is located on the left bank just upstream of the Gordon above Franklin gauge site in an alluvial pocket between bedrock outcrops. This site has been observed to be a large back eddy at high flow which accounts for the large deposits of woody debris on the banks. There is a cavity at the back of the site. The bank has a moderate slope, and the sandy bank supports tea tree above denuded toe.

Erosional processes: The woody debris and sands on the lower bank are frequently moved by the river's current resulting in variability of the bank toe. The erosion pin results show the toe is more frequently recording deposition, which is likely associated with the scour of the 1-2 turbine bank level, and fluvial deposition under backwater conditions. The sands on the toe of this bank have been observed to shift as woody debris moves. The ongoing scour of the root-mat continues to expose sands which are likely contributing to the deposition in the 2-3 turbine bank level.

Erosion pin results

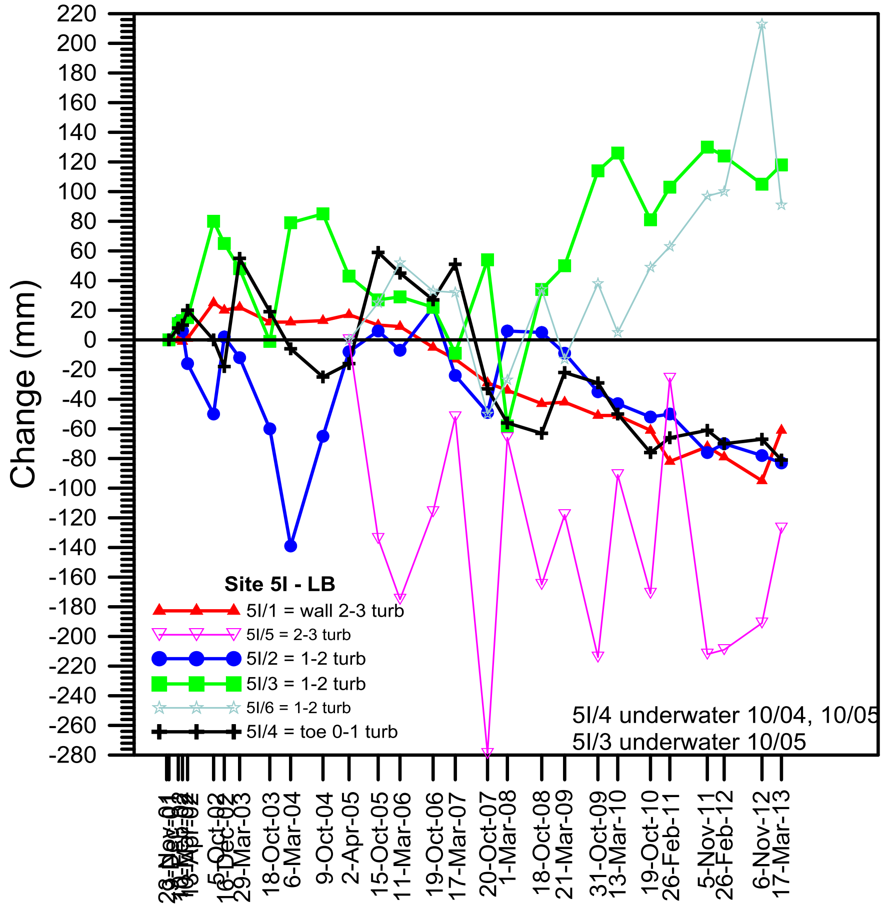


Figure 4.335: Erosion pin results from site 5I.

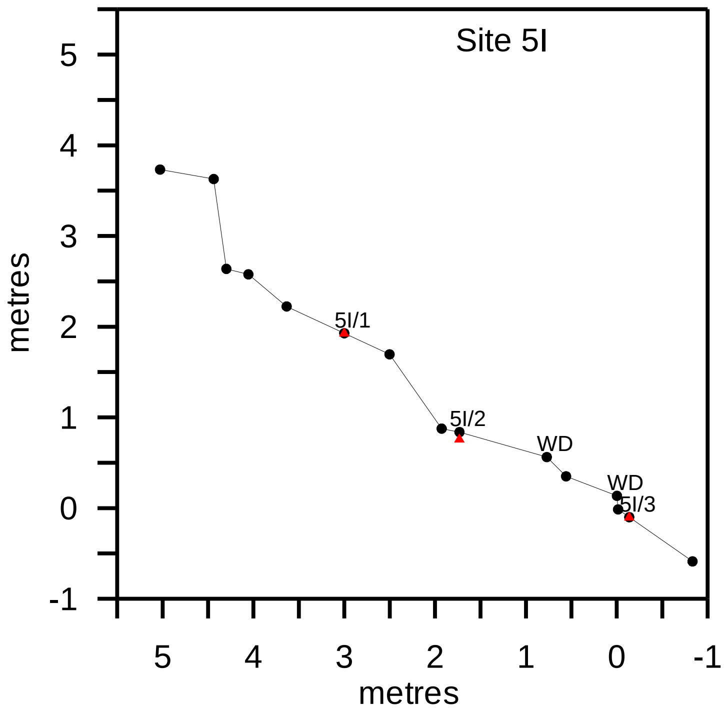


Figure 4.336: Bank profile in 2004 from site 5I. 'WD' is location of woody debris.

Photos

Figure 4.337: Site 5I December 2001.

Figure 4.338: Site 5I March 2007.

Figure 4.339: Site 5I October 2008.

4.5.10 Site 5J

Description: Site 5J is located on the right bank on an inside bend in sands overlying bedrock, with a degraded root-mat and vegetation present in the 2-3 turbine bank level. There is a large log in the 1-2 turbine bank level which provides buttressing for the upper bank.

Erosional processes: Prior to the large flood event in August 2007, the erosion pins at the site generally recorded erosion. The event resulted in deposition on the bank associated with slumping. An unidentified event between October 2009 and March 2010 resulted in the scour of sands from behind the large log, and the loss of erosion pins which were found lying on the ground. The 1-2 turbine bank level continues to change, recording both deposition and erosion within the same turbine level. It is likely that these changes are associated with the local dynamics of the log, combined with the continued regression of the root-mat and underlying sands.

Erosion pin results

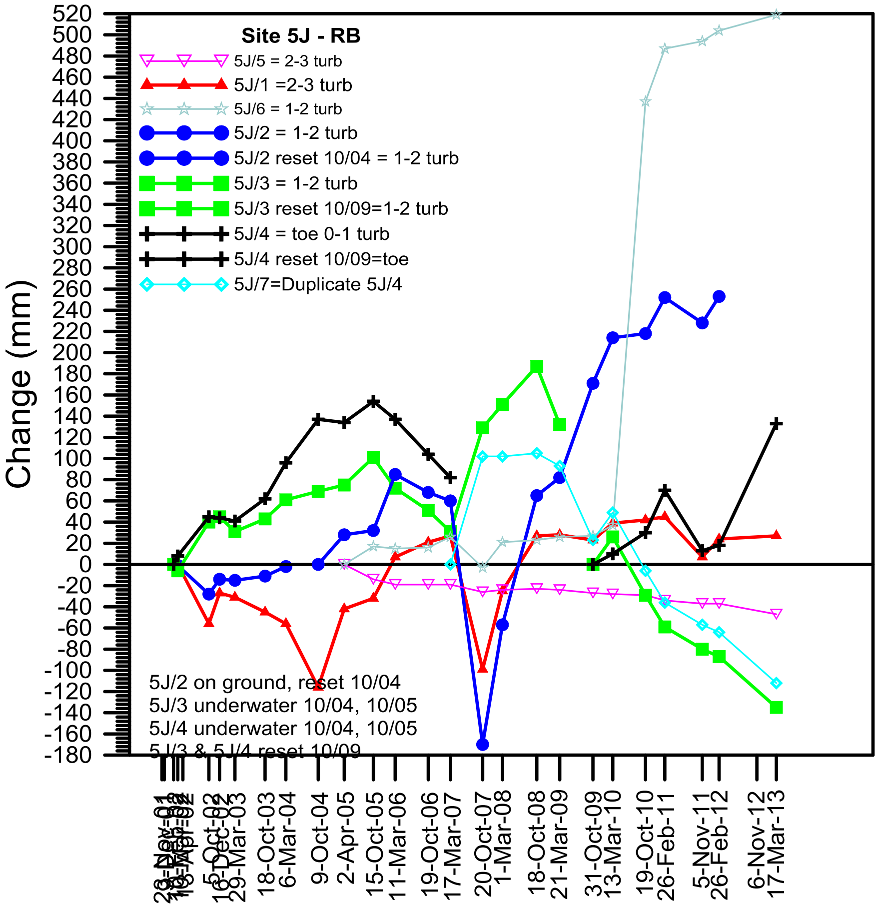


Figure 4.340: Erosion pin results from site 5J.

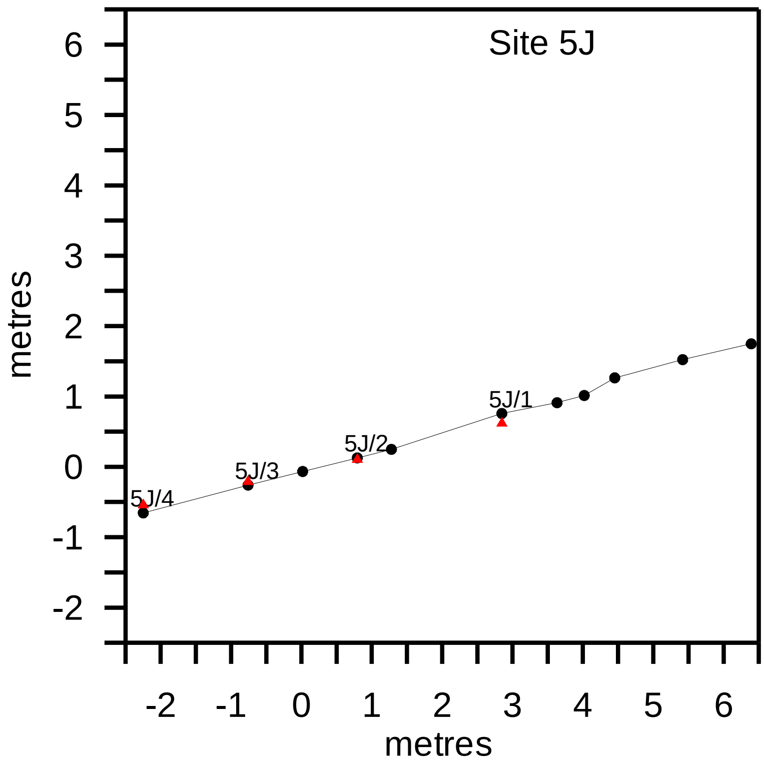


Figure 4.341: Bank profile in 2004 from site 5J.

Photos

Figure 4.342: Site 5J December 2001.

Figure 4.343: Site 5J Oct 2005.

Figure 4.344: Site 5J 2007.

Figure 4.345: Site 5J October 2008.

4.5.11 Site 5K

Description: Site 5K is located on the right bank at the head of an inside bend. The relatively steep bank is composed of sands, muds and abundant leaf litter and woody debris. The site is just upstream of a rapid, and it is likely that at high flows it is a backwater.

Erosional processes: this site shows a lot of variability with shifting and transient woody debris affecting the site. The site has recorded overall deposition, but in the last few years, when the power station discharge has been low, the pins have generally recorded erosion. This would be consistent with scour affecting the site at low to moderate flows, and deposition at high flows when it is a backwater.

Erosion pin results

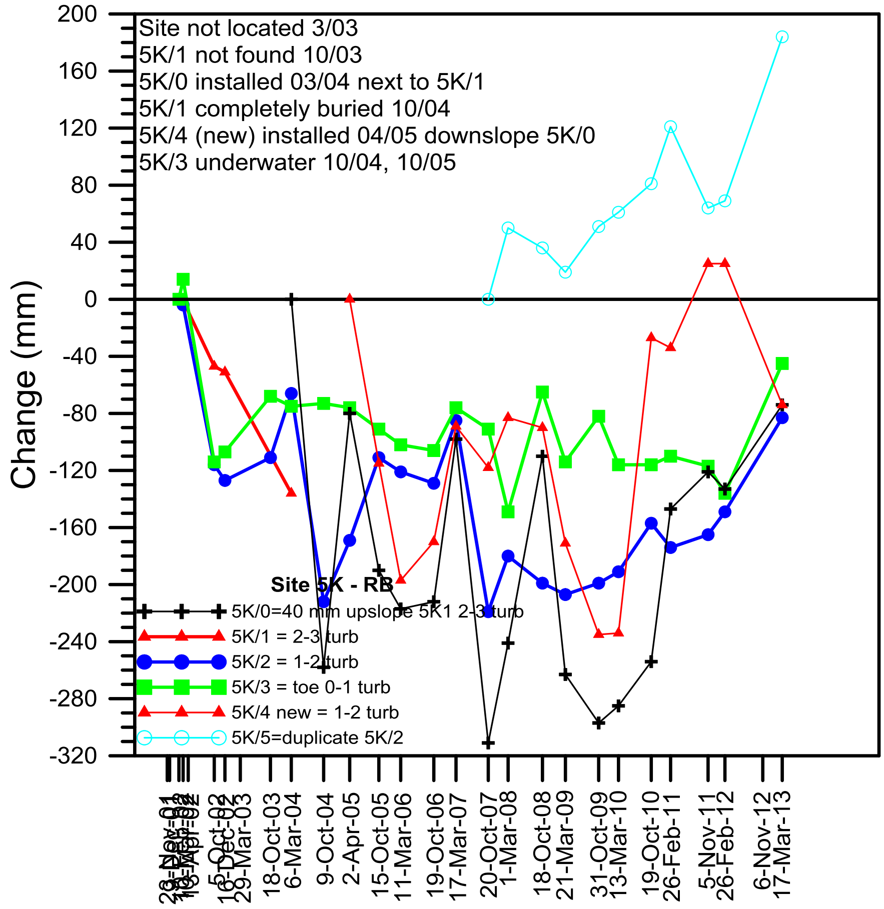


Figure 4.346: Erosion pin results from site 5K.

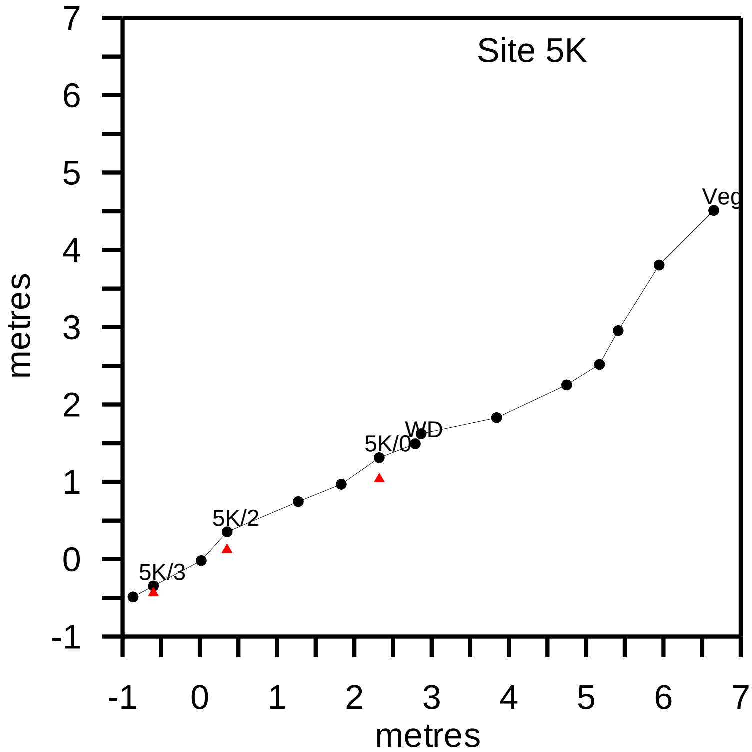


Figure 4.347: Bank profile in 2004 from site 5K.

Photos

Figure 4.348: Site 5K February 2002.

Figure 4.349: Site 5K 2007.

4.5.12 Site 5L

Description: Site 5L is located on the left bank in a straight reach and consists of sands overlying bedrock. The steep bank face has a lot of woody debris, with much of it derived from large tree falls that have affected the site. The sandy bank underlies a degraded root-mat and supports tea tree in the 2-3 turbine bank level.

Erosional processes: The site recorded erosion between the time of establishment and October 2007, consistent with other sites on straight reaches. Following October 2007, the site has recorded deposition which exceeds the original erosion. It is hypothesised that the flood weakened / removed the remnant root-mat and tea tree in the 2-3 turbine bank level which has promoted the movement of sands from the upper bank to the lower bank.

Erosion pin results

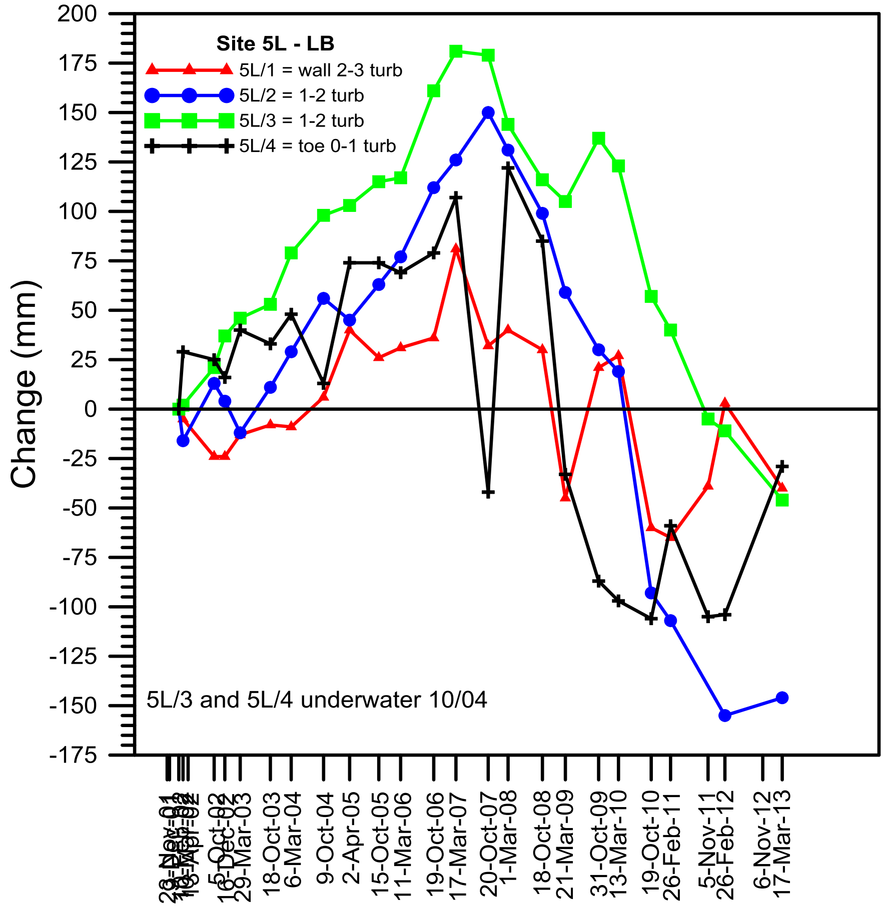


Figure 4.350: Erosion pin results from site 5L.

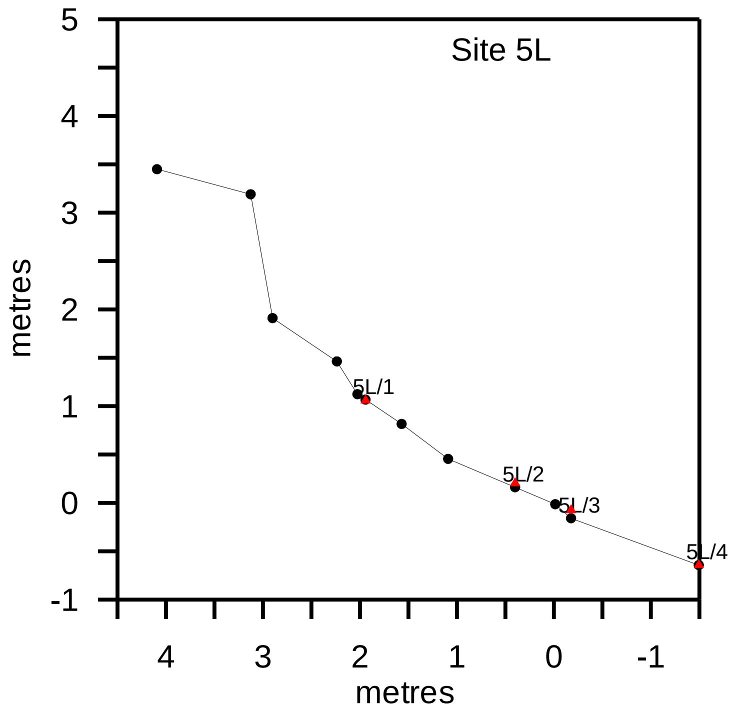


Figure 4.351: Bank profile in 2004 from site 5L.

Photos

Figure 4.352: Site 5L February 2002.

Figure 4.353: Site 5L October 2003.

Figure 4.354: Site 5L 2007.

Figure 4.355: 5L October 2008.

4.5.13 Site 5M

Description: Site 5M is the most downstream site and is located on the right bank at the downstream end of a broad outside bend upstream of the confluence with the Franklin River. The site is just upstream of a rapid (Traps and Snares Rapid), and is composed of sands, silts, muds and organic matter. There is a small drainage line running through the site which commonly results in rilling on the bank face, and maintains a high degree of bank saturation. The site is subject to backwater effects from the Franklin River.

Erosional processes: The site has generally recorded variable levels of deposition except for October 2007 when a large erosive change was documented. The variable deposition is consistent with the backwater setting of the site.

Erosion pin results

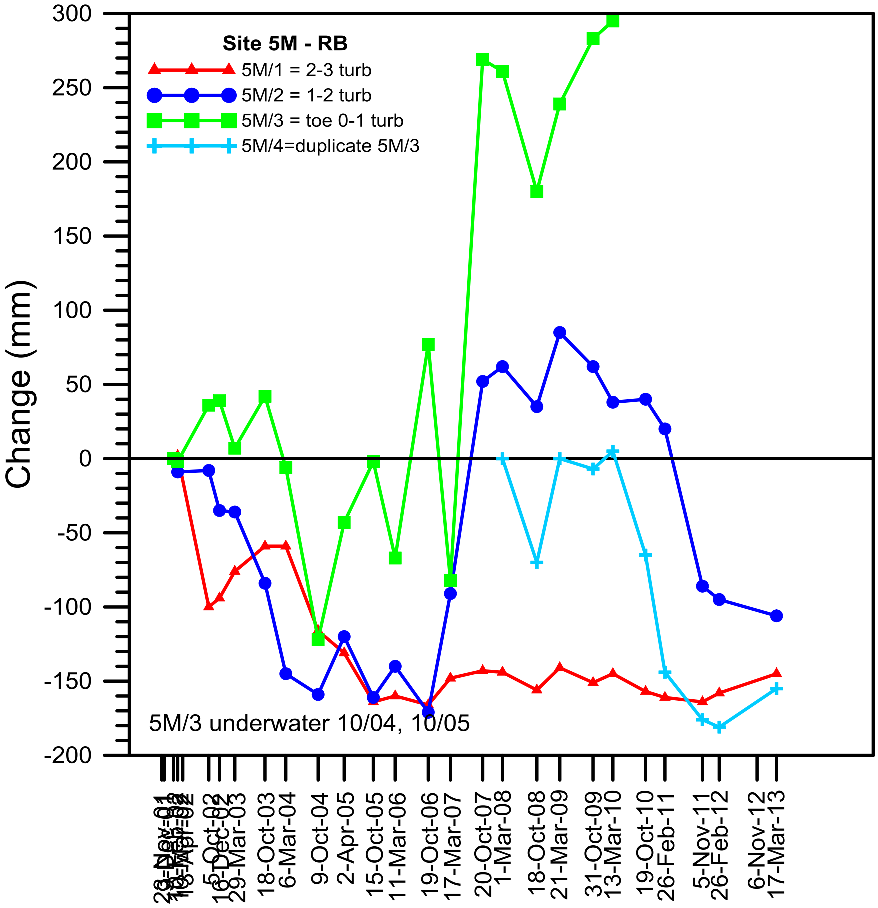


Figure 4.356: Erosion pin results from site 5M.

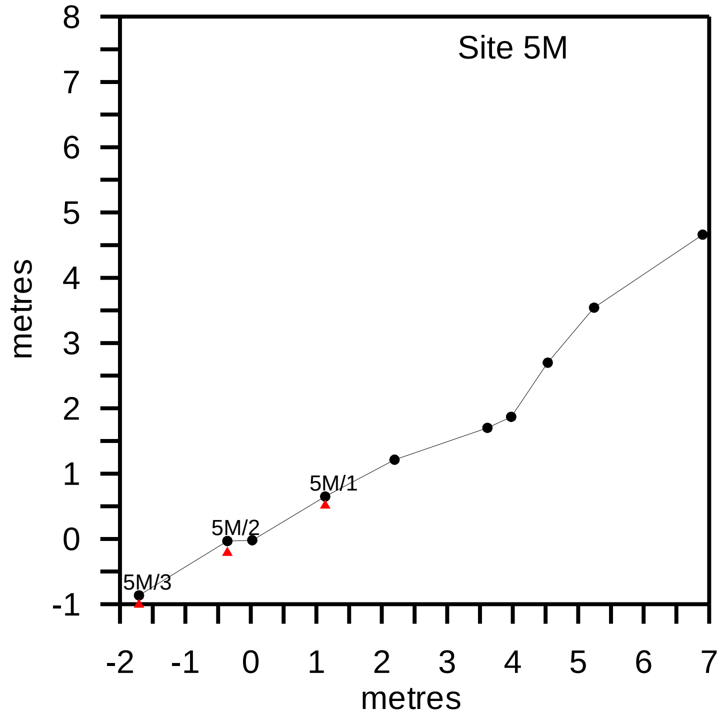


Figure 4.357: Bank profile in 2004 from site 5M.

Photos

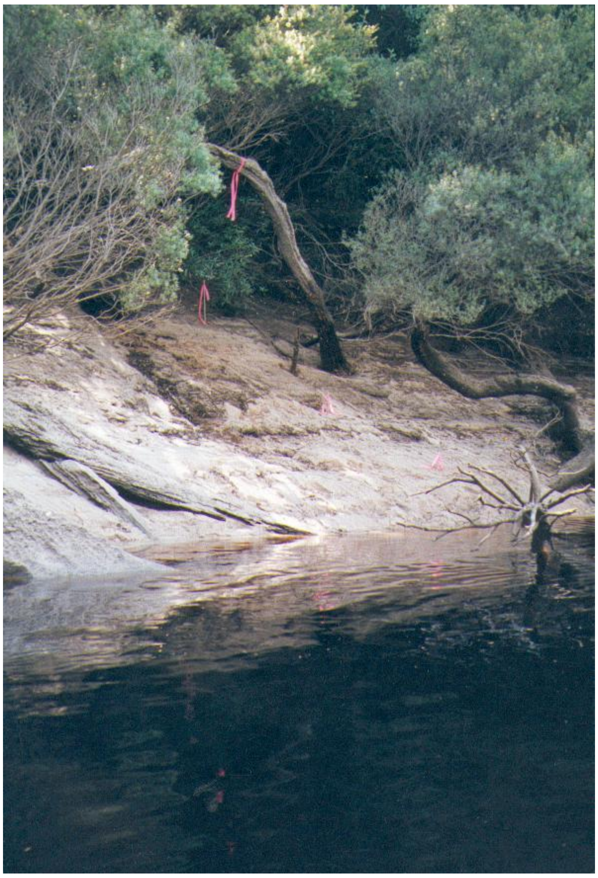


Figure 4.358: Site 5M February 2002.

Figure 4.359: Site 5M March 2007.

Figure 4.360: Site 5M October 2008.

Comparison of erosion pin results in zone 5

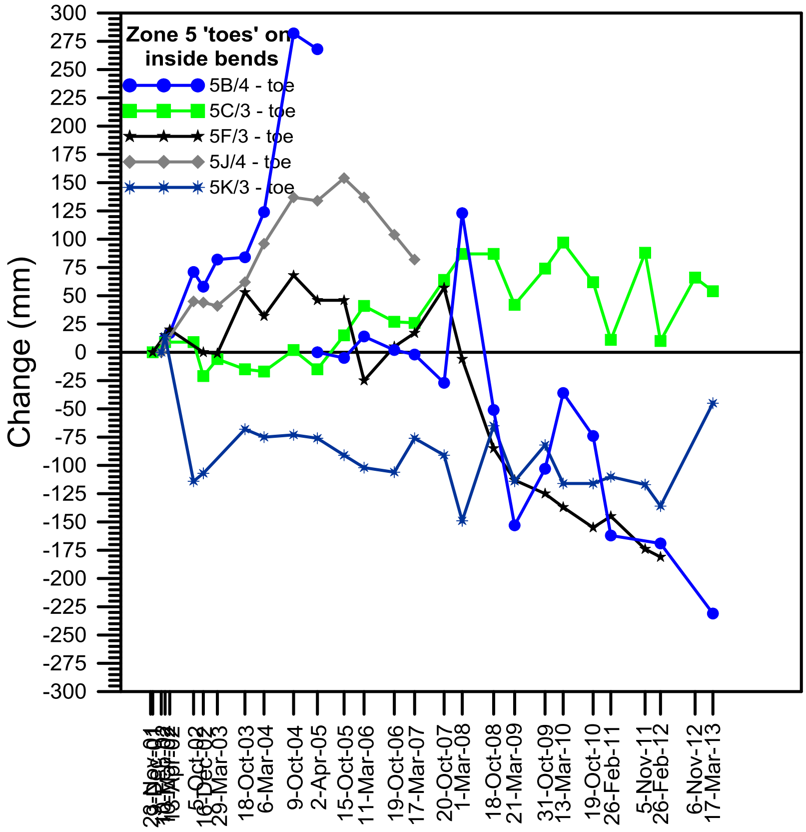


Figure 4.361: Erosion pin results for toe pins on inside bends in zone 5.

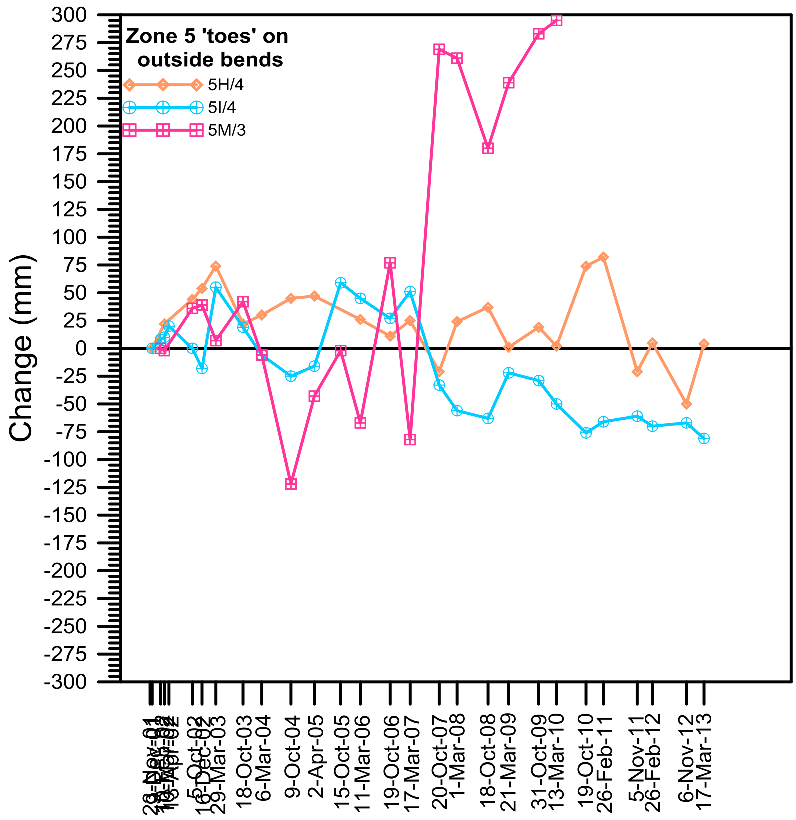


Figure 4.362: Erosion pin results for toe pins on outside bends in zone 5.

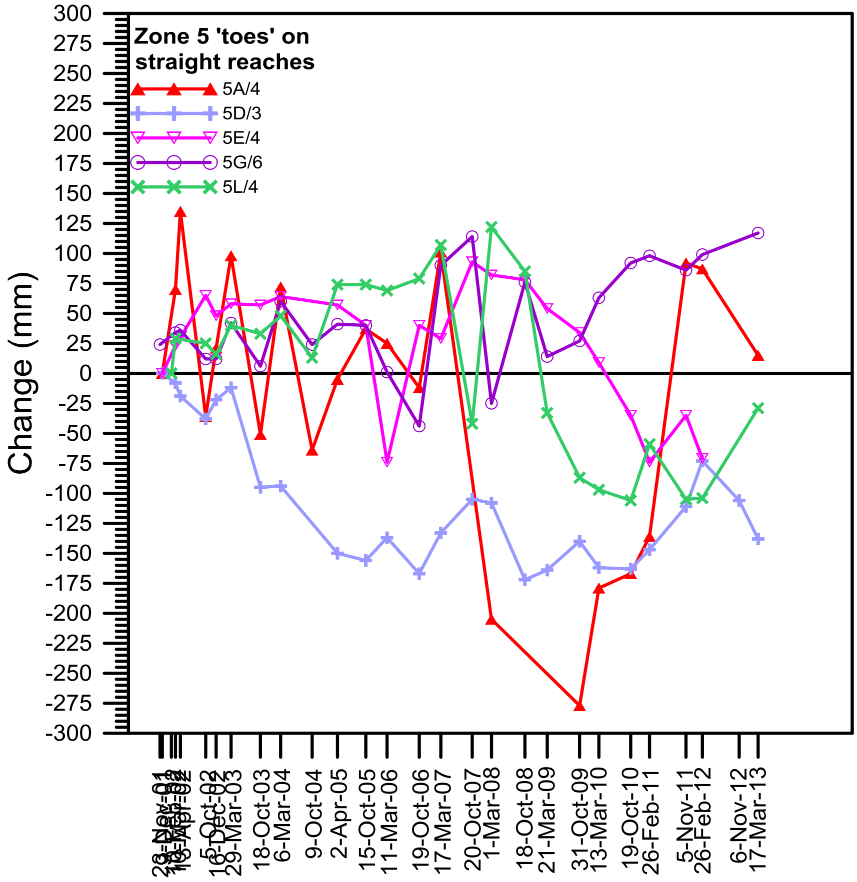


Figure 4.363: Erosion pin results for toe pins on straight reaches in zone 5.

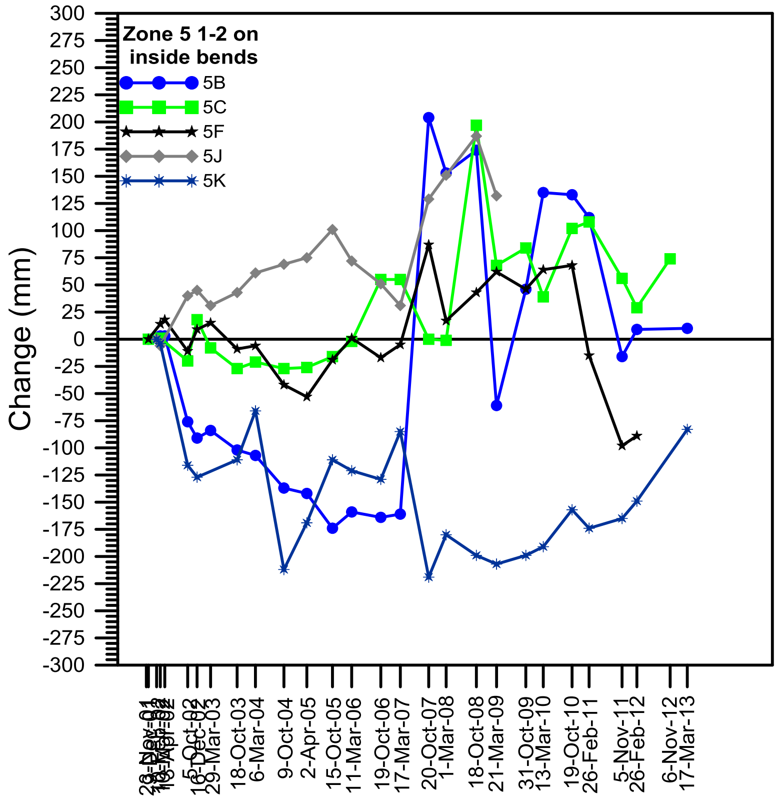


Figure 4.364: Erosion pin results for pins in 1-2 turbine bank level on inside bends in zone 5.

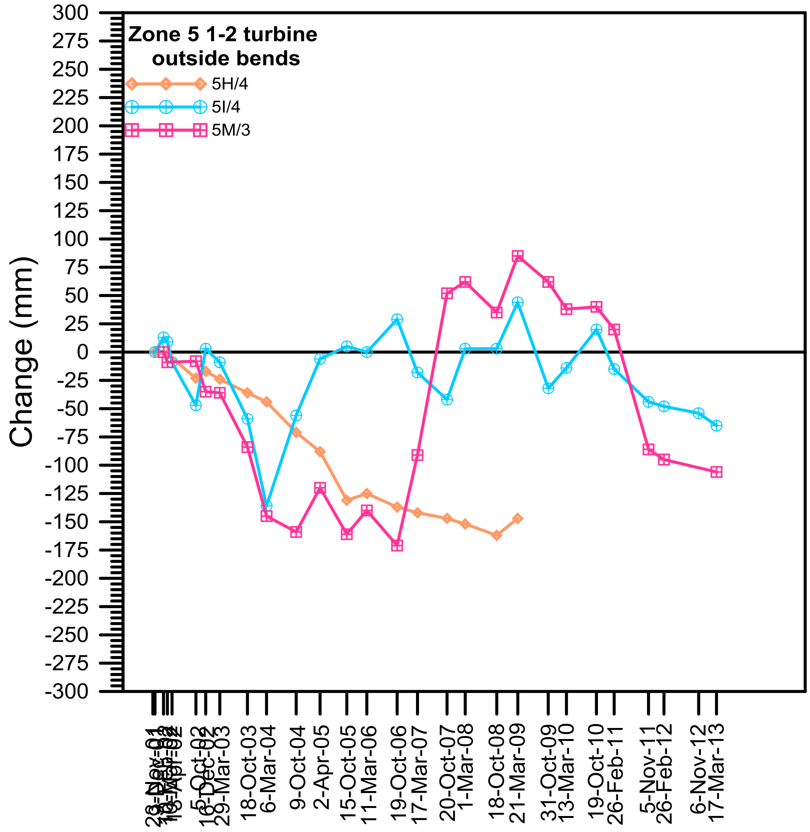


Figure 4.365: Erosion pin results for pins in 1-2 turbine bank level on outside bends in zone 5.

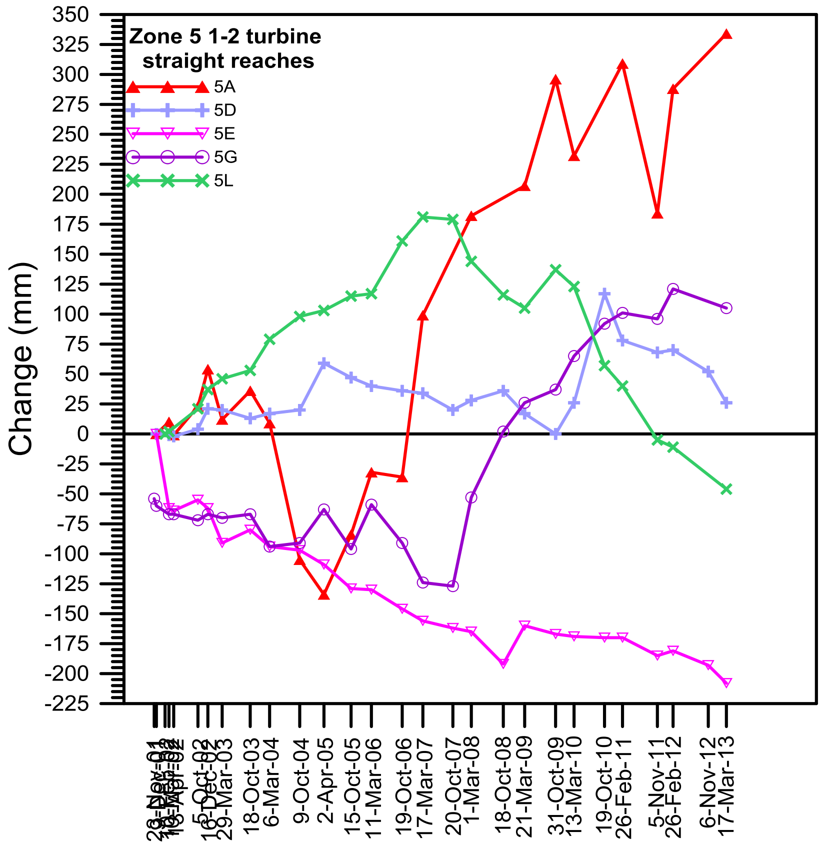


Figure 4.366: Erosion pin results for pins in 1-2 turbine bank level on straight reaches in zone 5.

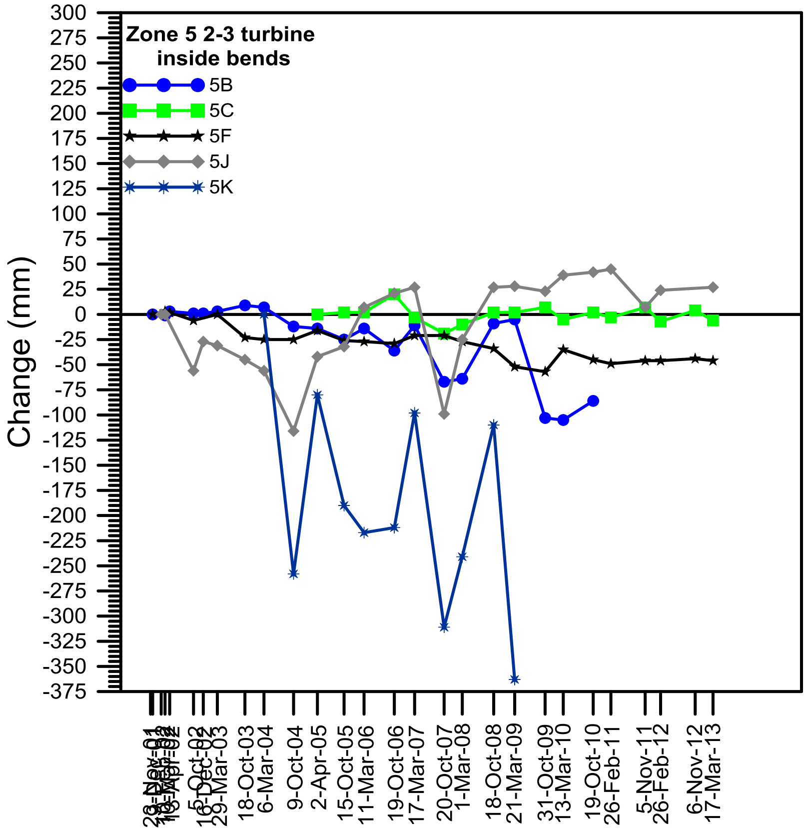


Figure 4.367: Erosion pin results for pins in 2-3 turbine bank level on inside bends in zone 5.

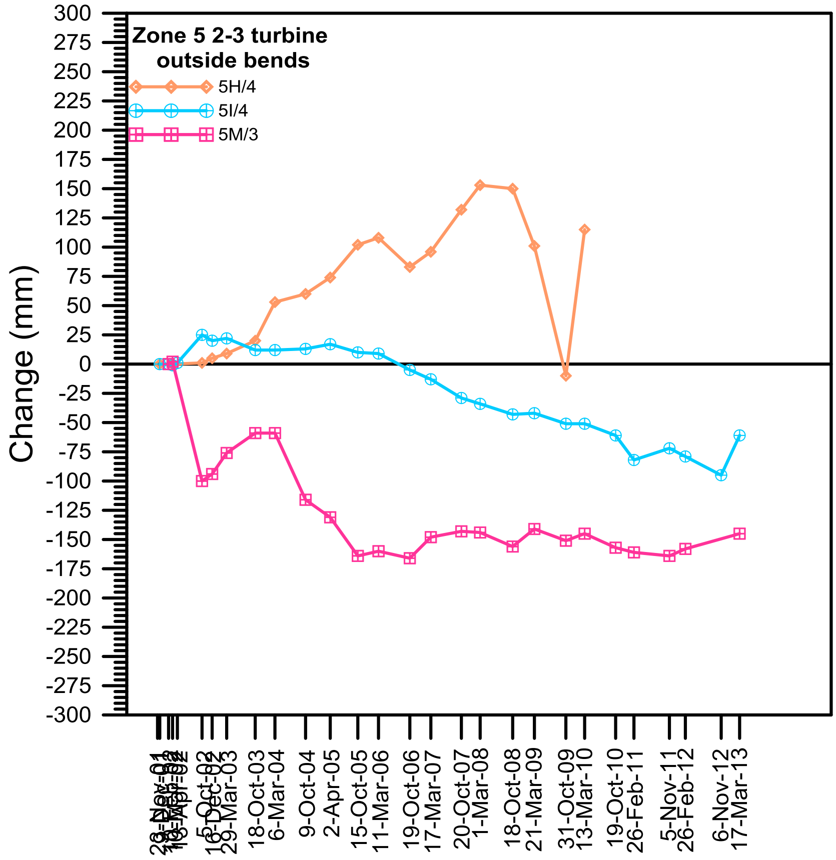


Figure 4.368: Erosion pin results for pins in 2-3 turbine bank level on outside bends in zone 5.

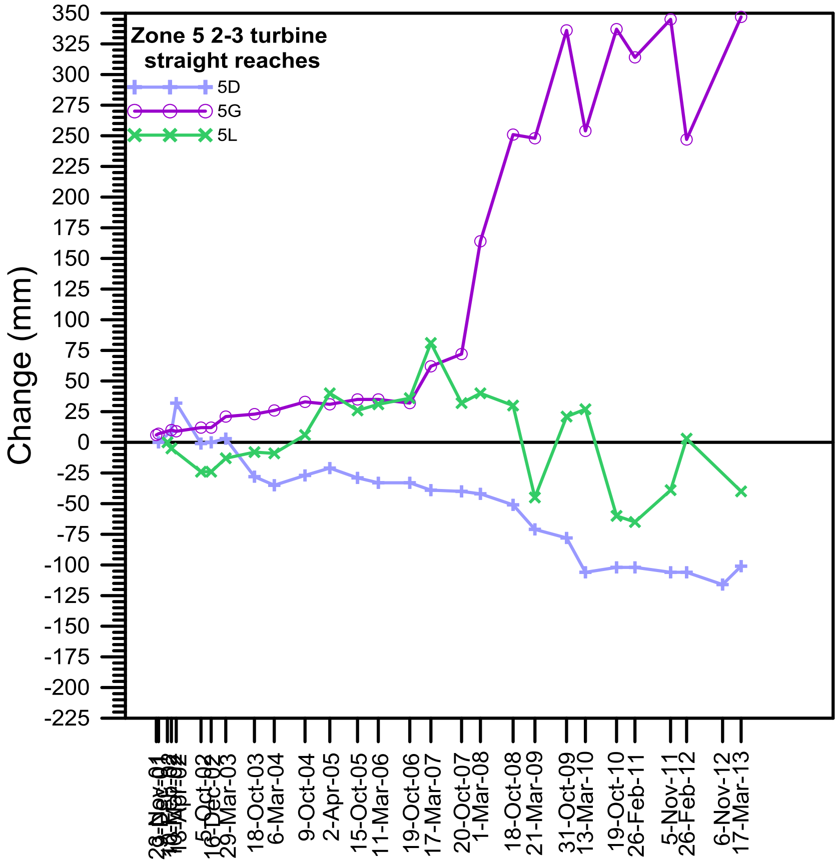


Figure 4.369: Erosion pin results for pins in 2-3 turbine bank level on straight reaches in zone 5.

5. Fish length-frequency data

The following graphs are length frequency histograms *for Anguilla australis, Galaxias brevipinnis, Galaxias truttaceus* and *Salmo trutta* captured in the Gordon River between December 2001 and March 2012. These results are discussed in Section 9.3.2.

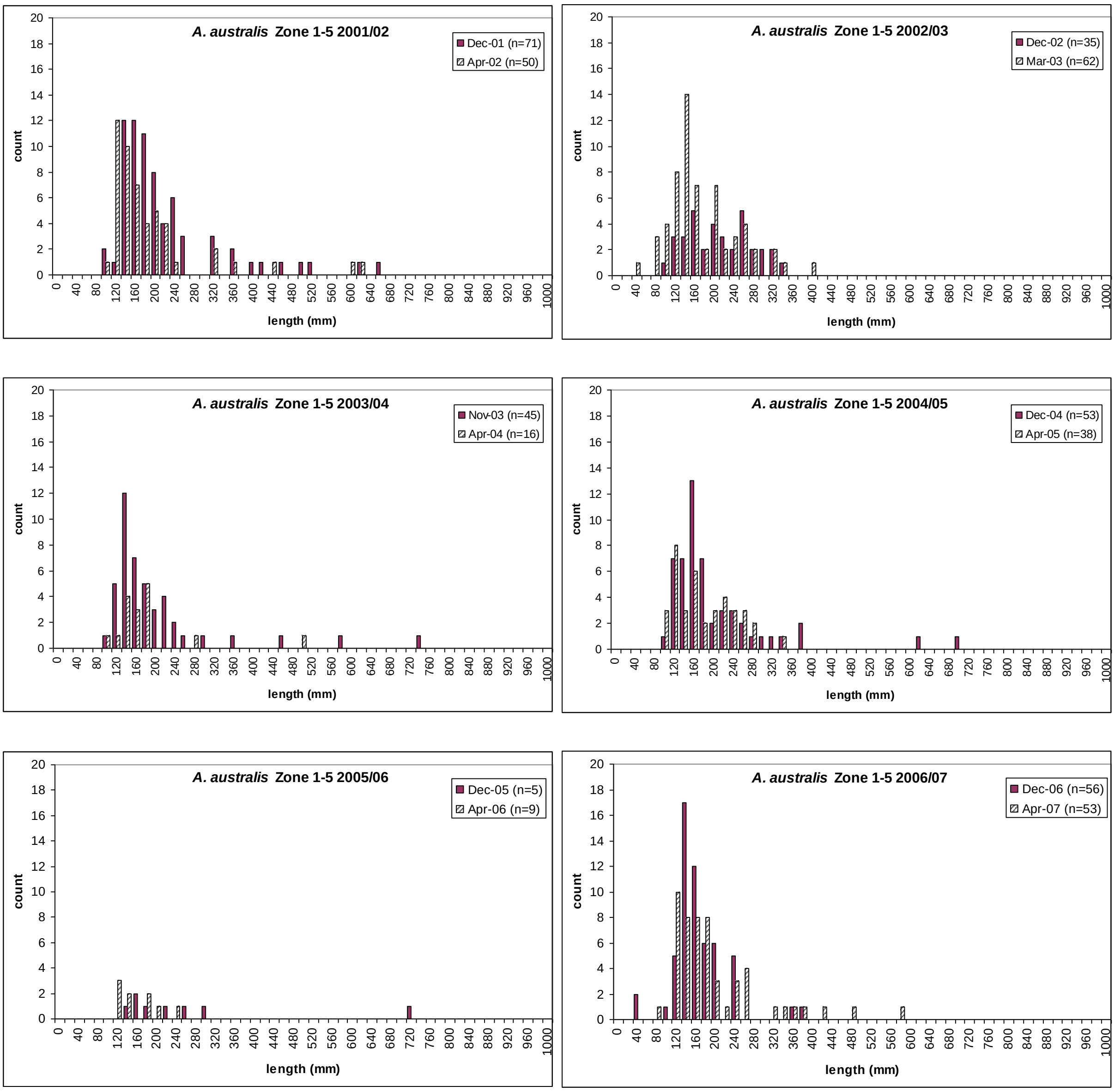


Figure 5.1: Length-frequency histograms for *Anguilla australis,* captured in Gordon zones 1-5, 2001-02 to 2006-07.

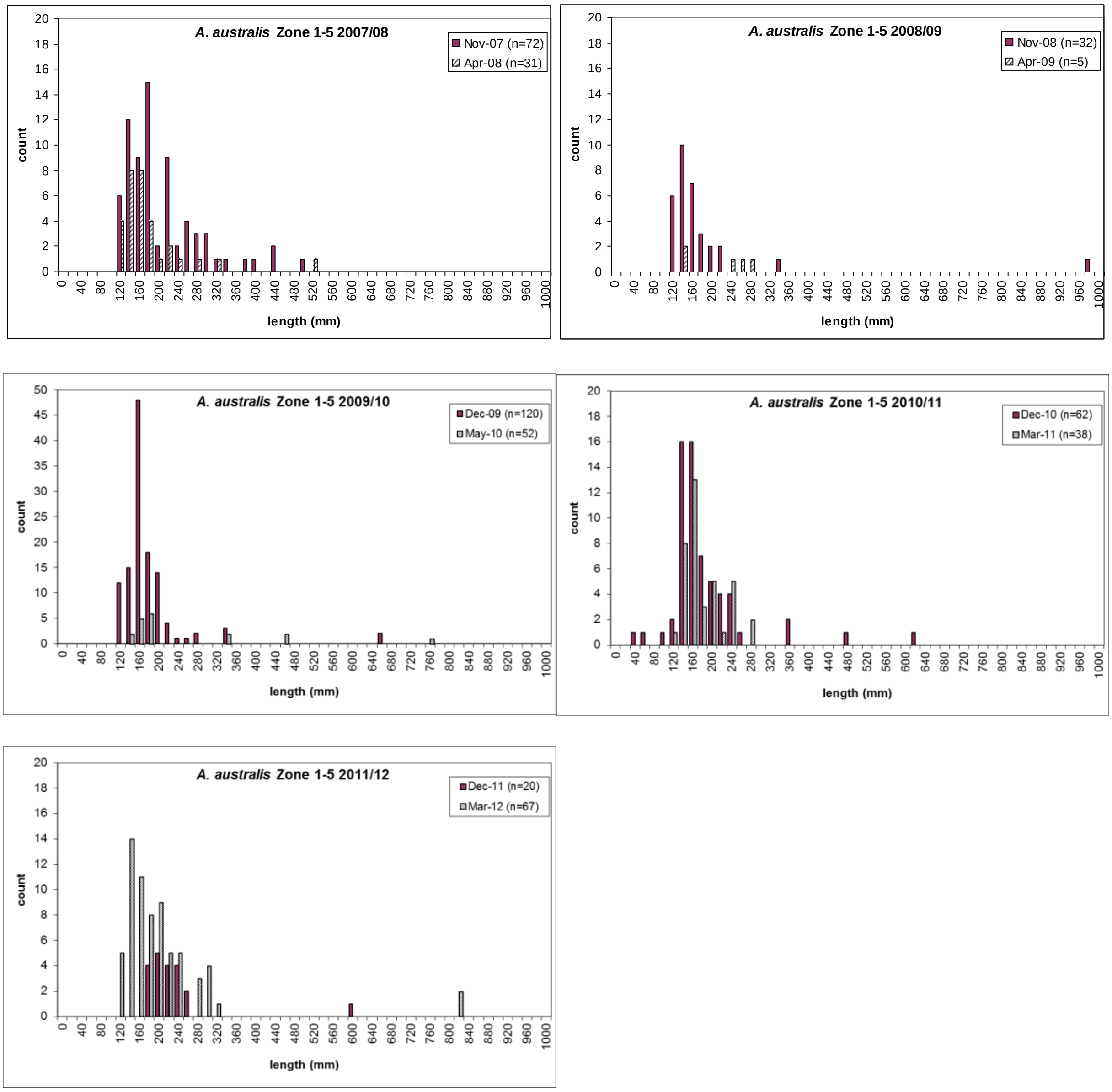


Figure 5.2: Length-frequency histograms for *Anguilla australis,* captured in Gordon zones 1-5, 2007-08 to 2011-12.

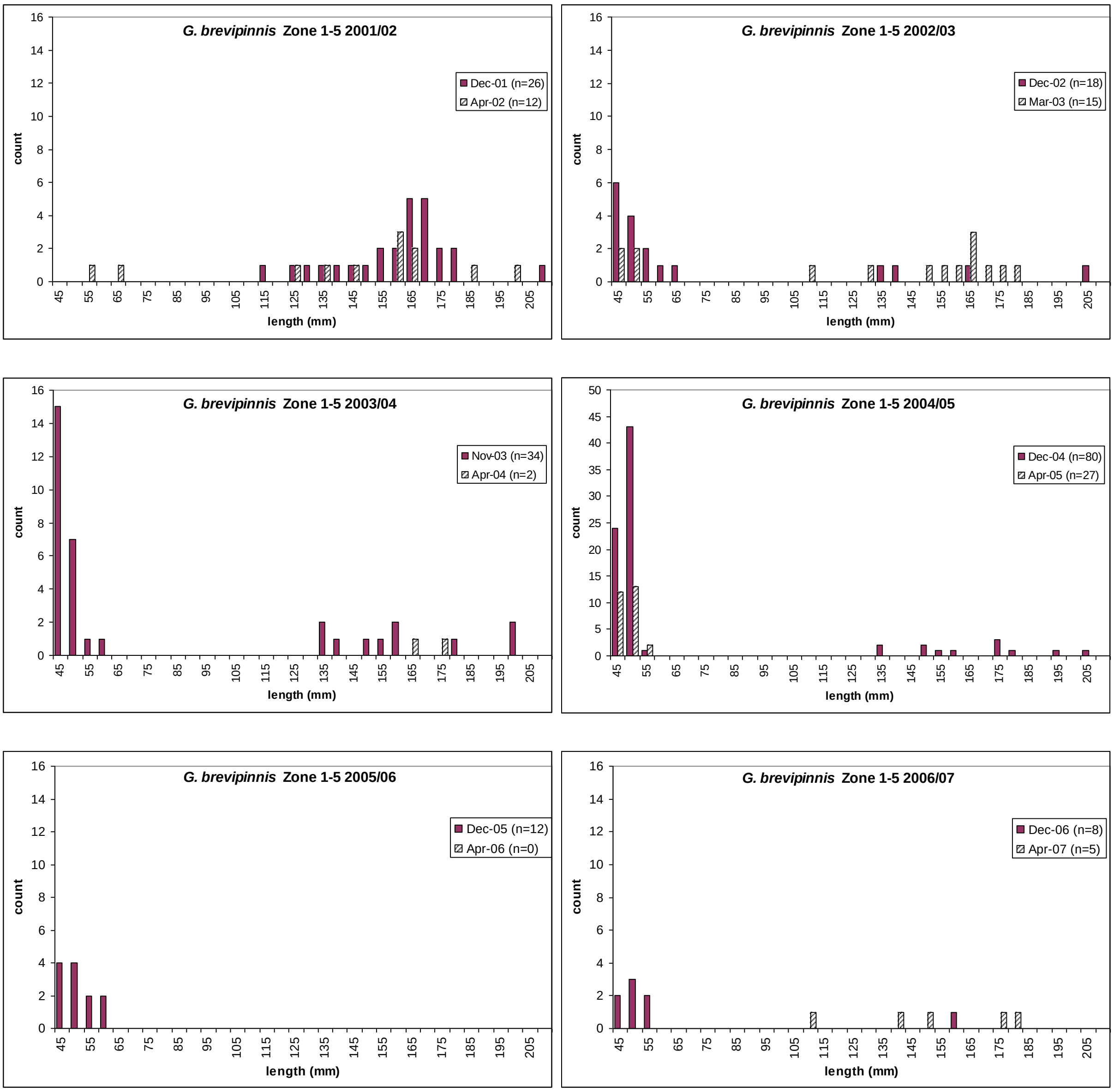


Figure 5.3: Length-frequency histograms for *Galaxias brevipinnis,* captured in Gordon zones 1-5, 2001-02 to 2006-07.

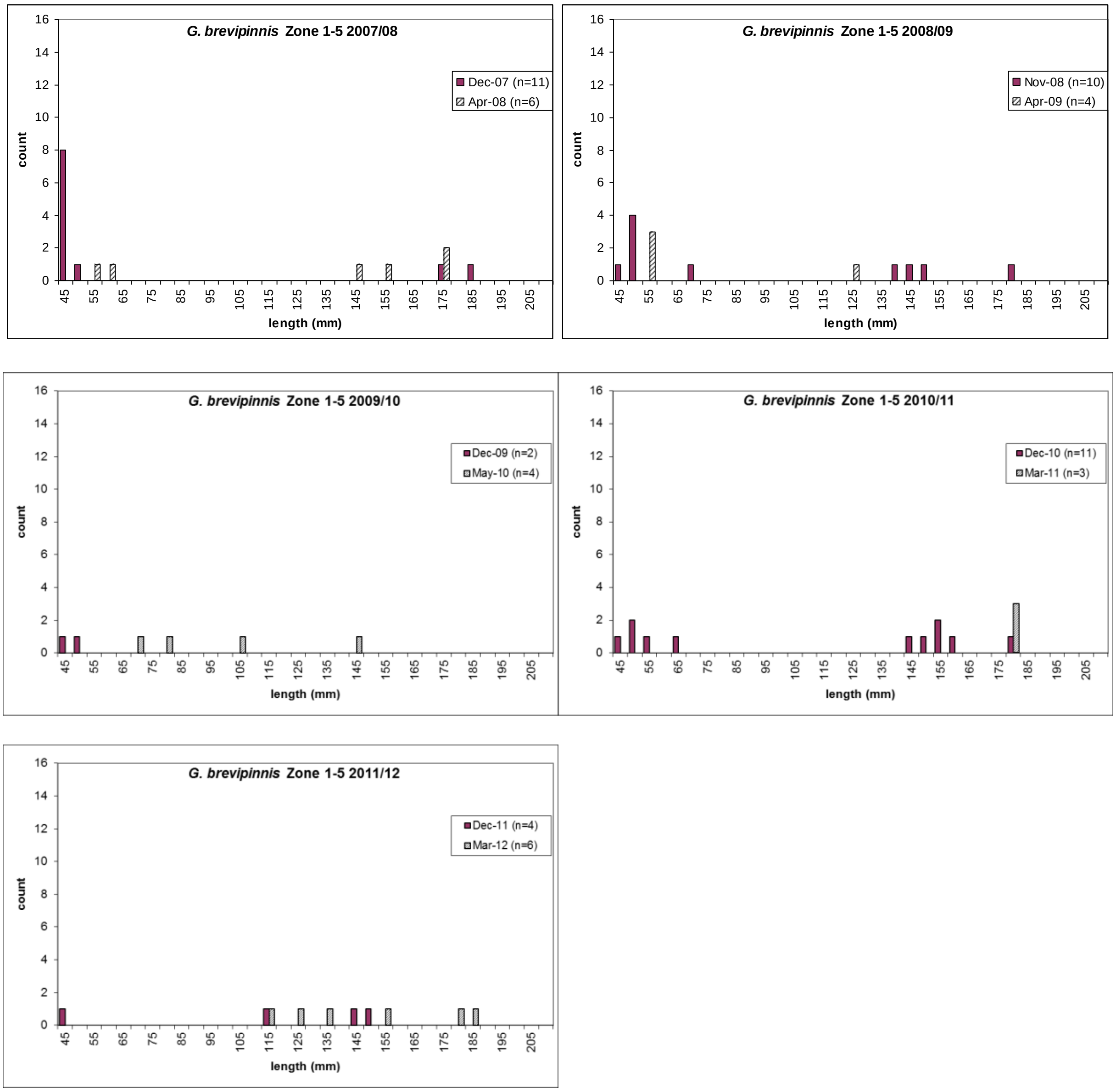


Figure 5.4: Length-frequency histograms for *Galaxias brevipinnis,* captured in Gordon zones 1-5, 2007-08 to 2011-12.

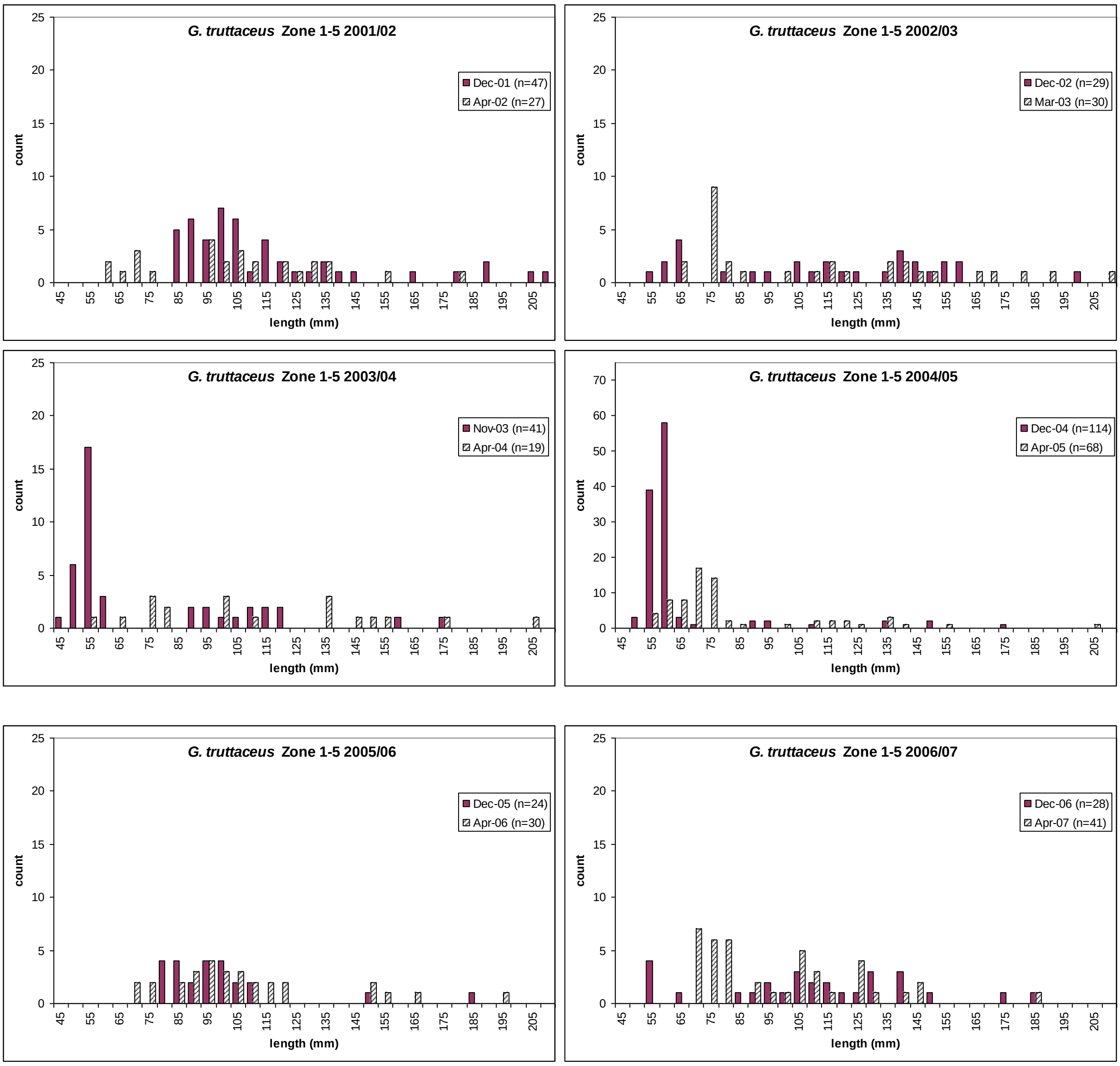


Figure 5.5: Length-frequency histograms for *Galaxias truttaceus,* captured in Gordon zones 1-5, 2001-02 to 2006-07.

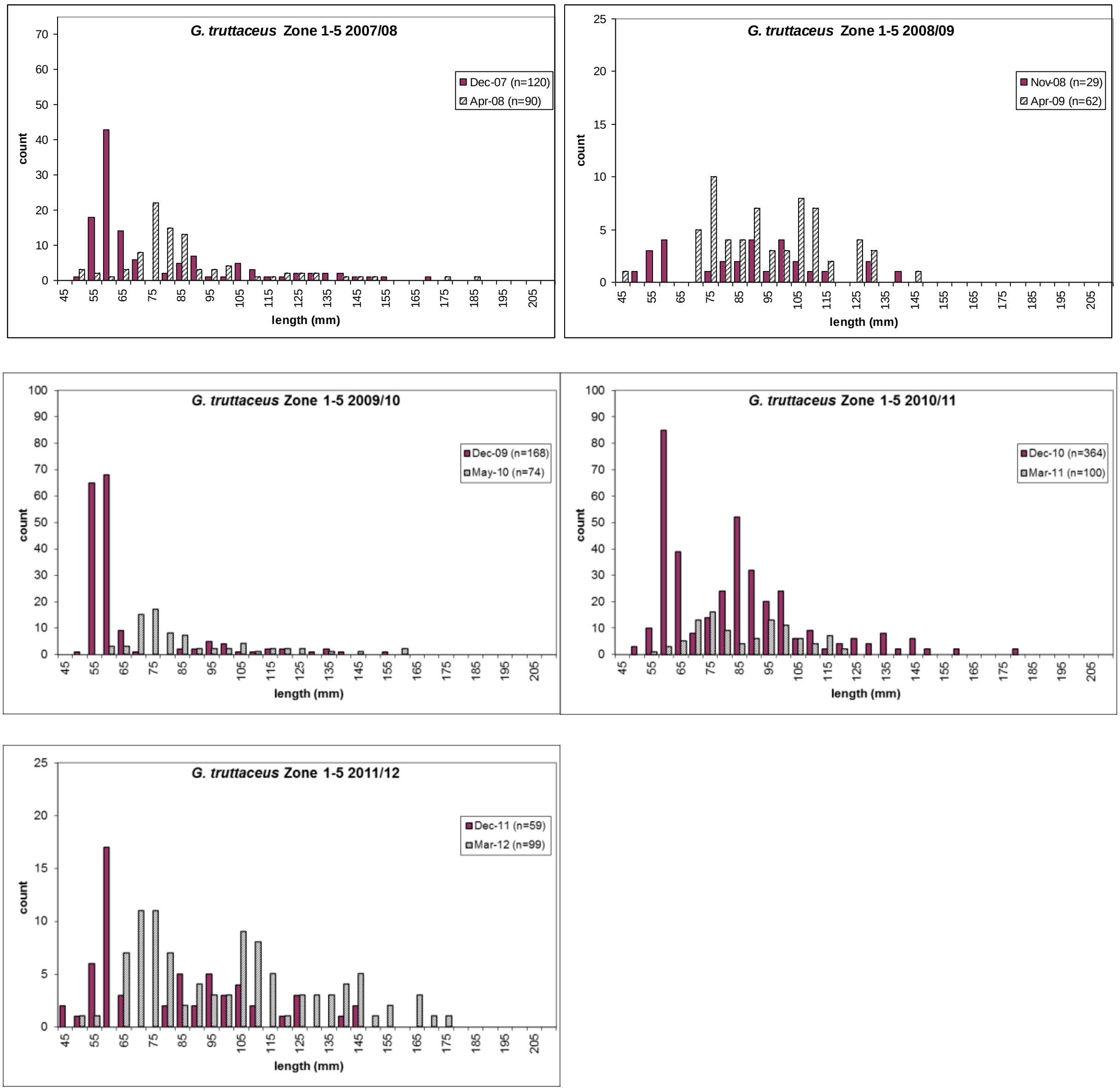


Figure 5.6: Length-frequency histograms for *Galaxias truttaceus,* captured in Gordon zones 1-5, 2007-08 to 2011-12.

6. Fish metric and hydro-peaking analysis graphs

This appendix presents graphs of the fish metrics plotted in conjunction with the number of occurrences of rapid low to mid-range flow increases ('hydro-peaking') for periods of 30, 60, 90 or 365 days prior to each sampling occasion. Low to mid-range flow increases are defined as an increase from <25 m^3s^{-1} to >100 m^3s^{-1} in a period of 2 hours or less. This statistic is not indicative of full range (0-3 turbine) hydro-peaking but is indicative of rapid changes in flow and water level and habitat conditions relevant to biota.

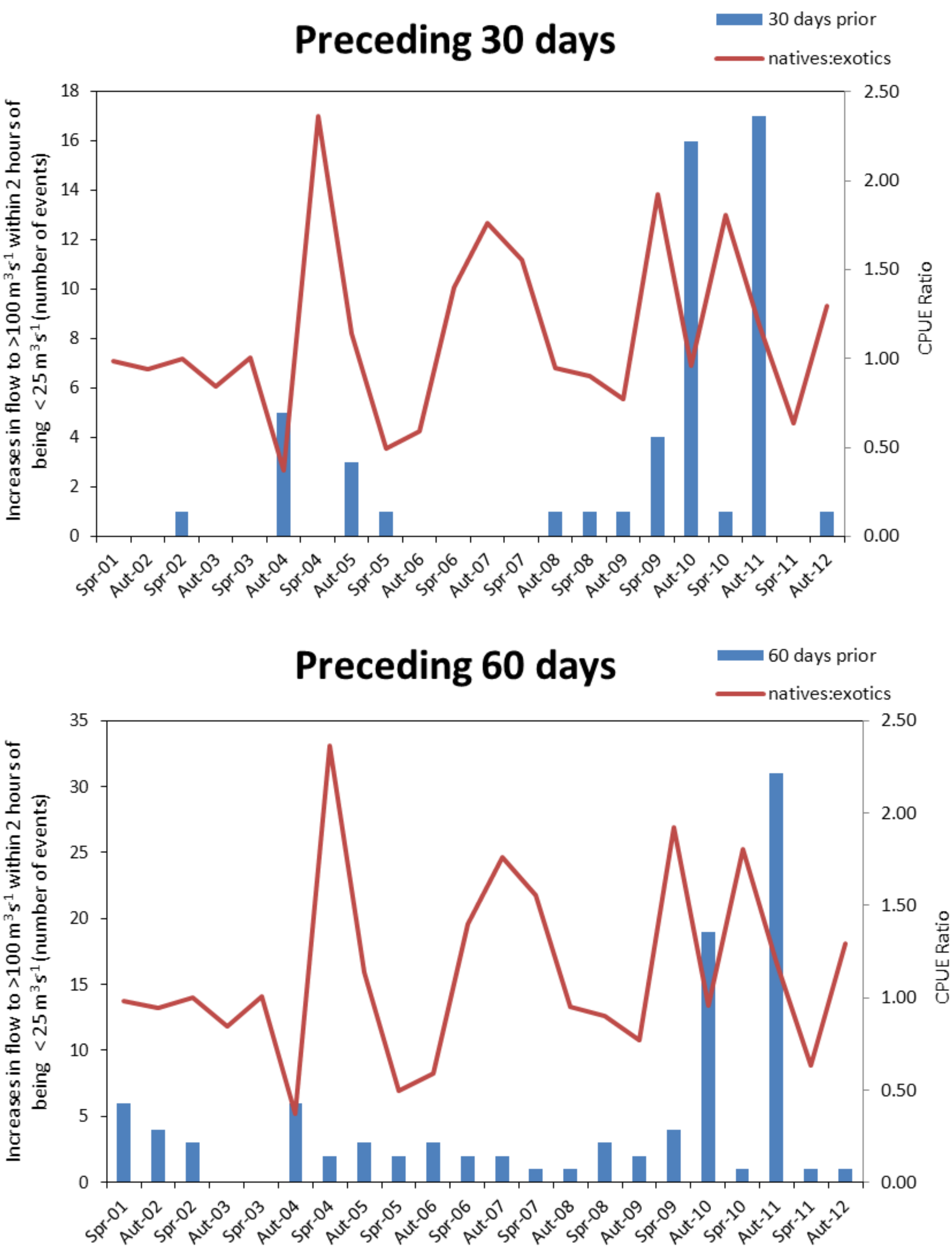
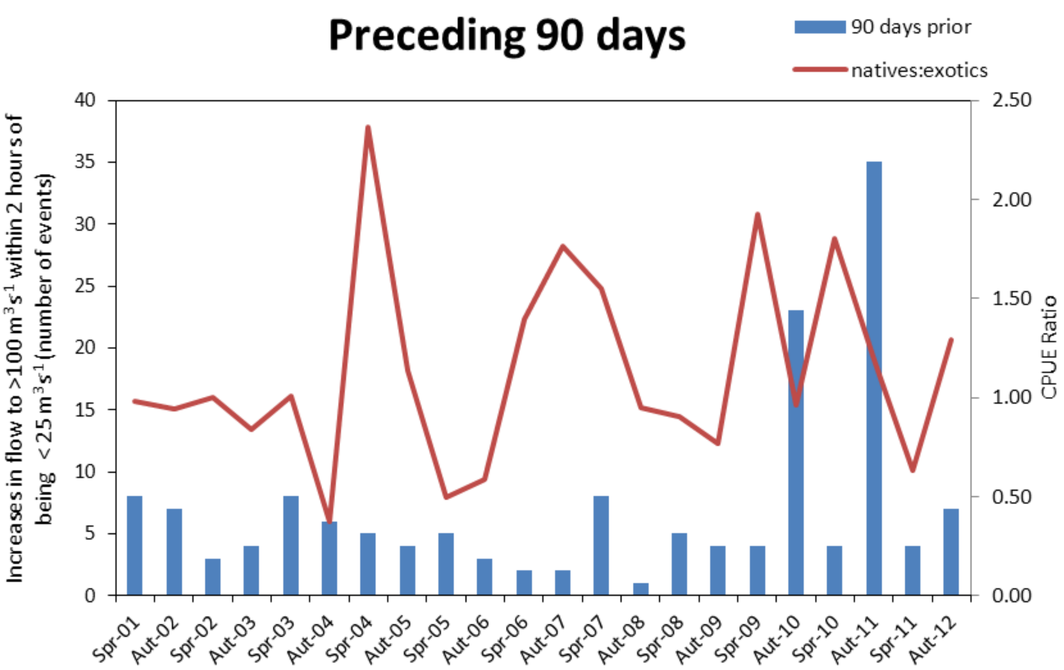


Figure 6.1: Natives:exotics fish metric plotted with occurrences of rapid low to mid-range flow increases (low-mid range “hydro-peaking”) for the previous 30 or 60 day periods prior to each sampling event.



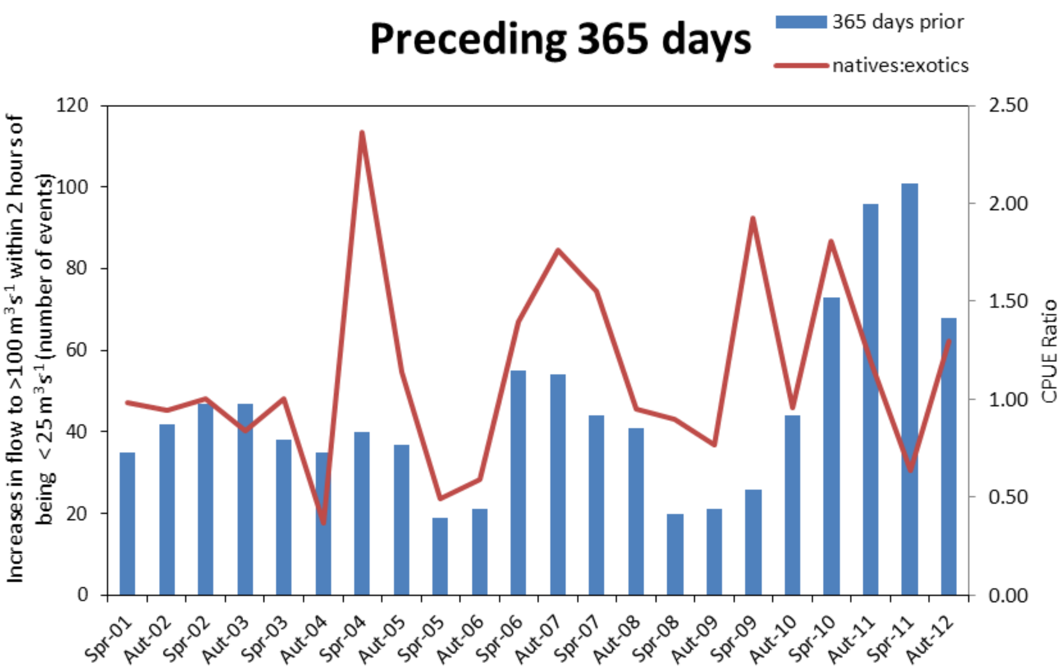
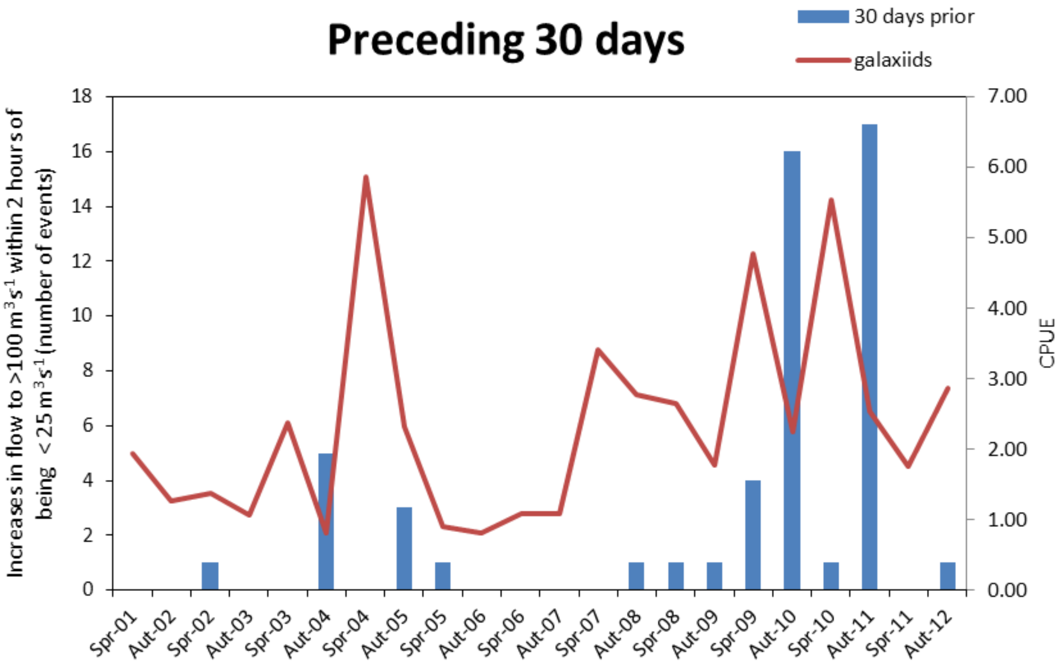


Figure 6.2: Natives:exotics fish metric plotted with occurrences of rapid low to mid-range flow increases (low-mid range “hydro-peaking”) for the previous 90 or 365 day periods prior to each sampling event.



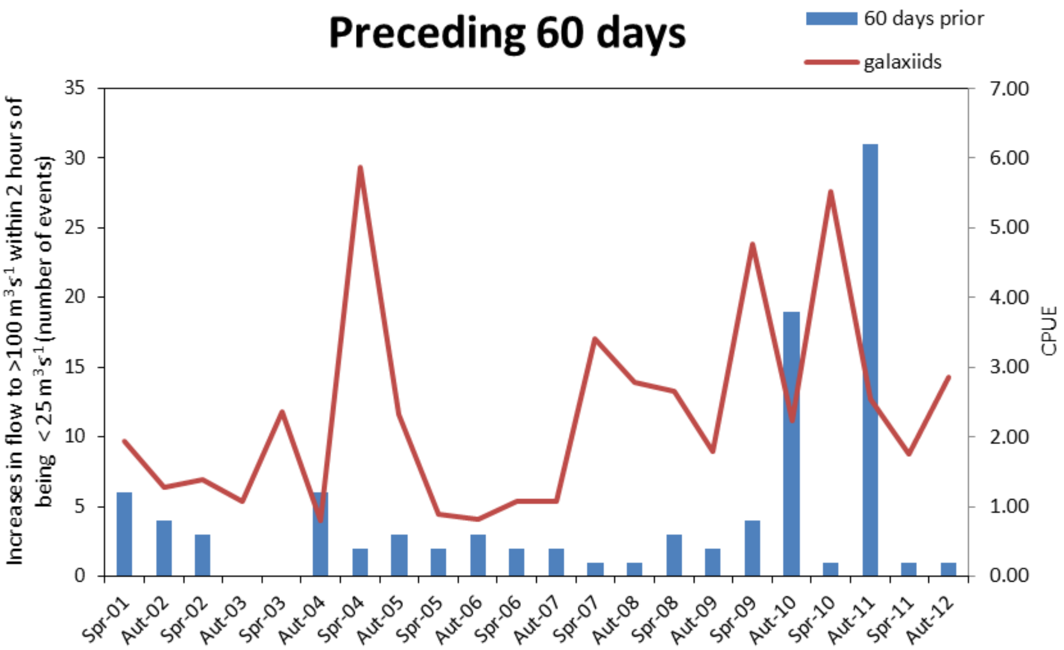
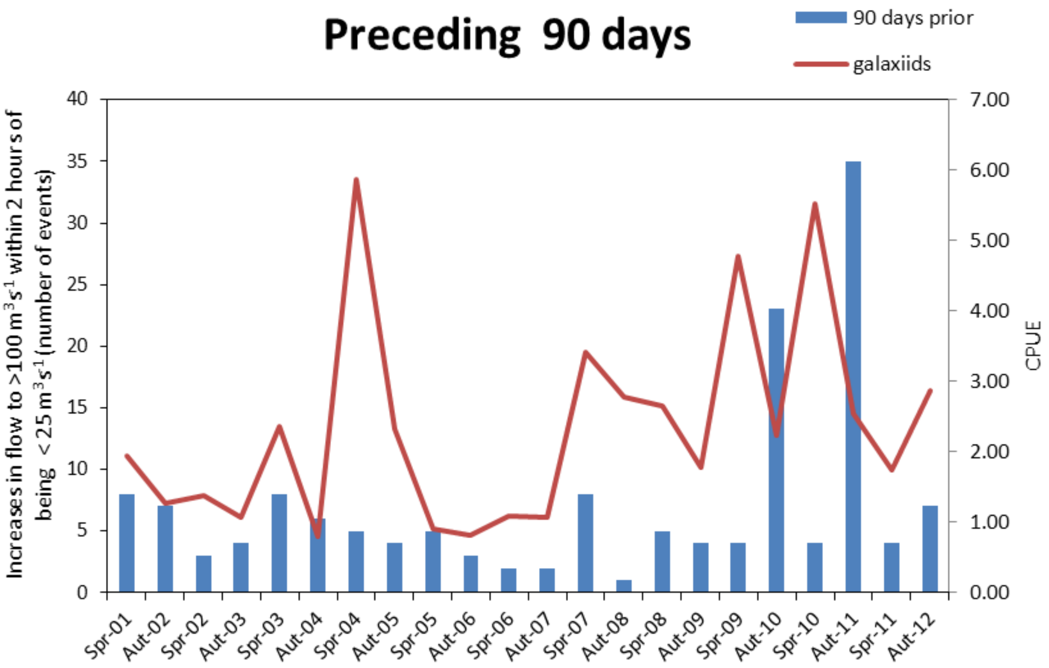


Figure 6.3: Galaxiid fish metric plotted with occurrences of rapid low to mid-range flow increases (low-mid range "hydro-peaking") for the previous 30 or 60 day periods prior to each sampling event.



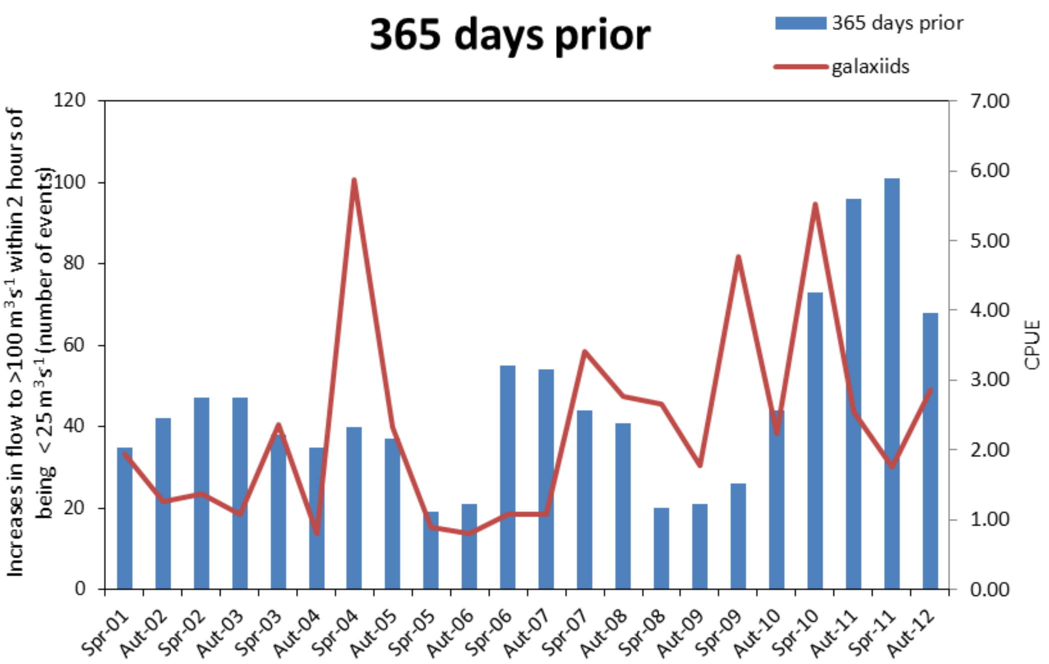
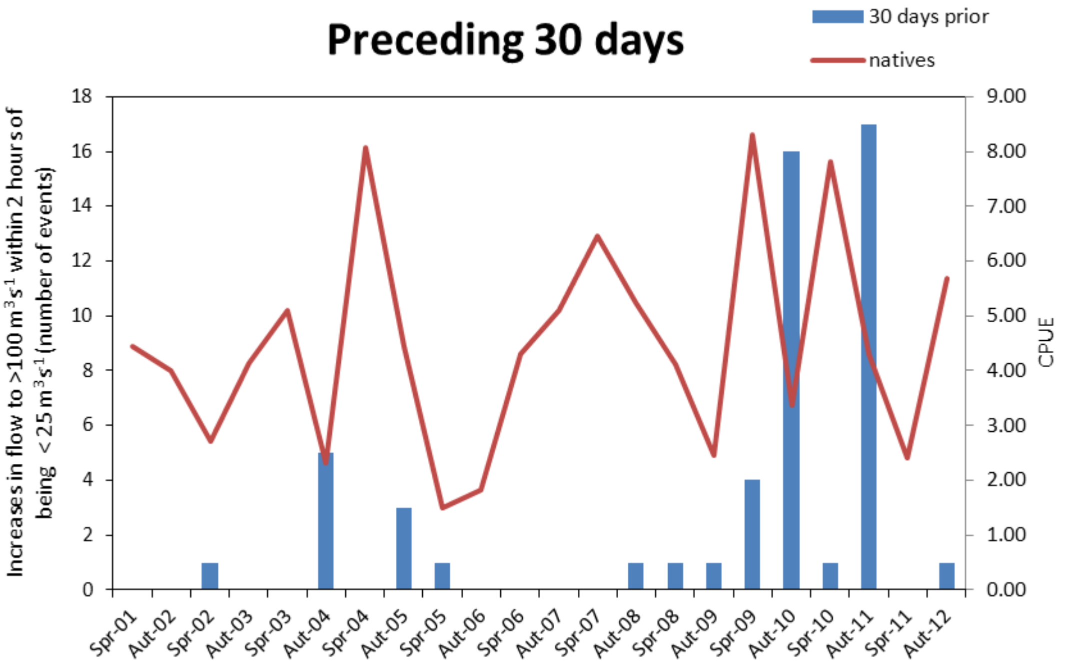


Figure 6.4: Galaxiid fish metric plotted with occurrences of rapid low to mid-range flow increases (low-mid range "hydro-peaking") for the previous 90 or 365 day periods prior to each sampling event.



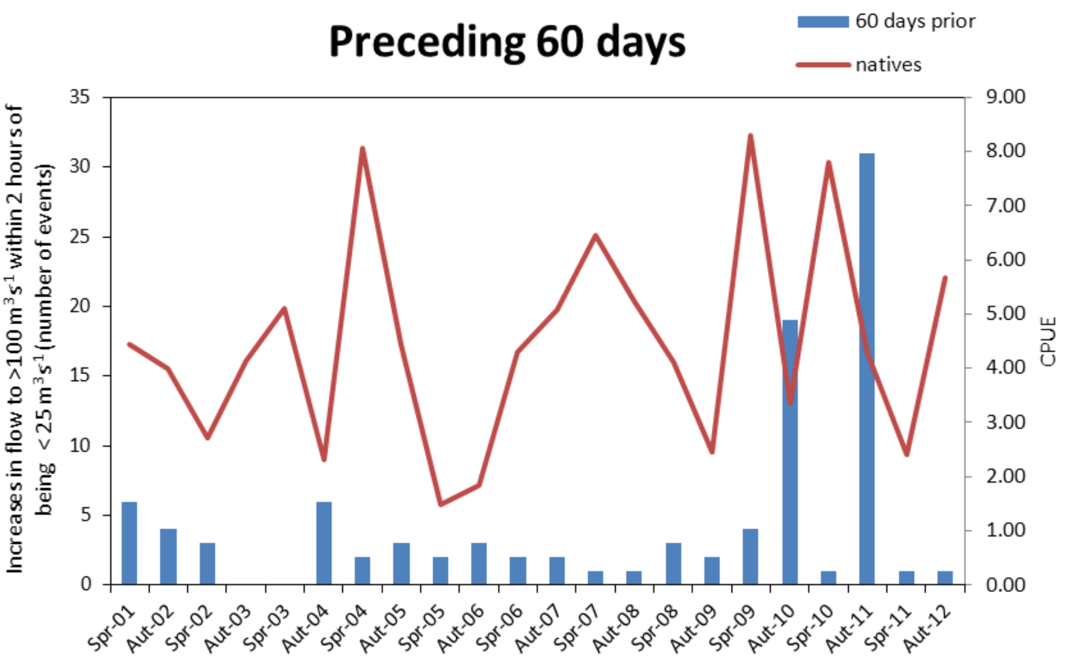
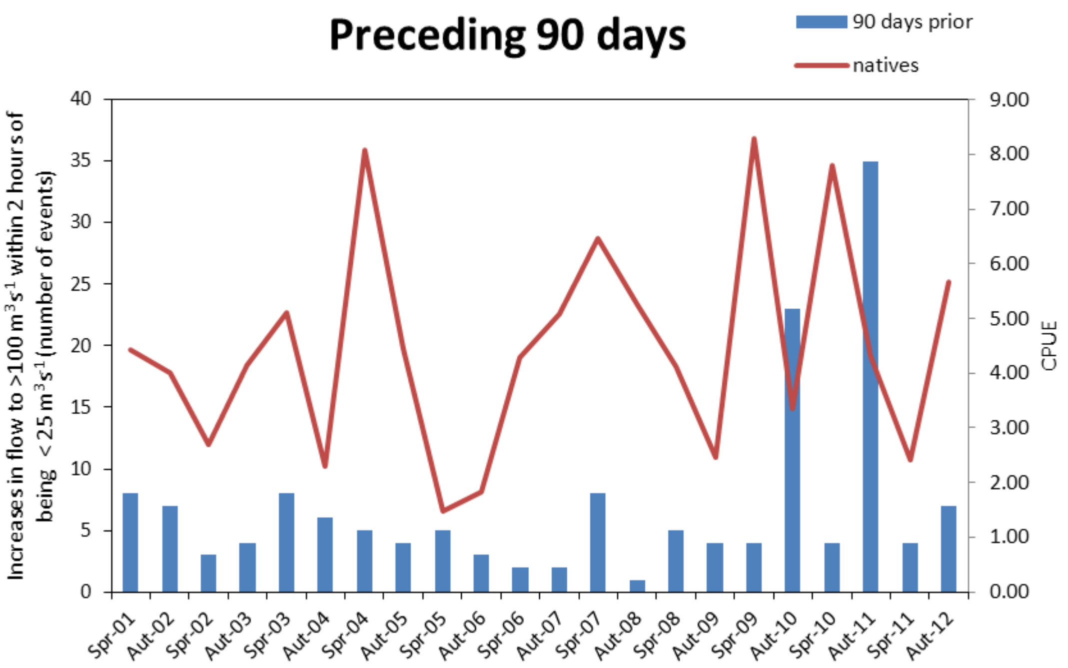


Figure 6.5: Natives fish metric plotted with occurrences of rapid low to mid-range flow increases (low-mid range “hydro-peaking”) for the previous 30 or 60 day periods prior to each sampling event.



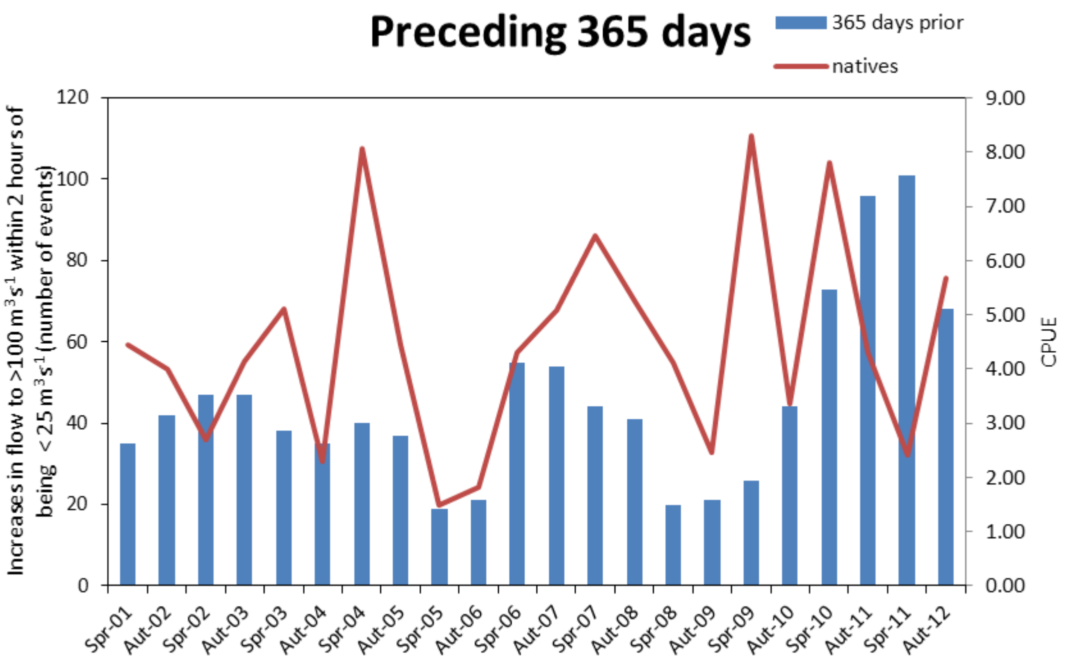
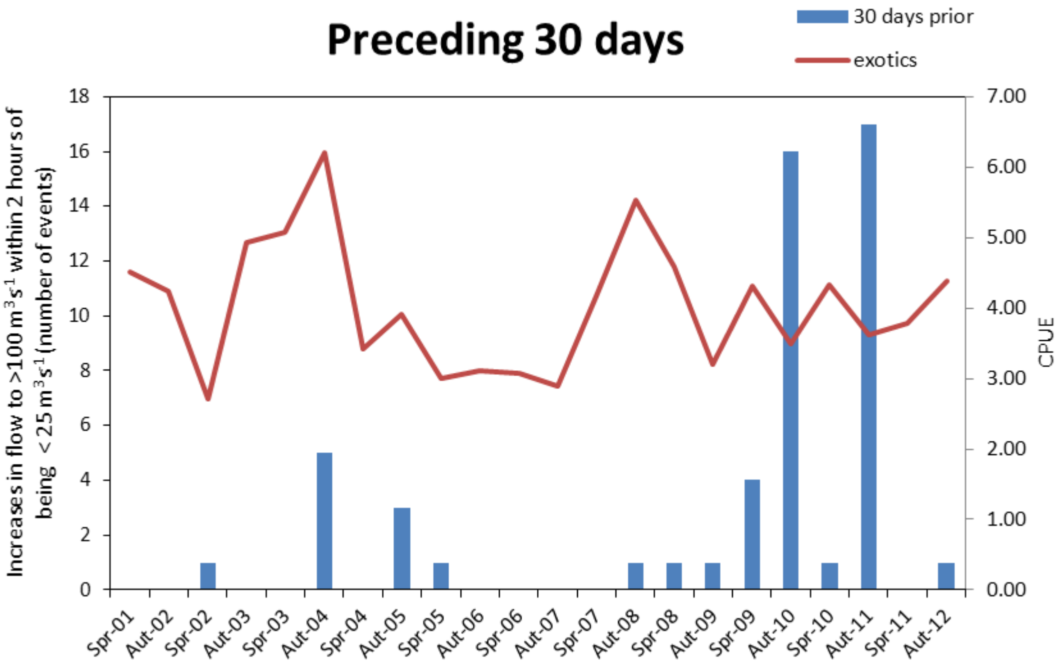


Figure 6.6: Native fish metric plotted with occurrences of rapid low to mid-range flow increases (low-mid range "hydro-peaking") for the previous 90 or 365 day periods prior to each sampling event.



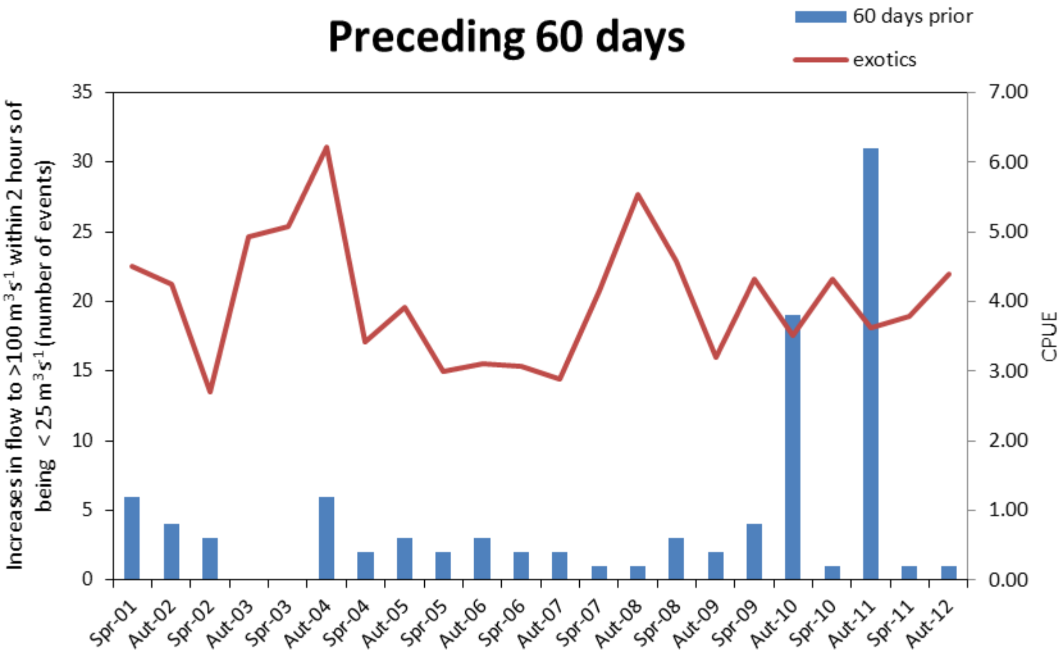
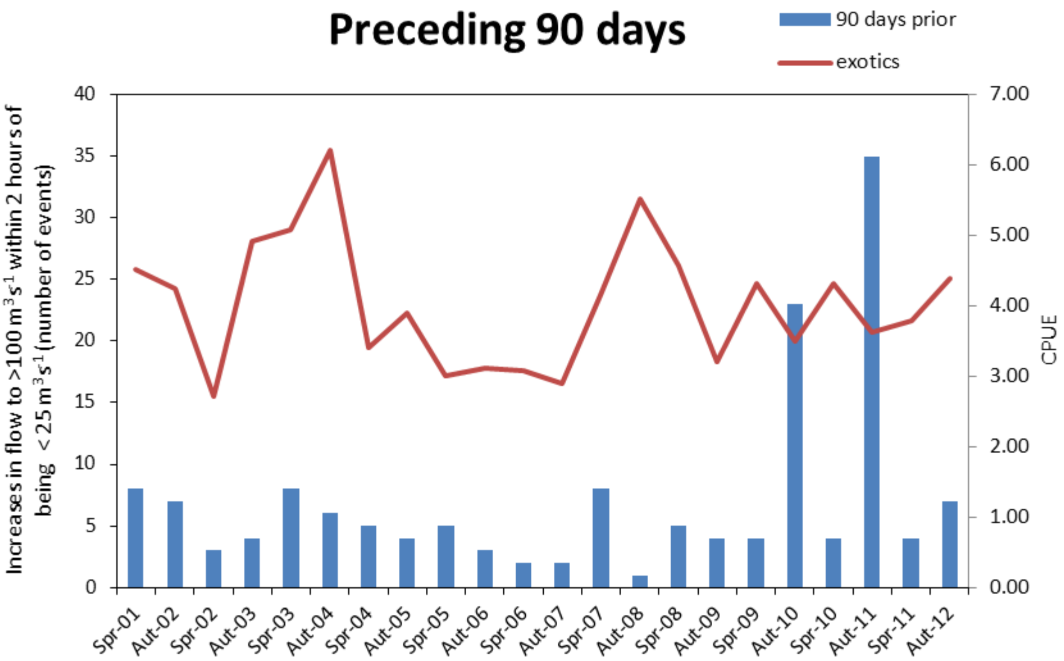


Figure 6.7: Exotics fish metric plotted with occurrences of rapid low to mid-range flow increases (low-mid range “hydro-peaking”) for the previous 30 or 60 day periods prior to each sampling event.



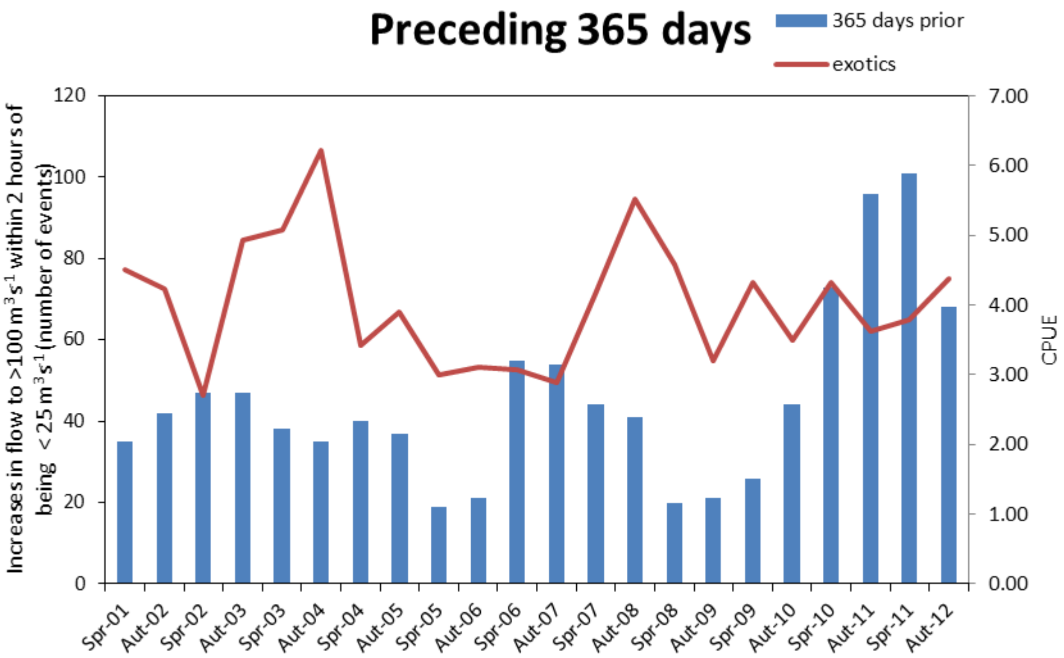
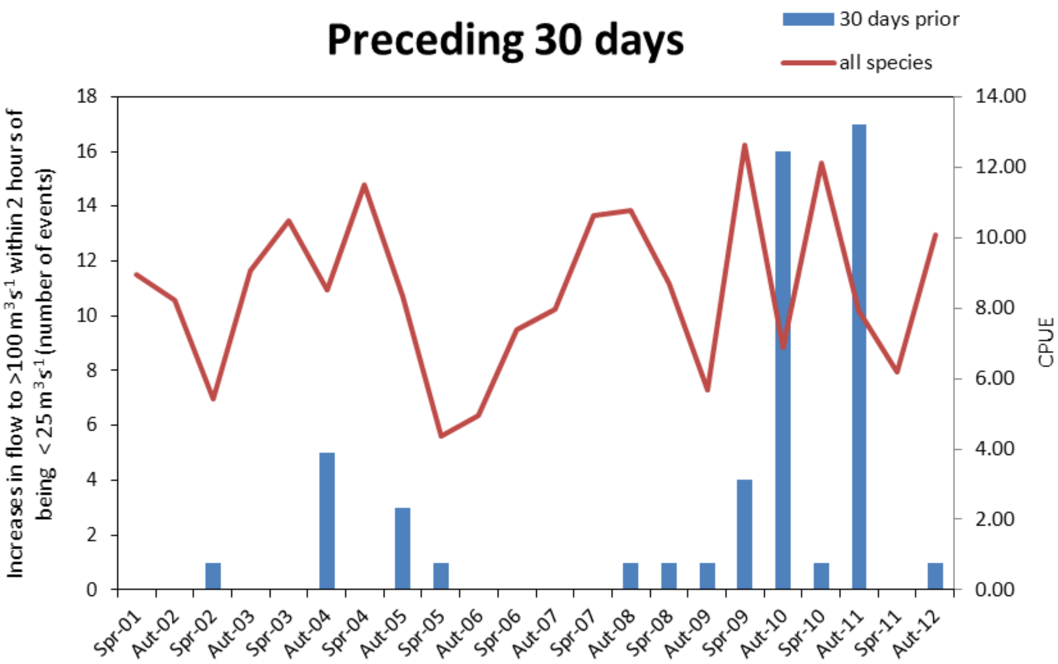


Figure 6.8: Exotics fish metric plotted with occurrences of rapid low to mid-range flow increases (low-mid range “hydro-peaking”) for the previous 90 or 365 day periods prior to each sampling event.



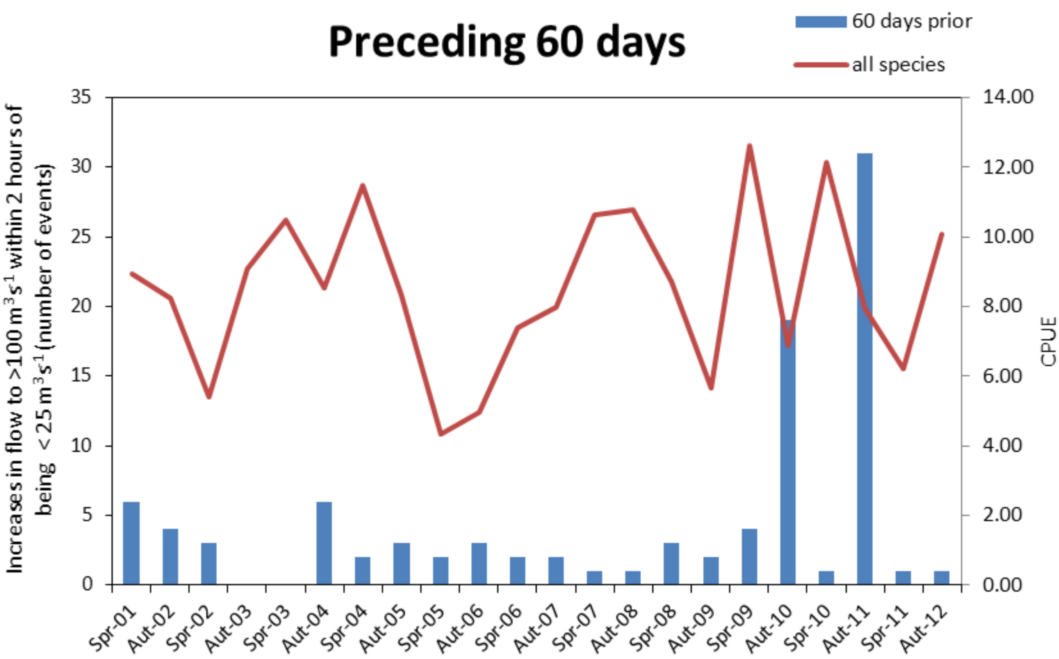
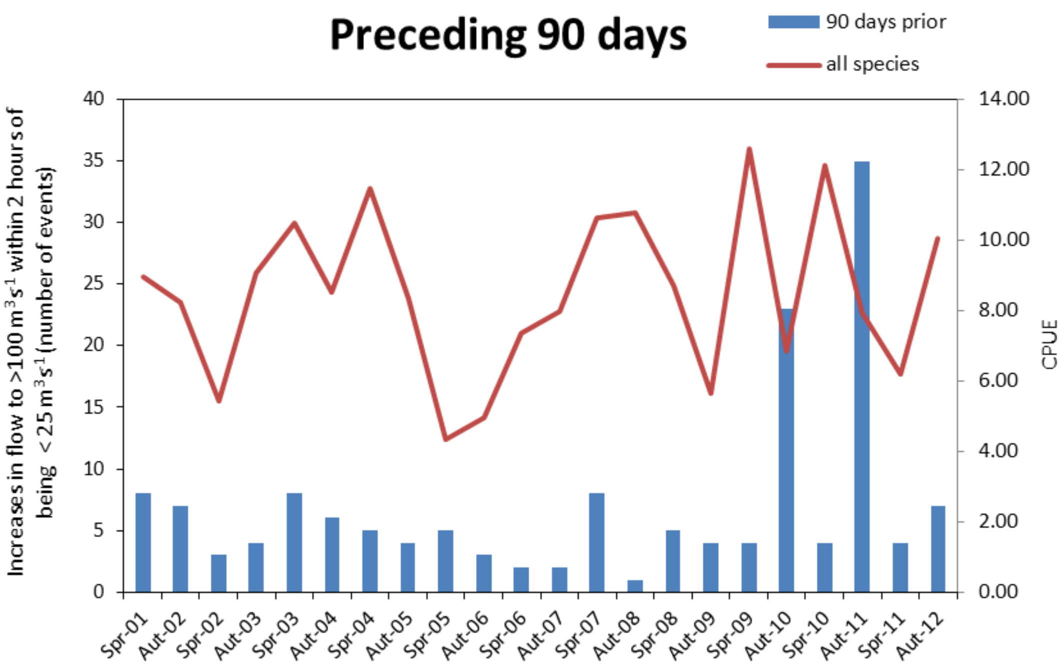


Figure 6.9: All species fish metric plotted with occurrences of rapid low to mid-range flow increases (low-mid range "hydro-peaking") for the previous 30 or 60 day periods prior to each sampling event.



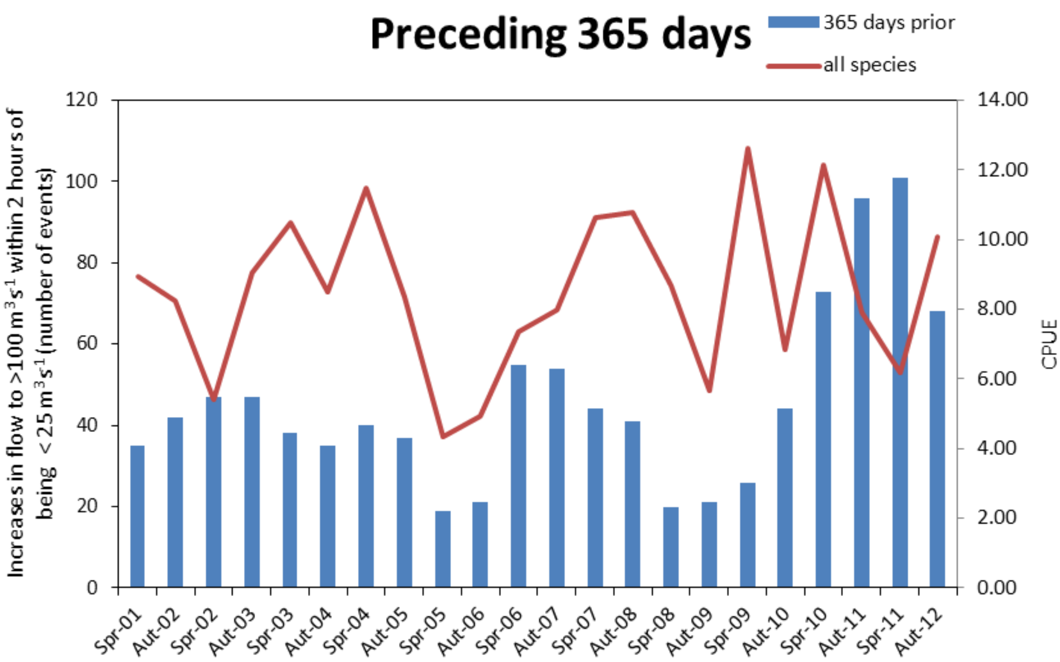


Figure 6.10: All species fish metric fish metric plotted with occurrences of rapid low to mid-range flow increases (low-mid range "hydro-peaking") for the previous 90 or 365 day periods prior to each sampling event.