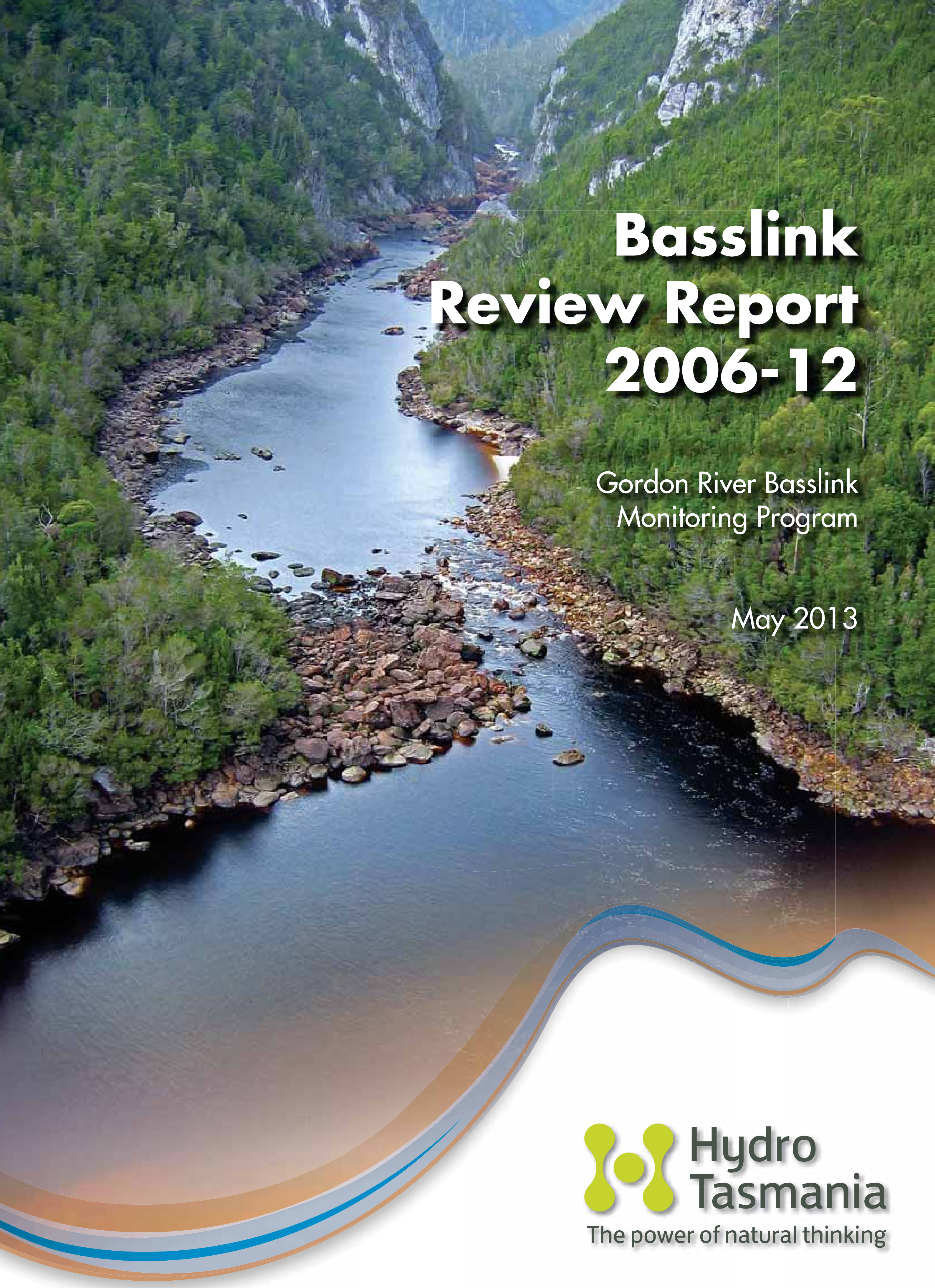

Basslink Review Report 2006-12

Gordon River Basslink Monitoring Program

May 2013

Hydro Tasmania
The power of natural thinking

Executive summary

This report evaluates the Gordon River Basslink Monitoring Program after six years of Basslink operations (2006-2012). The report presents trends from the consolidated data, evaluates the adequacy of the monitoring program, and evaluates the appropriateness and effectiveness of triggers and the mitigation measures.

Hydrology

The first three years of the post-Basslink period (2006-2009) were dry across Tasmania. Discharges from Gordon Power Station were higher in the first two years of operation as the Gordon storage was drawn upon heavily. Subsequent years (2008-12) saw much reduced use of Gordon Power Station. The patterns of discharge differed throughout the post-Basslink period. Flows were not dominated by 0-3 turbine hydro-peaking, as was predicted prior to the commissioning of Basslink. Instead, flow patterns varied significantly over time, and a range of flow patterns was seen, of which hydro-peaking was one. Flow patterns ranged from 2-3 turbine baseload (steady) flow to steady low flow dominant patterns. The implementation of the minimum environmental flow resulted in significantly fewer hours of zero discharge.

The discharge from Gordon Power Station depends on a number of independent factors such as market price signals, outages elsewhere in the system, drought, storage levels and Tasmanian electricity supply and demand. In the post-Basslink period, it has become apparent that the combination of these influences has resulted in less predictable discharge, with greater short-term variability in comparison to the pre-Basslink period.

Post-Basslink conceptual models

Simple conceptual models were developed for each of five different discharge patterns or flow regimes. These models can be used to understand the expected environmental responses to power station operation patterns in future.

Water quality

Water quality in Lakes Gordon and Pedder and in the Gordon River was good during the monitoring period. Fluctuations in water temperature and dissolved oxygen have varied in the Gordon River downstream the dam, as expected, in relation to the water storage levels and the discharge operations from the power station.

Fluvial geomorphology

Post-Basslink rates of net erosion were lower relative to pre-Basslink, which is attributable to the large reduction in total flow in the last four years of monitoring (2008-2012), combined with increased deposition associated with local seepage processes resulting from increased hydro-peaking. Changes at erosion pins were governed primarily by the magnitude, duration and draw down frequency of flows in the river, which translate into scour and seepage erosion on the banks. The flow patterns in the post-Basslink period have resulted in a substantial reduction in erosion in conjunction with an increase in deposition on the bank toes due to seepage, and limited change in the 1 to 2 and 2 to 3 turbine bank levels.

The monitoring program has enhanced the understanding of spatial changes on the banks, both at the individual bank scale, and at the zone scale.

The multiple lines of evidence approach adopted, as opposed to solely relying on triggers, for understanding geomorphic changes in the river has proved to be valuable. The piezometer results captured short-term bank saturation changes in response to flow conditions, as well as the influence of combined power station and natural inflows on bank saturation. The photo monitoring results have been most useful for understanding how the river is changing at larger spatial and temporal scales, including the processes and time-scale associated with the revegetation of landslips and slumps.

The monitoring program has provided a good understanding of how flow regulation has affected the Gordon River at a large scale. While the program was established specifically to determine the impacts of flow dominated by hydro-peaking in the post-Basslink period, this flow pattern did not dominate. Instead, under the hydrological conditions observed, the monitoring program has provided a consistent picture of how the flow regime determines the relative contributions of erosional processes in the river, and how these processes are shaping the banks over time frames of months to years.

Karst geomorphology

The sediment changes recorded in the caves post-Basslink were small and are considered to be of little significance from an ecological, geomorphological or conservation perspective. All the evidence suggests that the sediments in the caves are more protected and buffered from the effects of the power station operations than the sediments in the river channel, and that the caves are relatively robust.

The post-Basslink Monitoring Program is considered to have met its objectives and worked well within its limitations. The informal triggers were found to be a useful tool for highlighting changes to existing trends, for further assessment against hydrological change due to power station operations.

There has been no significant impact on the Gordon River karst areas in the post-Basslink period.

Vegetation

In the post-Basslink period there has been a net recovery of vegetation on the banks of the Gordon River. There has been a measurable increase in total vegetation cover at all bank levels. However, it is most pronounced in the quadrats above 3 turbine operation. There has also been an overall increase in species richness over the monitoring period. The increase in vegetation cover and associated increase in species richness have been promoted by the low flows observed over the last four years (2008-2012). The flow regime experienced since the commissioning of Basslink, has had a positive impact on the recovery of vegetation on the banks of the Gordon River.

Limited replication, small sample size and high degree of variability presented difficulties when attempting to detect significant vegetation changes due to changes in power station operation. Despite these limitations, the vegetation monitoring program was able to identify trends in species composition and diversity as well as vegetation cover. The photo monitoring was successful in providing an understanding of the processes influencing riparian vegetation.Whilst the triggers themselves may not have been of particular ecological significance, they were useful in setting benchmarks against which to explain ecological change and the processes likely to be responsible for it.

Macroinvertebrates

The general condition of macroinvertebrates in the Gordon River post-Basslink was broadly similar to the pre-Basslink period. There has been a positive impact on the macroinvertebrate community, with increases in abundance or diversity of flow-dependent taxa due to the increase in the occurrence of low flows in the latter years of the post-Basslink period (2008-12) in conjunction with the minimum environmental flow.

Trigger values have been effective in detecting change in the macroinvertebrate community and associated trigger exceedances indicate a positive response to the minimum environmental flow.

The Basslink Monitoring Program has provided insights into the influence of discharge patterns from the Gordon Power Station on macroinvertebrate community composition and abundance.

Algae and mosses

There have been no major post-Basslink changes in the cover of either algae or mosses in the middle Gordon River but some increasing trends have been observed for filamentous algae.

The monitoring program and the triggers have been adequate in describing changes in algal and moss cover.

Fish

There has been no significant impact on the fish in the Gordon River post-Basslink. There have been indications of improved native recruitment and upstream migration in the post-Basslink period.

The low numbers and patchy distribution of fish make it difficult to quantitatively assess the impacts in the post-Basslink period on a species level. However, taking the limitations into account, the fish monitoring program has performed to expectations.

The triggers have been adequate in describing changes in the fish community.

Mitigation measures

Minimum environmental flow

The 10/20 minimum environmental flow has been effective to date and had a positive effect on macroinvertebrates. Indications of improvements in native fish recruitment and migration also suggest that the minimum environmental flow had a positive impact on fish.

Ramp-down rule

The original ramp-down rule, which was first implemented in 2006, did not fully achieve its aim of minimising seepage erosion, although the rule may have contributed to the decrease in seepage processes observed post-Basslink (along with the large reduction in flow volumes). Significant work has since been undertaken to apply the principles of adaptive management to improve the ramp-down rule. This has culminated in the revision of the rule and its inception into operation in April 2012. The new rule combines environmental goals with operational flexibility. Under the revised rule, maximum operational flexibility is maintained under conditions of low bank saturation but ramping is required whenever banks are saturated and discharge is above 150 m^3s^{-1}. As the rule has been in place for only a short period, the effectiveness of the revised ramp-down rule is to be monitored and assessed from 2012-2014.

Conclusion and Recommendations

At the completion of the Basslink Monitoring Program it is concluded that the program has met the aims of determining the effects of post-Basslink operations and assessing the effectiveness of the Mitigation Measures. Hydro Tasmania has fulfilled its licence requirements and added significant understanding to the processes occurring in the Gordon River. The following recommendations and commitments are proposed by Hydro Tasmania:

- Maintain the ramp-down rule and 10/20 minimum environmental flow.
- Complete the agreed interim monitoring program (2012-14) under Hydro Tasmania's current licence to enable continued examination of the effectiveness of the mitigation measures.
- Evaluate the need for future monitoring requirements in consultation with DPIPWE.
- Maintain a commitment to adaptive management in the Gordon River.

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Acronyms and abbreviations

AEMO	Australian Energy Market Operator – founded in 2009 with NEMMCO as a founding entity
AETV	Aurora Energy Tamar Valley
ANOVA	analysis of variance
ANZECC	Australian and New Zealand Environment and Conservation Council
AUSRIVAS	Australian River Assessment System
BBR	Basslink Baseline Report
BMP	Basslink Monitoring Program
CPUE	catch per unit effort
CWD	coarse woody debris
dbRDA	Distance based single redundancy analysis
DISTLIM	Distance based linear modelling
DO	dissolved oxygen
DPIPWE	Department of Primary Industries, Parks, Water and Environment
EC	electrical conductivity
EPT	Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies)
FRP	filterable reactive phosphorus
GRBMAR	Gordon River Basslink Monitoring Annual Report
IIAS	Basslink Integrated Impact Assessment Statement: Potential Effects of Changes to Hydro Power Generation
LOAC	Level of acceptable change
mASL	metres above sea level
NEMMCO	National Electricity Market Management Company – incorporated into AEMO in 2009
NTU	Nephelometric turbidity units
PCA	Principal component analysis

O/E	is a biological index of the ‘observed’ to ‘expected’ ratio which describes the proportion of macroinvertebrate taxa predicted to be at a site under undisturbed conditions that are actually found at that site. O/E scores range between 0, with no predicted taxa occurring at the site, to around 1, with all expected taxa being observed (i.e. a community composition equivalent to reference condition).
O/Epa	the O/E value calculated using an AUSRIVAS model based on presence-absence data
O/Erk	the O/E value calculated based on rank abundance category data
RBA	rapid biological assessment - macroinvertebrate sampling protocol
TKN	total Kjeldahl nitrogen
WOR	whole-of-river

Glossary

Ambient	background or baseline conditions
Anoxic	absence of oxygen
Benthic	the bottom of a lake
Bray-Curtis index	a measure of assemblage similarity between sites/samples
Catch per unit effort (CPUE)	the catch related to a standardised measure of effort. In this case, the number of fish collected by electrofishing at a site, standardised to a shocking time of 1200 seconds
Cavitation	the formation and subsequent collapse of vapour bubbles (cavities) within water moving at high velocity. Cavitation is responsible for the pitting of turbine blades.
Colluvium	loose bodies of sediment that have been deposited or built up at the bottom of a low-grade slope or against a barrier on that slope, transported by gravity. The deposits that collect at the foot of a steep slope or cliff are also known by the same name.
Confluence	the location when two rivers or tributaries flow together
Diurnal	relating to or occurring in a 24-hour period
Dolines	karst features which are present as depressions or collapses of the land surface. Dolines are formed when a solution cavity in the underlying rock becomes enlarged enough for overlying sediment to collapse into it.
Environmental flow	water which has been provided or released for the benefit of the downstream aquatic ecosystem and broader environment
Exotic	introduced organisms or species
Full-gate	is the discharge which produces the maximum amount of energy by the turbine
Geomorphic	the study of the earth's shape or configuration
GordonRatingApp	the stand-alone application used for calculating discharge from the Gordon Power Station
GWh	gigawatt hours (10^9 watt hours) – a standard measure of energy equivalent to the production of one gigawatt of power for one hour

Hydrology	the study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks and in the atmosphere
Hydro-peaking	Variable flow in power station discharge on a daily scale
Inundation	an area of vegetation or bank which becomes covered by water associated with flows from either an upstream dam or tributary input
Karst	an area of irregular limestone in which erosion has produced fissures, sinkholes, underground streams and caverns
m^3s^{-1}	cubic metres per second, units for the measure of flow rate
mg L^{-1}	milligrams per litre, units for the concentration of a substance dissolved in a solution
µg L^{-1}	micrograms per litre
µS cm^{-1}	micro Siemens per centimetre, measure of electrical conductivity
Morphology	the consideration of the form and structure of organisms
MW	megawatts (10^6 watts) - a standard measure of power
Oxycline	level at which dissolved oxygen decreases rapidly
pH	a measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity (scale of 0-14)
Piezometer	an instrument for measuring pressure
Pielou’s evenness index	a measurement of diversity in samples using abundance and species richness data developed by Pielou in 1966
post-Basslink	the period following commissioning of the Basslink interconnector
pre-Basslink	the period prior to commissioning of the Basslink interconnector
Riffle habitat	habitat comprising rocky shoal or sandbar lying just below the surface of a waterway
Rill	An erosional feature caused by flowing water. In the Gordon River, a rill is a small channel incised into a sandy bank due to water draining from the bank
Tailrace	the outflow structure of the power station, from which water is discharged into the river

Taxon	a taxonomic category or group, such as a phylum, order, family, genus, or species
Temporal	change or pattern over time
Thermal stratification	change in temperature profiles over the depth of a water column

1. Introduction

1.1 Purpose

This Basslink Review Report evaluates the Gordon River Basslink Monitoring Program, and assesses the appropriateness and effectiveness of the current mitigation measures in place in the Gordon River. After a total of eleven years of data collection, six of those post-Basslink commissioning, the monitoring outputs are presented in this final review report which evaluates the monitoring program and assesses the effectiveness of the mitigation measures. This review considers in detail the data collected over the last six years of monitoring and relates this to the hydrology of the middle Gordon River and discharge patterns of the Gordon Power Station.

1.2 Basslink and the Gordon River

Basslink is an undersea power cable, commissioned on 28 April 2006, that connects Tasmania to Australia's national electricity grid. Basslink has allowed Tasmania to join the National Electricty Market (NEM), importing or exporting electricity across Bass Strait in response to demand and market opportunities.

The Gordon Power Station is the largest generating station in Tasmania and plays a key role in the State's electricity network. It uses water that is stored in Lakes Gordon and Pedder for electricity production and discharges water to the middle Gordon River below the Gordon Dam. Located in south-west Tasmania, the middle Gordon River flows through the Tasmanian Wilderness World Heritage Area (Figure 1.1), an area recognised internationally for its high natural values. The operating regime of the Gordon Power Station was anticipated to change after Basslink was commissioned with consequent impacts on the middle reaches of the Gordon River.

The Gordon River Basslink Monitoring Program was developed and incorporated into Hydro Tasmania's Special Licence Agreement. Its aim has been to detect impacts on the ecology and geomorphology of the Gordon River caused by NEM influenced changes to the operation of Gordon Power Station. The program was also developed to assess the mitigation measures (see Section 1.4.1) that have been implemented to limit the impact of the changed operations resulting from Basslink.

Figure 1.1: The Gordon catchment showing the position of the catchment in south-west Tasmania, the World Heritage Area, Lakes Gordon and Pedder, and the Gordon Power Station.

1.3 Predicted hydrological changes and environmental issues

Trading in the NEM, enabled by Basslink, was anticipated to significantly change the way the Gordon Power Station operates, altering the pattern of discharge from the power station into the Gordon River. System modelling using the Tasmanian Electricty Market Simulation Model (TEMSIM) predicted that, in the NEM, operation of the Gordon Power Station would:

- significantly increase the frequency of on-off operation (called hydro-peaking) throughout the full range of discharges;
- result in more winter discharge than pre-Basslink operation;
- increase the occurrence of high power station discharges;
- increase occurrences of short-term and weekend shutdowns; and
- reduce inter-annual variability in power station operating patterns.

Extensive environmental investigations of the middle Gordon River prior to Basslink commissioning resulted in the following predicted environmental impacts of post-Basslink operations, based on anticipated changes to the power station operating regime:

- fluvial geomorphology: altering the geomorphic processes controlling stability of the Gordon River banks relative to pre-Basslink processes, principally scour and seepage erosion;
- riparian vegetation: accelerating pre-Basslink rates of loss of riparian vegetation communities;
- aquatic macroinvertebrates: altering the composition of macroinvertebrate communities and further reducing diversity and abundance below pre-Basslink levels; and
- fish: reducing fish populations by further restricting the amount of fish habitat available, as well as reducing fish food supply through adverse impacts on macroinvertebrates.

Two mitigation measures, a minimum environmental flow and a ramp-down rule, were implemented to address these anticipated impacts. These mitigation measures constrain power station operation to manage discharges into the middle Gordon River and are discussed in greater detail in Section 1.4 ‘Gordon River Basslink Special Water Licence requirements’. For details about the work undertaken prior to Basslink and the commencement of this monitoring program, please refer to the Basslink Integrated Impact Assessment Studies (IIAS) (Locher 2001) and the Basslink Baseline Report (BBR)(Hydro Tasmania 2005a).

1.4 Gordon River Basslink Special Water Licence Agreement requirements

Hydro Tasmania was required to undertake a number of activities designed to monitor, assess and mitigate predicted Basslink effects. These requirements were incorporated into the Special Water Licence Agreement held by Hydro Tasmania under the *Water Management Act 1999* in 2002. The monitoring requirements included six years of post-Basslink monitoring which was completed in April 2012.

The Special Water Licence Agreement amendment (2002) detailed the requirements of the Gordon River Basslink Monitoring Program, described the composition and functions of the Scientific Reference Committee (SRC), and listed Hydro Tasmania’s pre-Basslink monitoring and reporting commitments. The Agreement also outlined Hydro Tasmania’s operating and monitoring obligations in the post-Basslink period, including the implementation of a ramp-down rule and the provision of a minimum environmental flow.

Following the completion of the Basslink monitoring tasks in 2012, some components of the Agreement requirements have continued in a two year interim monitoring program to monitor the effectiveness of the mitigation measures while this review report is being assessed.

1.4.1 Mitigation measures

The Special Water Licence Agreement sets out requirements for the two Basslink mitigation measures implemented in the Gordon River. These mitigation measures are designed to ensure there is ‘no net Basslink environmental impact’ on the Gordon River, meaning that any impacts ‘remain within the pre-Basslink boundaries, recognising inherent variability in the environmental indicators as well as long-term presently occurring trends’. Following adaptive management principles, the two mitigation measures as well as changes made to these during the Basslink monitoring period are documented in the Special Water Licence Agreement and summarised below:

- **Gordon Power Station ramp-down rule** – the original rule stated that the power station must be operated so that when the Gordon Power Station has been discharging above 180 m^3s^{-1} for greater than 60 minutes and Hydro Tasmania intended to reduce discharges to below 150 m^3s^{-1} that this reduction in flow should occur at or below a rate of 30 m^3s^{-1} per hour.

  The ramp-down rule was designed to decrease the incidence of seepage erosion, and thus the potential for bank sediment erosion and collapse. It was intended to prevent rapid decreases in water level when banks were saturated, allowing bank sediments to drain gradually as the water level falls.

  The wording of the original ramp-down rule in the Agreement was changed in 2009 to clarify the interpretation of the compliance requirements and to introduce tolerances designed to improve compliance whilst accommodating the operational requirements and limitations of the Gordon Power Station.

  Following identified short-comings in the original ramp-down rule and additional work undertaken since the three year review (Hydro Tasmania 2010a), a revised ramp-down rule was recommended and approved by the Minister in April 2012. This rule is based on the saturation of the banks, recognising that seepage erosion is most severe at high bank saturation levels. The revised rule utilises a regression model to estimate the saturation of banks in the Gordon River based on antecedent flow from Gordon Power Station. When the model indicates that a critical bank level saturation of 2.75 m is reached, all flows above 150 m^3s^{-1} are ramped at a rate equivalent to 1 MW/min (approximately 45 m^3s^{-1}/h).

- **Gordon River minimum environmental flow** – originally, from the time of Basslink commissioning, a minimum environmental flow was to be maintained in the Gordon River of at least:

  - 19 m^3s^{-1} summer flow (from 1 December to 31 May); and
  - 38 m^3s^{-1} winter flow (from 1 June to 30 November)

  The minimum environmental flow was designed to ensure that important aquatic habitats remain inundated even when the power station is not generating. The flow rates set out were intended to inundate the ‘mid-tidal’ zone and marginal snag habitats, increasing the amount of habitat available for fish and improving food supplies (macroinvertebrates) for fish and platypus.

In February 2006 the minimum environmental flow requirement was amended to allow Hydro Tasmania to trial a smaller environmental flow for the first three years of the post-Basslink period. The 10/20 minimum environmental flow regime provides:

- 10 m^3s^{-1} summer flow (from 1 December to 31 May); and
- 20 m^3s^{-1} winter flow (from 1 June to 30 November).

Permissions have since been granted by the Minister to extend the 10/20 minimum environmental flow period until April 2014.

These extensions allow the continuation of the assessment of the effectiveness of the minimum environmental flow to ensure that sufficient data is available from which to draw firm conclusions.

1.4.2 Gordon River Basslink Monitoring Program

The Special Water Licence Agreement amendment in 2002 also established Hydro Tasmania's monitoring requirements in catchments likely to be affected by changed power station operation in response to Basslink. Hydro Tasmania was required to conduct annual monitoring and reporting on the effects of Basslink on the Gordon River (Gordon River Basslink Monitoring Program, Annual Reports and review reports). This monitoring was conducted pre-Basslink (2001-05) and for six years post-Basslink commissioning (2006-12).

The Gordon River Basslink Monitoring Program was designed to detect environmental impacts in the middle Gordon River associated with changed power station operations following Basslink commissioning and Hydro Tasmania's participation in the NEM. Spring, summer and autumn monitoring trips were carried out each year, with the results presented in annual reports.

The monitoring program assessed those aspects of river ecology thought to be most at risk of impact from post-Basslink changes in power station operation, based on the predicted operating regime of the Gordon Power Station and the modelled environmental responses. The environmental aspects monitored were:

- hydrology;
- water quality;
- fluvial geomorphology;
- karst geomorphology;
- riparian vegetation;
- benthic macroinvertebrates;
- benthic algae and moss; and
- fish.

The monitoring program and mitigation measures were designed based on the predicted changes in power station operation under Basslink and the potential environmental impacts of these changes. Extensive monitoring was undertaken pre-Basslink to establish baseline conditions (Hydro Tasmania 2005a). Post-Basslink conditions have been compared against this baseline and assessed against limits of acceptable change, or 'triggers', based on the pre-Basslink data and the anticipated operational changes.

1.4.3 Scientific Reference Committee

The Scientific Reference Committee (SRC) was established in 2003 to provide advice on, and review of the monitoring program, considering scientific and technical issues relating to the monitoring program and Gordon River Basslink scientific reports.

The SRC is made up of State and Commonwealth representatives from the Tasmanian Department of Primary Industry, Parks, Water and Environment (DPIPWE) and the Commonwealth Department of Sustainability, Environment, Water, Population and Community (DSEWPC), researchers nominated by Hydro Tasmania who are involved in developing and implementing the monitoring program as well as representatives of Hydro Tasmania.

1.4.4 Adaptive management

The impacts of Basslink on the Gordon River are assessed using an adaptive management framework. This approach recognises the scientific uncertainties associated with ecosystem monitoring, providing flexibility to respond to new knowledge and information and adapt the monitoring program accordingly.

Adaptive management techniques rely on long-term records, the assessment of experimental interventions and the collection of large amounts of data on the selected environmental indicators. Time effects and the interactions between ecosystem components are considered when determining outcomes and management actions.

In terms of Basslink and the Gordon River, the adaptive management approach has been:

- to make changes as needed to the monitoring program to optimise the information gained; and
- to assess and make changes (as necessary and if practicable) to the mitigation measures or to implement other management strategies.

The Basslink Review Report 2006-2012 (this report) forms part of the adaptive management strategy for the Gordon River.

The most notable instance of adaptive management has been the ongoing work associated with the assessment of the original ramp-down rule and evaluation and revision of the new rule. The work to develop a revised rule began in response to the early increases in erosion outside trigger bounds in 2007-08. Further details of this work are contained in Section 10.3.

1.5 Gordon River Basslink monitoring decision tree

The Gordon River Basslink monitoring decision tree (Figure 1.2) was developed as part of the annual reporting process in 2007–08 and refined in the Basslink Review Report 2006-09 (Hydro Tasmania 2010a). It assisted in providing a consistent and clear process for the interpretation of results to identify if action was required. It incorporated use of the conceptual model in the assessment of data, and defined the circumstances under which the role of Basslink was to be considered. It also guided the refinement and development of the conceptual model as new knowledge was gained.

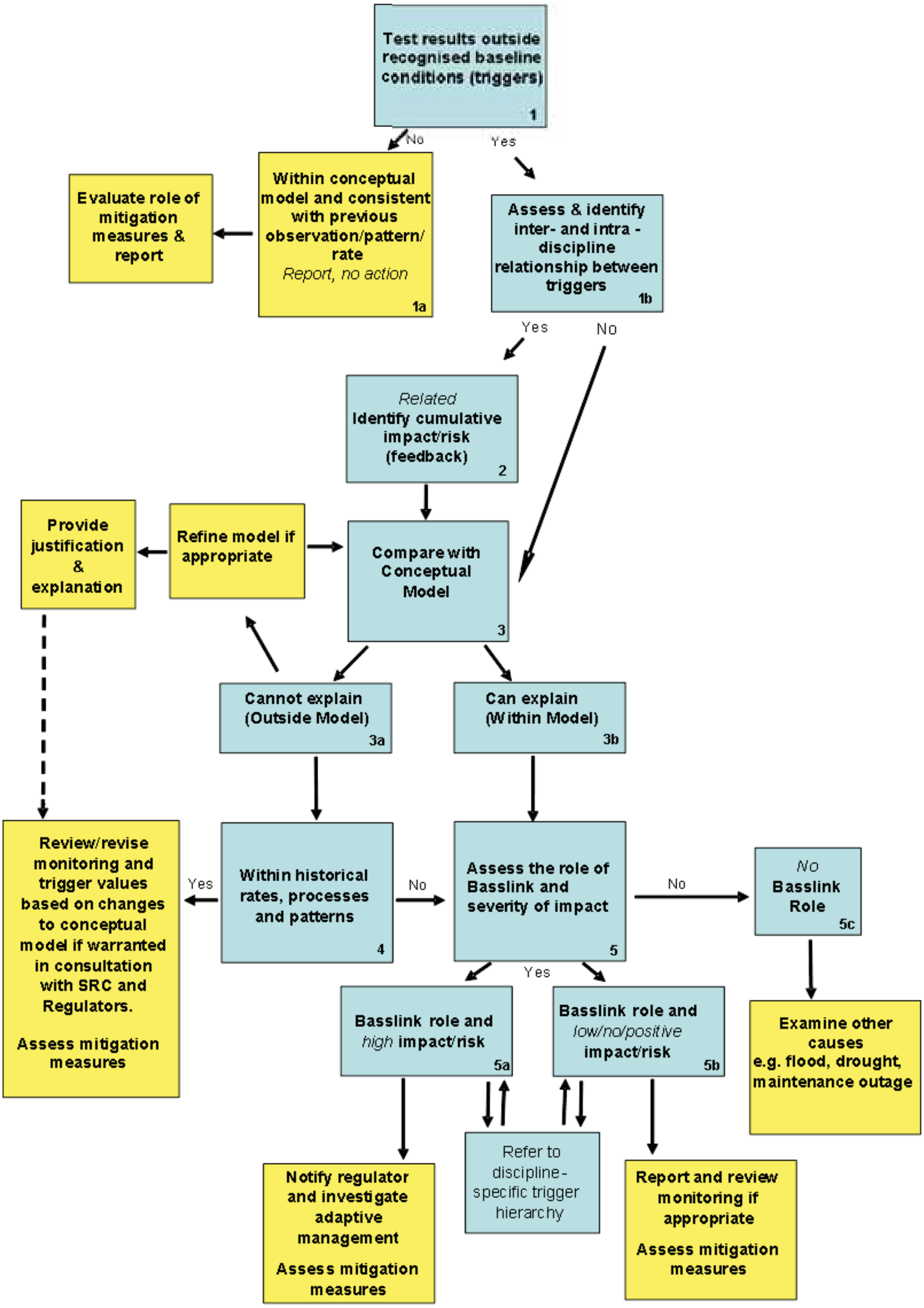

Figure 1.2: Decision tree for interpreting Basslink trigger results. Yellow boxes show outcomes and actions, numbers refer to 'streams' referred to in discussion.

The following steps present the logic underpinning the decision tree, with 2007–08 monitoring results used to provide examples where appropriate, as this was the most notable instance when significant trigger exceedances occurred:

1. Monitoring results are compared to the established trigger values:
    (a) If monitoring results are within the trigger limits, and all observations and documented rates are consistent with previous results, the information is reported and role of mitigation measures assessed, but no futher action is taken. This outcome results when all behaviour is statistically and conceptually consistent with trigger values and the conceptual model.

    (b) Trigger exceedances are compared (qualitatively and quantitatively) to other trigger values within and between disciplines to identify if a relationship exists. This may involve re-examining monitoring results which fall within trigger bounds (as described in ‘a’). If no relationship exists between trigger values, each trigger should be assessed independently.

2. If a relationship or link is identified between triggers, the cumulative impact of the trigger exceedances should be evaluated and any potential feedback relationships identified. The relationships between trigger values may be spatial, temporal or in a process context.

    Example: In 2007–08 vegetation triggers in zones 2 showed signs of increased inundation of quadrats which were previously above the power station operating level. Erosion pin results and field observations in zone 2 suggested increased seepage erosion (net erosion rate within zone 2 remained within the trigger values but was trending towards the limit). Combining this information indicated that over time, seepage erosion led to bank subsidence which caused inundation of areas previously above power station operating level. The cumulative impact of this process was bank subsidence through erosion and appears to have led to increased inundation of vegetation previously located upslope of power station operating levels.

3. The trigger exceedances are compared with the conceptual model to see if the ‘event’ is recognised within the existing model, i.e. can the event be explained by the observed hydrological regime and the understanding of the impacts that this is likely to have.
    (a) If the results are not consistent with the model, i.e. cannot be explained given the hydrological regime and the understanding of the impacts that this is likely to have, refinement of the model may be warranted to enable explaining the trigger exceedance. If so, a detailed justification for reviewing and updating the model should be made in the annual report. Otherwise, proceed to step ‘4’.

    (b) If the results are consistent with the model, i.e. can be explained given the hydrological regime and the understanding of the impacts that this is likely to have, proceed to step ‘5’.

4. The observed hydrology, rates and processes may be compared to historical (pre 2001) hydrology and likely rates and processes under these hydrological conditions. If current rates and processes are consistent with the likely historic values, the trigger values may need to be revised in the long-term to reflect a wider pre-Basslink baseline than captured in the pre-Basslink monitoring years (2001–05). The role of mitigation measures should also be considered when comparing results with likely historical rates and processes. If measured results are not consistent with the likely historic values, proceed to step ‘5’.

5. If the trigger exceedance is within the model and/or outside the likely range of historical rates and processes, the role of Basslink and the severity of impact is considered.

(a) In the event of an impact being considered 'high' and it would be attributed to Basslink related operation, adaptive management should be investigated. Management actions might include increased data analysis of the discipline and hydrology data, increased monitoring, or review of the role of the current mitigation measures.

(b) If an impact is considered to be 'low' and it could be attributed to, or exacerbated by, Basslink affected operations, this would be reported in the annual report along with a watching brief and possible review of the efficacy of mitigation measures. Monitoring would also be reviewed.

(c) If no Basslink role is identified, then alternative causes may be in effect.

Example: Impacts related to non-Basslink events such as floods or extended power station shutdowns would be identified in this step. An example is the large number of landslips identified in zone 5 following the large August 2007 flood event. It is postulated that the flood scoured the denuded banks within the power station operating level which led to the collapse of upslope banks. Power station impacts, combined with the flood event, were the drivers leading to bank failure. Note that there are no trigger values associated with landslips; this event has been identified in photo monitoring which is used to assist the interpretation of trigger results.

In the assessment of the role of Basslink in step '5', the effect of Basslink must be distinguished from other potential impacts. For instance, while the connection to the NEM via Basslink will affect the operation of the power station, other hydrological influences may have a more significant impact on the river. Of these, there are specific events in which Basslink has no role and include the effects on the river caused by floods and/or extended maintenance outages. In the event of impacts to the river, i.e. multiple exceedances of triggers or other lines of evidence where no defined event such as a flood or outage has occurred, a more detailed assessment of the impact of Basslink would occur.

Quantifying the extent to which changes in the operating regime (compared to historic and pre-Basslink operating regime) are affected by Basslink and how these may be of relevance to the identified impact on the river is a complex task. The many other factors affecting hydrology (e.g. inflows, long-term weather, system storage levels, local electricity demand) have varying influences over time on the operation of the power station, and must also be considered as possible contributing factors that influence the discharge patterns to the Gordon River.

1.6 Basslink Review Report 2006–12

This report forms a component of the Gordon River Basslink Monitoring Program, with the following report requirements specified under Hydro Tasmania's Special Water Licence Agreement. These requirements are addressed in this report.

1.6.1 Requirements

The requirements of the Six-Year Review Report, as described in the Special Water Licence Agreement, are to:

1. present trends from the consolidated data collected subsequent to the Basslink Baseline Monitoring Report or the immediately preceding Basslink Review Report
2. evaluate the adequacy of the Gordon River Basslink Monitoring Program, providing refinements if necessary;

3. evaluate the appropriateness and effectiveness of the mitigation measures; and
4. evaluate the appropriateness and effectiveness of any 'limits of acceptable change' (triggers).

1.6.2 Document structure

This review report is presented as a main report (Volume 1) with supporting appendices (Volume 2) attached as a CD. The main report is comprised of 12 chapters divided into three groups.

The three foundation chapters establish the rationale for the report and provide essential background information:

- Introduction;
- Hydrology and water management; and
- Post-Basslink conceptual models.

The hydrology and water management chapter provides an analysis of historical, pre-Basslink and post-Basslink data to examine how post-Basslink power station operations and the associated flow regimes in the river have varied from previous periods. This analysis has been used by the researchers in interpreting the data for the individual disciplines.

Newly developed post-basslink conceptual models are presented which summarise the understanding of the processes of the Gordon River under a range of typically experienced operating patterns that have been seen in the post-Basslink period. These models can be used to understand the expected environmental responses to the dominant discharge pattern.

The discipline chapters present trends of the consolidated data and assess the adequacy of the monitoring program, including evaluation of the triggers. The discipline chapters cover:

- Water quality;
- Fluvial geomorphology;
- Karst geomorphology;
- Riparian vegetation;
- Benthic macroinvertebrates, algae and moss; and
- Fish.

The final integration chapters link the information presented in the discipline chapters through assessment of the appropriateness of the mitigation measures and provide combined conclusions and recommendations at the completion of the Basslink Monitoring Program. The integration chapters are:

- Appropriateness and effectiveness of the mitigation measures;
- Conclusions; and
- Recommendations.

Six appendices on the CD include the following:

- Appendix 1 – General conditions influencing the pattern of Tasmanian generation 2006-12;

- Appendix 2 – Gordon River conceptual model from Basslink Baseline Report (Hydro Tasmania 2005a);
- Appendix 3– Tailrace water quality graphs
- Appendix 4 – Summary of individual geomorphic monitoring sites;
- Appendix 5 – Fish length-frequency data; and
- Appendix 6– Fish metric and hydro-peaking analysis graphs

1.7 Authorship of chapters

The information presented in chapters 2–10 was primarily written by the authors listed in Table 1.1. The efforts and original contributions of these researchers are duly acknowledged.

This document was collated by Malcolm McCausland, Ray Brereton and Stephen Casey of Entura, with internal review from Will Elvey, Ray Brereton, Malcolm McCausland (Entura), Marie Egerrup, Alison Howman, Greg Carson and Gerard Flack (Hydro Tasmania), and significant assistance from the researchers. Nita Marcus (Entura) produced the conceptual model diagrams in chapter 3.

Table 1.1: Chapter numbers, titles and authors of chapters 2–10.

Chapter	Chapter title	Lead Author(s)
2	Hydrology	Malcolm McCausland (Entura)
3	Conceptual models	Marie Egerrup (Hydro Tasmania)
4	Water quality	Malcolm McCausland (Entura)
5	Fluvial geomorphology	Lois Koehnken (Technical Advice on Water)
6	Karst geomorphology	Jenny Deakin (Consultant)
7	Riparian vegetation	Stephen Casey (Entura)
8	Macroinvertebrates, algae and moss	Peter Davies (Freshwater Systems)
9	Fish	David Ikedife (Entura)
10	Appropriateness of mitigation measures	Peter Davies (Freshwater Systems), David Ikedife (Entura), Lois Koehnken (Technical Advice on Water)

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2. Hydrology and water management

2.1 Summary

The hydrology of the post-Basslink period (2006-12) was compared to pre-Basslink (2001-05) and historical periods (1997-2000). The post-Basslink period was characterised as being one of low rainfall and low system-wide inflows and storage levels in the first three years, followed by three years of above average inflows and rising storages. The Gordon Power Station discharge in its six years of post-Basslink operation was characterised by a higher level of variability between and within years, and a lower level of seasonal predictability in comparison to the pre-Basslink and historical periods. During the post-Basslink period there were periods where particular discharge patterns tended to dominate. The first two years of Basslink operation had a high level of hydro-peaking and high discharges. Over the following four years there was an increased presence of low flow operation, with some defined periods of hydro-peaking. These variations in discharge pattern are related to the interaction between factors such as drought, market conditions, inflows, storage levels and the operational strategies underpinning the running of the Tasmanian generation system including the Gordon Power Station. Zero discharge periods were substantially lower in the post-Basslink period relative to previous periods following the implementation of the minimum environmental flow.

The relative contribution of Basslink, as one of several influences, on the hydrology of the Gordon River varied depending on the combination of circumstances. Basslink's influence appears to be one that provides a greater degree of flexibility in the operation of Gordon Power Station, rather than relying on it as a producer of high base load power over summer.

2.2 Introduction

It is the aim of this chapter to present analysis of the hydrological characteristics of the Gordon Power Station discharge that evaluates changes that have occurred since the introduction of Basslink. The hydrology of the six years following the commissioning of Basslink is compared with the hydrology of the pre-Basslink (2001–05) and historical (1997–2000) periods.

The basis for the development of the Basslink Monitoring Program was the expectation that there would be a major change in the operation of the power station towards a discharge pattern dominated by hydro-peaking. It was expected that the discharge would become more 'peaky' creating numerous high flow ramping events as Hydro Tasmania responded to market opportunities in the NEM.

2.3 Factors affecting Gordon Power Station discharge

The operating regime of the Gordon Power Station has always been heavily influenced by a number of factors. A timeline of some of the operational factors influencing the discharge at Gordon Power Station is presented in Figure 2.1. The most common factors affecting operation of Gordon Power Station are:

- inflows to Hydro Tasmania catchments (volume, distribution and sequence);
- overall storage position, in particular, the storage position of Great Lake and Lake Gordon;
- NEM price signals;

- overall energy supply/demand in Tasmania; and
- power station outages.

Of these factors, system-wide inflows have been found in the past to be the most influential on the operation of Gordon Power Station. For instance, it was established in the BBR (Hydro Tasmania 2005a) that dry autumns and wet winters had a major impact on the way in which the power station operated in the pre-Basslink period. Due to the associated low autumn and high winter run-of-rivers operation in other schemes in the Tasmanian hydro power system, this necessitated extended periods of high discharge during autumn and periods of low or no discharge during winter.

In all but four of the last 17 years, Tasmanian electricity demand was higher than the annual yield in the hydro scheme (Figure 2.2). The post-Basslink years began with a continuation of a downward trend in overall storage position until 2007–08 (Figure 2.3). Implementation of the storage rebuild strategy in June 2008, an opportunity made possible by the commissioning of Basslink, resulted in increasing storage levels, as Hydro Tasmania provided less hydro-generated electricity to the market. Consequently there was large net import of power in 2007–08 and 2008–09. As a consequence of increased yields and higher storages, in 2009–10 there was lower net import and in 2010–11, a small net export of power. In 2011–12, hydro generation was reduced from the previous year, while demand was similar. The difference was met by generation from Aurora Energy Tamar Valley (AETV), wind and a small net import of power.

Based on modelling undertaken prior to Basslink commissioning, it was expected that the Gordon Power Station running regime would become extremely ‘peaky’, increasing the number and severity of high to low flow reductions, as Hydro Tasmania was expected to respond to daily market opportunities. After six years of Basslink operation, there have been some changes to the operation of Gordon Power Station, but the anticipated degree of increased peaking operation was not observed. Factors that have influenced the power station operation over the post-Basslink period, resulting in lower than expected hydro-peaking have included:

- drought conditions and associated low water storages, which meant the lower use of Gordon Power Station to maintain storages and maintain Tasmanian electricity security into the future;
- conversion of Bell Bay Power Station to gas-fired generators, and the commissioning of the Aurora Energy Tamar Valley (AETV) gas fired power plant;
- market conditions that do not match assumptions used in the initial modelling; and
- the desire to hold water in storage until the carbon price was finalised.

The number and potential influence of factors on Gordon Power Station operation is vast, and the identification and quantification of the influence of these remains difficult to determine.

Some more specific details on factors influencing the pattern of Tasmania generation between 2006 and 2012 are contained in Appendix 1.

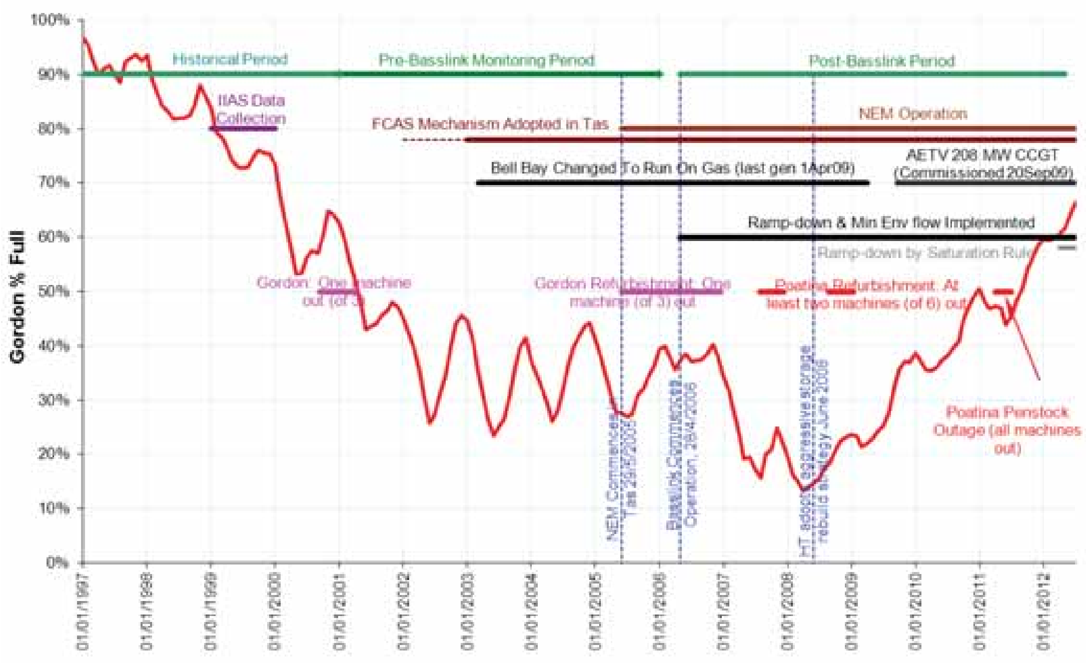

Figure 2.1: Timeline of major factors affecting Gordon Power Station operation (including storage levels) relative to Basslink monitoring periods.

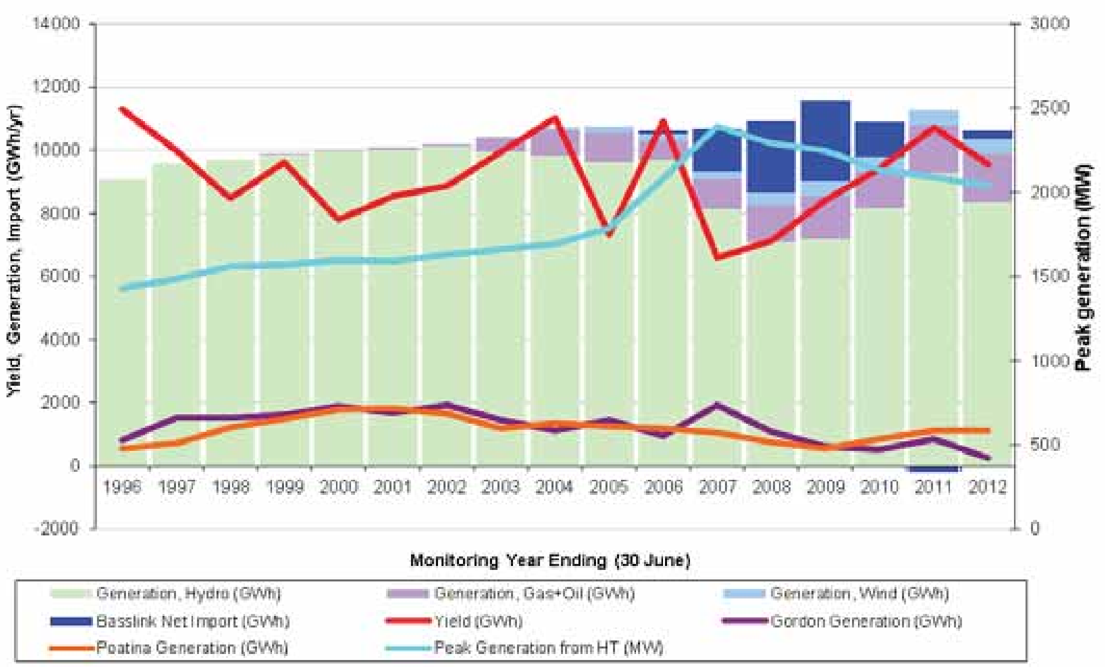

Figure 2.2: Annual Hydro generation, Basslink import, wind and gas generation, Gordon and Poatina generation in GWh and peak demand in MW from 1996–2012. Yield presents system inflows converted to GWh.

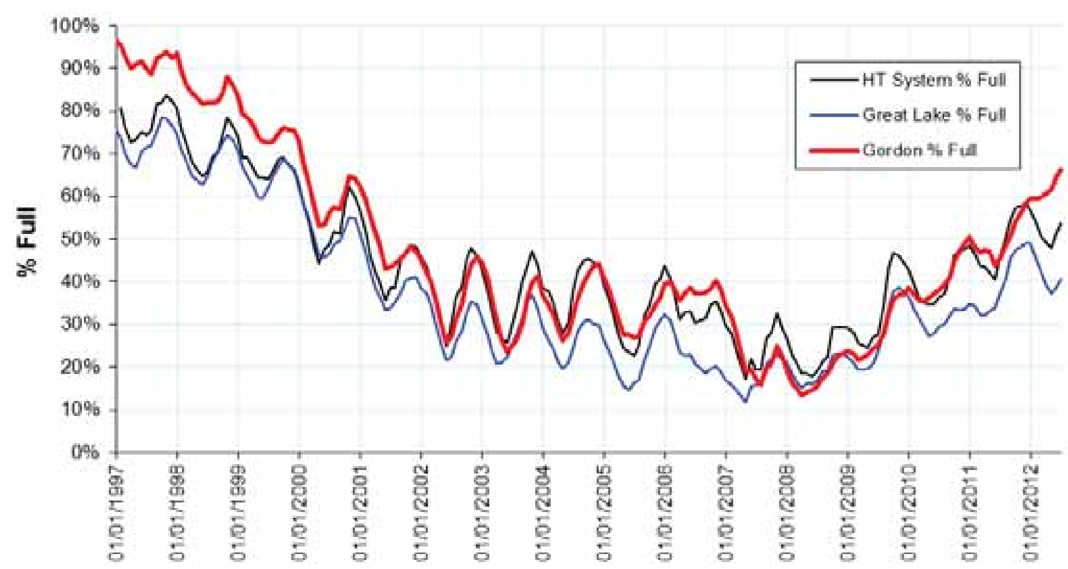

Figure 2.3: Hydro Tasmania System, Lake Gordon and Great Lake water level presented as percent full from 1 January 1997 to 30 June 2012.

2.4 Methods

2.4.1 Gordon discharge data

Due to the complexity of the Gordon tailrace site, there have been some difficulties in obtaining high quality and accurate flow data. As a result of the poor quality of the site rating, flow was initially measured using a two dimensional (2D) rating that converted the known total power output (in MW) to discharge. The rating was used for reporting the discharge from the power station up until 2007-08.

The 2D rating was unable to account for differences in the relationship between discharge and power output caused by lake level variation, and was only accurate over the range of storage levels from which the relationship was derived. A further factor not taken into consideration by this rating was the individual power output to flow relationships of each of the three turbines at Gordon Power Station.

As water levels in the storage reached very low levels in 2008-09, it was recognised that the 2D rating was considerably underestimating discharges. The inadequacy of the 2D rating to accurately determine the discharge across a broad range of storage levels and discharges prompted the use of a 3D rating from 2008-09 which took lake level into consideration, but not individual turbine output.

Further refinement of the 3D model occurred with the development of the stand-alone rating application (GordonRatingApp) in 2010–11. This application mimics the real-time application which was used by the operators to determine ramp-down compliance. It is the most accurate method of determining flow from the Gordon Power Station, and is presented in all analyses in reports from 2010-11 onwards. The GordonFlowApp utilises the following input data to determine discharge from Gordon Power Station:

- machine 1 power output;
- machine 2 power output;

- machine 3 power output;
- storage water height; and
- machine power-discharge rating

The application was run initially to determine discharge based on this rating for all archived records. It is currently run periodically, and has the capability to write the data to the hydrological data base for each five-minute interval.

2.4.2 Data analysis

This report compares the hydrology of the six years following the commissioning of Basslink with the hydrological characteristics of the pre-Basslink and historical periods. These periods are defined as:

- Historical: 1 January 1997–31 December 2000. The start of this period represents when hourly discharge data first became available for Gordon Power Station, and the finish is when the Basslink baseline monitoring began;
- Pre-Basslink: 1 January 2001–31 December 2005. This is the period in which Basslink baseline monitoring was undertaken; and
- Post-Basslink: 1 May 2006–30 April 2012. Basslink was commissioned on 28 April 2006, however this analysis was undertaken from the start of May 2006 for the simplicity of using whole months.

The analysis, though using different starting points in the year has ensured that each period encompasses whole years to remove likely seasonal variations, ensuring that they are comparable. The period between January and April 2006 involved the testing of Basslink prior to commissioning, and has been excluded from analysis as it is considered to be a transitional period.

The hydrological monitoring sites installed as part of the Basslink Monitoring Program are indicated in Figure 2.4.

2.4.2.1 Rainfall and system yield

Strathgordon rainfall and total state wide system yield data was analysed as monthly and annual averages for each of the data periods. In this report, the data is described and the periods compared for both rainfall and system yield to provide a broader hydrological perspective.

2.4.2.2 Annual discharge records and discharge duration curves

Discharge from the Gordon Power Station was plotted as discharge duration curves for each of the data periods. These were also broken down into annual duration curves for each of the years within each data period, to determine the degree of inter-annual variability within each period. Annual discharge curves are presented for each calendar year between 1997–2005 (historical and pre-Basslink periods) as well as duration curves for the periods May 2006–April 2007, May 2007–April 2008, May 2008–April 2009, May 2009-April 2010, May 2010-April 2011 and May 2011-April 2012 (post-Basslink period). Closer analysis of flows <50 m^3s^{-1} is provided for both the Gordon Power Station discharge and the available Compliance site (site 65) data. The flow duration curves are described in Section 2.5.2.2.

2.4.2.3 *Flow pattern analysis*

A qualitative analysis was undertaken to broadly define flow patterns that have been observed in the historical, pre-Basslink and post-Basslink periods. The aim was to provide an analysis of the difference in the type and duration of flow patterns that have occurred in these periods, and in each of the individual years in the post-Basslink period.

This analysis involved the identification of five main flow pattern types observed in post-Basslink period. The hydrograph was then split into 14 day periods. Based on visual assessment of the hydrograph, each 14 day period was assigned the flow pattern that was most dominant during that period.

The patterns were categorised as follows:

- Daily peaking (3 turbine): daily hydro-peaking with troughs < ~40 m^3s^{-1} and peaks >~180 m^3s^{-1}
- Daily peaking (2-3 turbine): daily hydro-peaking with troughs ~150 m^3s^{-1} and peaks >180 m^3s^{-1}
- Daily peaking up to 2 turbines (0-1 turbine, 0-2 turbine, 1-2 turbine peaking): daily hydro-peaking across a range of flows, with troughs ~10-70 m^3s^{-1} and peaks ~70-150 m^3s^{-1};
- Base load (2-3 turbines): constant operation with little flow variation at >180 m^3s^{-1};
- Low flow dominant: a pattern dominated by relatively constant flows between 10-40 m^3s^{-1}; and
- Power station off: no discharge.

The aim was to provide a broad understanding of the period of time for which particular flow patterns were dominant. This information is used where relevant in the individual discipline chapters and in the conceptual model to define the understanding of the impacts of these flow regimes on the physical and biological environment in the Gordon River.

A similar analysis was undertaken specifically for use in the exploration of the influence of flow pattern on the macroinvertebrates. This analysis was undertaken for the 182 day period immediately prior to each macroinvertebrate sampling occasion. This macroinvertebrate analysis is reported in Section 10.2.1.2.

2.4.2.4 *Flow components analysis*

Flow components analysis was undertaken on the flow record for the pre-Basslink and post-Basslink periods. This analysis was undertaken in consultation with discipline researchers to assess the influence of the hydrological regimes in the Gordon River on the various monitoring outputs.

The sites for which the flow components analysis was provided to each of the researchers were:

- Gordon tailrace (site 77) utilising the 3D flow rating;
- Compliance site (site 65);
- Gordon above Franklin (site 44); and
- Franklin River above Mt. Fincham.

The analysis was undertaken for periods of differing length (7, 30, 90 and 365 days) preceding each sampling event for each discipline. The analysis provided a break-down of the total hours of discharge volume delivered for each flow component. The components analysed were:

- very low flow: <10/20 m^3s^{-1}
- low flow: 10/20–40 m^3s^{-1}
- low–mid flow: 40–100 m^3s^{-1}
- mid–high flow: 100–200 m^3s^{-1}
- very high flow: >200 m^3s^{-1}

The primary use of this analysis was to aid interpretation of the individual discipline results relative to the flow regime, and it has been utilised in this manner in the individual discipline chapters where relevant.

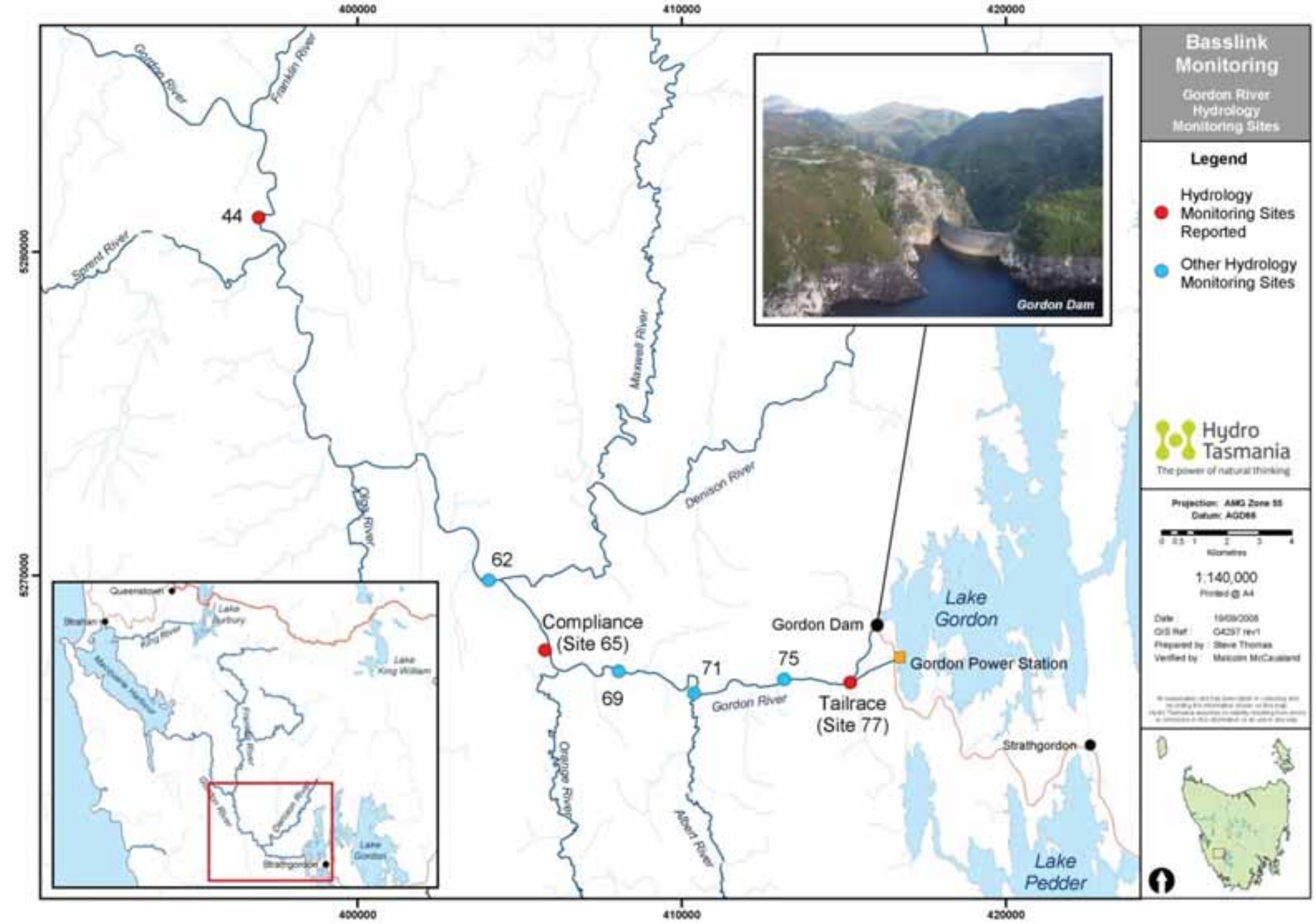

Figure 2.4: Map of the location of hydrology monitoring sites on the Gordon River. The key sites discussed in this chapter are marked with red circles.

2.4.2.5 Flow change frequency analysis

Changes in flow in the 2–3 turbine operating level during the last thirteen years (1997–2012) have been assessed. This information shows how individual periods vary with regard to flow changes above 180 m^3s^{-1}. The information assists with the interpretation of data in the discipline sections, in particular Section 5 - Fluvial geomorphology. Flow change frequency analysis was conducted on the actual data to determine the frequency with which different flow changes occurred, i.e. between one hour's average and the next hour's average[1].

The calculation of the one-hour lag difference was conducted applying the following rules:

- missing data was eliminated;
- only data where the start flow was above 180 m^3s^{-1} was selected; and
- data was ranked and plotted.

This analysis was undertaken for a number of different time periods including by financial year, by six monthly periods and, in post-Basslink period only, by monthly periods. Results of this analysis are presented in Section 2.5.2.7. Further analysis was undertaken for twelve month periods prior to each of the geomorphology monitoring trips and is presented in conjunction with the geomorphology analysis in Section 5 - Fluvial geomorphology.

2.4.2.6 Low to mid-range flow variability analysis

An analysis of the low to mid-range flow variability was undertaken on the Gordon Power Station discharge as a means of defining the 'peakiness' of flows. This was undertaken with specific relevance to the understanding of the influence of a variable flow regime on the macroinvertebrates and fish at the lower flow ranges. This examined the number of occasions when:

- flow reduced below 25 m^3s^{-1}; and
- subsequently increased to greater than 100 m^3s^{-1} within a two-hour period.

The analysis was undertaken for a number of periods (30, 60, 90, 365 days) preceding each of the sampling dates for macroinvertebrates and fish. The data was utilised by researchers in analysis of the likely influence of peaking frequency on macroinvertebrate and fish metrics. The results of these analyses are presented in Section 2.5.2.8.

2.4.2.7 Event analyses

Event analyses were undertaken for the historic, pre-Basslink and post-Basslink periods. The analyses identify the number of times the discharge goes above or below a specific discharge value, and for the period of time that it goes above or below that value. The value of this type of analysis is that it helps to better quantify the short-term variability of flow that is described by a duration curve. The event analyses were undertaken to examine the number and duration of flows that went above 150 m^3s^{-1}, 180 $m^3s^{-1}$and 210 m^3s^{-1}, and the number and duration of flow events that went below 10 m^3s^{-1}, 30 $m^3s^{-1}$and 50 m^3s^{-1}. The results of these analyses are presented in Section 2.5.2.9.

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[1] This method cannot be used to determine conformance with ramp-down rule.

2.5 Results

2.5.1 System yield and rainfall

System yield is a term used to describe water (coverted to an equivalent energy value) captured for hydro-power generation across the entire Tasmanian hydro power system. The system yield for each of the three periods is presented in Figure 2.5. This indicates that of the three periods, the post-Basslink period had the lowest system yield, and was only marginally lower than the historic period. The highest mean system yield occurred in the pre-Basslink period. The greatest variation, and major cause for differences in yields between the periods, occurred in the months between May and September, when the majority of system inflows typically occur.

The low yield over the post-Basslink period was most heavily influenced in the months of June and July, particularly in the first three years (2006-07 to 2008-09) of the post-Basslink period when low system yields were affected by a large reduction in early winter rains (Table 2.1). There was also lower than average yield from October-December. The low inflows in the first three years of the post-Basslink period were characteristic of intense drought conditions in Tasmania. While the most recent three years (2009-10 to 2011-12) saw higher system yields with the breaking of drought conditions (Figure 2.2).

Strathgordon rainfall for each of the three periods is presented in Figure 2.6. Patterns for Strathgordon rainfall are similar to those of system yield and indicate that the highest average annual rainfall was received in the pre-Basslink period, and the lowest in the post-Basslink period. The only month where the post-Basslink period had the highest monthly mean was September. The data indicate that late summer and autumn rainfall was greatest in the historical period, while winter rainfall at Strathgordon was greatest in the pre-Basslink period. Winter rains were particularly low at Strathgordon in the first three years of the post-Basslink period (2006-07 to 2008-09) (Table 2.1) However, greater winter rainfall in the last three years (2009-10 to 2011-12) have resulted in more similar average winter months totals to that of the other periods (Figure 2.6).

A summary of the seasonal and annual rainfall is presented in Table 2.1. Seasonal rainfall analysis utilises all of the same seasons total rainfall data from Strathgordon (e.g. compares rainfall from all summers on record) and where appropriate, categorises these as very dry (<10th percentile), dry (10-20th percentile), wet (80-90th percentile) or very wet (>90th percentile). This is an indicative measure of specific seasonal rainfall; there may be other periods of very wet or dry conditions that cross seasonal boundaries and will not be visible in this classification. Within the post-Basslink period there have been two dry winters (2006, 2007) and one very dry spring (2009) with one very wet winter (2009). There has been one very wet year in the post-Basslink period at Strathgordon (2009). In contrast, the pre-Basslink period is typified by a number of very wet or wet winter (2002, 2003, 2004) and spring (2002, 2003) periods, which contributed to the years 2002 and 2003 being very wet and wet, respectively.

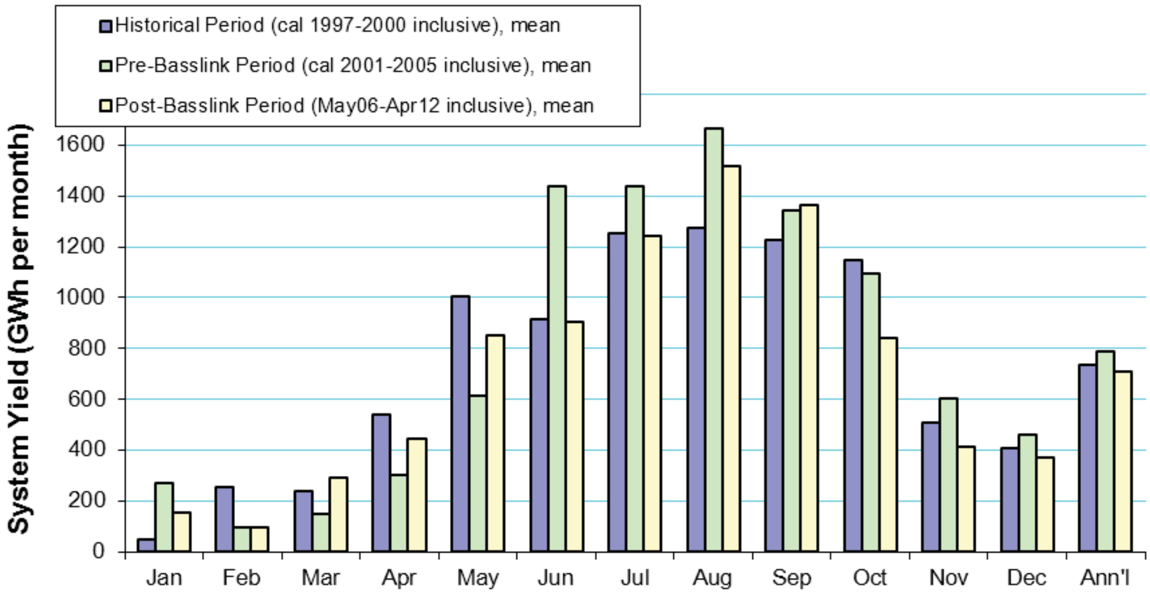


Figure 2.5: Annualised hydropower system yield for each of the data periods (historical, pre-Basslink and post-Basslink). Data presented are mean monthly and average annual yield (expressed as average per month).

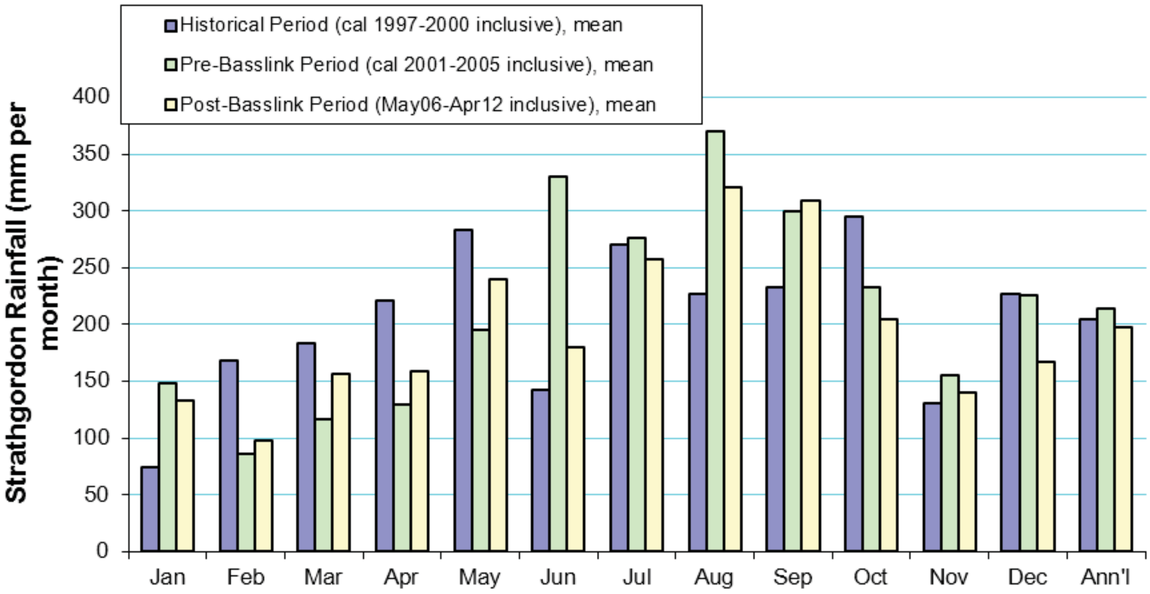


Figure 2.6: Annualised Strathgordon rainfall for each of the data periods (historical, pre-Basslink and post-Basslink). Data presented are mean monthly and average annual rainfall (expressed as average per month).

Table 2.1: Based on rainfall at Strathgordon: summary of very wet (>90th percentile), wet (80-90th percentile), dry (10-20th percentile) and very dry (<10th percentile) seasons and years in the historical, pre-Basslink and post-Basslink periods. Periods not indicated as wet or dry fell within the 20th–80th percentile rainfall limits.

	Year	Annual (Dec–Nov)	Summer (Dec–Feb)	Autumn (Mar–May)	Winter (Jun–Aug)	Spring (Sep–Nov)
Historical	**1997**					Dry
	1998				Dry	
	1999					
	2000			Very Wet		
Pre-Basslink	**2001**			Dry		
	2002	Very Wet		Very Dry	Very Wet	Very Wet
	2003	Wet		Dry	Very Wet	Wet
	2004				Wet	
	2005	Dry				Dry
Post-Basslink	**2006**		Very Wet		Dry	
	2007	Dry			Dry	
	2008	Dry		Dry		
	2009	Very Wet			Very Wet	Very Dry
	2010					
	2011			Dry		
	2012		Dry			

2.5.2 Gordon Power Station discharge and duration curves

2.5.2.1 Power station discharge

Power station discharge for individual years of the historical, pre-Basslink and post-Basslink periods is presented in Figure 2.7 to Figure 2.9. General observations of this data indicate that the historical period had few periods of sustained high flow, and relatively high flow variability through the middle discharge ranges. A more seasonal pattern emerged in the final year (2000) of the historical period. This was characterised by high but variable summer and autumn flows and low winter and/or spring flows. The seasonal pattern continued into the pre-Basslink period (2001–05) however the high autumn flows had little short-term variability.

The post-Basslink period had a generally more variable flow and less consistent seasonal discharge pattern, however there were periods in the first and second years where the seasonal patterns were maintained. Like the seasonal patterns in previous years, much of this high flow occurred in summer, however there were also high discharges that occurred throughout winter and spring 2006, and in large parts of winter and spring 2007. In the third year, the flow regime was distinctly different, with more of a baseline corresponding to the minimum environmental flow release, interspersed with peaks in flow. The flow regime was similar in the fourth and fifth years, with some additional high discharge from January to March 2011. The sixth year differed, having some high discharge in May and June 2011, followed by 3 turbine peaking regime into September 2011. The following period from September 2011 to April 2012 had fewer peaks and a greater period of low flow (minimum environmental flow) operation.

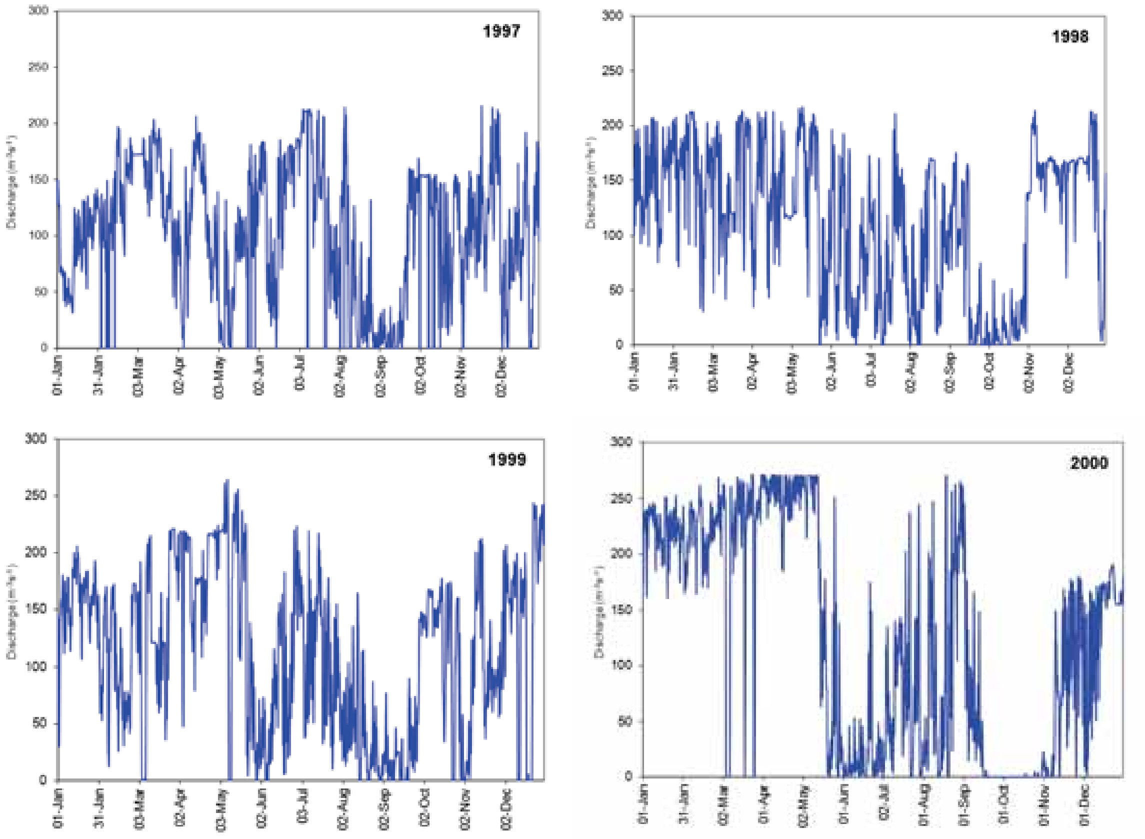


Figure 2.7: Gordon Power Station discharge for the historical data period (1997–2000). Data presented are a twelve hour moving average of hourly data.

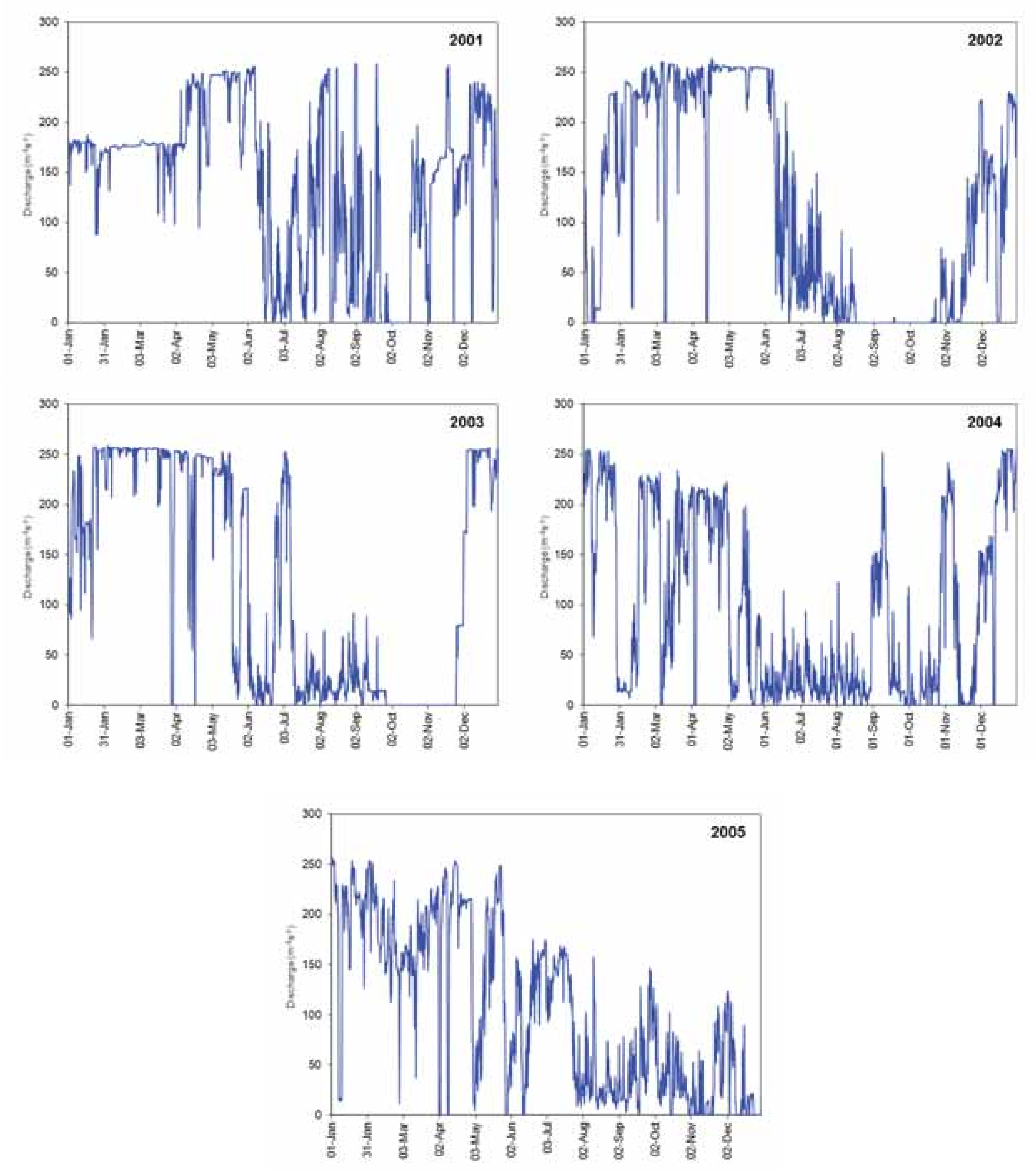


Figure 2.8: Gordon Power Station discharge for the pre-Basslink data period (2000–05). Data presented are a twelve hour moving average of hourly data.

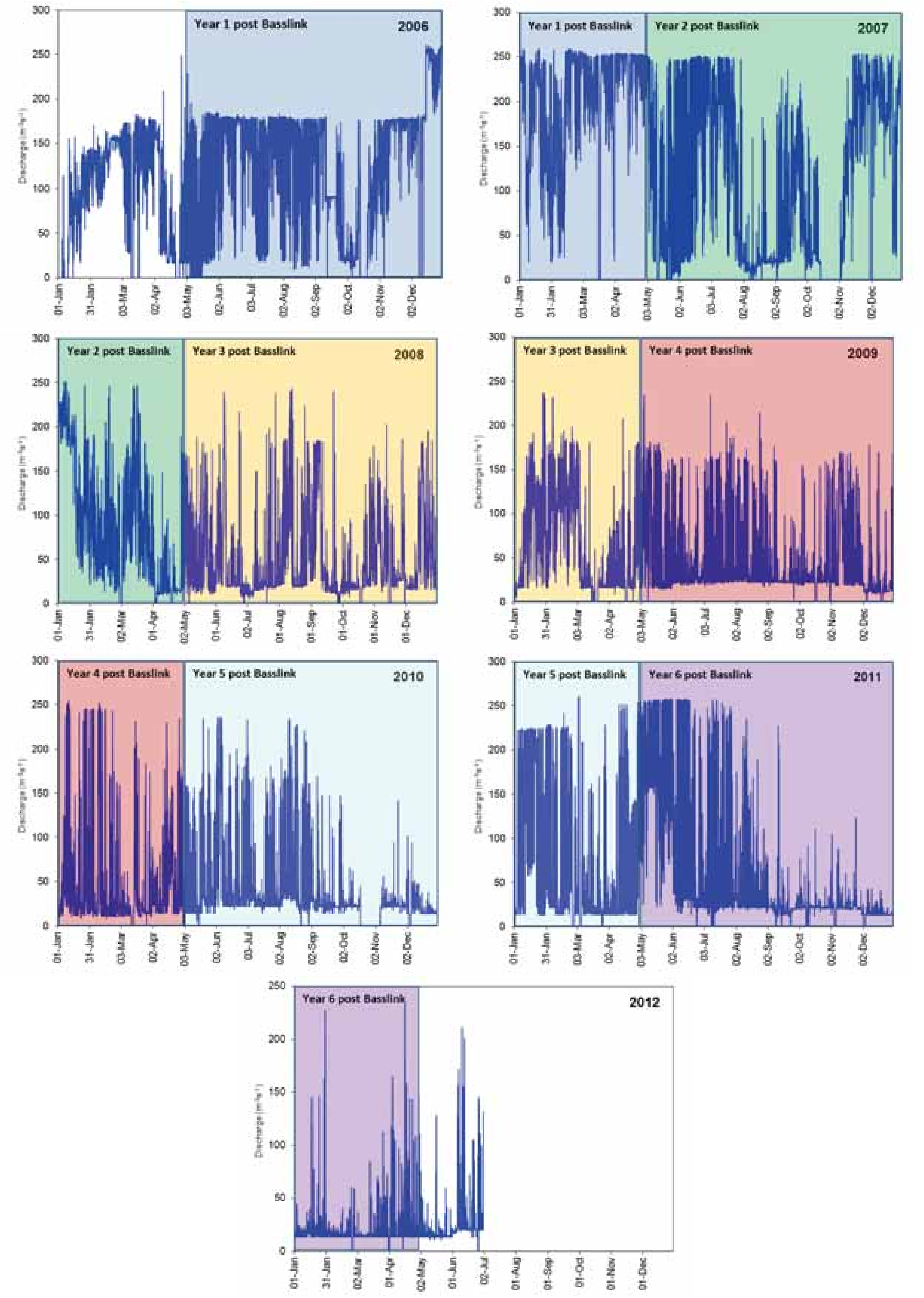


Figure 2.9: Gordon Power Station discharge for the first six post-Basslink years (May 2006-April 2012). Data presented are a twelve hour moving average of hourly data.

2.5.2.2 Period duration curves

The duration curves provide an indication of the differences in discharge between the historic, pre- and post-Basslink periods and are presented in Figure 2.10. These curves summarise flow data for periods of between four and six years (historical, pre- and post-Basslink), and inter-annual variation is smoothed out. The duration curves incorporating the whole-of-year data indicate that there was a greater proportion of flows >180 m^3s^{-1} (32 %) in the pre-Basslink period than the historical (22 %) and post-Basslink (12 %) periods. Flows <10 m^3s^{-1} were rare (4 %) in the post-Basslink period, due to the implementation of the minimum environmental flow. The vast majority of the periods of no flows were due to power station outages for maintenance and environmental monitoring. In contrast, the proportion of flows <10 m^3s^{-1} was substantially higher in the historic (17 %) and pre-Basslink (19 %) periods, and were the result of maintenance and monitoring shutdowns as well as shutdowns when generation was not required at Gordon Power Station.

The winter duration curves are indicative of the lower usage of Gordon Power Station over winter. This was contrary to the predictions of more winter discharge. This lower usage was primarily related to influence of rain at this time of year over the broader hydro-electric system. Run-of-river power stations (e.g. Derwent River cascade) increase their power output following inflows, and it is most efficient to use these power stations at this time, while decreasing the use of larger storages such as Lake Gordon and Great Lake. The winter discharge comparisons are similar to those for the full year of data, and also indicate that there were a larger proportion of time with high flows (>180 m^3s^{-1}) in the pre-Basslink period (16 %) than in post-Basslink (8 %) or historic (12 %) periods. Winter was the period where the greatest differences were seen in the low flows (i.e. <20 m^3s^{-1}); for example, flows <10 m^3s^{-1} in the post-Basslink period accounted for 5 % of the time, while the pre-Basslink and historical periods each had 28 % of the time where discharges were <10 m^3s^{-1}.

The summer duration curves are most notable for the long duration of high flows (>180 m^3s^{-1}) in the pre-Basslink and historic periods (48 % and 32 % of discharges >180 m^3s^{-1}, respectively).Gordon Power Station was often operated in the pre-Basslink period as a source of relatively constant, baseload power. The summer discharge pattern in the post-Basslink period was more similar to the winter post-Basslink discharge compared to the historical and pre-Basslink periods. An obvious stepped pattern was seen for the pre-Basslink data that indicates flow rates were maintained within specific discharge ranges (150–180 m^3s^{-1} and 210–250 m^3s^{-1}) for a large proportion of time. These ranges relate to the efficient running load of 2 and 3 turbines respectively. Patterns are not as obvious in the post-Basslink duration curves, however there was a small step indicating increased duration of flow at a level just below 180 m^3s^{-1}, that was likely to be related to the operation to avoid the need to invoke the original ramp-down rule in the early part of the post-Basslink period.

The shape of the duration curves indicates that in the post-Basslink period there has been a much lower volume of water discharged from Gordon Power Station. This has been due to the increased occurrence of periods of low discharge and reduced baseload (3 turbine) operation.

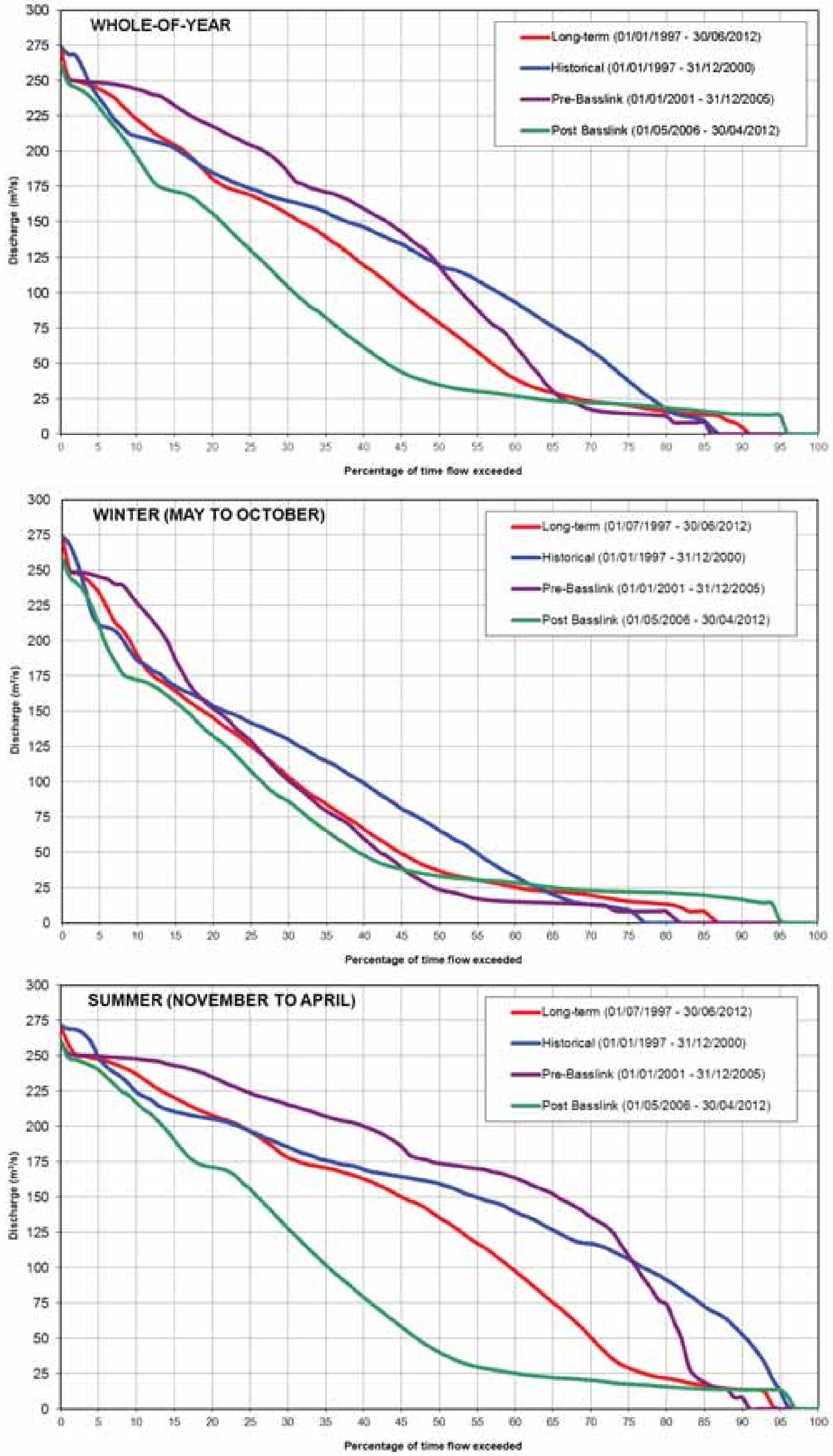


Figure 2.10: Flow duration curves for the Gordon Power Station discharge for data from all year, winter and summer for pre-Basslink, post-Basslink, historic and long-term periods.

2.5.2.3 Annual duration curves

By breaking down the historical, pre- and post-Basslink duration curves into annual duration curves (Figure 2.11), inter-annual variability can be shown.

Historical (1997–2000) inter-annual variability inflow was limited, with only 2000 having any difference from the other three years. The year 2000 had an extended period of high power station discharge over autumn (March–May 2000) that was influenced by the unusually low system wide inflows at that time, and an extended period where the power station had no discharge over spring, hence its bi-modal appearance. The other years in this period had relatively variable discharge, and this is indicated in the general lack of a ‘flat spot’ on the duration curves.

There was some clear inter-annual variability for the pre-Basslink period. The year most unlike any other within this group is 2001. This year was affected by a machine outage at the Gordon Power Station that limited discharge to two turbines for much of the year (Figure 2.1). The flow duration curves indicate long periods of discharge at around the 2 turbine level in the range of 150–180 m^3s^{-1}. The years 2002 and 2003 were more bi-modal and indicative of extended 3-turbine discharge during summer and periods of little or no discharge during winter or spring. The years 2004 and 2005 had duration curves indicating more variable flow, with some less obvious ‘flat spots’ in the curve, and less operation at high discharge. The lower occurrence of high discharge in 2005 is influenced by a large period of this year where only two turbines were available for operation due to refurbishments at the power station (Figure 2.1).

The post-Basslink duration curves were the most variable of the three periods. In the first year post-Basslink (May 2006–April 2007), there was a long period where discharges were around 175 m^3s^{-1}. This was primarily due to the fact that discharges during the first seven months were limited to the capacity of two turbines, during the power station refurbishment. Despite this, it is clear that there were long periods of near maximum available discharge through much of the first year post-Basslink. The second year (May 2007–April 2008) had had shorter duration of high discharge (>180 m^3s^{-1}) and an increase in mid to low range discharges (<150 m^3s^{-1}) in comparison to the first year. Years three (May 2008-April 2009) and four (May 2009-April 2010) post-Basslink had a low proportion of high discharges (>180 m^3s^{-1}; 2 % and 3 % respectively) and a high proportion of low flows (< 50 m^3s^{-1}; 73 % and 59 %, respectively). The fifth (May 2010-April 2011) and sixth (May 2011-April 2012) years post-Basslink had an increase in the proportion of higher flows compared to the third and fourth year (>180 m^3s^{-1}; 8 % each), and the highest periods of low discharge in the post-Basslink period (<50 m^3s^{-1}; 75 % and 82 % respectively), with little discharge in the mid-ranges.

The shape of the duration curves indicates that in the post-Basslink period there has been a much lower volume of water discharged from Gordon Power Station. This has been due to the increased occurrence of periods of low discharge and reduced baseload (3 turbine) operation.

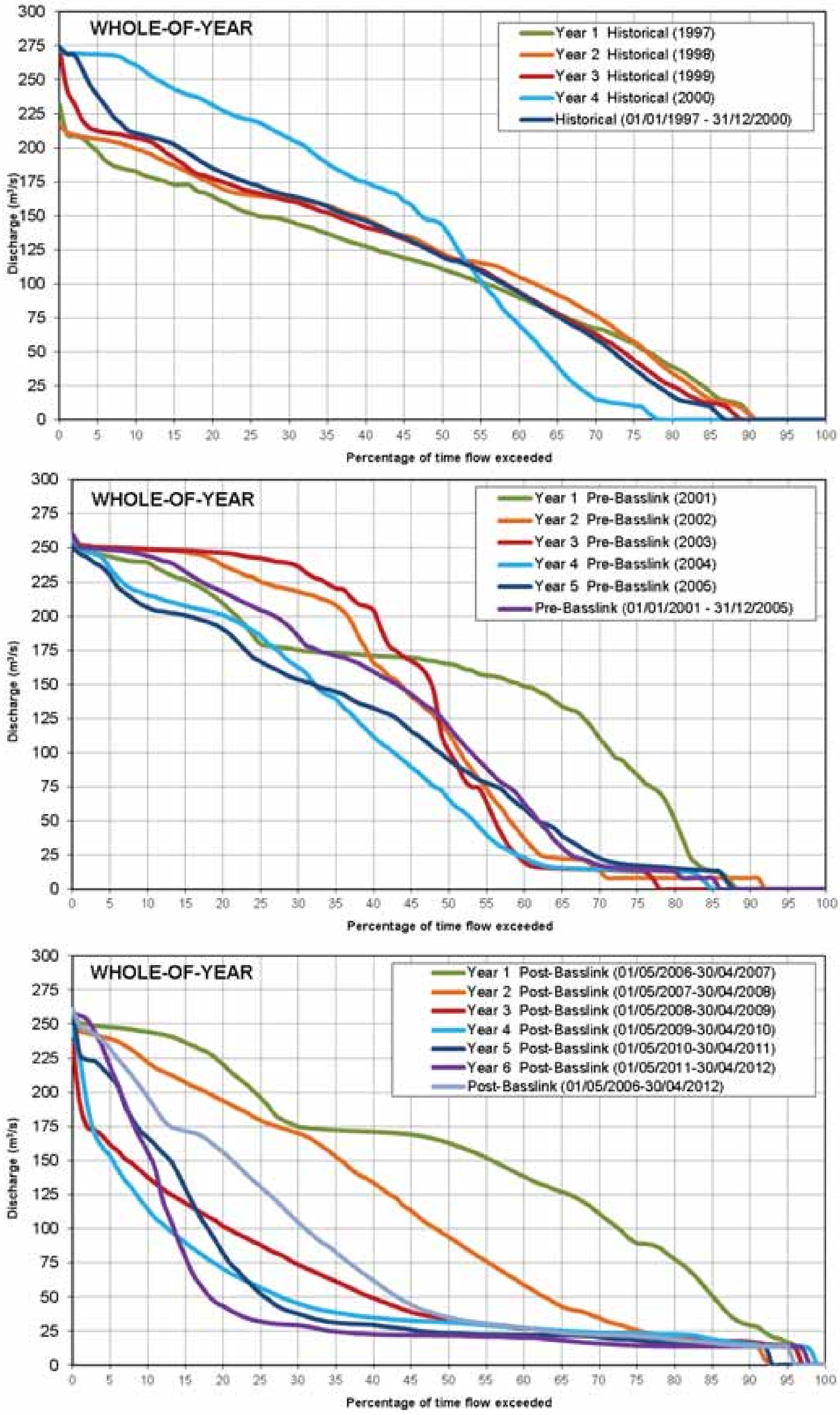


Figure 2.11: Annual duration curves for the Gordon Power Station discharge, separated into historical, pre-Basslink and post-Basslink periods.

2.5.2.4 Duration of low flows

Closer analysis of annual duration curves from the Gordon Power Station and site 65 (Compliance site) in the range <50 m^3s^{-1} is presented in Figure 2.12 and Figure 2.13. It is evident that there were greater periods in the historical and pre-Basslink years when there were power station discharges close to zero. In the historic period, the portion of flows where discharge was less than 1 m^3s^{-1}, ranged from 8 % (in 1997) to 22 % (in 2000). All years in the pre-Basslink period had a large portion of discharge <1 m^3s^{-1} ranging from 12 % (in 2005) to 29 % (in 2002). The post-Basslink period had a smaller portion of flows <1 m^3s^{-1} ranging from 2 % (in 2009–10) to 8 % (in 2007–08 and 2010-11). The incidence of a greater proportion of low flows in 2007–08 and 2010-11 was heavily influenced by three week maintenance outages in October 2007 and October 2010. The lower proportion of discharges close to zero in the post-Basslink years is clearly a result of the implementation of the minimum environmental flow.

The duration curve from the power station in the <50 m^3s^{-1} range in the post-Basslink period has ‘flat spots’ in 2007–08 in the 10–15 m^3s^{-1} and 20–22 m^3s^{-1} ranges indicating an intent to remain close to the minimum environmental flow.

Available annual data (from 2004) for the site 65 indicate that, the post-Basslink period had fewer flows less than 20 m^3s^{-1} (4–10 %) compared to the two years for which data is available in the pre-Basslink period (12–21 %). The ‘flat spots’ obvious in power station discharge are smoothed due to catchment pick-up between site 77 and site 65.

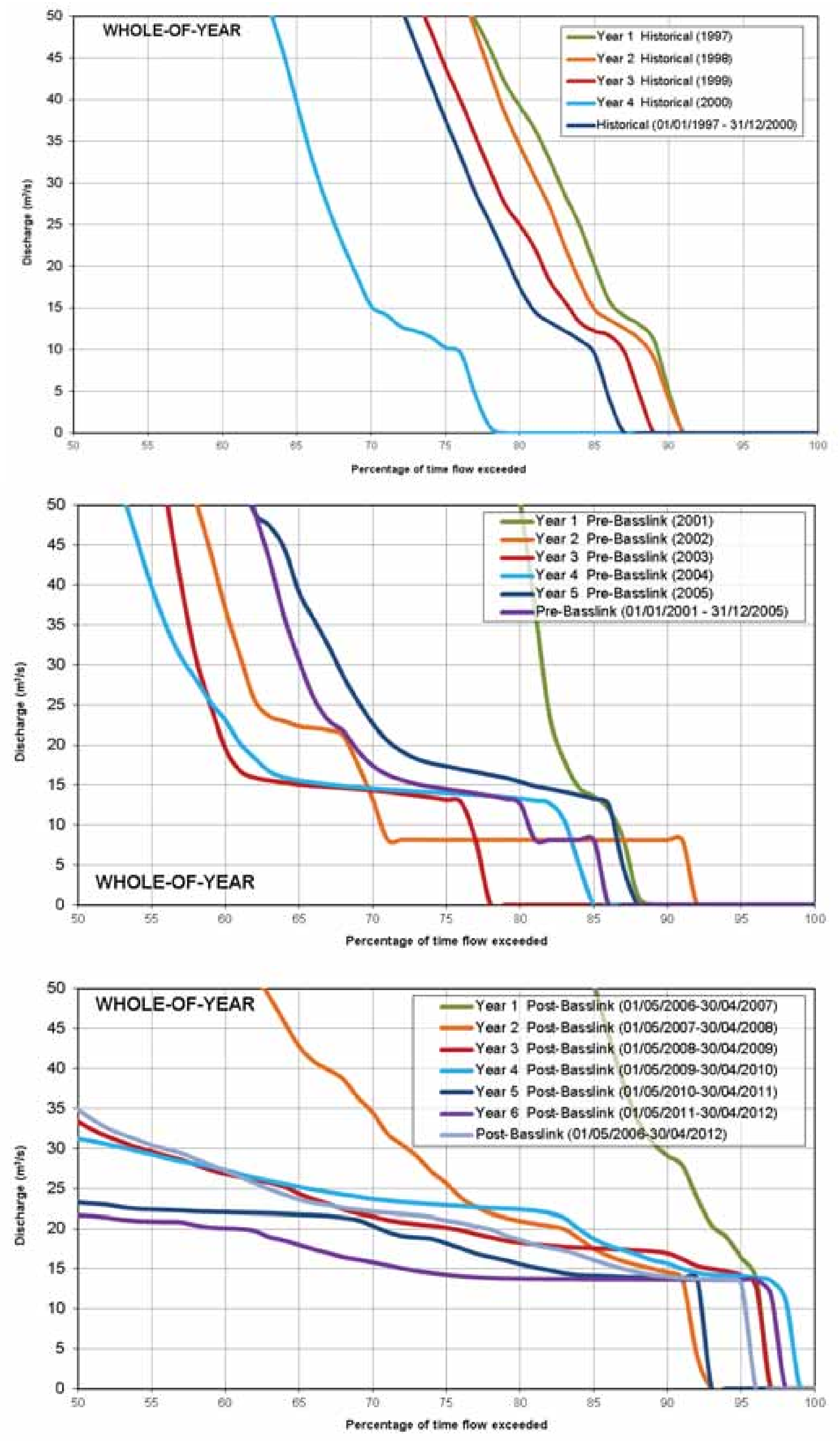


Figure 2.12: Annual duration curves for the Gordon Power Station discharge, focussed on the lower flows (<50 m^3s^{-1}) and separated into historical, pre-Basslink and post-Basslink periods.

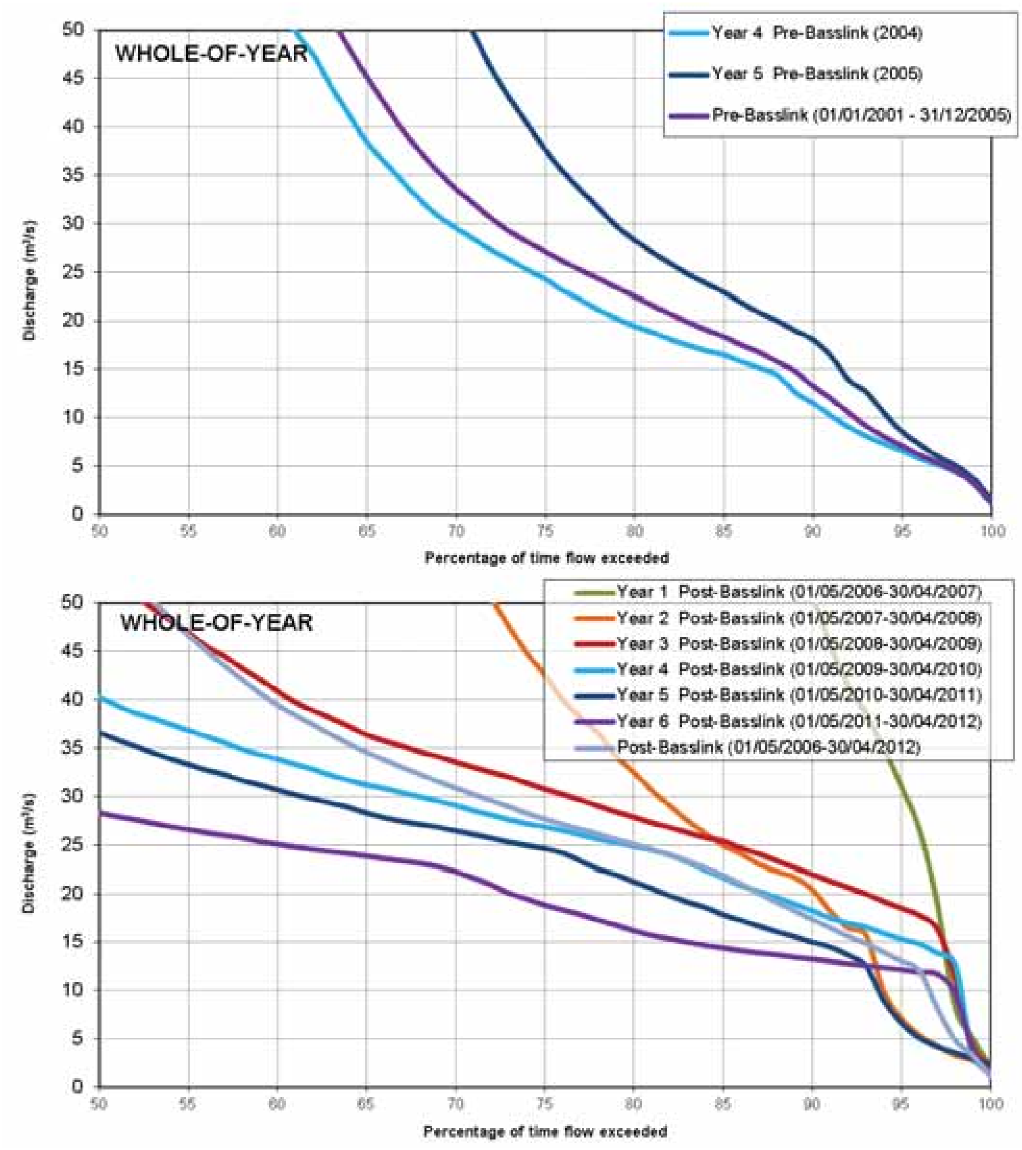


Figure 2.13: Annual duration curves for site 65 (Compliance site) for years where data is available, focussed on the lower flows (<50 m^3s^{-1}) and separated into pre-Basslink and post-Basslink periods.

2.5.2.5 *Flow pattern analysis*

The qualitative flow pattern analysis has been undertaken to identify the general pattern of power station operation and the proportion of use of the main discharge patterns. Examples of the five pattern types of power station operation are presented in Figure 2.14. These examples were compiled from the Gordon Power Station discharge hydrograph.

The results of the flow pattern analysis are presented in Figure 2.15 to Figure 2.17. The method uses a qualitative approach to define the dominant discharge pattern and is useful for describing the general patterns of discharge. The method has been used to broadly describe the changes in discharge pattern that have been observed in the post-Basslink period.

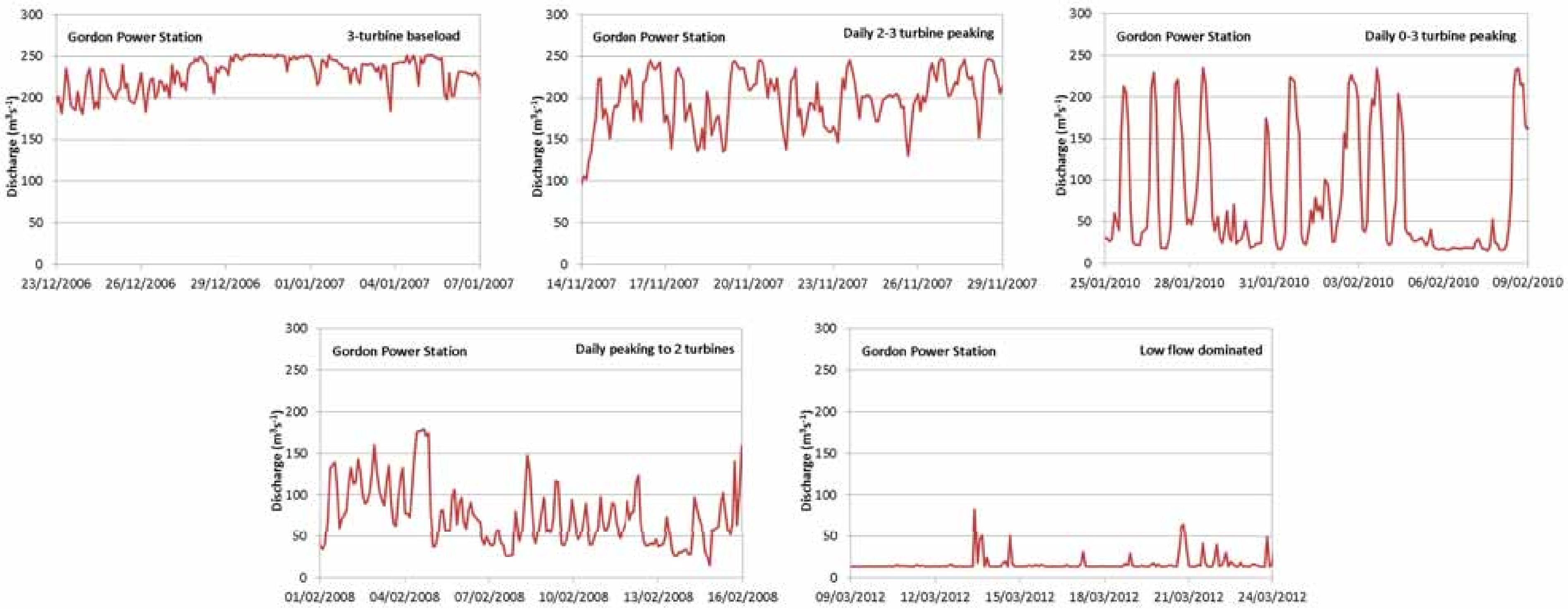


Figure 2.14: Examples of five typical flow patterns observed at the Gordon Power Station in the post-Basslink period.

The historical and pre-Basslink periods were similar in many respects, having the same basic patterns of operation, but with some differences in the proportion of time in which these patterns were observed to operate. Both the historical and pre-Basslink periods had a high proportion of daily peaking to 2 turbine discharge (48 and 49 %, respectively). Three turbine baseload operation was a prominent flow pattern of the pre-Basslink period accounting for 27 % of the fortnightly observations of the hydrograph. This was higher than the historical period, which had only 11 % of the observation of baseload pattern. The historical and pre-Basslink periods also had a large proportion of 2-3 turbine peaking (20 % and 11 % respectively), and each had a period of 0-3 turbine daily peaking (11 and 3 %, respectively). Power station off was a pattern observed for a large proportion of both periods (10 % each).

The post-Basslink flow patterns contrast with the preceding periods. The major difference is the presence of a large proportion of observations of a low flow pattern (29 %), which has been introduced predominantly as a result of the minimum environmental flow. The post-Basslink period has seen some of the operating regimes that were predicted to occur, while others differ from the original TEMSIM predictions as follows:

- increased proportion of low flows (as predicted);
- much lower proportion of power station off observations (due to the minimum environmental flow);
- greater proportion of 0-3 turbine daily peaking observations (as predicted);
- low proportion of baseload (continuous 3 turbine) operation and associated lower periods of high discharge (not as predicted); and
- increased inter-annual variability (not as predicted).

In general terms it could be said that there are a number of recognisable operating patterns that have been observed in the post-Basslink period. The most dominant over the six years has been daily peaking to around the 2 turbine level, followed by the low flow pattern. The three turbine peaking is the next most common pattern. The use of these operating patterns has not been consistent over time, and can be observed by looking at each of the individual years.

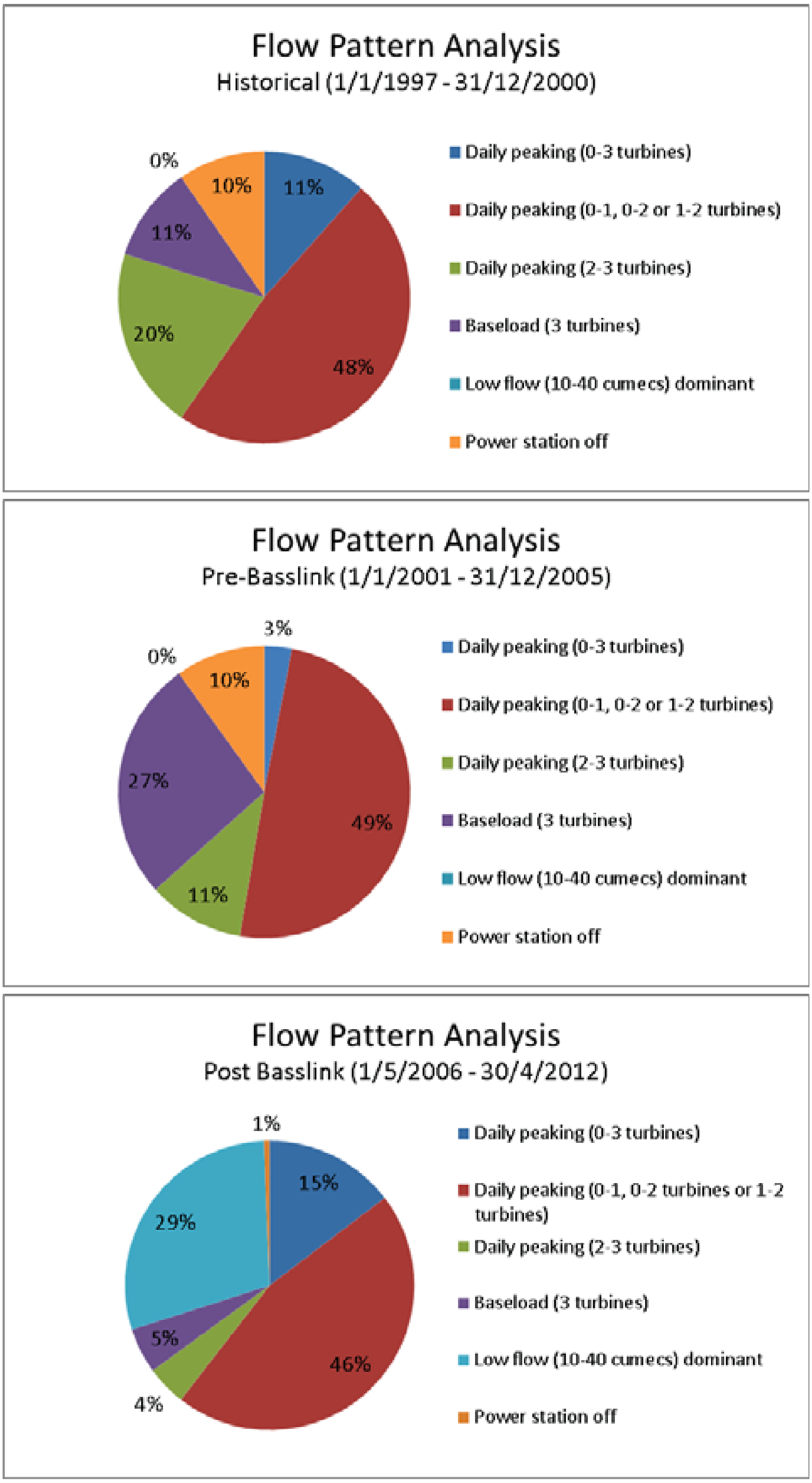


Figure 2.15: Comparison of flow patterns observed in a qualitative analysis of the Gordon Power Station discharge for historical, pre-Basslink and post-Basslink periods.

The individual annual post-Basslink flow patterns (Figure 2.16 and Figure 2.17) demonstrate the large annual variability that has occurred since the commissioning of Basslink, which is also visible in the hydrograph. It indicates that:

- Year one was strongly dominated by daily peaking up to two turbines. This was influenced by the availability of only two turbines for a substantial period of the year. There was also substantial 3 turbine baseload and 2-3 turbine daily peaking operation;
- Year two was less dominated by the peaking to two turbines, with a greater variability in flow patterns over the year. There was a greater proportion of the daily 2-3 turbine peaking, as well as 0-3 turbine peaking. The greater period of the low flow dominated pattern is indicative of the influence of the minimum environmental flow on the discharge;
- Years 3 and 4 were similar, both having substantially reduced 3 turbine peaking or little operation to 3 turbines and much increased operation of the low flow pattern. This was influenced by the storage rebuild strategy;
- Year 5 had the highest proportion of 0-3 turbine peaking of all annual periods, which replaced peaking to 2 turbine discharges. Similar to year 4, there was also a high proportion of low flow dominated pattern. A small power station off period was the result of an extended power station maintenance outage; and
- Year 6 was dominated by the low flow pattern, accounting for 62 % of fortnightly observations. The 0-3 turbine pattern remained a major pattern, while peaking to lower discharges (1 and 2 turbines) was utilised to a lesser in this year.

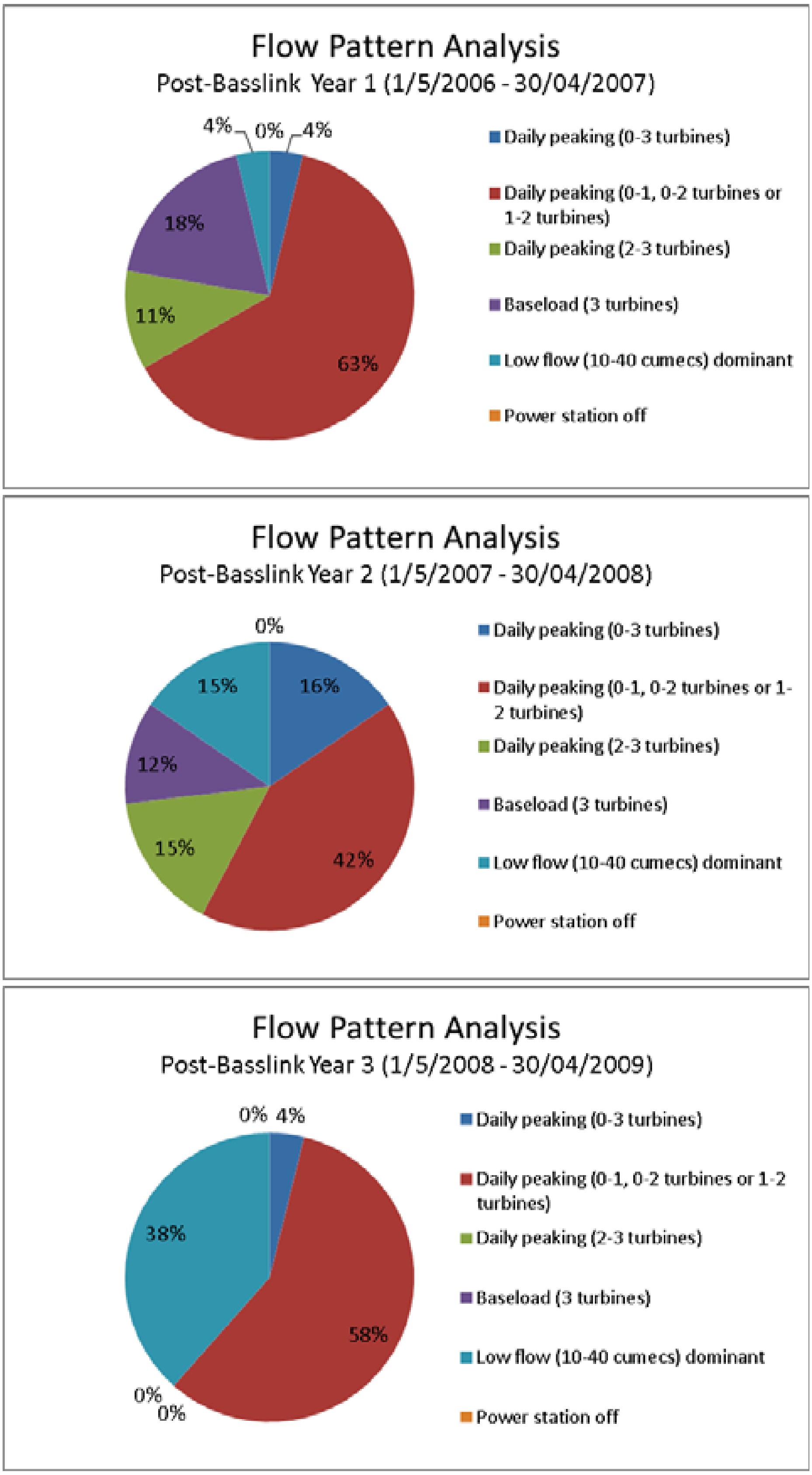


Figure 2.16: Proportion of flow patterns observed in a qualitative analysis of the Gordon Power Station discharge for years 1-3 of the post-Basslink period.

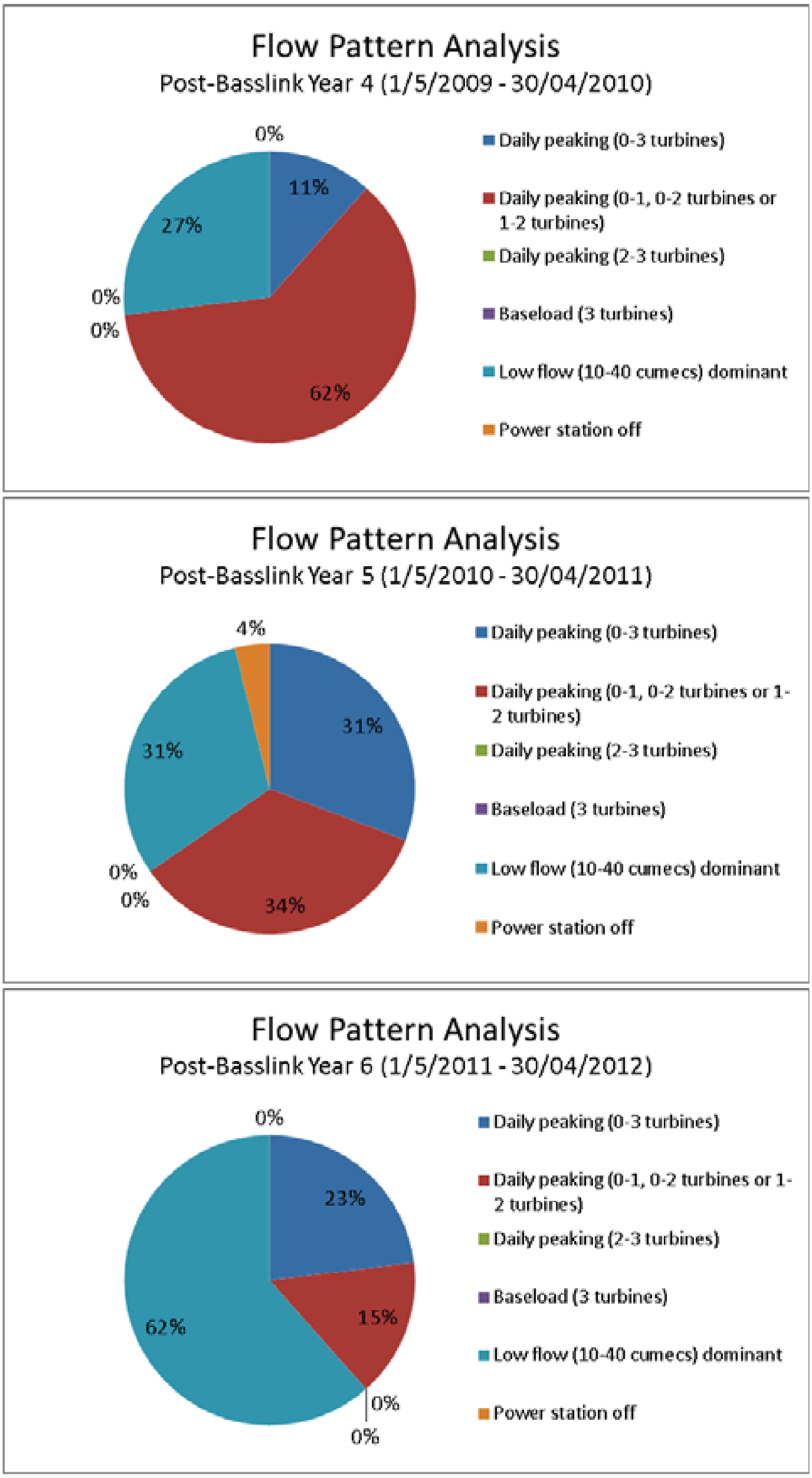


Figure 2.17: Proportion of flow patterns observed in a qualitative analysis of the Gordon Power Station discharge for years 4-6 of the post-Basslink period.

2.5.2.6 Flow components analysis

The flow components analysis was undertaken for the purpose of undertaking statistical analyses in relation to data collected for each of the disciplines. The data provided against which discipline specific field data could be tested consisted of a different analysis examining the flow in the preceding 7, 30, 90 or 365 days prior to each discipline sampling event. Figure 2.18 and Figure 2.19 are examples of the data provided to researchers for the purpose of the analysis which shows components of the Gordon Power Station discharge for the 365 day period prior to each spring and autumn macroinvertebrate/geomorphology sampling event.

Of the data provided to researchers, the flow period showing the strongest correlations with the field data for geomorphology and riparian vegetation tended to be 365 days (e.g. see Section 5.4.5 and Section 7.4.4), while the relationships to flow were more pronounced over the shorter 90 day period for macroinvertebrates (see Section 10.1.1.3), and a 30 day period for fish (see Section 10.2.2.1).

Hydrologically, the results demonstrate that, during both the pre-Basslink and post-Basslink periods, there were large variations in the 365 days before each sampling date in both the proportion of time and the volumetric contribution by the different flow components. The variations in the post-Basslink period between sampling periods were, however greater than those in the pre-Basslink period.

In the post-Basslink period the 365 days prior to October 2007 the >200 m^3s^{-1} flow component contributed over half of the total flow (and 33 % of the time). This is the highest contribution in the post-Basslink period for the >200 m^3s^{-1} flow category, with the 12 months prior to October 2006 and October 2009 contributing the lowest total flow (1 % and 1.5 %, respectively) and proportion of time (both <0.4 %). The low and very low flows components (<40 m^3s^{-1}) increased in duration during the post-Basslink period, and combined with a large decrease in high discharges, led to this flow class contributing between 26 % and 33 % of total flow volume (66-68 % of time) for the year preceding sampling dates between March 2009 and February 2012.

Trends in total flow volumes over the monitoring period indicate there were much lower flow volumes in the 12 month periods prior to sampling events in the latter part of the post-Basslink period between March 2009 and February 2012 (Figure 2.18). Total volume discharged from Gordon Power Station, in the 365 days prior to these dates, were between 1500 and 2100 GL. This volume was much lower than the early part of the pre-Basslink period which is evident from the higher volume of flow recorded in the 365 days prior to sampling between March 2007 and October 2008 (between 2600 and 4600 GL). In the historic and pre-Basslink periods the total volume discharged in the 365 days prior to sampling events showed some large variation (between 2700 and 4400 GL). The highest of these total flows were seen throughout the historic period and early part of the pre-Basslink section. On the whole flow volumes in the historic and pre-Basslink periods were similar to total flows observed in the early part of the post-Basslink period (March 2007 and October 2008).

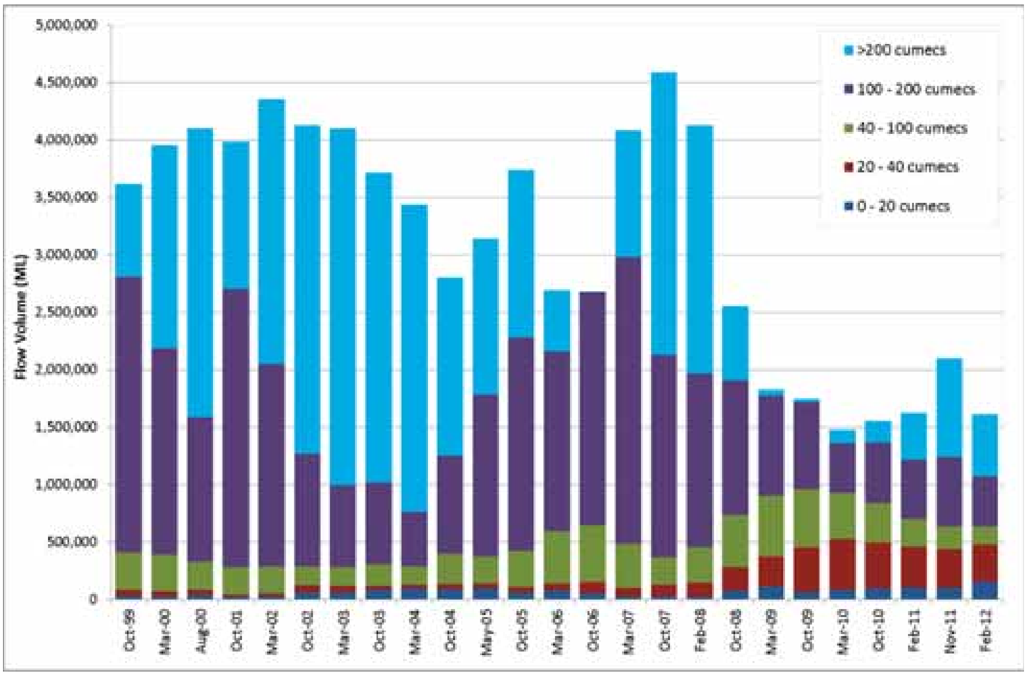


Figure 2.18: Volume discharged within specific flow ranges and total flow from the Gordon Power Station over previous 365 day period prior to the sampling dates for geomorphology, macroinvertebrate, algae and karst monitoring.

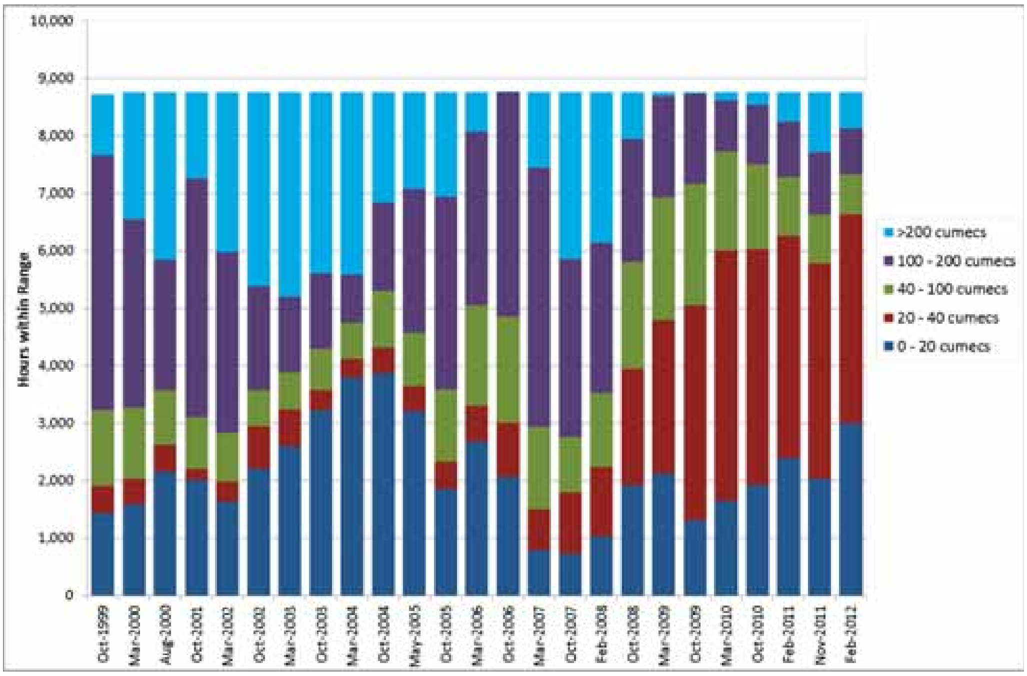


Figure 2.19: Hours of operation within specific flow ranges from the Gordon Power Station over previous 365 day period prior to the sampling dates for geomorphology, macroinvertebrate, algae and karst monitoring.

2.5.2.7 Flow change frequency analysis

The flow change frequency analysis is displayed for the six months preceding each April and October for the available flow record (Figure 2.20 to Figure 2.22). This analysis was initially undertaken to examine the possible links between hydrology and observations of increased seepage erosion and trigger exceedances in both the geomorphology and riparian vegetation disciplines in 2007-08. This analysis plots the ranked data for rates of change in flow for flows greater than 180 m^3s^{-1}. The analysis indicates that of the six month periods since hourly data were available the periods with the greatest high flow reduction from >180 m^3s^{-1} were April-October 2007 and April-October 2011. The implementation of the ramp-down rule is evident mainly in April to October 2011 (Figure 2.20), with an obvious flat spot between 28 and 30 m^3s^{-1}.

The monthly analysis of this data in the post-Basslink period indicates that the periods of high flow change from flows above 180 m^3s^{-1} were most highly concentrated around the end of year 1 and the beginning of year 2 in the post-Basslink period (January – July 2007), with monthly cumulative periods of high flow reduction often of 20 hours, and the highest of periods of 52 and 45 hours in June and July 2007 respectively (Figure 2.22). These reductions tended to coincide with the high use of 2-3 turbine peaking which was used to minimise the need to use the original ramp-down rule.

Reflective of the 6-monthly data, the second concentration of such flow reductions occurred at the end of year 5 and beginning of year 6 (January - July 2011). The maximum number of high flow reductions were seen in May 2011 which had 37 hours of such flow reductions (Figure 2.22). These reductions were the result of dominance by 1-3 turbine peaking with some 2-3 turbine peaking operation.

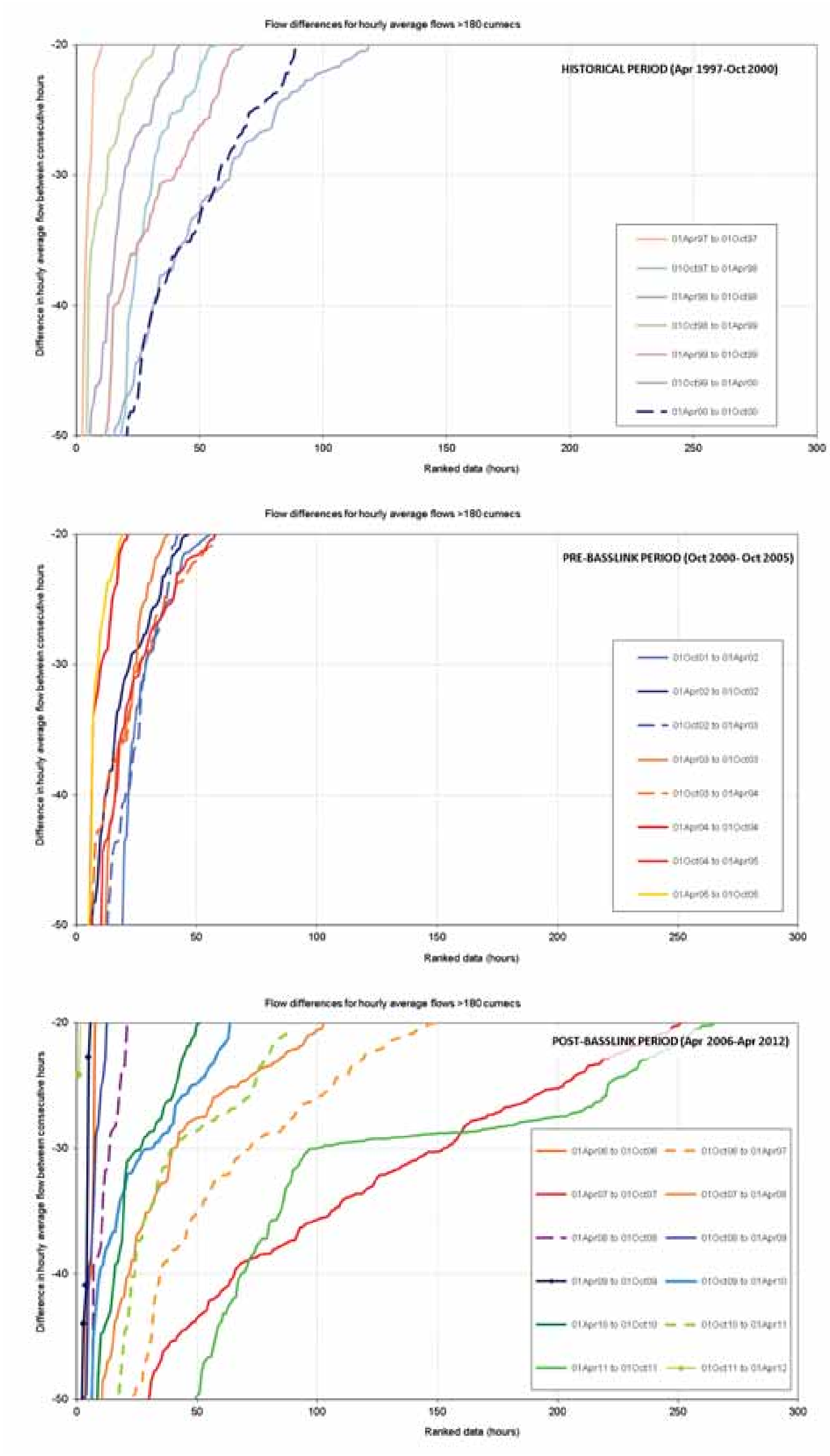


Figure 2.20: Flow change frequency plots showing the ranked rate of flow reductions data for six month periods occurring while power station discharge was greater than 180 m^3s^{-1} for historical, pre-Basslink and post-Basslink periods.

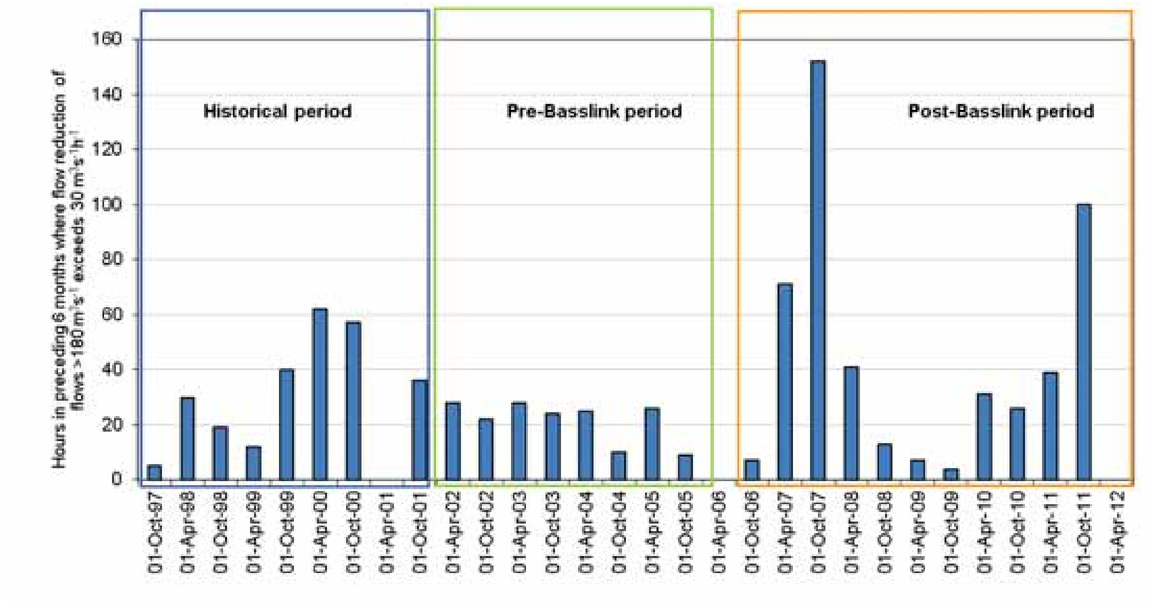


Figure 2.21: Number of hours for each prior six-month period where flow reductions from >180 m^3s^{-1} exceed 30 m^3s^{-1} per hour.

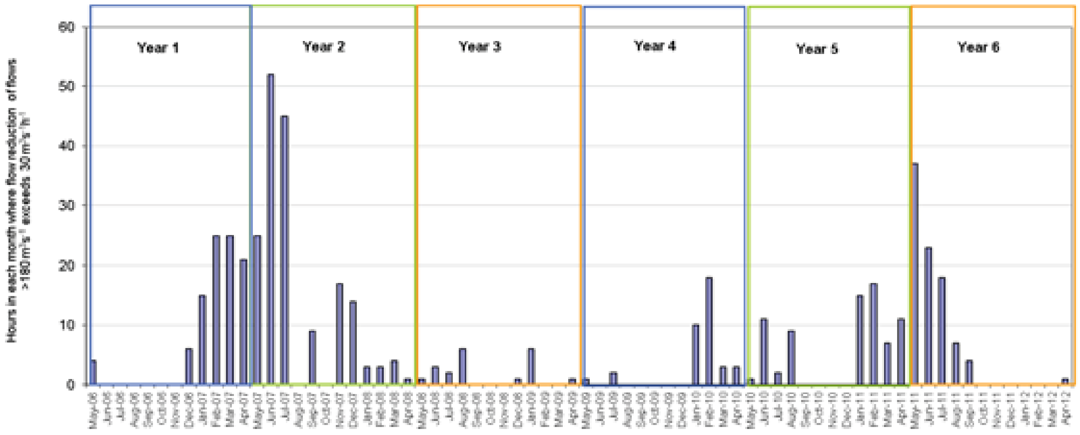


Figure 2.22: Number of hours for each-month of the post-Basslink period where flow reductions from >180 m^3s^{-1} exceed 30 m^3s^{-1} per hour.

2.5.2.8 *Low to mid-range flow variability analysis*

This analysis of rapid increases between low and mid-range flows provides an indicator of the occurrence of flow variability that is at a scale of relevance to the macroinvertebrates and fish. It should be noted that this is not indicative of the occurrence of full-range hydro-peaking, but is indicative of the degree to which rapid changes between low and mid-range flows take place. The analysis describes the number of occasions where discharges from Gordon Power Station decline below 25 m^3s^{-1} and then increase to above 100 m^3s^{-1} within 2 hours. The results of this analysis are presented on an annual basis (July to June) in Figure 2.23, and for the 30, 60, 90 and 365 day periods preceding macroinvertebrate sampling dates in Figure 2.24. The latter of these data have been used in the analysis of factors affecting the macroinvertebrate metrics, while similar data prepared for fish sampling dates have been presented relative to fish metrics.

The data indicate that in the post-Basslink period, there was a varying level of such rapid increases over time. The highest level of such increases was seen in 2010-11, where there were

100 occurrences, and is indicative of highly variable flow over the low to mid range flows. One of the lowest levels was seen in the post-Basslink period when there were 18 occurrences in 2007-08, and is indicative of low flow variability over the low to mid flow range. The remaining post-Basslink years had between 26 and 55 occurrences of the rapid increases from low to high flows.

The analysis of the numbers of rapid increases in flow in the 365 days preceding macroinvertebrate sampling dates shows a similar though slightly different pattern. This also indicates that the post-Basslink period had a varying number of rapid increases in flow. The periods where the greatest flow variability between low and mid-range flows occurred in the 365 days prior to spring 2010 to autumn 2012 (73 to 103 occurrences). A second, far less pronounced period of this operation was seen in the 365 day periods prior to sampling between spring 2006 and autumn 2008 (42 to 54 occurrences). The remaining post-Basslink sampling periods (autumn 2006, spring 2008 to autumn 2010) had generally low flow variability between low and mid-range flows (19 to 33 occurrences) in the 365 days preceding sampling.

The differences in the pattern of the plots for the shorter periods of analysis indicate the temporal variability in the occurrence of rapid flow increases, and those sampling occasions where this type of operation was concentrated just prior to sampling. The most notable aspect of these shorter term analyses is the much higher incidence of rapid flow increases in the periods prior to sampling in autumn 2011 (19 occurrences in the 30 days prior to sampling; 33 occurrences in 60 days prior to sampling).

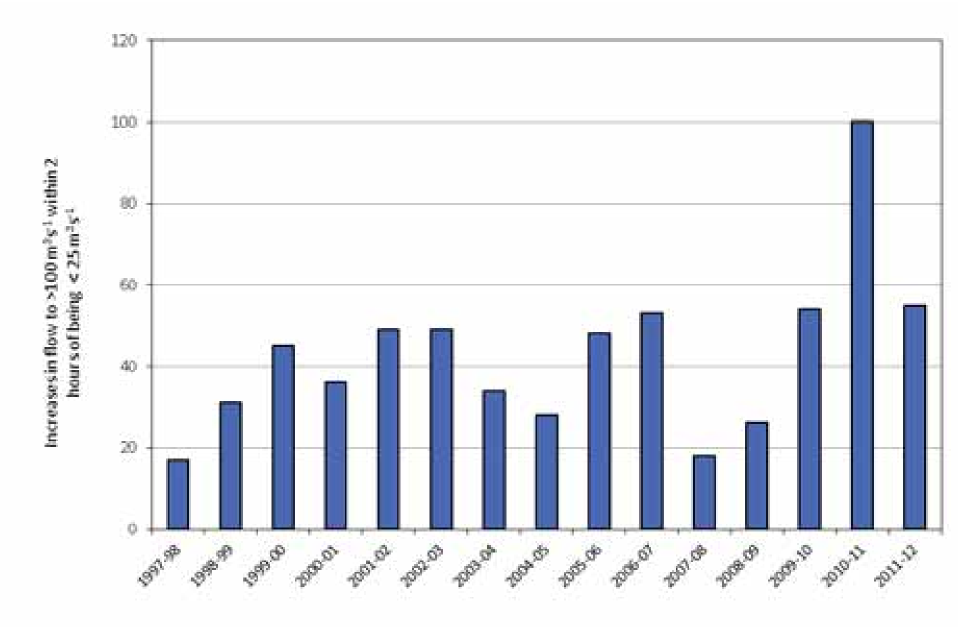


Figure 2.23: Low to mid-range flow variability analysis for discharges from Gordon Power Station occurring in each financial year.

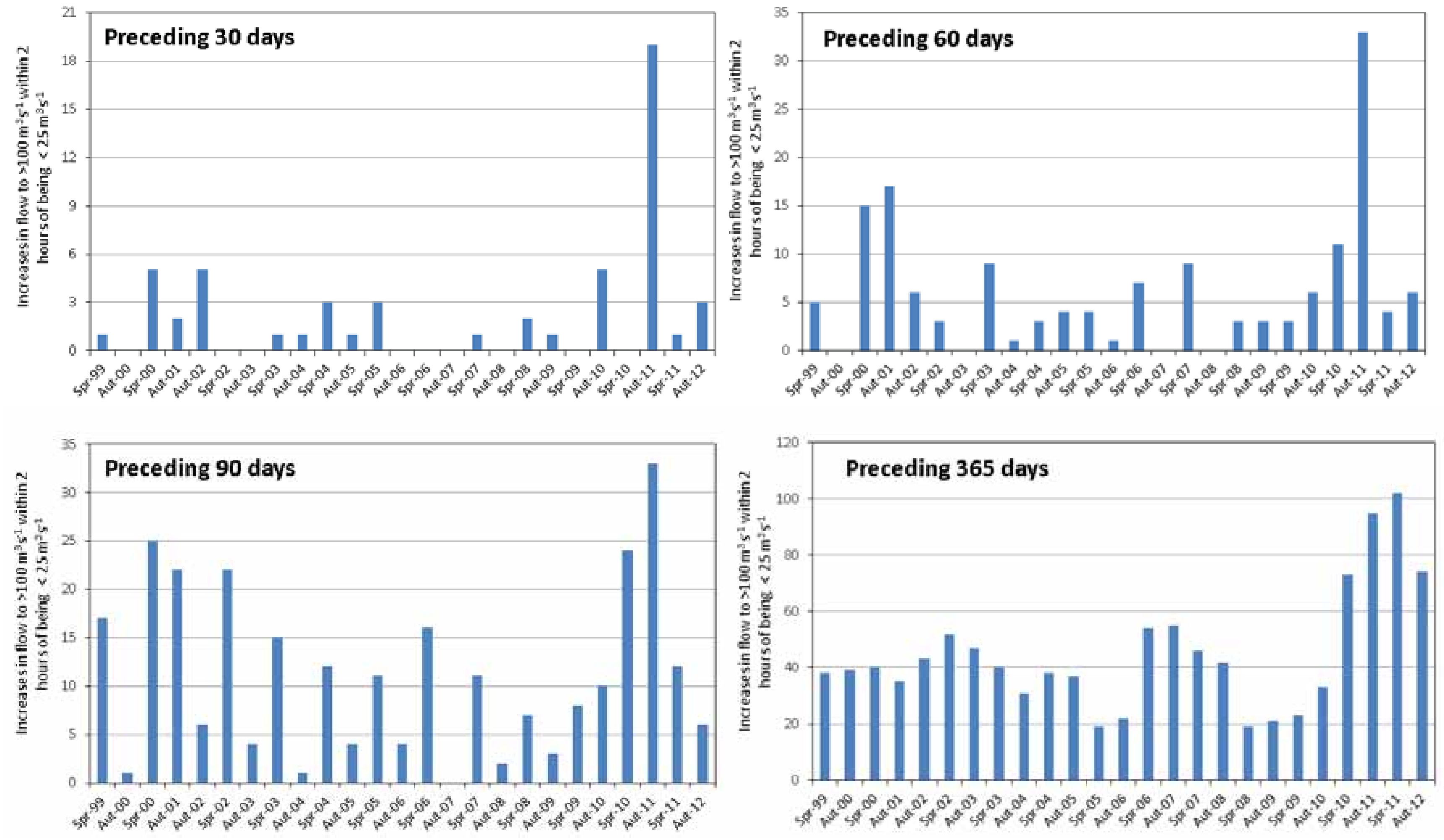


Figure 2.24: Low to mid-range flow variability analysis undertaken for 30, 60, 90 and 365 day periods preceding macroinvertebrate sampling to be used in analysis of its influence on metrics.

2.5.2.9 Event analyses

Event analyses undertaken are presented in Figure 2.25 to Figure 2.30. Each event is defined as when the discharge from Gordon Power Station either increases above, or decreases below, a specific flow level.

These analyses indicate that the number and timing of events at low flow ranges (i.e. <10, 30 and 50 m^3s^{-1}) differs markedly in the post-Basslink period compared to previous periods (Figure 2.25 to Figure 2.27). Most notable in the analysis is events of <10 m^3s^{-1} in the post-Basslink period were of short duration (<8 hours) and represented only a small period of time. In addition, it confirms that there were far fewer <10 m^3s^{-1} events in most other time periods as a result of the implementation of the minimum environmental flow. There were a small number of events in the 16 to 24 and 40 to 72 hour ranges which represents outages for monitoring and short maintenance outages, and further longer events of 168 and 504 hours that were due to maintenance outages at the power station.

The event analyses for the <30 m^3s^{-1} and <50 m^3s^{-1} flows also indicate quite a different pattern in the post-Basslink period. The major difference is that there are substantially more short-duration (<5 hours) events in the post-Basslink period, the majority of which are <2 hours duration. This indicates that there has been greater short-term variation in lower range discharges in the post-Basslink period.

The event analyses (Figure 2.28 to Figure 2.30) indicate that the post-Basslink period had a different pattern of flow variation at the higher end of the discharge range. There were a higher number of short-duration events >150 m^3s^{-1}, >180 m^3s^{-1} and >210 m^3s^{-1} in the post-Basslink period, than both the historical and pre-Basslink periods. These short-duration events were most obvious in the 0–1 hour range in the >180 m^3s^{-1} and >210 m^3s^{-1} analysis, but are also highest in the post-Basslink period in the 0-3 hour range in the >150 m^3s^{-1} analysis. This is expected to be partly due to the operation to minimise the use of the original ramp-down rule, particularly in the one hour range >180 m^3s^{-1} and >210 m^3s^{-1} in the early post-Basslink operation (2007-2008). As the original rule was to be applied after a one hour period when discharge exceeded 180 m^3s^{-1}, time in excess of this flow was actively restricted to avoid its application and maintain flexibility in power station operation.

It is expected that under the new ramp-down rule, the high occurrence of short duration events at flows >180 m^3s^{-1} will be reduced. Unlike the original rule, the new rule is only applicable when bank saturation reaches a certain level. The time required to reach that critical bank saturation level will differ depending on the operation of the power station and the starting bank saturation level (Entura 2010).

With the exception of these short range event differences, the historical and post-Basslink periods are similar, particularly in the >180 m^3s^{-1} and >210 m^3s^{-1} ranges where events in the ranges of 5-10 hours and 12–20 hours were similar, and greater than those of the pre-Basslink period indicating greater variability (i.e. peakiness) over the high flow range in these two periods compared to the pre-Basslink period. The higher number of short-term events (i.e. higher degree of peakiness) in the post-Basslink period was balanced by there being fewer longer events where flows of this magnitude were exceeded, which was a feature common in the pre-Basslink period.

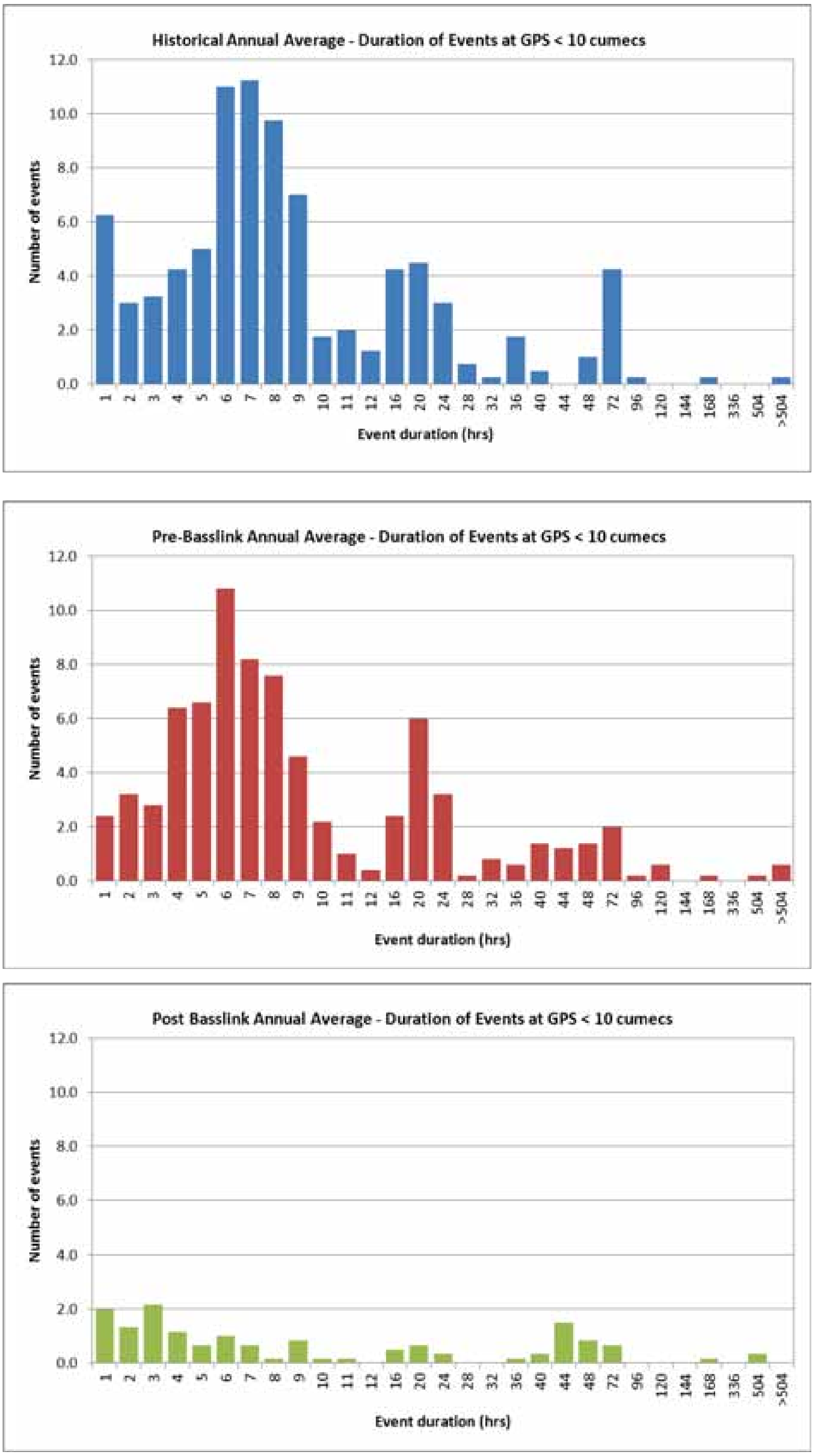


Figure 2.25. Duration of events at Gordon Power Station (GPS) for the historical, pre-Basslink and post-Basslink periods for flows <10 m^3s^{-1}. Partial events are presented in this graph, as these are annual averages of each of the periods.

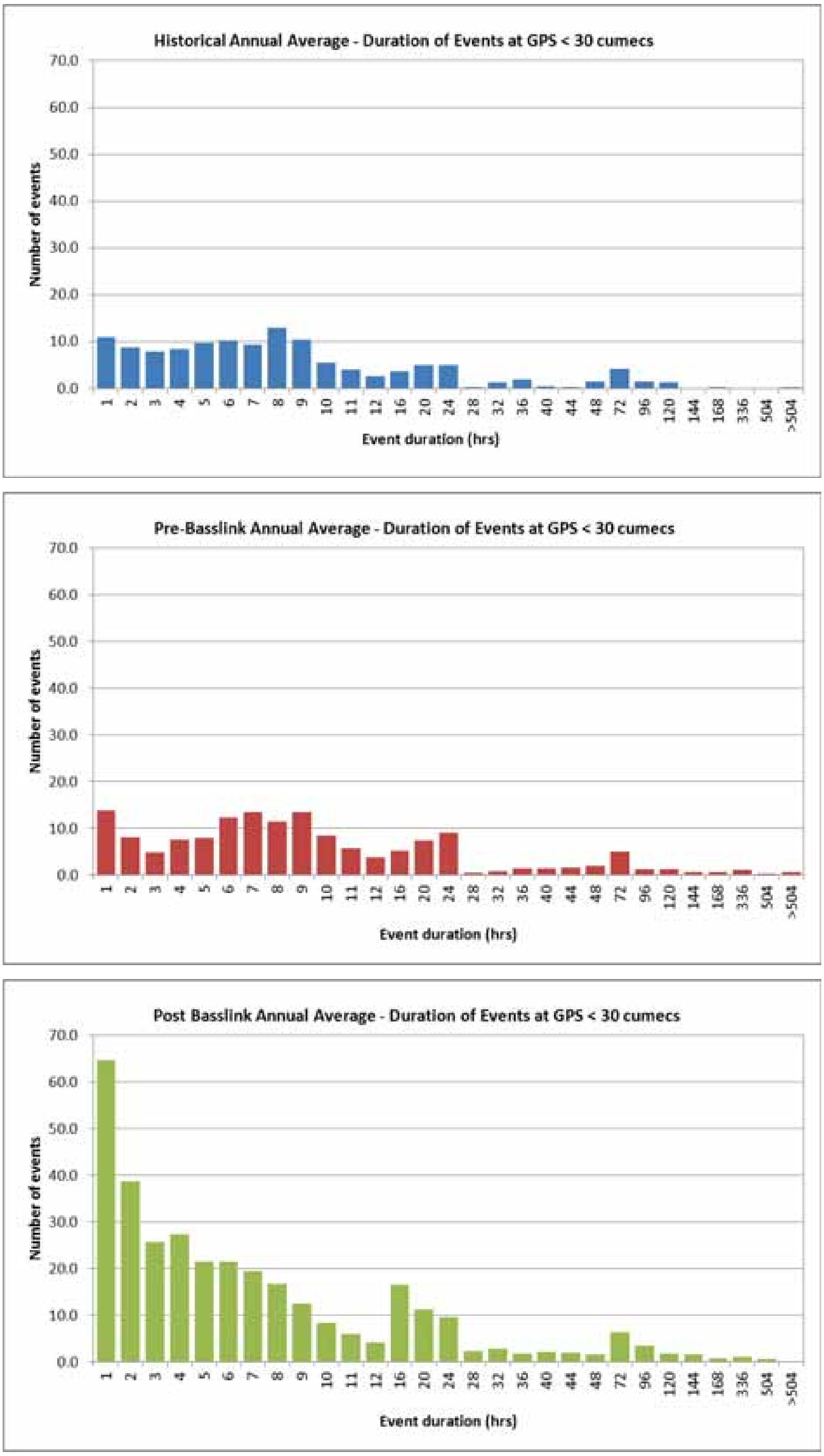


Figure 2.26: Duration of events at Gordon Power Station (GPS) for the historical, pre-Basslink and post-Basslink periods for all flows <30 m^3s^{-1}. Partial events are presented in this graph, as these are annual averages of each of the periods.

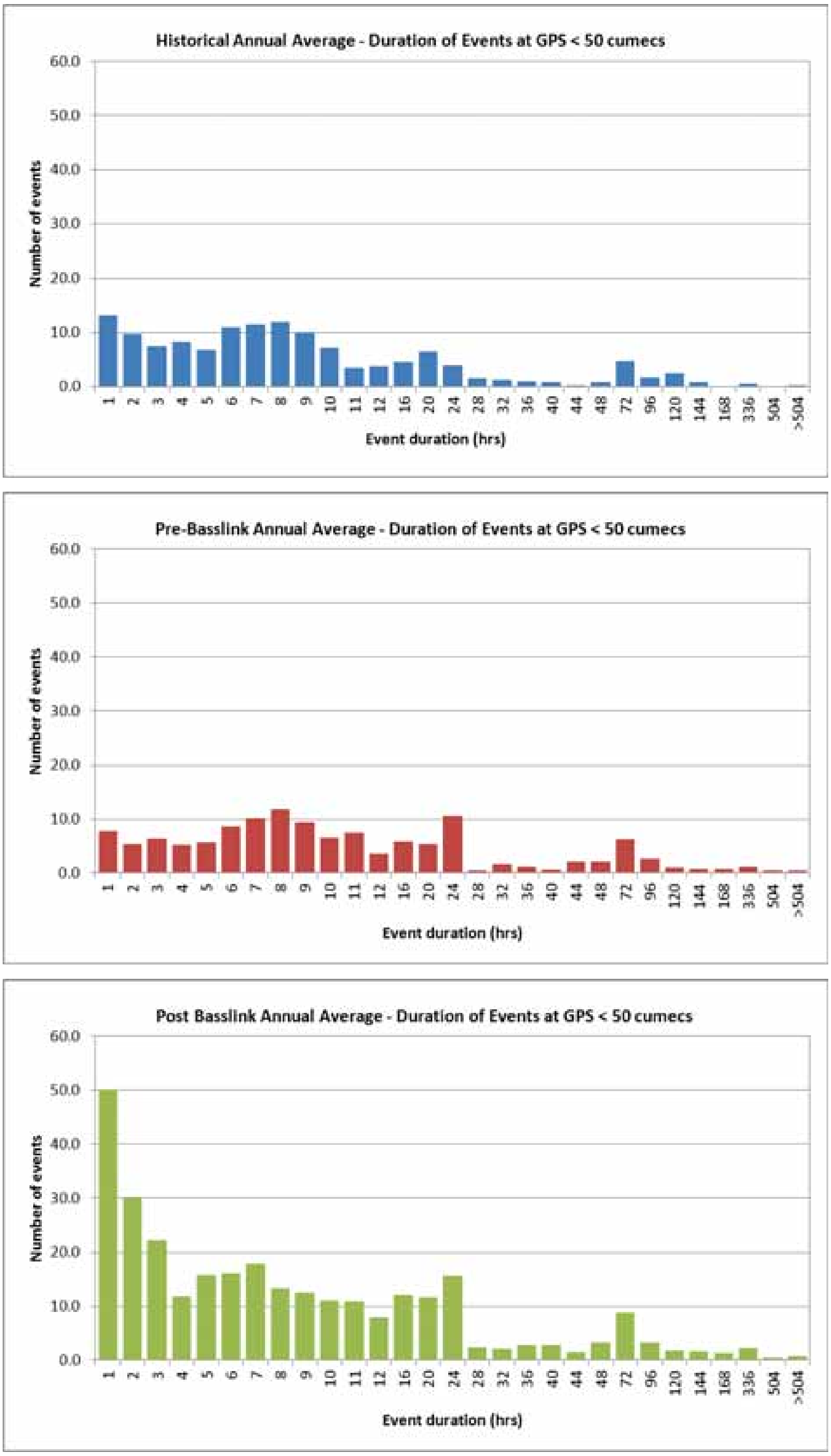


Figure 2.27: Duration of events at Gordon Power Station (GPS) for the historical, pre-Basslink and post-Basslink periods for flows <50 m^3s^{-1}. Partial events are presented in this graph, as these are annual averages of each of the periods.

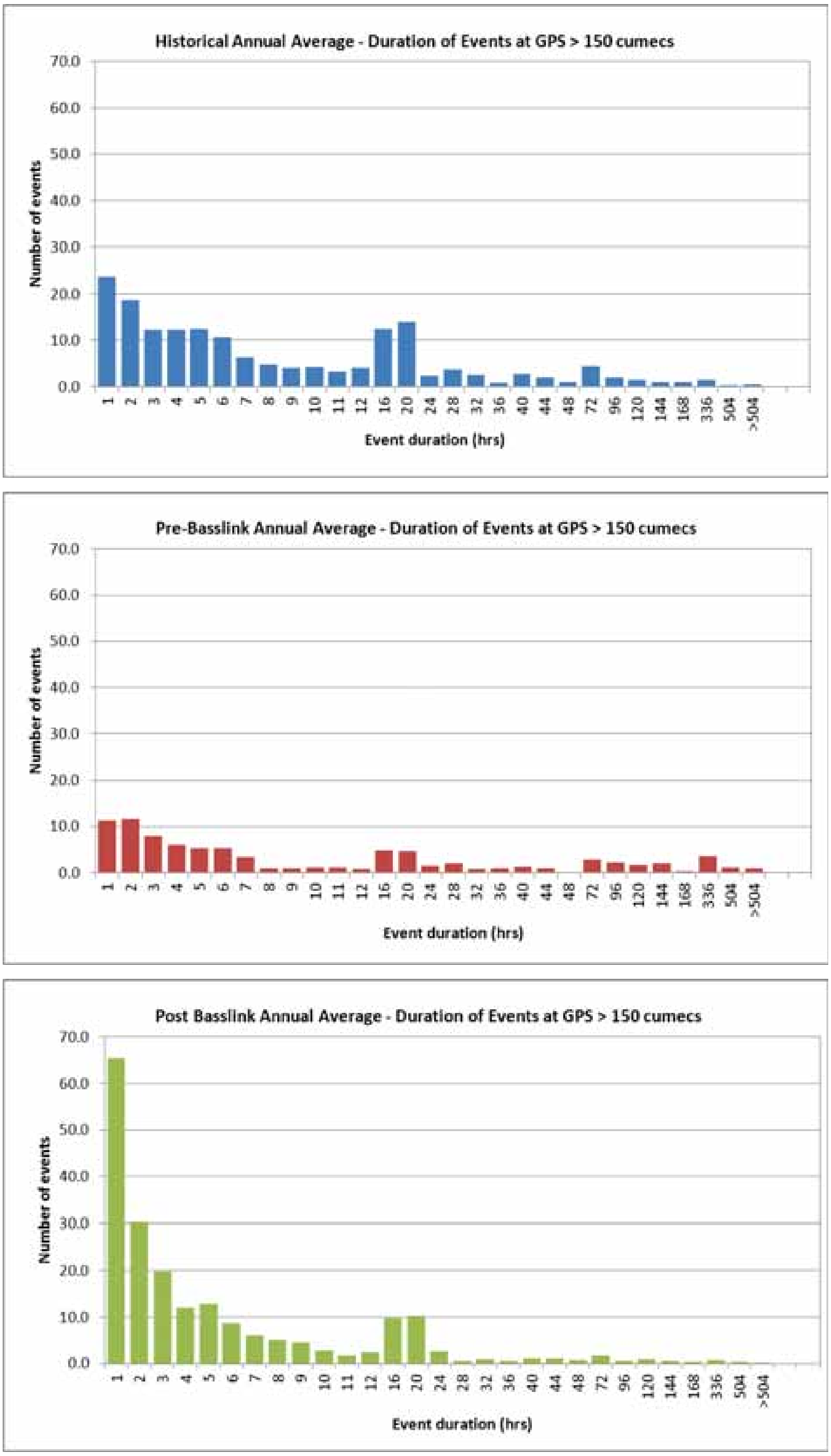


Figure 2.28: Duration of events at Gordon Power Station (GPS) for the historical, pre-Basslink and post-Basslink periods for flows >150 m^3s^{-1}. Partial events are presented in this graph, as these are annual averages of each of the periods.

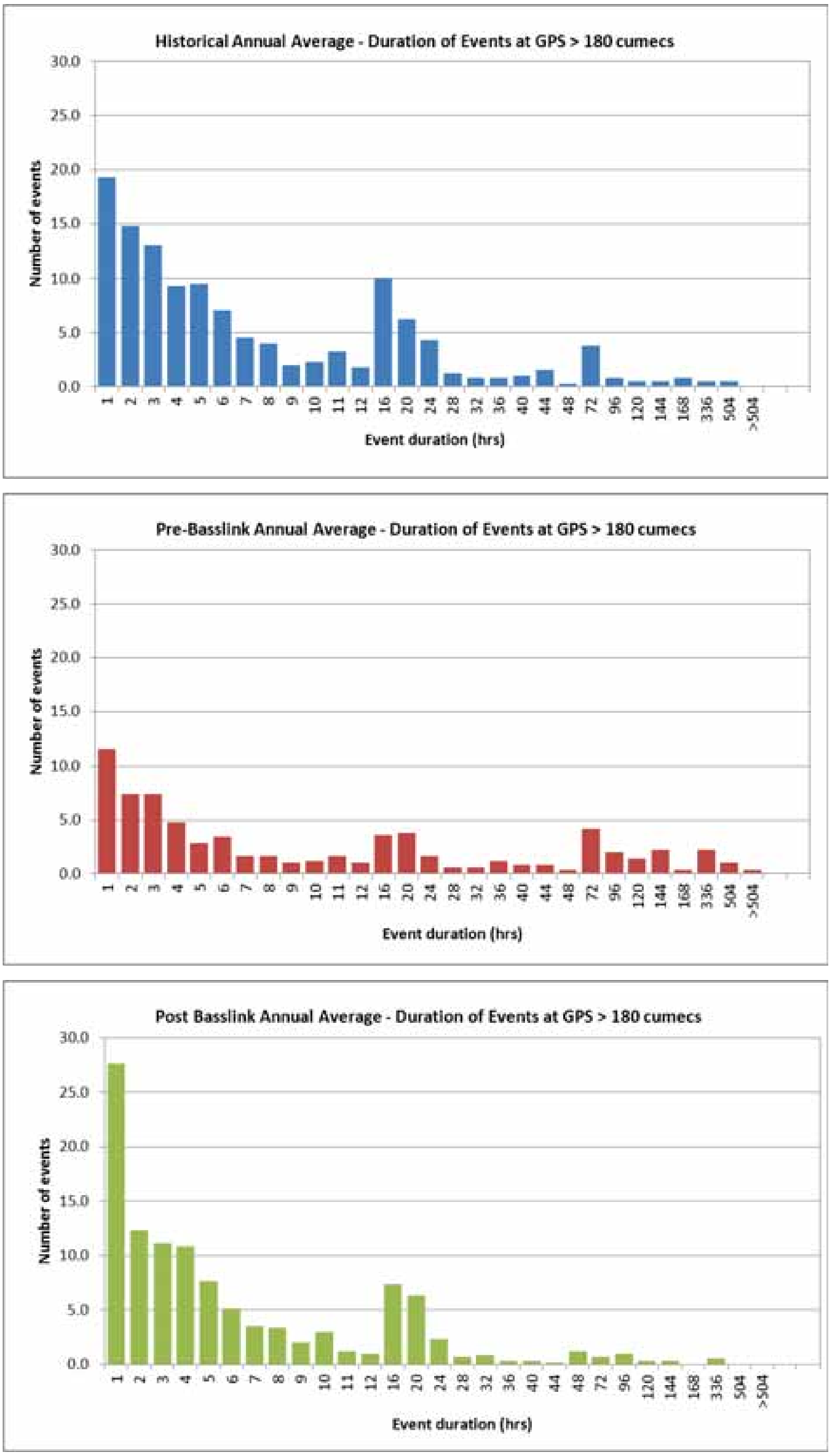


Figure 2.29: Duration of events at Gordon Power Station (GPS) for the historical, pre-Basslink and post-Basslink periods for flows >180 m^3s^{-1}. Partial events are presented in this graph, as these are annual averages of each of the periods.

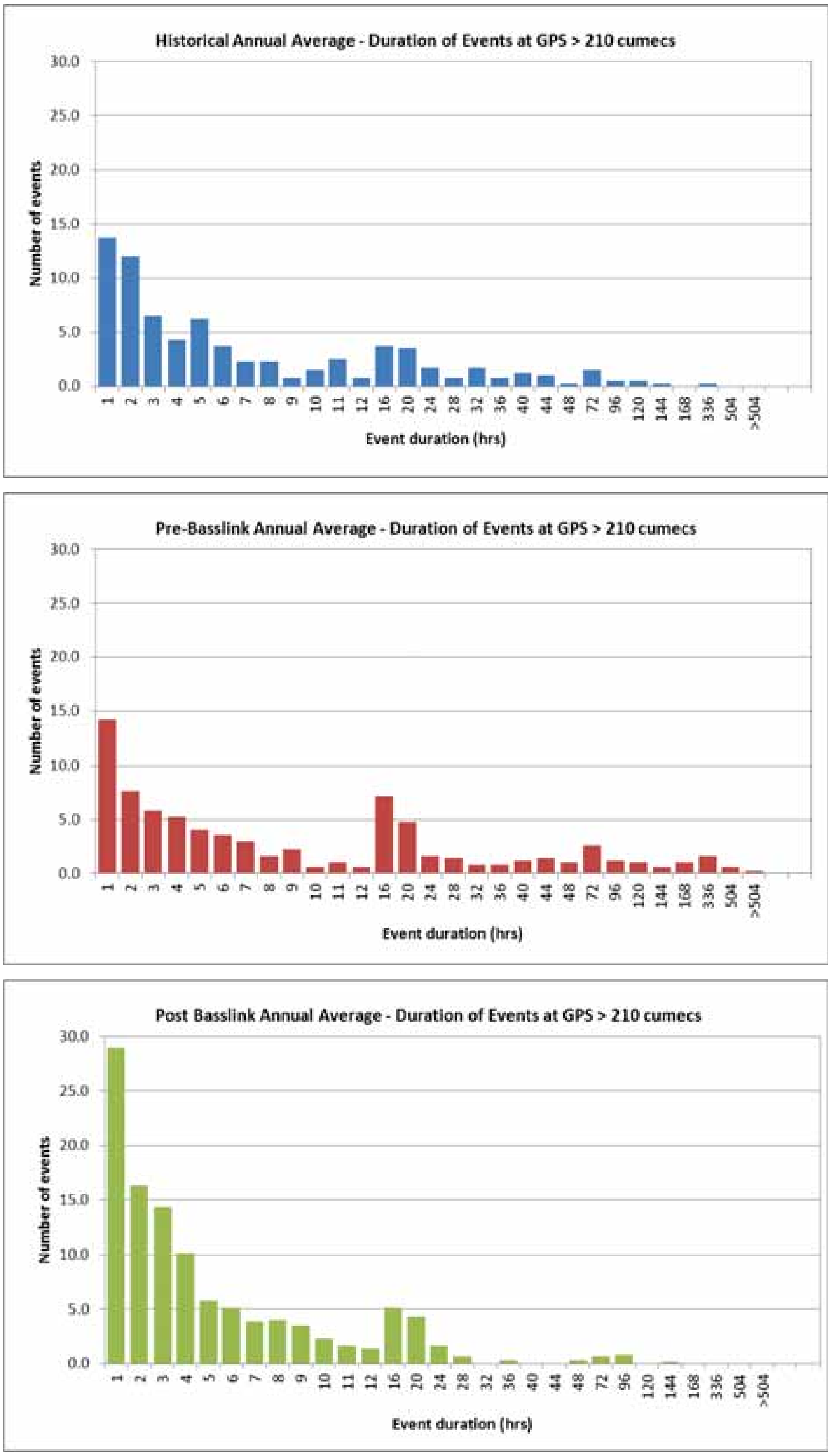


Figure 2.30: Duration of events at Gordon Power Station (GPS) for the historical, pre-Basslink and post-Basslink periods for flows >210 m^3s^{-1}. Partial events are presented in this graph, as these are annual averages of each of the periods.

Event analysis of the six individual post-Basslink years (Figure 2.31, Figure 2.32) for a high flow (>180 m^3s^{-1}) and a low flow (<30 m^3s^{-1}) emphasises the vastly different operations that have occurred at Gordon Power Station over the post-Basslink period. The high flow events (>180 m^3s^{-1}) for each year can be summarised as follows:

- The first year of post-Basslink operation saw some of the trend of high short-term events at >180 m^3s^{-1}.
- In the second year the occurrence of a large number of short events (0–10 hours) was most apparent, in addition to an increase in events of the 12–20 hour range.
- The third and fourth years post-Basslink were similar, and also followed the pattern of a bias towards short events, however there were few events that exceeded 180 m^3s^{-1} and those that did were mostly <10 hours' duration.
- The fifth and sixth years were similar in their patterns. There were a larger number of events >180 m^3s^{-1}. The majority of events were of a duration <10 hours, however there was an increase in the number of events in the 16-24 h range.

The low flow (<30 m^3s^{-1}) analysis indicates that there were also considerable differences between years:

- A sequential increase over the first three years was seen in the number of events as well a greater bias towards shorter events. This event pattern was similar in the third and fourth years and indicates that there were much more variable flows over the low range in years 3 and 4.
- The fifth and sixth years both had fewer short events and a greater number of long events >72h, which is indicative of the lower variability at low flows and reflective of the extended low flow experienced during these years.

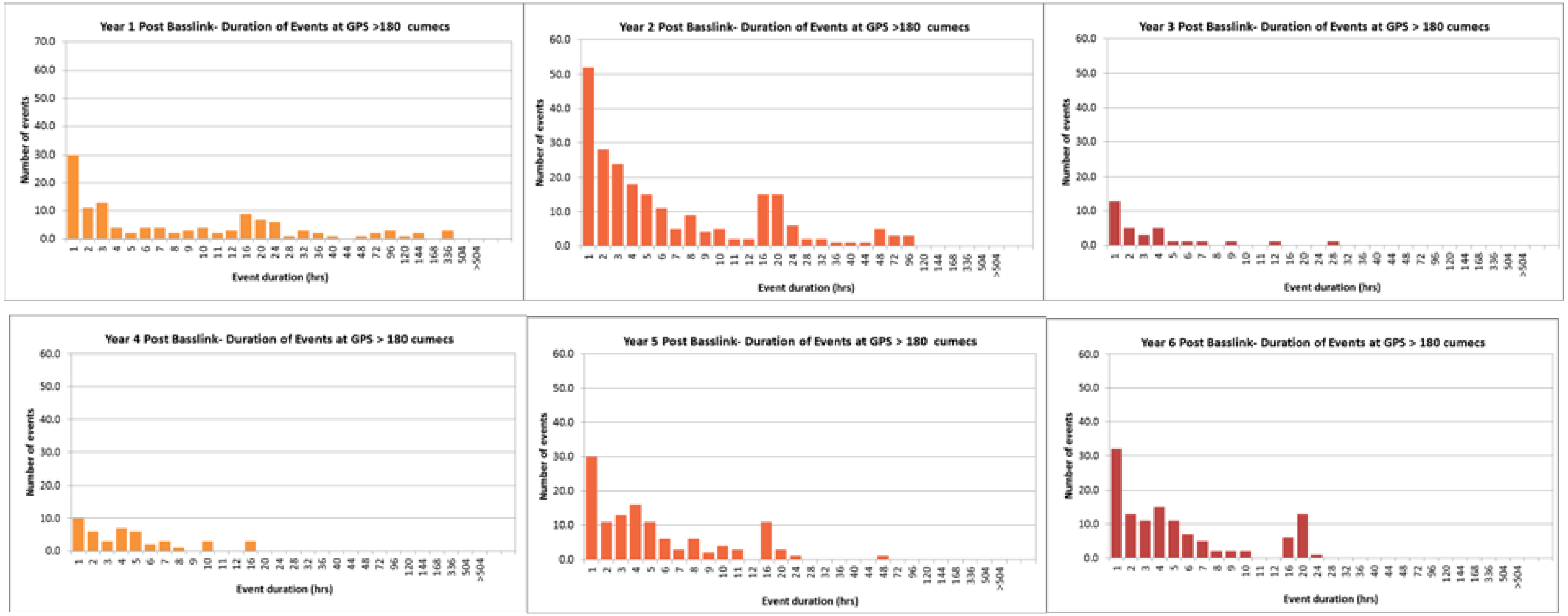


Figure 2.31: Duration of events at Gordon Power Station (GPS) for the six post-Basslink years (May 2006–April 2012) for flows >180 m^3s^{-1}.

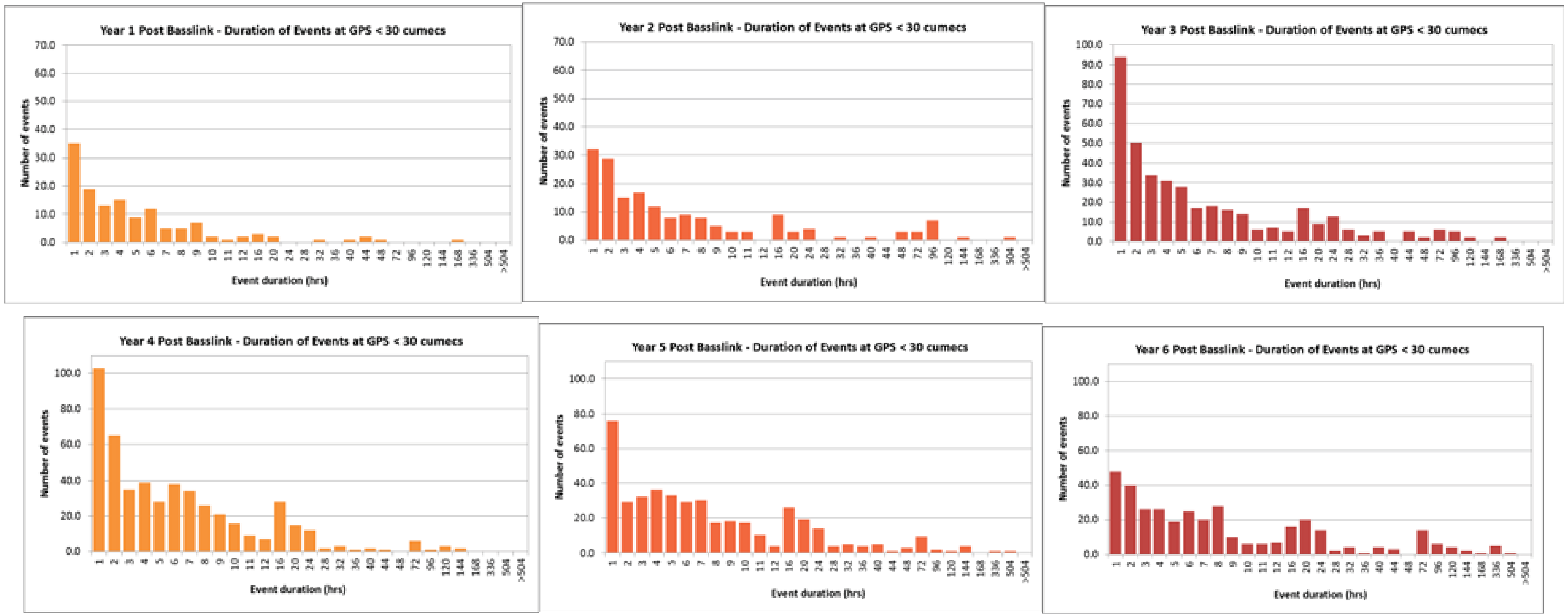


Figure 2.32: Duration of events at Gordon Power Station (GPS) for the six post-Basslink years (May 2006- April 2012) for flows <30 m^3s^{-1}.

2.5.3 Summary of hydrological features by period

The analyses undertaken indicate the following hydrological features of the historical, pre-Basslink and post-Basslink periods.

2.5.3.1 Historical period

- Rainfall and system-wide inflows were generally sufficient to meet demand, and had few seasonal outliers (dry or wet seasons);
- There was high short-term variability in power station discharges indicative of a relatively ‘peaky’ operation, but generally little inter-annual variability in discharge;
- Peaking patterns of flow, over a number of flow ranges, including a large portion of peaking to 3 turbine operation, were dominant during this period; and
- There was a large proportion of zero discharge.

2.5.3.2 Pre-Basslink period

- The pre-Basslink period was strongly characterised by seasonal rainfall outliers (dry autumns and wet springs and winters) that emphasised the seasonality of inflows;
- The high seasonality of system inflows was cause for a clearly seasonal (bi-modal) pattern of power station discharge in most years in the pre-Basslink period which resulted in low short-term and inter-annual variability in discharge;
- Baseload and low level peaking were the two dominant flow patterns; and
- There were long periods of zero discharge.

2.5.3.3 Post-Basslink period

- The post-Basslink period was characterised by its variability;
- The first three years of operation under Basslink had primarily dry winter and spring periods resulting in drought conditions and low storages elsewhere in the State; the subsequent three years had increased rainfall and increasing storages;
- There was inter-annual variability in the power station discharge post-Basslink, and these did not follow seasonal (bi-modal) patterns seen in the pre-Basslink period. These differences are related to the interaction between drought, and the operational strategies undertaken in the running of the power station;
- There were a range of discharge patterns from Gordon Power Station, that were dominant for different periods;
- There was a large decrease in the periods of no power station discharge as a result of the implementation of the minimum environmental flow; and
- The highest reductions in flow >30 m^3s^{-1} per hour from discharges >180 m^3s^{-1} occurred in the post-Basslink period. These incidences were most prevalent in January–July 2007 and were related to the running of the power station at generally high, but variable discharge for an extended period.

2.5.4 Has Basslink influenced the discharge from Gordon Power Station?

The high variability of annual flow patterns in the Gordon River has been the most obvious characteristic of the post-Basslink period. This observation differs significantly from the predictions made during the IIAS (Peterson and Locher 2001) which suggested a dominant full range hydro-peaking flow pattern would be seen. Instead, dominant flow patterns have differed from year to year, and have included 2 turbine daily peaking, 2-3 turbine daily peaking, low-3 turbine daily peaking and low flow dominant patterns. A combination of these was found each year, however there has been increasing occurrence since the third year of the low flow pattern of operation.

The main driver of Gordon Power Station operation remains the preceding and prevailing weather pattern which determines how much water is available across the broader hydro generation system. However, the influence of connection to the NEM via Basslink has provided a greater degree of flexibility in the use of Gordon Power Station, due to the lower reliance on this station to provide seasonal baseload power for Tasmania. The following are specific hydrological characteristics which can be identified as being influenced by Basslink:

- the prolonged periods of lower flows (i.e. <50 m^3s^{-1}) in fourth, fifth and sixth years post-Basslink, were partially facilitated by Basslink and the ability to import power. This provided much needed relief on Lake Gordon to allow the storage to rebuild after substantial drawdowns following very low inflows. This was driven by the need to rebuild storages, and other conditions including good system inflows and the state of the market which also drove the limited use of the Gordon Power Station;
- the higher incidence of hydro-peaking in much of the second, fifth and sixth years post-Basslink (2007–08, 2010-11, 2011-12) was influenced to a substantial degree by the presence of Basslink;
- the greatest occurrence of reductions in flow >30 m^3s^{-1} per hour at discharges >180 m^3s^{-1} is partially influenced by market volatility, and is linked to the higher flow variability. In addition, the previous licence condition allowed for unlimited flow changes in the 2–3 turbine range (>150 m^3s^{-1}), and it is likely that minimisation of operations that would require the use of the original ramp rule was a factor influencing this type of operation; and
- the vast reduction in time where there was zero discharge is the result of the implementation of the minimum environmental flow.

2.6 Conclusions

The Gordon Power Station discharge in the six years of post-Basslink operation was characterised by a higher level of variability between and within years, and a lower level of seasonal predictability in comparison to the pre-Basslink and historical periods. The observed discharge patterns are more similar to the historical period than the pre-Basslink period, with generally greater short-term variability in flow.

The variability between the six years post-Basslink and lack of seasonal pattern was heavily influenced by the change in strategy in mid 2008 that put more emphasis on rebuilding depleted storages by relying on net power import. This had an impact on the hydrology of the Gordon River, reducing the use of Gordon Power Station in 2008–09 resulting in greatly increased periods of reduced flow. Prior to this change, in 2006 and early 2007, discharges were high and there was high variability in flow.

This was likely due to greater emphasis placed on using Gordon Power Station to meet baseload and peak power demands during the dry summer of 2006-07 and winter of 2007 and being heavily influenced by high market volatility.

An important aspect of the measures undertaken to mitigate against potential impacts of Basslink has been the implementation of the minimum environmental flow. The minimum environmental flow has greatly reduced the incidence of very low or zero flows from the power station in the post-Basslink period.

Future patterns of discharge from Gordon Power Station are difficult to predict. A large number of factors are likely to impact upon the operation of the power station and the trading strategy employed. These include system inflows, storage levels, the local supply/demand balance (e.g. new generators, possible reductions or increases in demand) as well as factors in the Victorian market that influence market volatility (i.e. increase in demand or decrease in supply). The first six years of Basslink operation suggest that while periods of peaking are possible, they may be limited to short periods where the market conditions and trading strategy drive this type of operation to occur. Greater intra- and interannual variability and less predictability of discharge at Gordon Power Station is likely to be the continuing influence of Basslink.

3. Post-Basslink conceptual models

3.1 Introduction

A conceptual model of the Gordon River was first developed for the Basslink Baseline Report (Hydro Tasmania 2005a) and is presented in Appendix 2 of this report. The model focussed on the impacts associated with initial flow regulation, and spatial and temporal changes with distance downstream of the power station. It also provided an understanding of the processes operating in the middle Gordon River pre-dam. This understanding and information contained in the conceptual model are still current. The conceptual model has assisted in the interpretation of both pre- and post-Basslink monitoring data. The model was 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 was expanded in the Basslink Review Report 2006-09 (Hydro Tasmania 2010a) to include an improved understanding of the erosion and vegetation processes along the river. However, to translate this understanding and further understanding gained during the course of the Basslink Monitoring Program, a series of simple conceptual models have been developed.

The basis of the Basslink Monitoring Program is that significant hydrological changes could have the potential to cause significant change to river morphology and its ecosystem. Two mitigation measures, the ramp-down rule and the minimum environmental flow, were established to limit the potential impacts of an altered hydrological regime at Gordon Power Station. The monitoring program was established to assess changes from pre-Basslink and to determine the effectiveness of mitigation measures put in place to limit the effects of an altered hydrological regime.

Since Basslink commissioning the hydrological regime in the Gordon River has been different compared to the pre-Basslink period. Post-Basslink changes have included a number of recognisable flow patterns that have been dominant at different times (see section 2.4.2.3). The different flow regimes experienced post-Basslink can generally be categorised into 5 operating regimes:

- Low flow dominant – minimum flow with occasional peaks to 1-2 turbine level;
- Daily hydro-peaking to 1 or 2 turbines;
- Daily hydro-peaking to 3 turbine level – rapid, regular alternation between minimum flow and 3 turbine discharge – with and without mitigation;
- Daily hydro-peaking in 2-3 turbine level - rapid, regular alternation between flow at 2 and 3 turbine flow levels; and
- Base load utilising 3 turbines.

The prominence of each of the above patterns has been seen at various periods throughout the post-Basslink period and a better understanding of these has been gained. The aim of this section of the report is to present a series of conceptual models that apply to the current understanding of the processes of the river to each of these hydrological regimes, both in the absence and presence of the mitigation measures. It is considered that most of these patterns have the capacity to be seen in future operations and the models aim to present the potential impact of the long term influence of each of these discharge patterns.

The erosional and biotic processes operating in the Gordon River do not occur uniformly over its length. With distance from the power station, the proportion of flow derived from unregulated tributaries increases, there are decreased rates of flow-change, the channel widens and sediment and fine organic matter input increases. All of these factors lead to a reduction in the impact of flow regulation further down the river. The variability in how the erosional processes have progressed with distance downstream from the power station suggests there is an erosional ‘wave’ progressing down the Gordon River (Hydro Tasmania 2005a). Fish and macroinvertebrate abundance and diversity increase with distance from the power station.

The conceptual models provided below describe the types of flow regimes and associated processes experienced post Basslink. Temporal and spatial aspects of the processes will also be commented on where possible.

3.2 Low flow dominant

This flow scenario consists of dominance by flows in the 10-40 m^3s^{-1} range, with occasional peaks up to the 2 turbine level (Figure 3.1). It is characterised by little flow variability with relative low flow volumes and velocities.

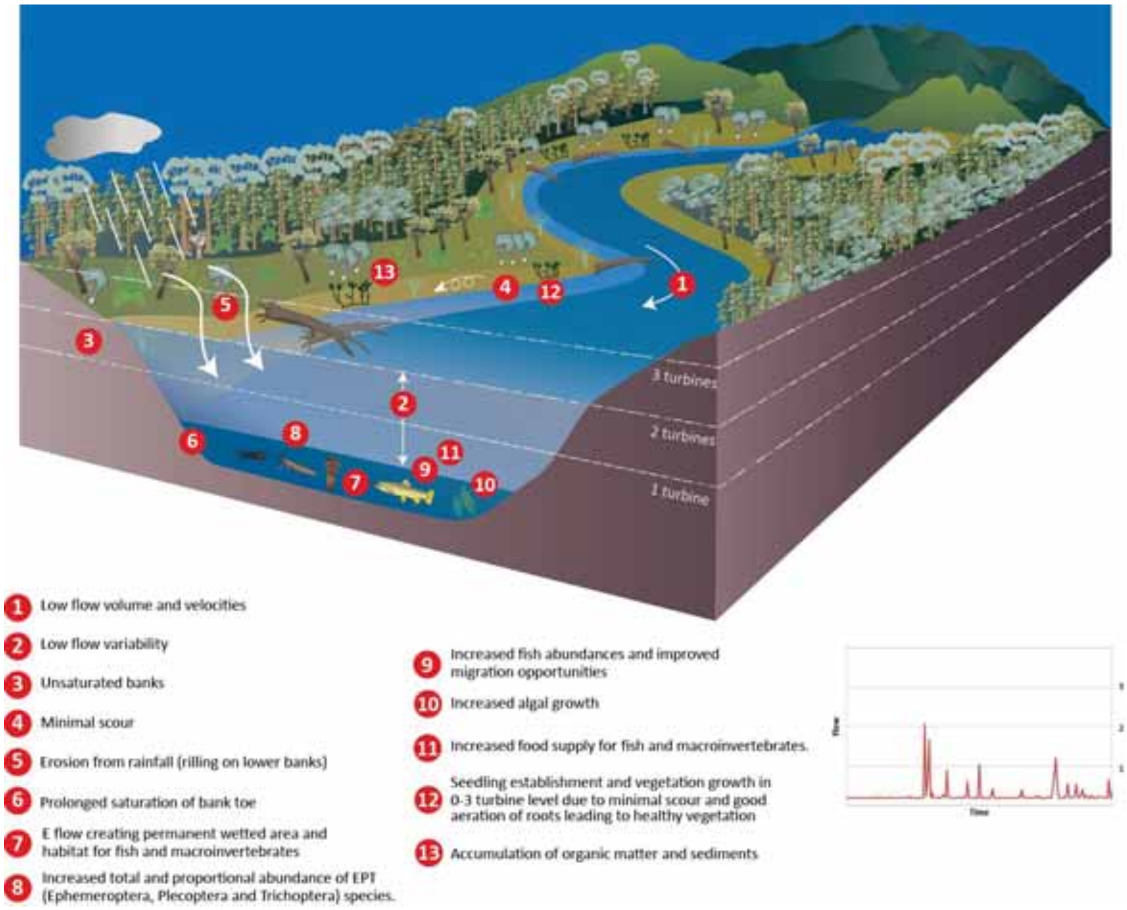


Figure 3.1: Conceptual model of processes occurring at low flow dominant scenario.

In the low flow scenario, the banks are unsaturated with a concomitant low risk of seepage erosion. However, some erosion such as rilling can occur due to rainfall impacts. Organic matter accumulates on the banks from overhanging vegetation and sediments can potentially accumulate in the geomorphology zones 4 and 5 (see chapter 5) from unregulated inflows. The vegetation on the banks is healthy with plants having aerated roots and seedlings are able to establish in the low flow environment.

The minimum flow provides stable low flow refuge habitat area between flow peaks for macroinvertebrates. This, combined with the absence of frequent high flow surges with high near-bed hydraulic stress, supports a lagged increase in abundance of Ephemeroptera, Plecoptera and Trichoptera (EPT) species. The habitat area is also increased, compared to the situation with no minimum flow, both for macroinvertebrate species and fish. Flow sensitive fish and macroinvertebrate species will be advantaged by this flow regime. The increased food source (invertebrates etc.) for fish can lead to lagged increases in fish condition and abundance. The benefits of the minimum flow to macroinvertebrates and fish are greatest upstream and in the vicinity of the Denison River, as tributary inflows above the Denison River are limited.

Low flows allow greater light availability to the stream bed and thus an increase in algal growth compared to flow regimes with sustained higher discharges.

3.3 Daily hydro-peaking up to two turbines

This flow scenario consists of higher flow variability than the low flow scenario with relatively moderate flow volumes and velocities that are low to medium (Figure 3.2).

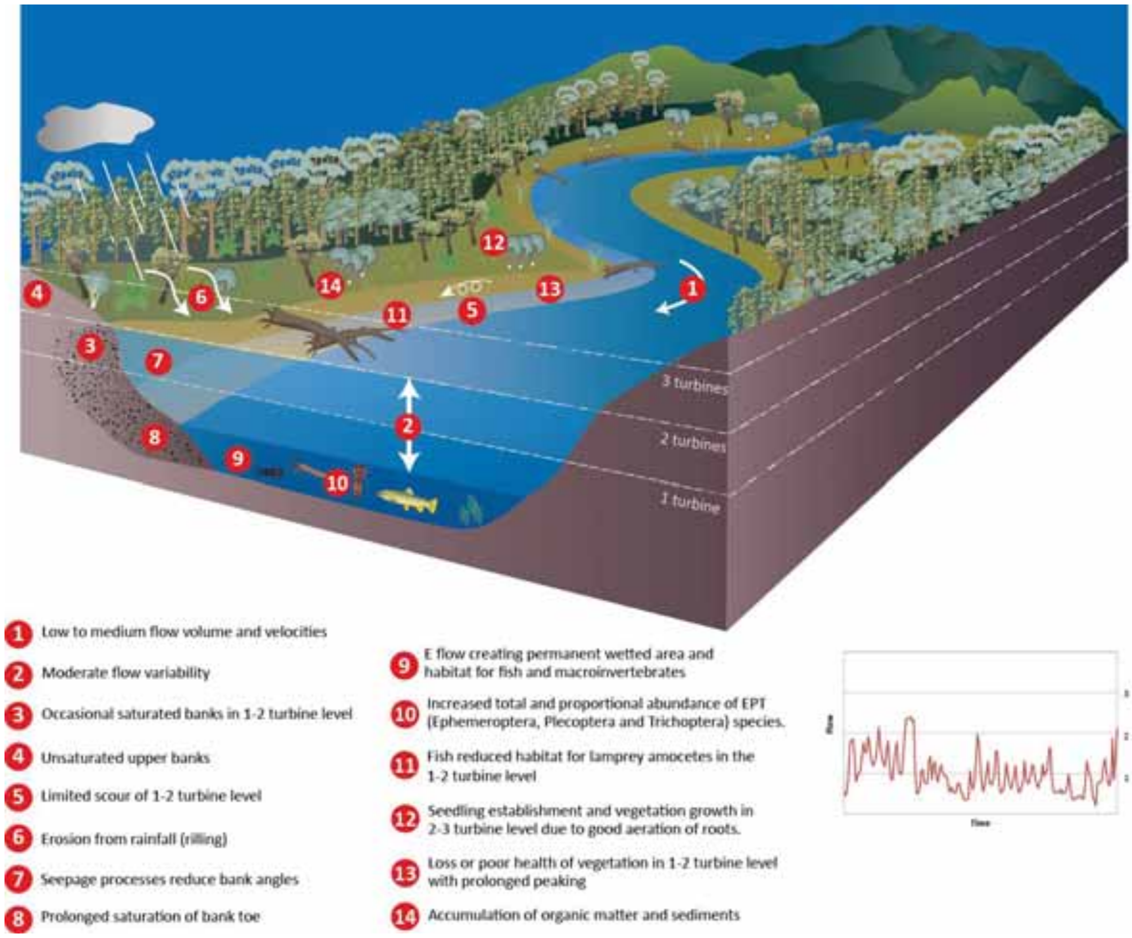


Figure 3.2: Conceptual model of processes occurring at hydro-peaking to 2 turbine level scenario.

The upper banks (2-3 turbine level) remain unsaturated and only rainfall induced erosion occurs on this bank level. Vegetation remains healthy on the upper banks and roots are well aerated. The vegetation in the 1-2 turbine level is in poor condition or disappears after prolonged peaking in this range. This process is most dominant in the upstream zones.

Organic matter accumulates on the banks from overhanging vegetation and sediments can potentially accumulate in the geomorphology zones 4 and 5 from unregulated inflows.

The banks are occasionally saturated in the 1-2 turbine level and seepage can occur if bank angles have not reached the 'stable seepage slopes' (see Hydro Tasmania 2005a and Hydro Tasmania 2010a for more detail).

The conceptual in-stream processes are similar to the minimum flow scenario. However, increased frequency of flow peaks causes frequent spikes in near-bed shear stress, and disadvantages for flow-sensitive macroinvertebrate taxa. Macroinvertebrate density and diversity declines with moderate flow volumes and velocities. The abundance of grazers and flow obligate taxa declines, and communities are dominated by worms (depending on local substrate composition), chironomids and stoneflies. Mobile flow obligate taxa are dislodged from inter-peak low flow areas as flows rise rapidly and emigrate as drift in the water column.

In addition, light penetration to the stream bed is frequently interrupted, constraining algal growth and hence reducing food resource availability to grazing macroinvertebrates.

The habitat availability for lamprey ammocetes is reduced in the 1-2 turbine level. Sudden drops in flow between peaks leads to bed dewatering and increased risk of stranding for fish and macroinvertebrates.

3.4 Peaking to 3 turbine level – with and without mitigation

It was predicted that the post-Basslink hydrological regime would be dominated by peaking operation up to the 3 turbine level. Two measures were put in place, the minimum environmental flow and the ramp down rule, to mitigate against the predicted impacts of the peaking operation. The ramp-down rule has since been revised to improve environmental outcomes. The following model (Figure 3.3) presents conceptual processes both with and without the current mitigation measures in place.

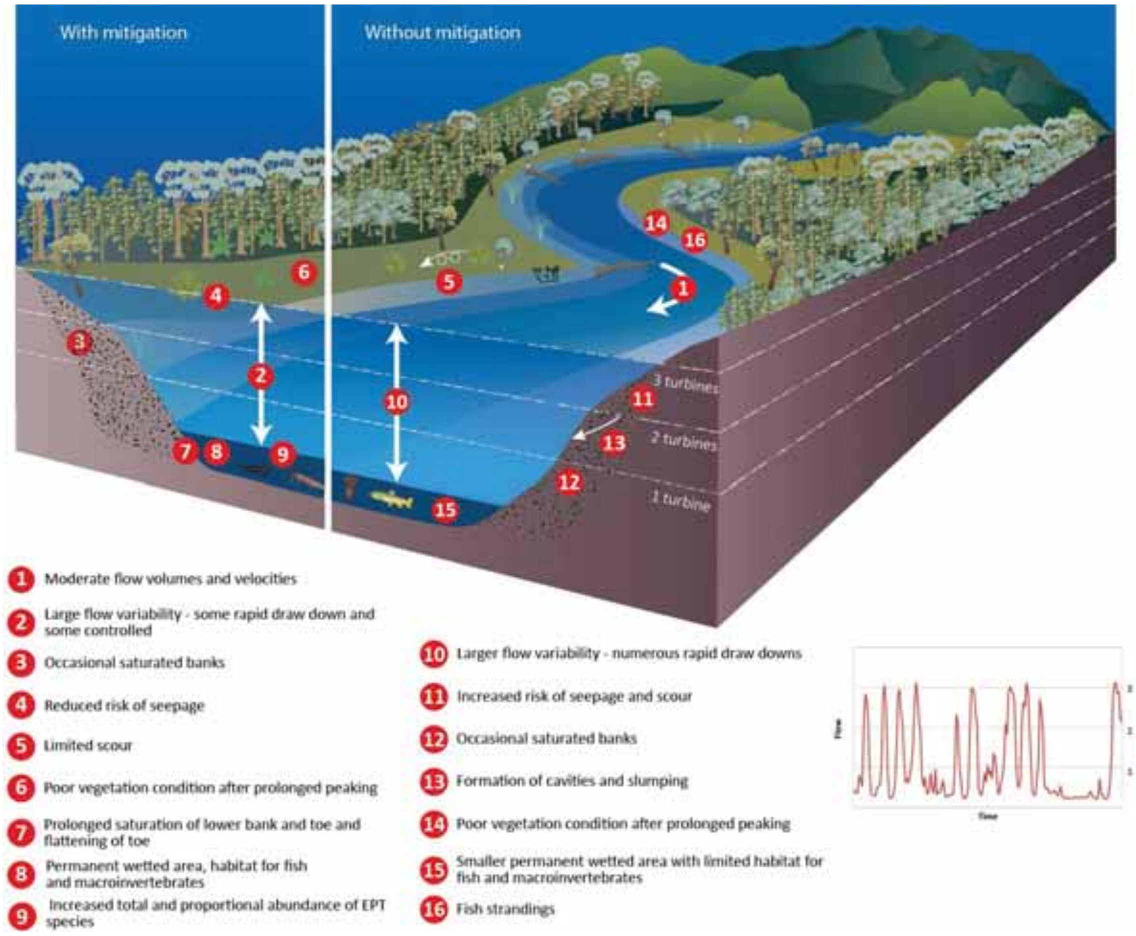


Figure 3.3: Conceptual model of processes occurring at peaking to 3 turbine level, with and without mitigation scenario.

With mitigation in place: the flow variability is large compared to other flow scenarios, flow volumes are moderate and short term high velocities are experienced. Implementation of the revised ramp down rule will lead to controlled drawdowns when banks are saturated.

The ramping reduces the risk of seepage erosion in the 2-3 turbine level and scour erosion rates will be moderate. Established vegetation and seedlings can survive individual peaks, however vegetation will not be able to survive under prolonged, repeated, peaking operation. The vegetation will most likely disappear in the upstream zones first.

The lower banks remain saturated which will flatten the bank toe.

The in-stream biota will benefit from the minimum flow providing refuge habitat between flow peaks. Macroinvertebrate communities will persist within areas inundated by minimum flows. However, some fish species sensitive to high velocities may still be disadvantaged by hydro peaking to the three turbine level which will reduce upstream migration opportunities because of high velocity flows through hydraulic restrictions. The habitat availability for lamprey ammocetes is reduced in the 1-3 turbine level and there is an increased risk of fish stranding.

Algal growth will be light limited during frequent peaking periods during daylight hours. Periods of high flow leads to sustained high shear stress on the bed, combined with reduced algal production due to reduced light levels. Some algal production establishes on banks and marginal snags during prolonged baseflow periods; however,this does not constitute a food resource as macroinvertebrate colonisation of these habitats is minimal and is lost when flows drop.

Without mitigation in place: The flow variability will be even larger without the minimum flow in place. The flow volumes discharged will be slightly smaller than with the minimum flow and ramp down rule in place. There will be rapid drawdowns on many occasions.

This scenario has an increased risk of seepage erosion in the 2-3 turbine level when banks are saturated. The Gordon River upstream of the Denison River are mostly affected by seepage as significant areas of root mat and vegetation have already been lost due to scour, seepage and inundation. The level of scour will increaseand the loss of sediments during seepage events can create cavities under root mats increasing bank collapse or slumps.

The in-stream habitat area will be reduced without a minimum flow as there will be longer periods with very low flow. There will be reduced habitat for fish and macroinvertebrates and an increased risk of stranding mortality, both due to the lack of minimum flow and lack of ramping during drawdowns. Reduced habitat will be most pronounced above the Denison River.

Macroinvertebrate abundance will decline substantially upstream of the Denison River, and this group will be dependent on natural flows from much smaller tributaries. Specifically the abundance of grazers and flow obligate taxa declines, and communities are dominated by worms (depending on local substrate composition), chironomids and stoneflies. Again, the strongest impact will be above the Denison River confluence.

3.5 Daily hydro-peaking in 2-3 turbine level

This flow scenario has been seen post-Basslink while the original ramp-down rule was in place (Figure 3.4). No ramping was required as long as discharge stayed above 150 m^3s^{-1} (3 turbine level) which encouraged discharging above this level.

Flow variability is experienced in the 2-3 turbine level and flow volumes and velocities are moderate to high.

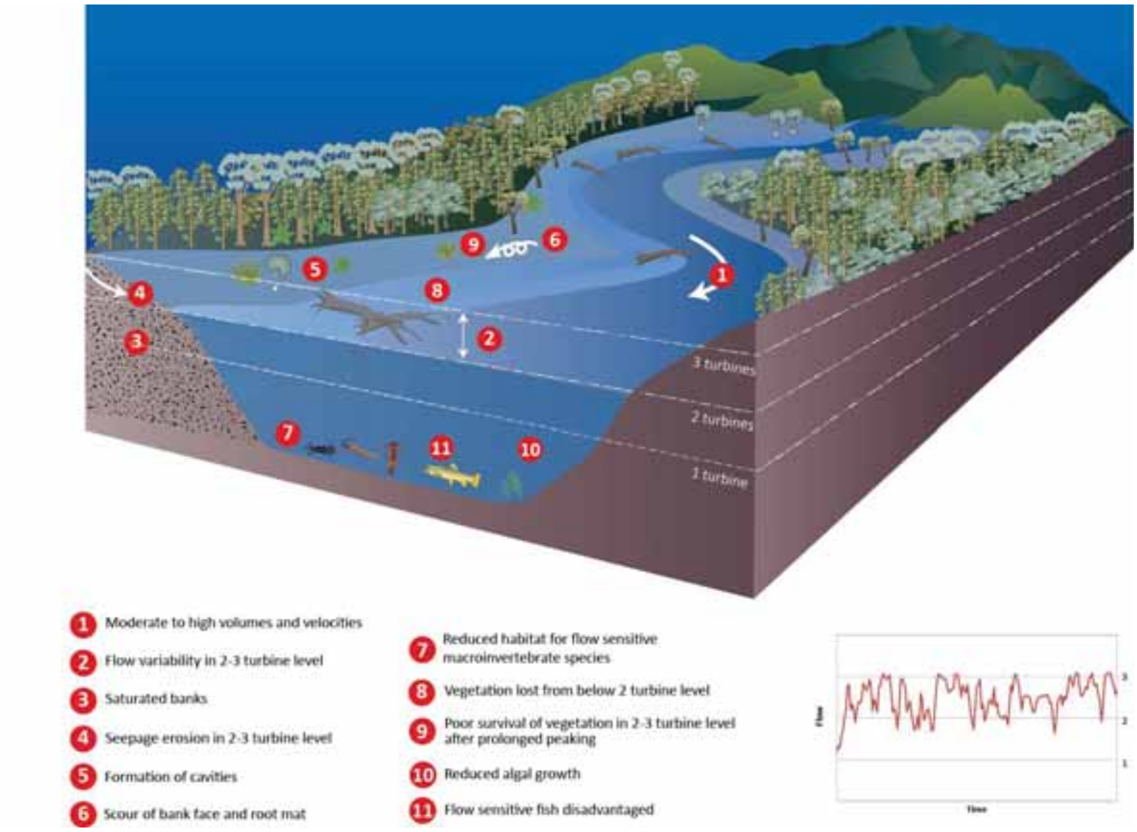


Figure 3.4: Conceptual model of processes occurring during hydro-peaking in 2-3 turbine level scenario.

Extended 2 to 3 turbine power station operation increases bank saturation which increases the risk of seepage processes during draw down. This happens initially in the upstream zones and later, and to a lesser extent, in the downstream zones. Seepage processes lead to the loss of sediment in the 2-3 turbine bank level which under cuts vegetation, leading to the formation of ‘cavities’ and the collapse of over lying vegetation. Over time, seepage processes remove sediment and reduce bank angles to ‘stable seepage slopes’ which extend to a sharp break in slope at the maximum power station operating level.

Following extended seepage erosion events, scour of the bank face and root mats or prolonged inundation, vegetation will disappear in the 2-3 turbine level. The vegetation cannot survive in the 1-2 turbine level due to prolonged inundation.

Algal growth will be limited due to lack of light. Sustained high flows will lead to reduced light availability at the stream bed and hence reduced algal production.The 2-3 turbine peaking disadvantages flow sensitive fish species due to reduced upstream migration opportunities and limited habitat availability. Constant high near-bed hydraulic stress will reduce habitat suitability for many flow-sensitive macroinvertebrate taxa. Macroinvertebrate density and diversity will decline particularly upstream of the Denison River. The abundance of grazers and flow obligate taxa will decline, and communities will be dominated by worms (depending on local substrate composition), chironomids and stoneflies. Lower abundance of macroinvertebrates will limit food resources for fish.

3.6 Base load with three turbines

This flow scenario does not have much flow variability and flow volumes and velocities will be consistently high (Figure 3.5).

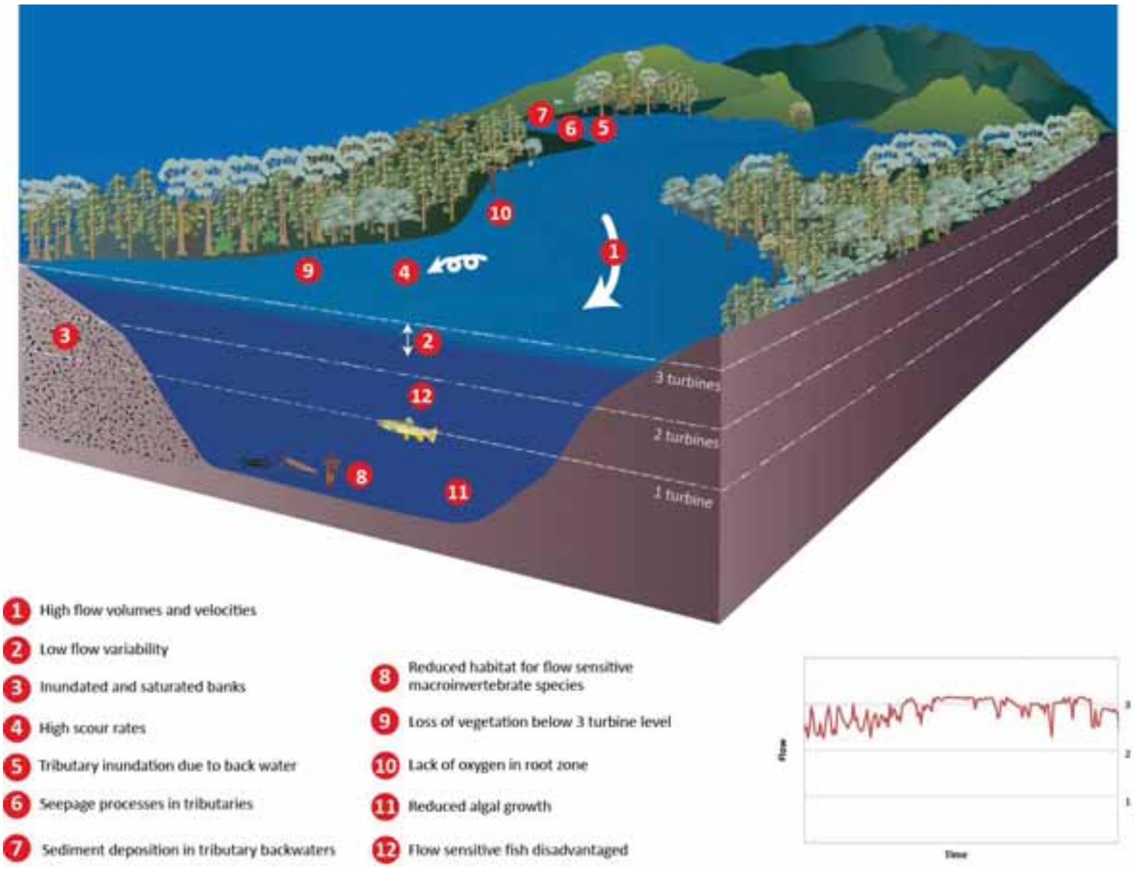


Figure 3.5: Conceptual model of processes occurring at base load with three turbines scenario.

The banks are saturated under this scenario, which increases the risk of seepage erosion in the 2-3 turbine level. However, after this type of operation the revised ramp rule will be applied when draw down occurs, to limit seepage processes. Scour will be the dominant erosion process under this scenario.

Seepage may occur in tributaries near the Gordon confluence due to bank saturation caused by backwater from the Gordon River. The sediment removed by seepage events may be deposited in tributary backwaters.

The vegetation is inundated for extended periods and exposed to high velocities. Both processes lead to loss of vegetation on the banks.

Responses of macroinvertebrates and algae will be similar to those for the scenario of rapid rise and fall in 2-3 turbine level. That is macroinvertebrate density and diversity will decline and algal growth will be limited due to lack of light.

The constant high discharge reduces fish migration opportunities and flow sensitive fish species are disadvantaged.

4. Water quality

4.1 Summary

The water quality in Lake Pedder, Lake Gordon and the middle Gordon River has been monitored since 1999, with monitoring undertaken as part of the Basslink investigations and the Gordon River Basslink Monitoring Program. Three sites have been monitored in each lake, along with four water quality monitoring sites between the Gordon Power Station tailrace to below the confluence with the Denison River (Figure 4.1). This monitoring has identified that the water quality in both lakes and in the river is generally excellent; falling within the expected ranges for similar storages and rivers in south-western Tasmania.

Changes in water quality in the middle Gordon River are largely related to the water level in Lake Gordon and discharge from the power station. The water level in Lake Gordon is the main driver of annual variation in the water temperature of the river, while discharge from the power station and dissolved oxygen levels in Lake Gordon in the vicinity of the power station intake affect dissolved oxygen concentrations downstream of the dam. A decline in water level in Lake Gordon over the period 1999-2008 resulted in greater seasonal variation in water temperatures and increased dissolved oxygen concentrations at the intake depth. This improved water quality was also reflected in the Gordon River immediately below the power station, with the tailrace and upper river sites showing similar increases in seasonality of temperature and higher dissolved oxygen levels. A subsequent rise in lake water levels (~70 % capacity) has seen a return to a reduction in seasonal differences in water temperature. Dissolved oxygen levels in the tailrace have not been affected significantly by the rise to higher levels, due in part to the dominant low flow discharge which causes elevated dissolved oxygen.

Water temperatures in the Gordon River are cooler closer to the tailrace for most of the year when cold water is released from the lake. However, this is reversed in winter when discharge from the power station is slightly warmer than natural inflows from downstream tributaries such as the Denison River.

Dissolved oxygen concentrations at the compliance site (site 65) show little seasonal or short-term variation as the turbulence experienced upstream of this site quickly returns the concentration of dissolved oxygen to close to 100 % saturation. The dissolved oxygen levels in the river from the compliance site (site 65) and downstream is not substantially affected by discharge patterns at the power station.

4.2 Introduction

This section focusses on five key water quality monitoring sites – the Lake Gordon power station intake site (Knob Basin), the Gordon tailrace (site 77), the Gordon River 2 km downstream of the power station tailrace at Albert Rapids (site 75), the Gordon River above Denison (site 65) and the Gordon River below Denison (site 62) (Figure 4.1) . Three key parameters are the focus – water temperature, dissolved oxygen and total dissolved gas (TDG) – as these have some potential for influence on the Gordon River biota (Hydro Tasmania 2005b, 2006, 2007, 2008, 2009, 2010b, 2011, 2012).

Analyses were undertaken to determine if there have been significant changes to the water quality in the middle Gordon River over the monitoring period. Potential influences on the daily, seasonal and inter-annual variation in water temperature and dissolved oxygen are explored to help explain the observed trends.

Although trigger values for water quality were initially developed through the BBR (Hydro Tasmania 2005a), these triggers were reviewed after the first year of monitoring. The review found that trigger values were of little relevance to water quality in the middle Gordon River, as the river is largely controlled by patterns of power station discharge (Hydro Tasmania 2006). Subsequently, water quality was not assessed against triggers but was maintained as an input variable for other monitoring disciplines.

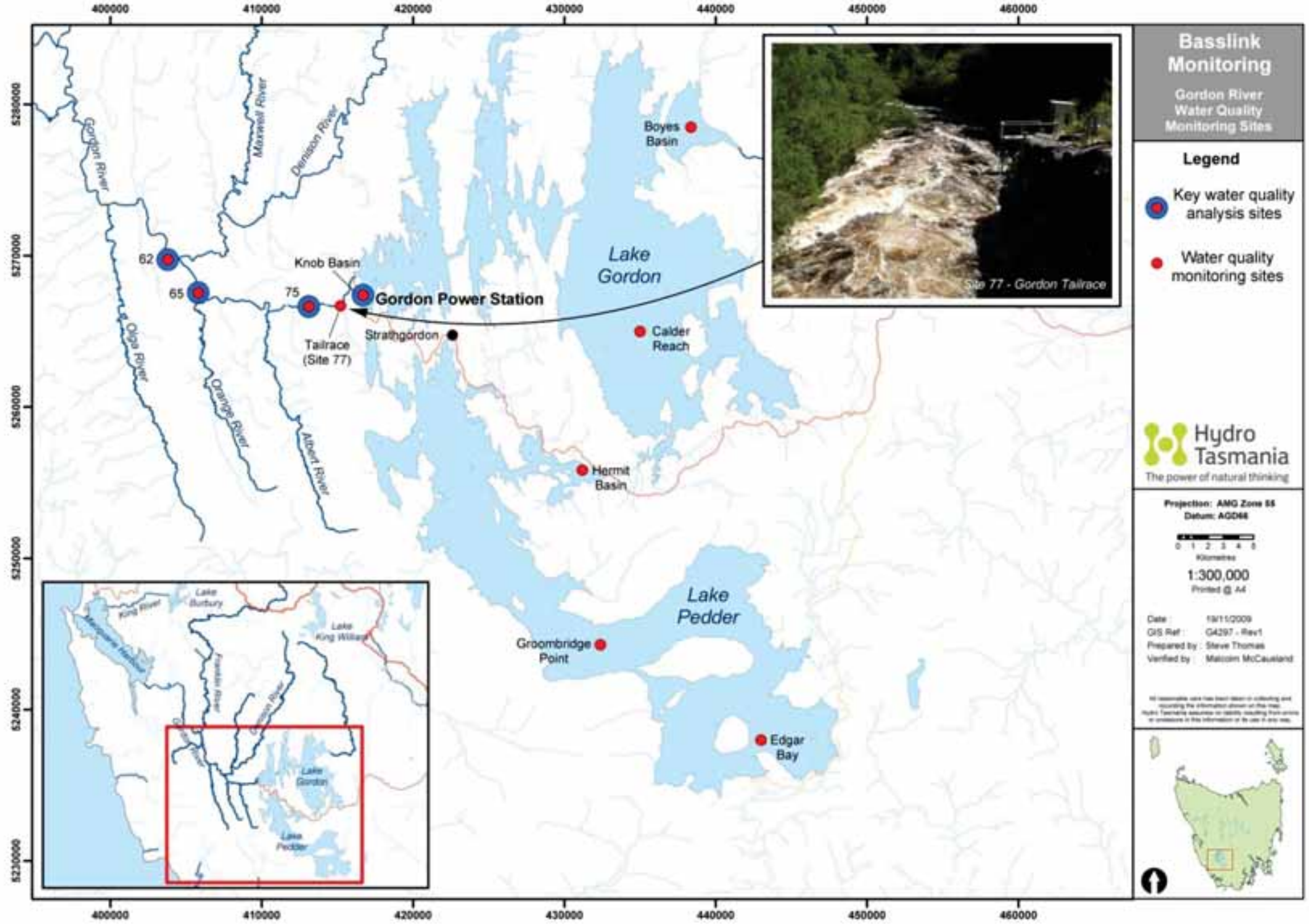


Figure 4.1: Locations of water quality sites in Lakes Pedder and Gordon and the Gordon River. The key sites discussed in this chapter are marked with blue circles.

4.3 Methods

Water quality monitoring was conducted as part of the Basslink Monitoring Program from 2001-12. The monitoring involved two main components; continuous monitoring of river sites and quarterly monitoring of Lakes Gordon and Pedder. A summary of the program follows for each component.

4.3.1 Lake Gordon and Lake Pedder

Water quality monitoring data were collected quarterly from six locations in Lakes Gordon and Pedder. Monitoring sites were located at Knob Basin (approximately 100 m from the power station intake), Calder Reach and Boyes Basin (adjacent to the upper Gordon River inflow) in Lake Gordon and Groombridge Point, Hermit Basin and Edgar Bay in Lake Pedder.

Chemical analyses were carried out on surface water samples collected from each site, and *In situ* depth profiles of basic physico-chemical parameters (water temperature, dissolved oxygen, electrical conductivity and pH) were measured at each site.

4.3.2 Gordon River monitoring

Continuous water quality monitoring data were collected from five sites on the Gordon River downstream from the Gordon Power Station:

- Gordon Power Station tailrace (site 77);
- Gordon River at site 75 (G4 – Albert Rapids), located 2 km downstream of the tailrace;
- Gordon River at site 65 (upstream of the Denison confluence – compliance site), located 12 km downstream of the tailrace;
- Gordon River at site 62 (downstream of the Denison confluence), located 15 km downstream of the tailrace; and
- Gordon River at site 44 (Gordon River above Franklin), located 33 km downstream of the tailrace.

Water temperature was logged at all sites, with dissolved oxygen also recorded at sites 65 (compliance site) and 77 (tailrace). Total dissolved gas was also logged for a short duration at site 77.

4.3.2.1 Missing or poor quality continuous data

The continuous dataset for water temperature and dissolved oxygen at river sites had some periods of poor or missing data. These missing or poor quality data were caused by temporary equipment failures or problems with the appropriateness of the location being measured. In addition, the location of downstream sites (sites 44-75) in remote locations, has at times limited the ability to quickly repair any faulty equipment or ensure that more appropriate installations were made.

A summary of each of the sites, the water quality parameters, length of record and estimate of the proportion of fair to good quality data is presented in Table 4.1.

Table 4.1: Continuous water quality parameters, their period of collection and estimate of fair or good quality record.

Site	Name	River reach	Parameter	Period of record	Estimate of fair or good quality
77	Gordon tailrace	Immediately below dam	Dissolved oxygen	14 May 1999 – 30 April 2012	82 %
			Water temperature	21 July 1999 – 30 April 2012	51 %
			Total Dissolved Gas	5 June 2008 – 26 August 2009	78 %
75	G4-Albert Rapids	Immediately below dam	Water temperature	12 December 1999 – 1 April 2012	78 %
65	Gordon above Denison (Compliance site)	Downstream	Dissolved oxygen	22 April 2006 – 30 April 2012	94 %
			Water temperature	22 April 2006 – 30 April 2012	94 %
62	Gordon downstream Denison	Below Denison	Water temperature	20 December 1999 30 April 2012	86 %
44	Gordon below Franklin	Below Denison	Water temperature	23 February 2005 30 April 2012	99 %

4.4 Trends of consolidated data

4.4.1 Lakes Gordon and Pedder

There were occasional instances of a minor exceedance of ANZECC toxicity guidelines in Lake Gordon and Lake Pedder for the metals aluminium, copper and zinc. Elevated aluminium concentrations are typical of the naturally acidic waters of storages in western Tasmania and the toxicity of all metals is likely to be reduced by the presence of humic substances (ANZECC & ARMCANZ 2000), an effect likely to occur in Lake Gordon due to its high humic content. There were also occasionally elevated chlorophyll *a* concentrations, particularly at the Boyes Basin site. There was no specific trend over time that was evident for either metal or chlorophyll *a* concentrations. For detailed information on the quarterly surface sample water quality at all monitoring sites, please refer to the Basslink Baseline Report and the Gordon Basslink Annual reports (Hydro Tasmania 2005b, 2006, 2007, 2008, 2009, 2010b, 2011, 2012).

4.4.1.1 Gordon Power Station intake (Knob Basin)

Water temperature

At 70-90 m depth (depending on lake level), the intake location is the deepest monitoring site in Lake Gordon and has always shown a strong seasonal pattern of thermal stratification (Hydro Tasmania 2005b, 2010b, 2011, 2012). Stratification is most pronounced in summer and early autumn, breaking down to a uniform profile in winter and spring (Hydro Tasmania 2005a). The autumn thermal stratification depth has varied over the post-Basslink monitoring period occurring at a depth of between 10 and 20 m from the surface (Figure 4.2).

Lake levels decreased by more than 30 m from 2003-2009 (Table 4.2) in response to drought conditions, resulting in warmer summer temperatures at the intake depth. Decreasing water levels also resulted in a more pronounced patterns of seasonal variation in temperature at the intake site (Figure 4.3) with a clear pattern of summer warming and winter cooling apparent each year (Hydro Tasmania 2005a, 2006, 2007, 2008, 2009). Maximum temperatures at the intake depth occurred in early autumn and coincided with seasonal lows in water level, while minimum temperatures in early spring coincide with water level peaks. Subsequent increases in water level (2010-12) resulted in a return to cooler summer temperatures and reduced seasonal variation. Annual water temperature variation was at its lowest (<1.5°C) in 1999–2000 and 2011-12 and at its greatest between 2007–08 and 2008–09 (4 °C).

Observation of the depth at which the temperature 10 °C is exceeded (Figure 4.4) affirms the temperature patterns observed at the intake depth (Figure 4.3). Figure 4.4 shows that the intake level is increasingly close to, or within, the warmer surface mixed layer (epilimnion) during summer and autumn at lower water levels in 2006-09. This is a result of the fixed intake level being close enough to the surface to be within the epilimnion (Table 4.2). The stratification depth threshold in Lake Gordon has previously been identified as 35 m (Locher 2001); this is the depth where the summer thermocline has its potential maximum and below which depth there is little influence of mixing from the surface. Taking water into the power station from below this depth has greater possible thermal implications for the Gordon River. The threshold depth corresponds to a storage height of approximately 288 m, and as water levels have increased towards and beyond this height since 2011 the annual temperature variation has decreased and the likelihood of cold-water pollution increased.

Overall, the lower water levels in Lake Gordon during the first three years of the post-Basslink period (2006-09) contributed to an increased degree of seasonal variability in temperature at the intake depth, while increased water levels in the subsequent three years (2010-12) corresponded to lower variability in temperature at this depth. The resulting discharges from the power station have the potential to be representative of this water temperature pattern at the intake depth, however the effect of this will be dependent on the discharge volume from the power station.

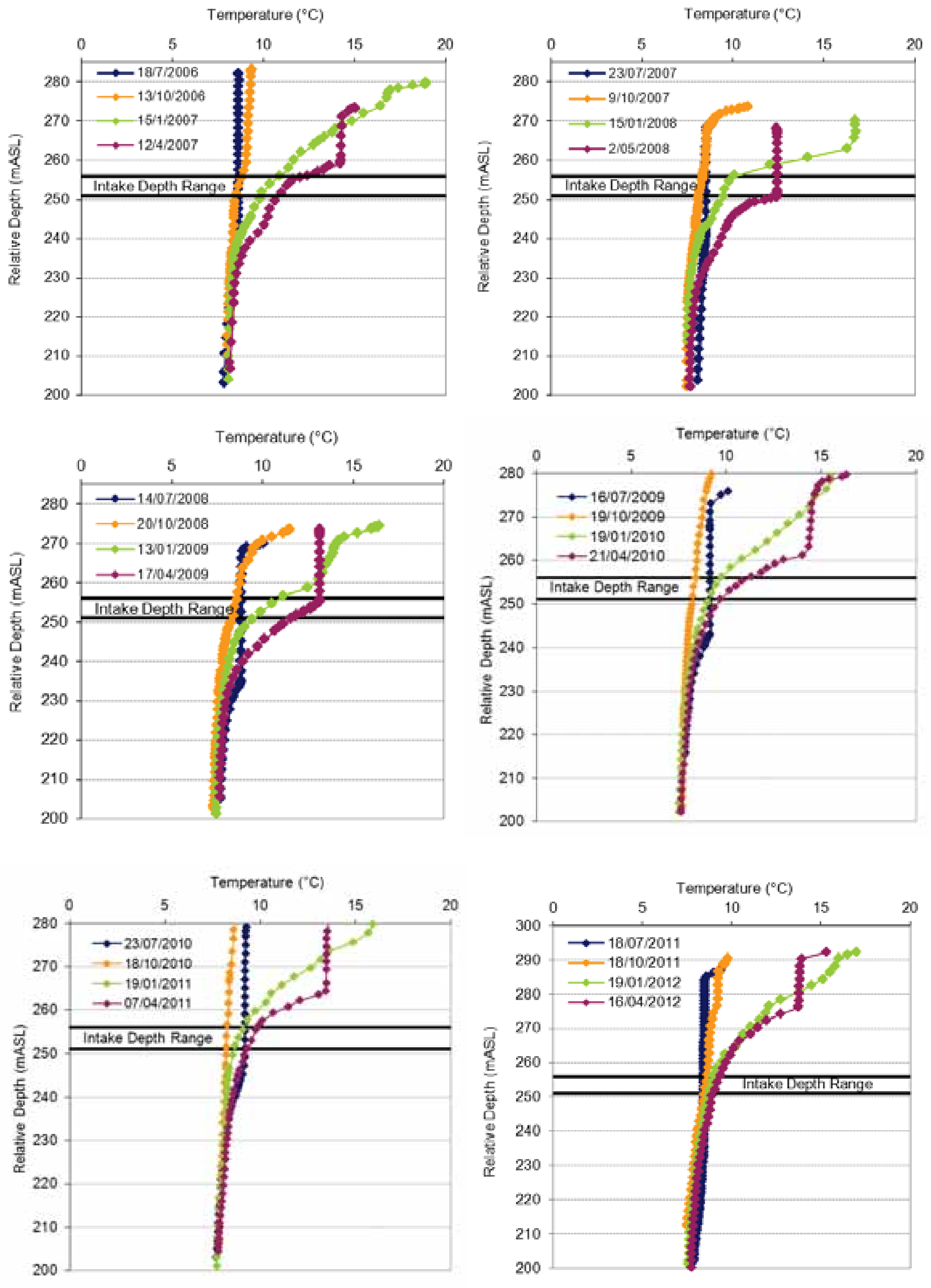


Figure 4.2: Water temperature depth profiles for the power station intake site over the post-Basslink period showing how stratification varies relative to the intake depth.

Table 4.2: Depths from the Lake Gordon surface to the Gordon Power Station intake over the course of Basslink-related monitoring activities. Depths greater than the stratification threshold of 35 m (Locher 2001) are shown in bold type. Records from the post-Basslink period are shaded green.

Date of monitoring	Surface level (mASL)	Depth from surface to intake (m)
04/08/1999	**298.0**	**44**
30/09/1999	**299.2**	**45.2**
01/12/1999	**299.0**	**45**
21/01/2000	**296.6**	**42.6**
29/03/2000	**291.9**	**37.9**
01/06/2000	**289.8**	**35.8**
31/08/2000	**291.5**	**37.5**
05/12/2000	**294.4**	**40.4**
01/03/2001	**290.7**	**36.7**
18/06/2001	284.4	30.4
19/09/2001	286.3	32.3
01/08/2002	278.8	24.8
30/10/2002	285.4	31.4
05/02/2003	283.6	29.6
13/05/2003	275.0	21
28/07/2003	276.1	22.1
15/10/2003	282.4	28.4
25/02/2004	279.8	25.8
11/05/2004	276.4	22.4
20/07/2004	280.9	26.9
18/10/2004	285.3	31.3
11/01/2005	283.8	29.8
11/04/2005	278.0	24
19/07/2005	276.1	22.1
18/10/2005	280.3	26.3
18/01/2006	283.6	29.6
11/04/2006	281.2	27.2
18/07/2006	282.4	28.4
13/10/2006	283.2	29.2
15/01/2007	279.8	25.8
12/04/2007	273.4	19.4
23/07/2007	269.3	15.3
09/10/2007	273.6	19.6

Table 4.2 continued next page

Date of monitoring	Surface level (mASL)	Depth from surface to intake (m)
15/01/2008	270.5	16.5
02/05/2008	268.1	14.1
14/07/2008	270.2	16.2
20/10/2008	273.8	19.8
13/01/2009	274.8	20.8
17/04/2009	273.9	19.9
16/07/2009	276.1	22.1
19/10/2009	282.2	28.2
19/01/2010	282.4	28.4
24/04/2010	281.2	27.2
23/7/2010	283.1	29.1
18/10/2010	286.6	32.6
19/01/2011	287.8	33.8
07/04/2011	287.1	33.1
18/07/2011	287.3	33.3
18/10/2011	**290.8**	**36.8**
19/01/2012	**292.6**	**38.6**
16/04/2012	**293.2**	**39.2**

Table 4.2 continued

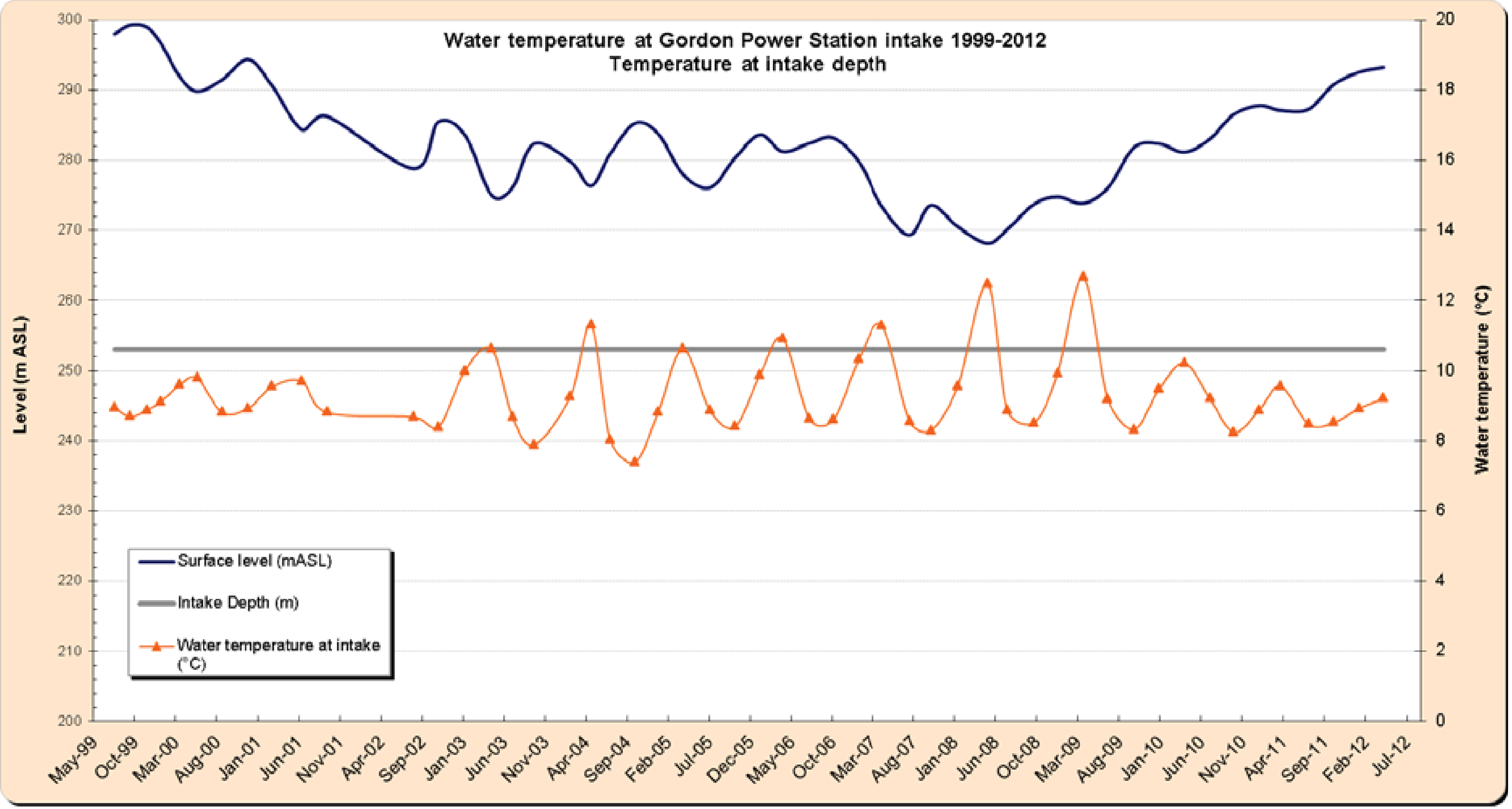


Figure 4.3: The correspondence between surface water level and water temperature at the Gordon Power Station intake depth for the period July 1999 to April 2012.

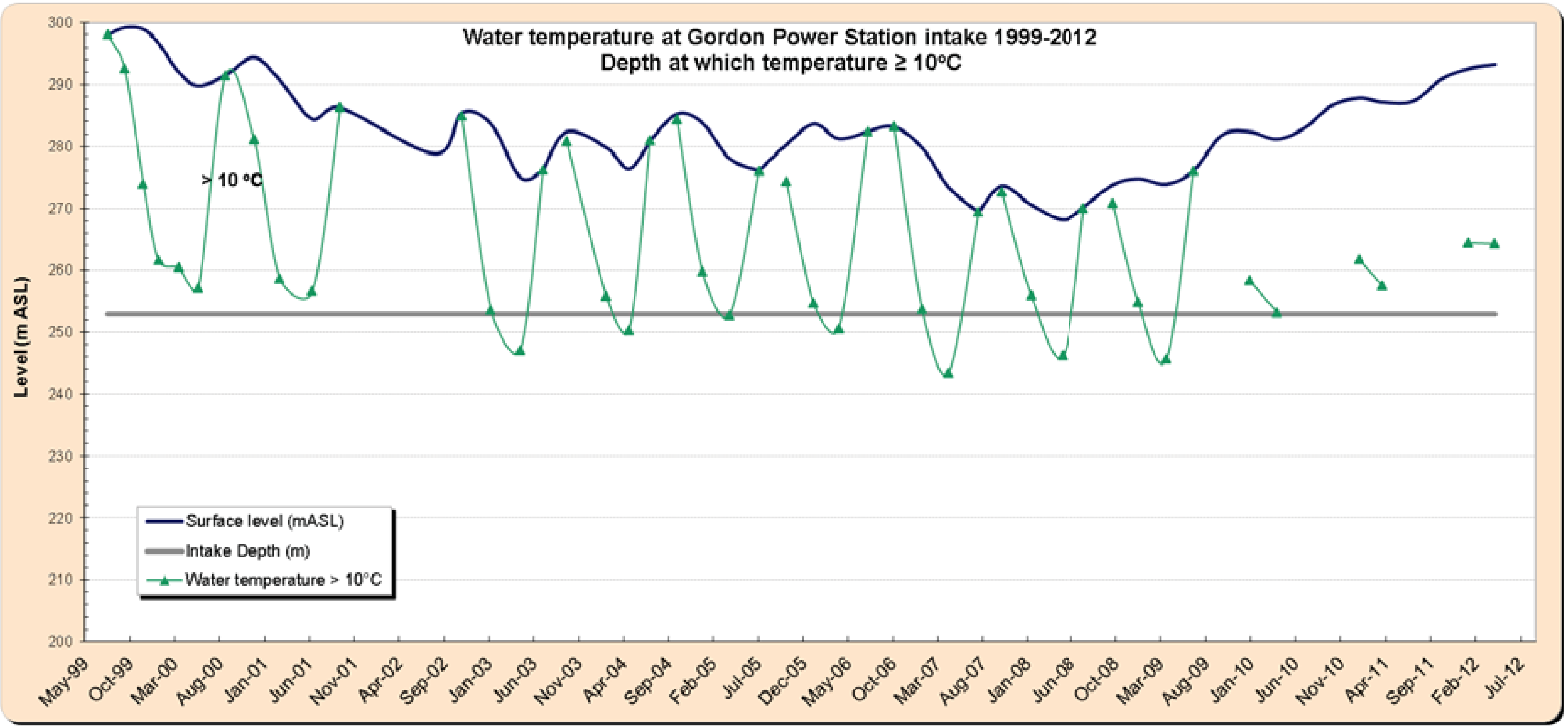


Figure 4.4: The correspondence between surface water level and 10 °C temperature fluctuations at the intake depth shows downward movement of the epilimnion relative to the intake as lake level decreases.

Dissolved oxygen

Seasonal depth profiles of dissolved oxygen concentrations in Lake Gordon (Figure 4.5) have shown varying degrees of oxygen stratification, with the depth of the oxycline varying on a seasonal basis from 15 to 60 m.

Oxygen stratification followed broad seasonal patterns that varied from year to year in the post-Basslink period, and was consistent with monitoring since 1999 (Locher 2001, Hydro Tasmania 2005a). Stratification developed during the warmer months, with depleted oxygen levels (<6 mg L^{-1}) that rose to within 20 m from the surface in late autumn and fell to depths greater than 30 m in spring (Figure 4.6). Thus the greatest risk of low dissolved oxygen entering the intake was during autumn. In the first three years (2006-09) of the post-Basslink period, the oxycline coincided with, or was slightly below, the intake depth (Figure 4.5 and Figure 4.6). In the subsequent three years (2010-12), the intake was well below the first 'step' in the autumn oxycline.

The depth of the oxycline relative to the intake is influenced by storage level as well as seasonal patterns. Figure 4.5 illustrates the relationship between intake level, lake level, and the depth at which dissolved oxygen is lower than 2 mg L^{-1} and 6 mg L^{-1}. The occurrence of dissolved oxygen < 6 mg L^{-1} at the intake depth showed a decrease when water levels were low from 2006-09. There has since been an increase in the occurrence of autumn concentrations < 6 mg L^{-1} in response to the rising storage levels. The closer proximity of the intake to the epilimnion at lower water levels in 2006-09 was responsible for the higher concentration of dissolved oxygen, and is related to the degree of surface mixing and the formation of the thermocline.

The variation in depth where dissolved oxygen concentrations < 2 mg L^{-1} occur shows a weaker pattern in relation to the storage height (Figure 4.6). The deeper levels of this threshold correspond to the spring period and are coincident with the deeper mixing that occurs at this time. There has been no incidence of this level of dissolved oxygen ever being detected at the intake, however it was close to this in June 2000 when water levels were high (Figure 4.6). The likelihood of water with dissolved oxygen as low as 2 mg L^{-1} entering the power station intake is low; however, if water levels increase to levels approaching capacity, the likelihood of this occurring also increases.

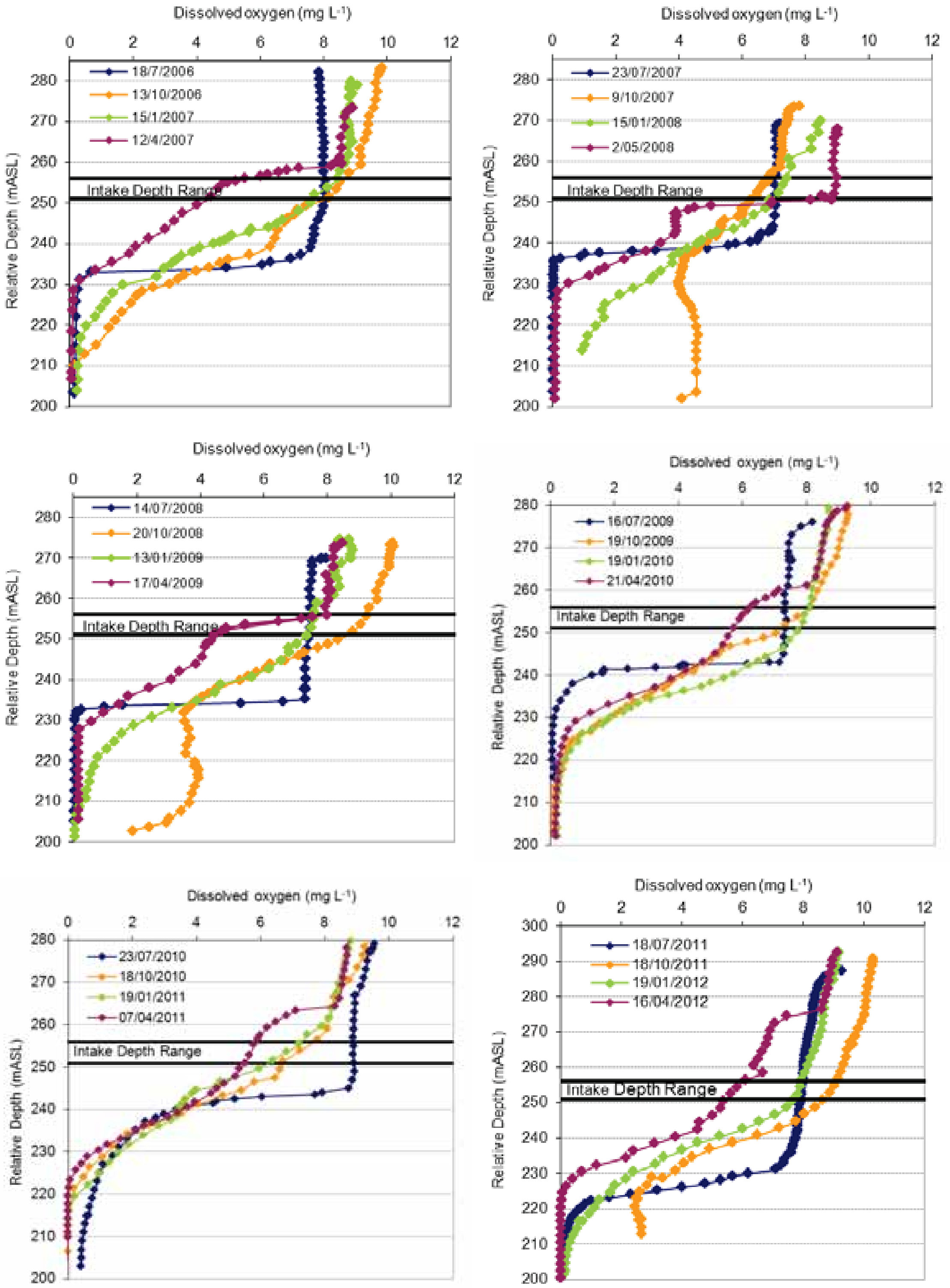


Figure 4.5: Depth profiles of dissolved oxygen concentration (mg/L) at the Gordon Power Station intake site, showing the position of the thermocline relative to the intake depth over the post-Basslink period.

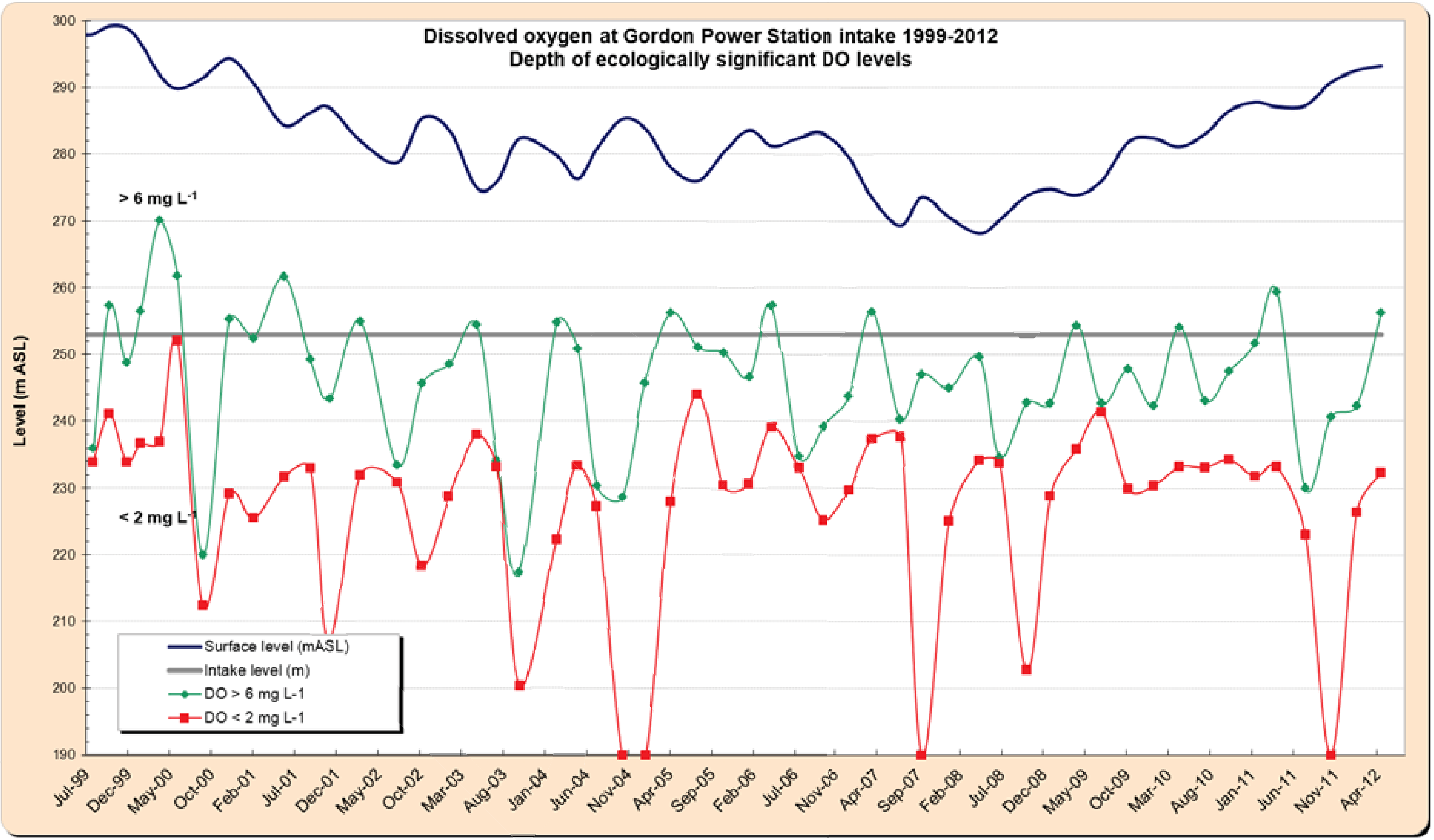


Figure 4.6: The correspondence between surface water level, intake depth and dissolved oxygen ranges at the intake site, Lake Gordon for the period July 1999 to April 2012.

4.4.2 Gordon River

4.4.2.1 Water temperature

General patterns

The hydrological regime and conditions in Lake Gordon, particularly at the intake, would be expected to govern water temperature in the Gordon River immediately below the power station. As discussed above, the temperature of water released into the river is influenced by lake level and degree of thermal stratification (Hydro Tasmania 2005b, 2006, 2007, 2008, 2009, 2010b, 2011, 2012). In this section, water temperature data from the Gordon River at Albert Rapids (site 75) are primarily used when comparing long-term trends, rather than those from the tailrace (site 77). Gordon River at Albert Rapids (site 75), being only 2 km downstream, is representative of tailrace temperatures and the quality of data from this site has been better over the majority of the monitoring period. Temperatures further downstream at site 65 and site 62 are examined to determine the longitudinal variation in water temperature and the influence of tributary inputs.

Differences between the water temperatures at the different sites on the river can be related to their distance downstream from the power station. Figure 4.7 shows the water temperature record from the Gordon River at sites 75 and 62 for 2006–11. Figure 4.8 shows a small portion of the continuous temperature record to differentiate the diurnal patterns, and Figure 4.9 shows the mean monthly water temperatures at different sites in the Gordon River from the start of monitoring in 1999.

For warmer parts of the year (September–March), the coolest water was generally found immediately downstream of the tailrace (site 75), while the warmest was often below the confluence with the Denison River at site 62. The increase in temperature downstream over the summer period is related to a combination of the influence of ambient air temperature and the greater proportion of water contributed from tributaries. This longitudinal difference in water temperature is also evident on a shorter scale, where there is a larger diurnal variation in air temperature at site 62 (Figure 4.8). In 2009-10 and 2010-11, the difference in seasonal peak water temperature between site 75 and site 62 is greater than in previous years (Figure 4.10). The dominance of low flows over the warmer months in these years appears to have influenced the water temperature downstream of the Denison River, by reducing the relative input of cooler Lake Gordon water.

The mean monthly temperature patterns in Figure 4.9 are indicative of the seasonal variation of water discharged from the Gordon Power Station. Over the first three years of the post-Basslink period (2006-07 to 2008-09), the lower lake levels were responsible for increased seasonal variability and warmer maximum temperatures at the intake depth. These changes were reflected in water temperature records from the middle Gordon River, with similar increases in seasonal variability and maximum temperatures also recorded in the river. As water levels have risen in 2009-10 to 2011-12, the seasonal variability, as reflected in the mean monthly temperature, has been reduced.

During the cooler months (April–August) there is a less defined longitudinal difference in temperature (Figure 4.10) with occasional periods of cooler temperatures downstream at site 62. This is due to the comparatively warmer temperatures at the power station intake, combined with the cooling effect of ambient air temperature and the greater influence downstream of cooler water sourced from tributaries.

In summary, the temperature data indicate that:

- diurnal variability at the Gordon River at Albert Rapids (site 75) is constrained for most of the time. This is a result of discharging water from Lake Gordon, which has a relatively stable diurnal temperature variation at the intake depth;
- diurnal variability at site 62 is greater than site 75 due to the greater influence of ambient temperatures and natural inflows, but is still somewhat constrained whenever the power station is discharging (Hydro Tasmania 2005a);
- sites 75 and 62 show a seasonal cycle in water temperature, with a maximum of around 13–14 °C in April and minimum of around 7–8 °C in September–October;
- the peak in autumn temperature at site 75 was noticeably lower in 2009-10 to 2011-12 as a result of the higher storage level and the intake being below the thermocline; and
- temperature at site 62 are higher (by about 1 °C on average) than site 75 during the warmer months (October–March) and similar during the cooler months (April–August).

Figure 4.7 shows some sudden and dramatic increases or decreases in temperature throughout the year at sites 75 and 62. These were mostly the result of the complete cessation of power station discharge due to scheduled outages to undertake monitoring for the Gordon River Basslink Monitoring Program, or maintenance outages (Hydro Tasmania 2010b). Low power station discharges (10 m^3s^{-1}) were observed to have a significant degree of temperature control, with significant changes in water temperature only evident during outages (Hydro Tasmania 2010b).

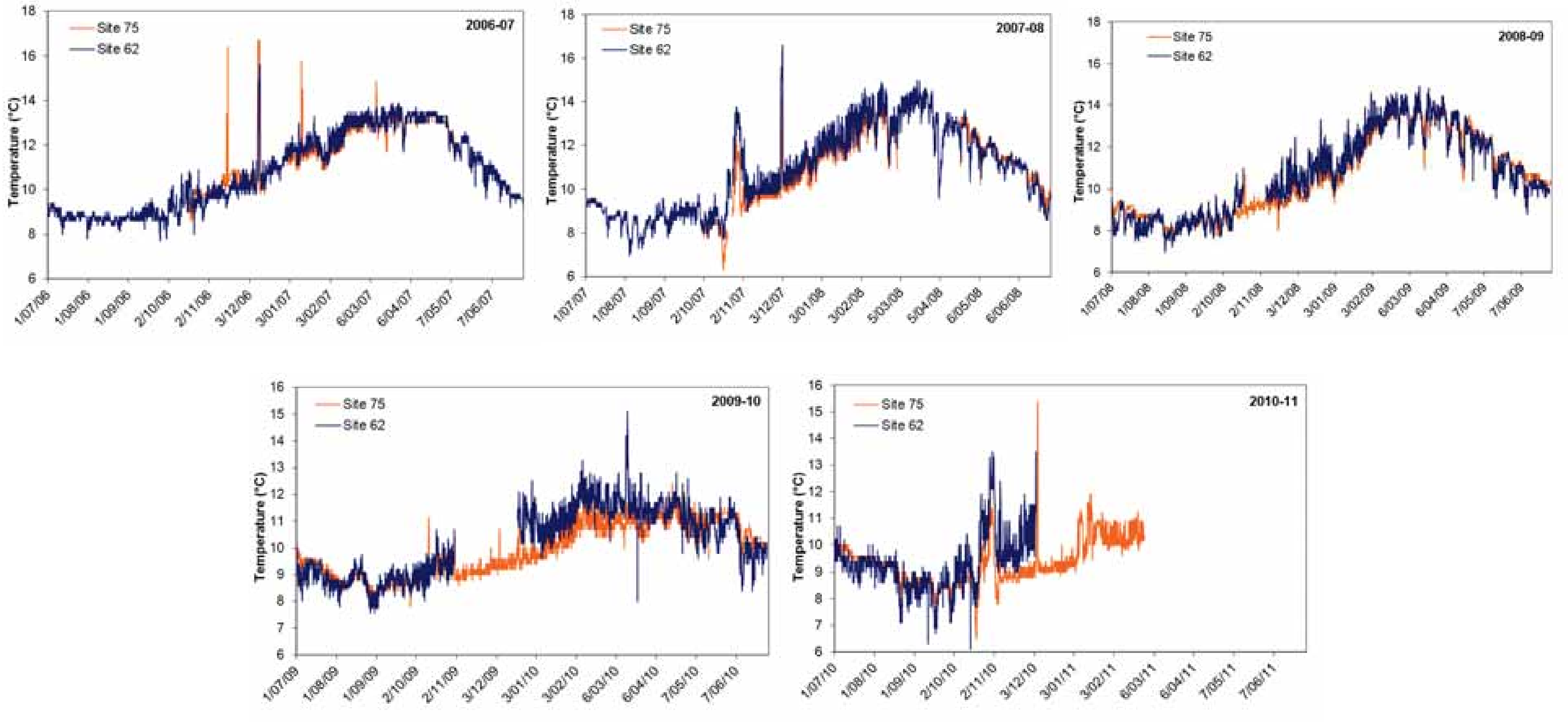


Figure 4.7: Water temperature for the Gordon River at Albert Rapids (site 75) and downstream of the Denison confluence (site 62) for the years 2006–11. All data from these sites was of poor quality for 2011-12, and a graph is not presented.

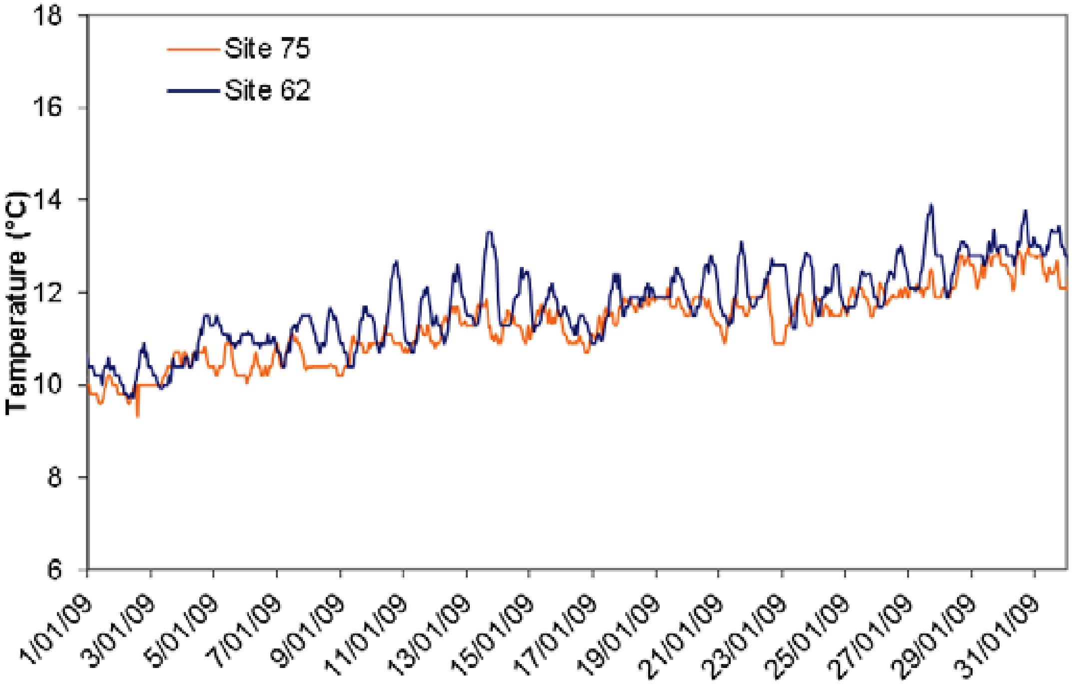


Figure 4.8: Short-term comparison of summer water temperature at sites 62 and 75, indicating differing degrees of diurnal temperature variation.

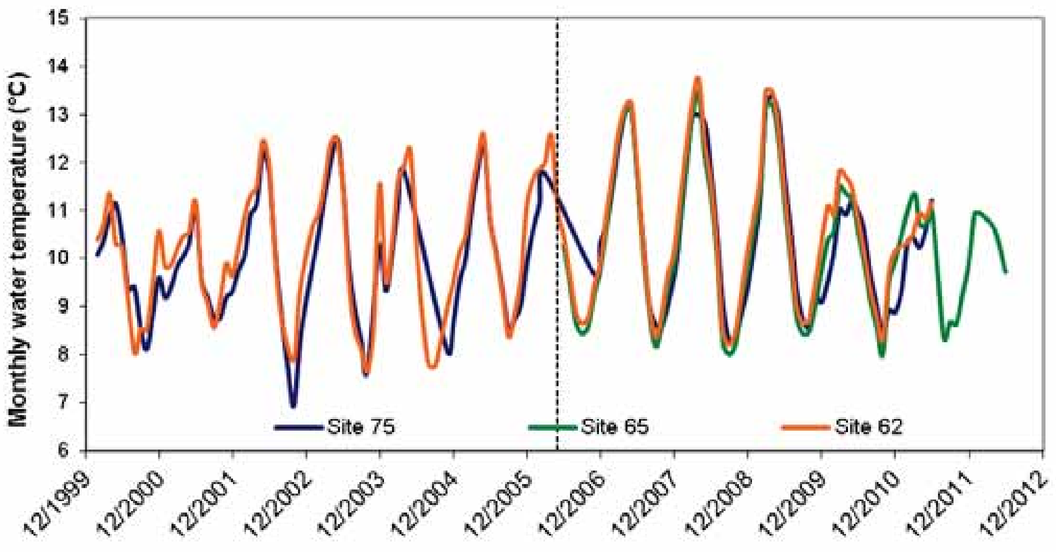


Figure 4.9: Mean monthly water temperature for hourly data collected at the Gordon River at Albert Rapids (site 75), Gordon below Denison (site 62) and Gordon above Denison (site 65) from 1999 to 2012. Black dotted line indicates date of Basslink commissioning.

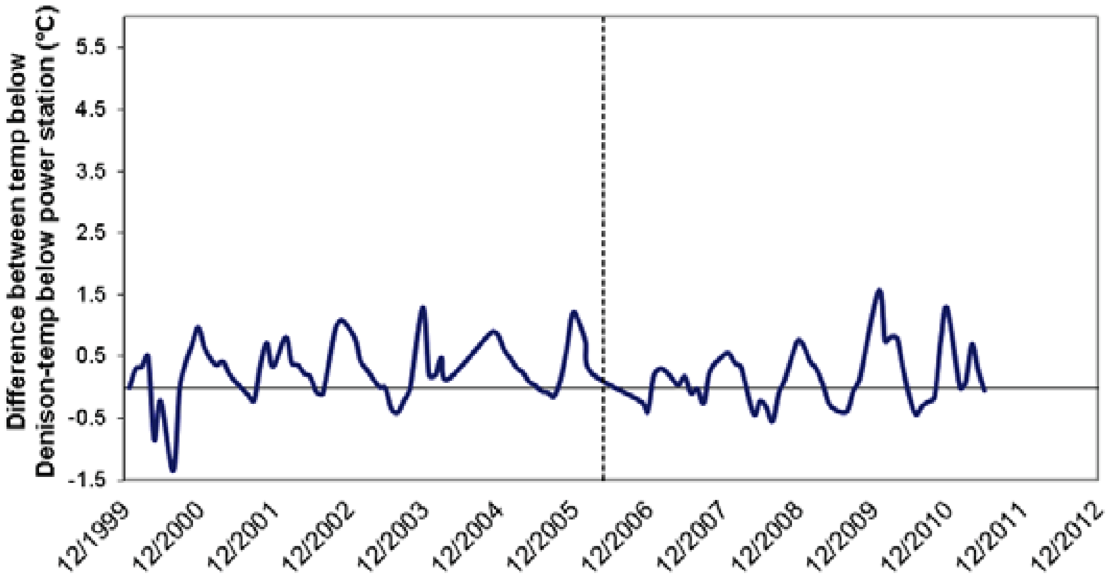


Figure 4.10: Difference in average monthly water temperature at the Gordon below Denison site (site 62) and Gordon at Albert Rapids (site 75). Negative values indicate that water at site 75 is warmer than the water below the Denison. Black dotted line indicates date of Basslink commissioning.

Water temperature statistical analysis

A number of analyses were undertaken on the continuously collected water temperature data at site 75. Water temperature data for site 75 was analysed by pooling all available fair to good quality pre- and post-Basslink continuous data. The data was aggregated to two hourly intervals and analysed by t-test to determine the statistical significance of any temperature differences between pre- and post-Basslink periods. Comparisons were made for the whole pre- and post-Basslink period and for each calendar month to determine the seasonal differences.

Water temperature was significantly higher post-Basslink for the whole period ($p < 0.0001$) and for all calendar months ($p < 0.0001$) other than July ($p = 0.38$) and November ($p = 0.98$) (Table 4.3, Figure 4.11, Figure 4.12). Though the temperature differences were statistically significant, the temperature variance between pre- and post-Basslink means was small. The most pronounced difference was observed in January and February, when there was a difference between pre- and post-Basslink means of 0.88 and 1.10 °C, respectively.

Table 4.3: Mean water temperature in pre- and post-Basslink periods for all months and each calendar month and the statistical significance of the differences.

Month	**Mean water temperature (°C)**		**Difference between mean water temperature (°C)**	**p**
	Pre-Basslink	Post-Basslink		
All	9.91	10.00	0.09	<0.0001
January	10.03	10.91	0.88	<0.0001
February	10.81	11.91	1.10	<0.0001
March	11.40	11.60	0.20	<0.0001
April	11.86	11.65	-0.21	<0.0001
May	11.33	11.49	0.16	<0.0001
June	10.05	10.43	0.38	<0.0001
July	9.14	9.15	0.01	0.38
August	8.35	8.70	0.35	<0.0001
September	8.01	8.54	0.53	<0.0001
October	8.37	9.06	0.69	<0.0001
November	9.43	9.43	0.00	0.98
December	9.78	10.12	0.32	<0.0001

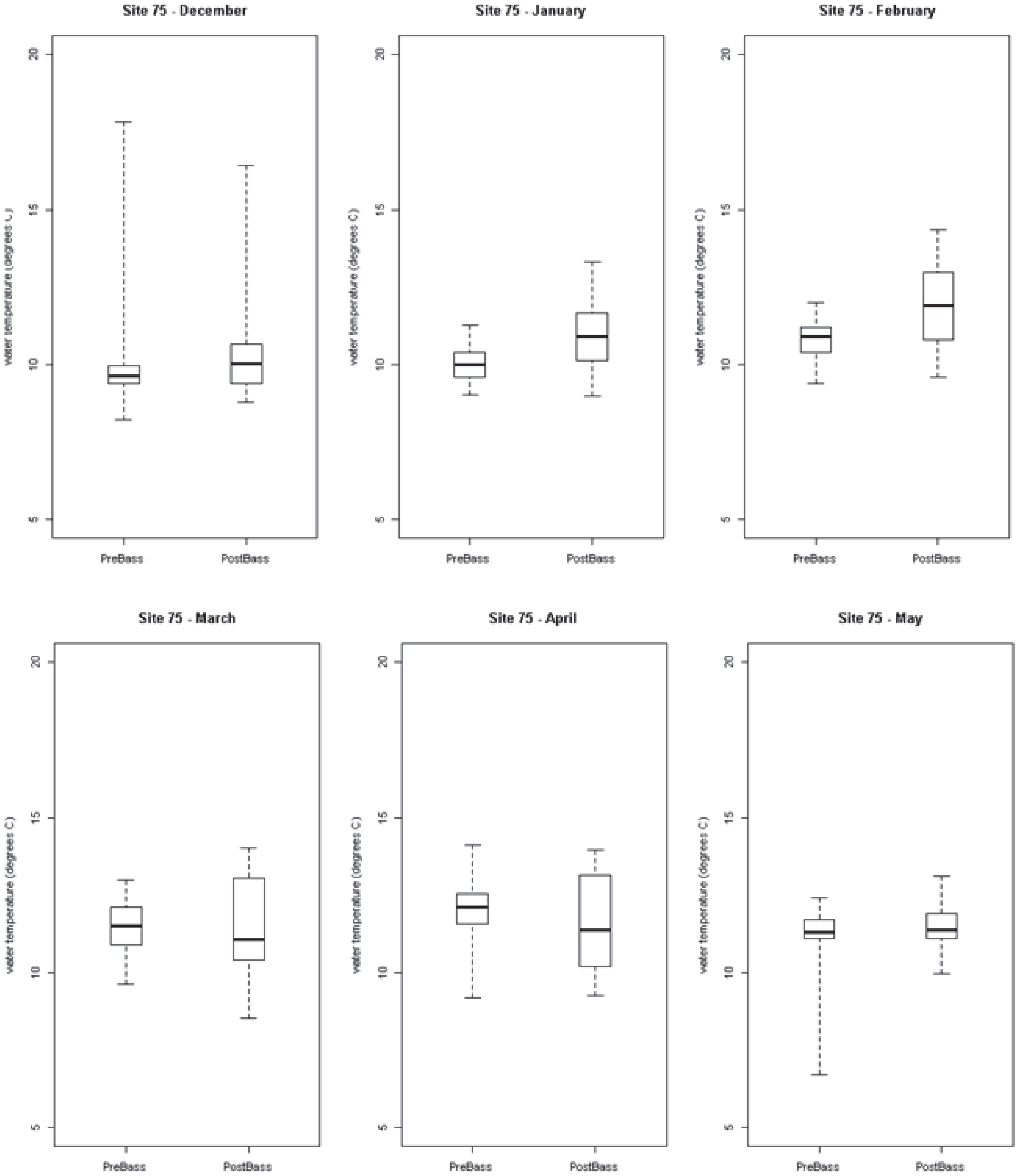


Figure 4.11: Monthly water temperature at site 75 (summer and autumn) for pre- and post-Basslink periods showing median value (solid black line), 25th and 75th percentiles (lower and upper box extents), and minimum and maximum values.

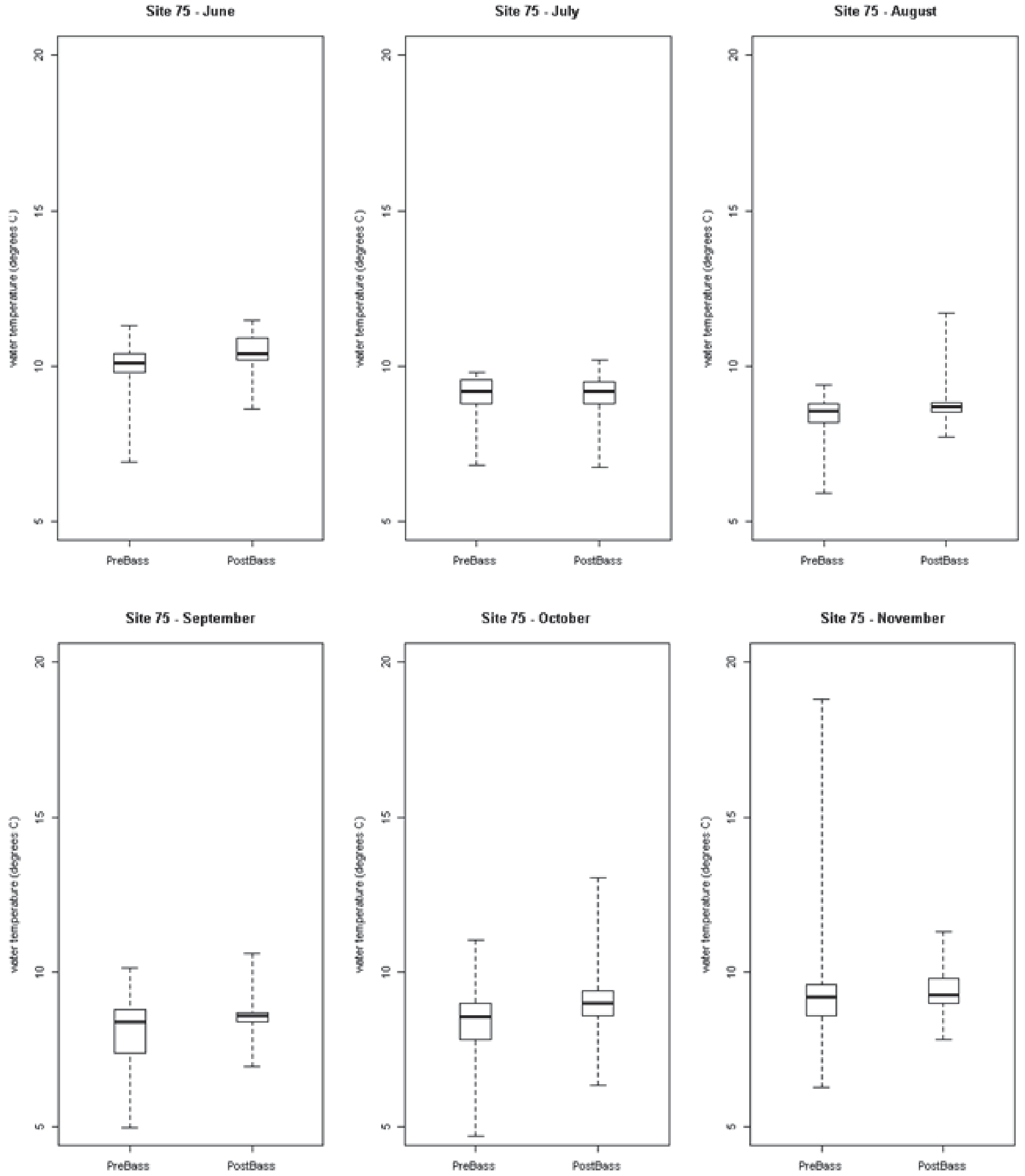


Figure 4.12: Monthly water temperature at site 75 (winter and spring) for pre- and post-Basslink periods showing median value (solid black line), 25th and 75th percentiles (lower and upper box extents), and minimum and maximum values.

The factors influencing water temperature at site 75 were further explored. The continuous data were used to statistically test whether water temperature is influenced by storage level and/or discharge. This analysis was undertaken with daily aggregated data. For the factor most closely correlated with water temperature, further plots of month by month pre- and post-Basslink data are presented in Appendix 3.

The correlation analysis indicated that decreasing storage levels in Lake Gordon are associated with increasing water temperature at site 75 (Table 4.4). These negative correlations between water temperature and storage level were strong during summer (particularly in January and February) and autumn (particularly in March and April). (Table 4.4). The seasonal differences between correlations appear to be driven by the seasonal mixing of Lake Gordon and storage level. For those months in which strong correlations are seen, water temperatures are near their seasonal maximum when stratification in Lake Gordon is at its most pronounced. This appears to confirm that the temperature which the water is able to reach at the substantial depth of the power station intake at this time of year is determined by the depth of the storage. A lower storage means that the intake will be above the thermocline and temperature of water being discharged to the Gordon River via the power station will be warmer than in years when the water level is higher. When water levels are higher, the intake will be further from the surface of Lake Gordon and may also fall at or below the thermocline so water could be substantially cooler.

The weak correlations seen in winter and spring months are related to the occurrence of mixing and the devolution of stratification at this time of year. Following overturn in Lake Gordon, the water temperature differences between years will be less pronounced and storage level will have less influence on water temperature at this time.

There were a number of significant correlations between temperature and discharge at site 75; however, these correlations were weak and suggest that discharge has little influence on temperature in the Gordon River at site 75 (Table 4.4).

Table 4.4: Correlation coefficients and r^2 values for temperature/storage level and temperature/ discharge in Lake Gordon. Bolded values are statistically significant ($p < 0.001$), and values in red indicate strong correlations ($r^2 > 0.4$).

Month	**Temperature Site 75 Storage level**		**Temperature Site 75 Discharge**	
	Correlation coefficient	**r^2**	**Correlation coefficient**	**r^2**
Jan	**-0.6409**	**0.4107**	0.0472	0.0022
Feb	**-0.7402**	**0.5480**	-0.1220	0.0149
Mar	**-0.8406**	**0.7066**	**0.1925**	**0.0371**
Apr	**-0.8928**	**0.7970**	**0.3028**	**0.0917**
May	**-0.4490**	**0.2016**	**0.2840**	**0.0807**
Jun	**-0.3206**	**0.1028**	**0.3763**	**0.1416**
Jul	**-0.2735**	**0.0748**	**0.1818**	**0.0330**
Aug	**-0.3015**	**0.0909**	**0.4061**	**0.1649**
Sep	-0.0161	0.0003	**0.3216**	**0.1034**
Oct	-0.0249	0.0006	**0.1658**	**0.0275**
Nov	**-0.1713**	**0.0293**	0.0211	0.0004
Dec	**-0.4050**	**0.1640**	-0.0840	0.0071

4.4.2.2 Dissolved oxygen

General patterns

Since 1999, high dissolved oxygen values have been recorded at the tailrace, with a maximum of 17.2 mg L^{-1} recorded in November 2000 and September 2011. Median values have increased over the post-Basslink period, with the highest median of 13.6 mg L^{-1} in 2010-11 (Figure 4.13; Table 4.5). The percentage of readings > 12 mg L^{-1} has increased dramatically from 0 % in 2005-06 to 92 % of readings in 2011-12, whilst those < 6 mg L^{-1} (the level required to sustain aquatic life) have declined, with no dissolved oxygen values < 6 mg L^{-1} recorded during 2006-07 and 2008–09 to 2011-12 (Table 4.5). The percentage of time where the dissolved oxygen has been < 6 mg L^{-1} has reduced significantly since 2001–02, with oxygen levels being at this level for < 1 % of the time in most years since from 2002–03 (Table 4.5).

Alteration of operating patterns is the main reason for the higher concentration of dissolved oxygen in the tailrace, particularly in the most recent post-Basslink years. There has been a lower use of regular long-term high discharge over the late summer and autumn period post-Basslink and thus the dissolved oxygen concentration in Lake Gordon is less reflected in the Gordon River. The higher concentration of dissolved oxygen in the tailrace post-Basslink is likely an effect of the “injection” of air in the turbines that occurs at lower operating loads. The large proportion of time with low discharge over the late summer and autumn period in 2011-12 is likely to have influenced the high dissolved oxygen concentration downstream of the tailrace, despite the lower concentrations of dissolved oxygen found in Lake Gordon at the intake depth.

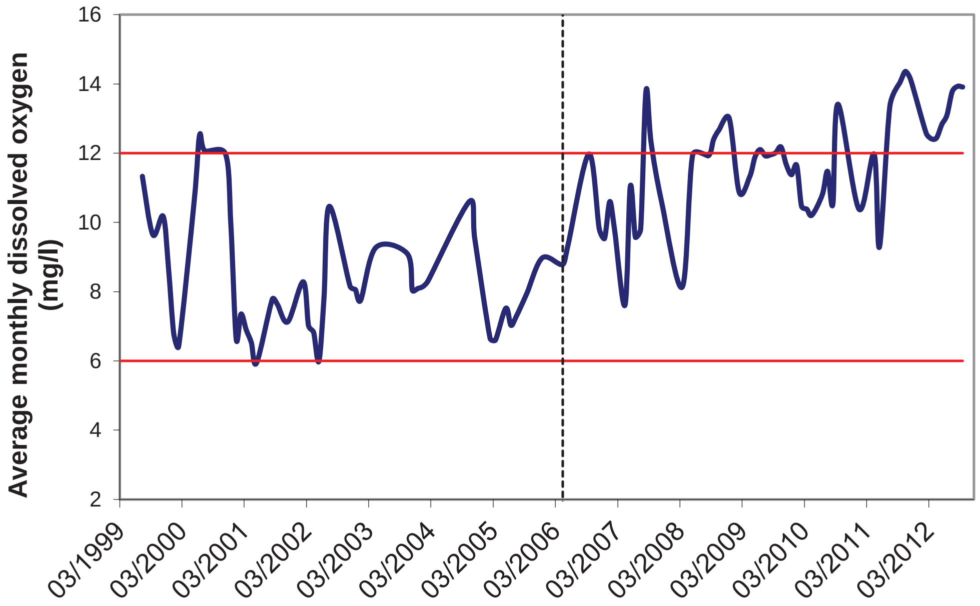


Figure 4.13: Average monthly dissolved oxygen levels at Gordon Power Station tailrace (site 77) since 1999.

Table 4.5: Annual dissolved oxygen statistics for the Gordon Power Station tailrace site, including: the maximum, median and minimum dissolved oxygen values; and the percent of readings which were above 12 mg L^{-1} and below 6 mg L^{-1}.

Year	Maximum (mg/L)	Median (mg/L)	Minimum (mg/L)	%>12 (mg/L)	%<6 (mg/L)
1999–2000	15.7	8.7	4.8	18.0	17.6
2000–01	17.2	7.8	4.1	16.1	25.0
2001–02	14.6	7.2	4.0	2.2	18.6
2002–03	13.6	8.9	6.0	5.2	0.0
2003–04	13.8	8.6	5.8	6.6	0.1
2004–05	13.2	7.7	5.6	0.8	3.2
2005–06	12.0	8.3	5.5	0.0	0.2
2006–07	15.1	6.5	9.2	22.1	0.0
2007–08	15.2	10.9	4.5	36.9	0.7
2008–09	14.6	12.3	7.1	61.4	0.0
2009-10	15.1	11.5	5.7	32.5	0.04
2010-11	15.3	12.5	5.7	57.0	0.01
2011-12	17.2	13.6	6.1	92.0	0.0

Figure 4.14 shows the average monthly dissolved oxygen levels at site 77 compared to site 65 from 2006 to 2012 (post-Basslink period). There was no evidence of sustained low dissolved oxygen at site 77 or site 65 during this period with measurements varying from 8 to 14.4 mg L^{-1} (Figure 4.14). The extent of potential daily fluctuation at both sites due to power station operations is illustrated by Figure 4.15 which shows hourly changes in dissolved oxygen concentration over a one month period (February 2007 was selected as it represents a period of high variability at site 77 compared to site 65). Daily variability is primarily the result of the changing loading of the power station and its subsequent effect on dissolved oxygen concentrations. Under low to mid-range turbine operations, air injection occurs automatically to prevent cavitation in the turbines and has the effect of increasing the concentration of dissolved oxygen in the discharge waters. Low dissolved oxygen values in the daily range therefore are the result of operating at high turbine load when air injection is not required. These values reflect the concentration of dissolved oxygen in Lake Gordon at the intake site. In addition to the daily variation, seasonal variation in dissolved oxygen occurred in response to changing stratification in Lake Gordon (Hydro Tasmania 2008).

Dissolved oxygen concentrations at site 65 were generally high, with a median of 12.1 mg L^{-1} and a significantly lower variability than the tailrace (Figure 4.14). There appears to be little relationship between variation in concentrations in dissolved oxygen in site 77 and site 65 (Figure 4.14 and Figure 4.15), with concentration responding primarily to flow rate: at higher flows there were increases in dissolved oxygen at site 65, suggesting that dissolved oxygen is influenced by the degree of aeration in the river between site 77 and site 65. There were no specific seasonal trends in the dissolved oxygen at site 65.

Figure 4.14: Average monthly dissolved oxygen levels at Gordon Power Station tailrace and Gordon above Denison (site 65) over the post-Basslink period.

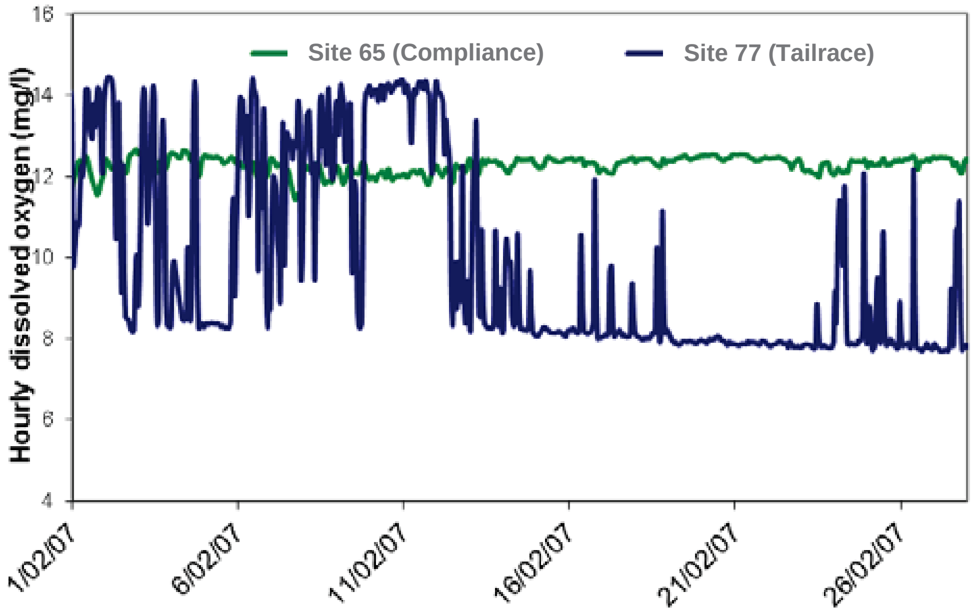


Figure 4.15: Hourly dissolved oxygen at Gordon Power Station tailrace and Gordon above Denison (compliance site 65) over the period of one month (February 2007).

Dissolved oxygen statistical analysis

Dissolved oxygen data for site 77 was analysed by pooling all available pre- and post-Basslink continuous data. The data was aggregated to two hourly intervals and analysed by t-test to determine the statistical significance of any temperature differences between pre- and post-Basslink periods. Comparisons were made for the whole pre- and post period and for each calendar month to determine seasonal differences.

Dissolved oxygen was significantly higher at site 77 during post-Basslink than pre-Basslink for the whole period (p < 0.0001) and for all calendar months (p < 0.0001) (Table 4.6, Figure 4.16 and Figure 4.17). The differences between mean dissolved oxygen concentrations were high, and ranged from 2.03 to 4.43 mg/L.

Table 4.6: Mean dissolved oxygen concentrations in pre- and post-Basslink periods for all months and each calendar month and the statistical significance of the differences.

Month	Mean dissolved oxygen (mg/L)		Difference between mean dissolved oxygen (mg/L)	p
	Pre-Basslink	**Post-Basslink**		
All	8.15	10.00	2.85	<0.0001
January	7.88	10.73	2.85	<0.0001
February	7.53	10.49	2.97	<0.0001
March	7.11	10.13	3.02	<0.0001
April	7.46	10.62	3.16	<0.0001
May	7.85	10.95	3.10	<0.0001
June	8.65	11.16	2.51	<0.0001
July	9.59	11.62	2.03	<0.0001
August	9.43	12.59	3.16	<0.0001
September	8.49	12.92	4.43	<0.0001
October	8.64	12.99	4.36	<0.0001
November	8.35	12.28	3.93	<0.0001
December	8.20	11.92	3.72	<0.0001

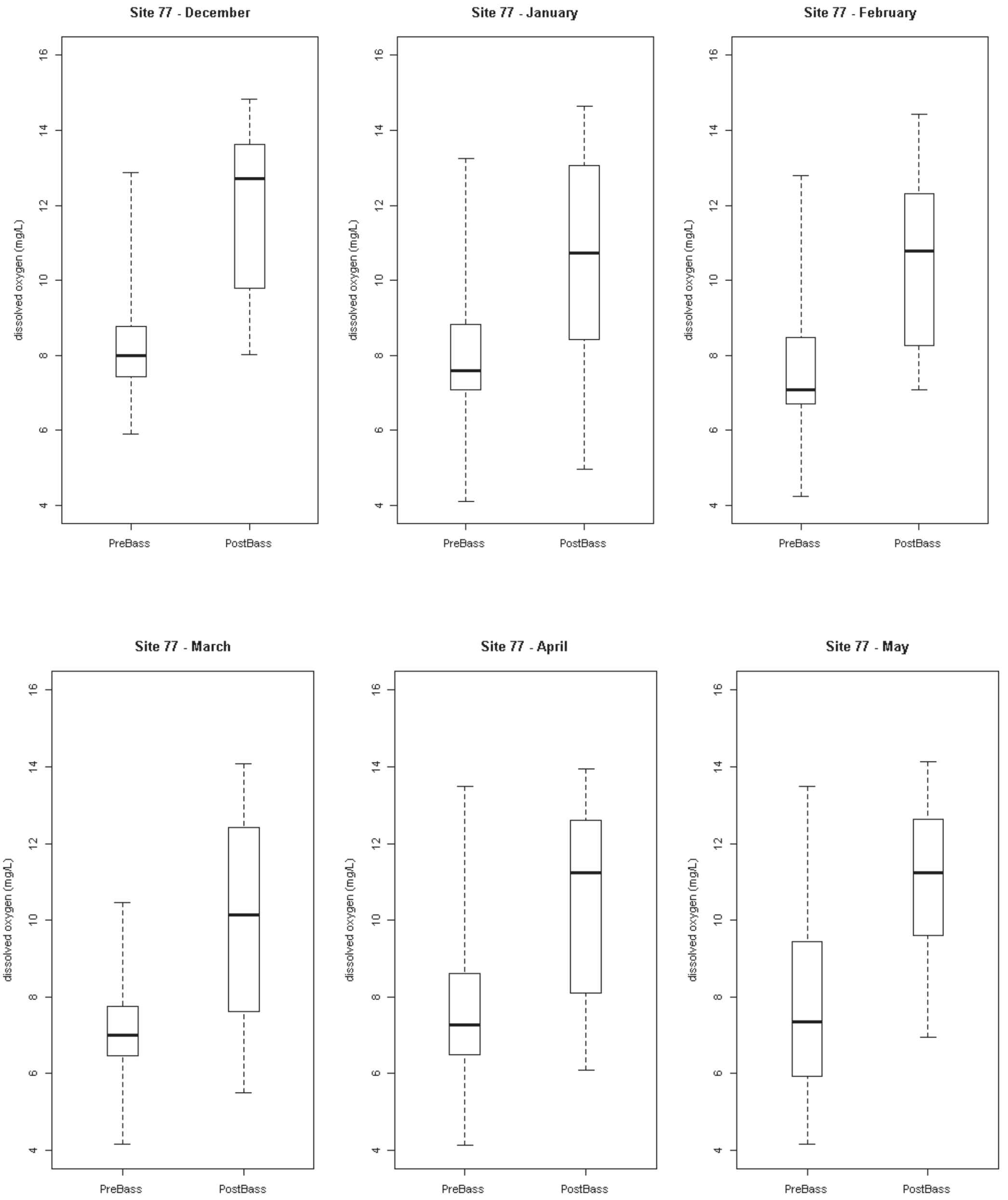


Figure 4.16: Monthly dissolved oxygen levels (December – May) at site 77 for pre- and post-Basslink periods showing median value (solid black line), 25th and 75th percentiles (lower and upper box extents), and minimum and maximum values.

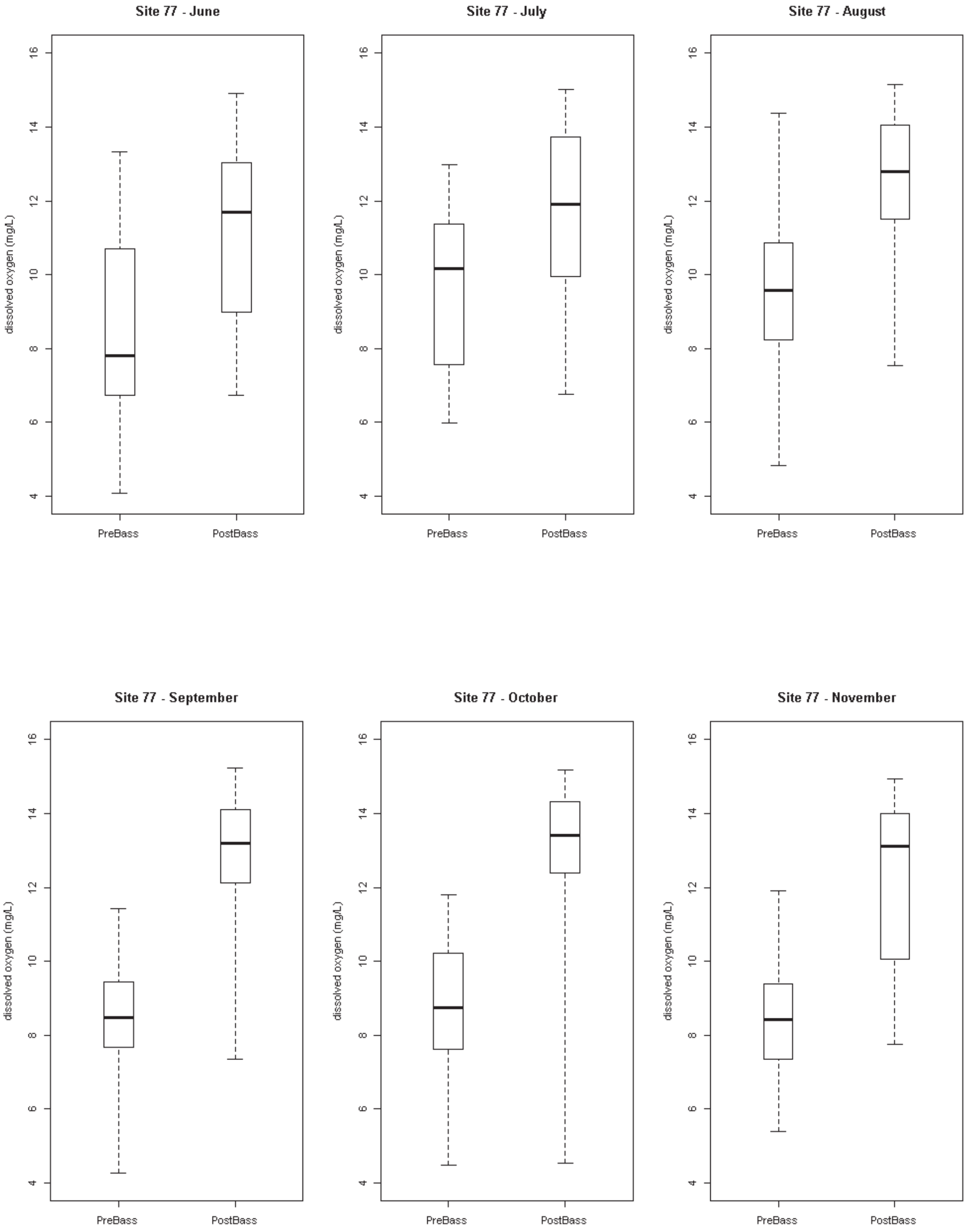


Figure 4.17: Monthly dissolved oxygen levels (June – November) at site 77 for pre- and post-Basslink periods showing median value (solid black line), 25th and 75th percentiles (lower and upper box extents), and minimum and maximum values.

The factors influencing the dissolved oxygen at site 77 were explored by undertaking correlation analysis for each calendar month for dissolved oxygen with both storage level and power station discharge. This analysis was undertaken with daily aggregated data.

Strong negative correlations were found for dissolved oxygen level and discharge from the power station and were significant for all months ($p < 0.001$) (Table 4.7). However, the strength of the relationship varied seasonally (Table 4.7). Strong correlations for dissolved oxygen and discharge was observed during summer and autumn and for the first two months of winter but were weak in autumn and spring (Table 4.7, Appendix 3). For pre- and post-Basslink operation, the negative relationship between dissolved oxygen and power station discharge is most likely to be related to air injection that occurs at low discharge. The higher dissolved oxygen in the post-Basslink period appears to be influenced by the greater operation at low discharge in the final four years of the post-Basslink period, and the resultant greater use of air injection.

Table 4.7: Correlation coefficients and r^2 values for dissolved oxygen and power station discharge and dissolved oxygen and water level in Lake Gordon. Bolded values are statistically significant ($p < 0.001$). Strong correlation are indicated in red ($r^2 > 0.4$)

Month	Dissolved oxygen Site 77 discharge		Dissolved oxygen Site 77 water level	
Correlation	**correlation coefficient**	**r^2**	**correlation coefficient**	**r^2**
Jan	**-0.7256**	**0.5265**	-0.1287	0.0166
Feb	**-0.7537**	**0.5681**	**-0.2141**	**0.0459**
Mar	**-0.8020**	**0.6433**	**-0.2095**	**0.0439**
Apr	**-0.7797**	**0.6080**	**0.3561**	**0.1268**
May	**-0.7615**	**0.5799**	**-0.4830**	**0.2333**
Jun	**-0.6589**	**0.4342**	**0.2712**	**0.0736**
Jul	**-0.6690**	**0.4476**	**0.4438**	**0.1969**
Aug	**-0.3110**	**0.0967**	-0.0969	0.0094
Sep	**-0.3773**	**0.1424**	-0.0364	0.0013
Oct	**-0.2330**	**0.0543**	0.0243	0.0006
Nov	**-0.2968**	**0.0881**	0.0009	0.0000
Dec	**-0.6905**	**0.4768**	0.1008	0.0102

4.4.2.3 Total dissolved gas

High concentrations of total dissolved gas (TDG) have the capacity to cause harm to aquatic biota, and have been known to cause large fish kills. Work undertaken by Sanger (1992) examined the effects of raised TDG on rainbow trout. This work determined that exposure at 120 % TDG saturation for periods of 24 hours would have the effect of killing 91 % of fish, with mortality beginning after six hours. Extended exposure at 115 % was not nearly as lethal, with a mean mortality rate of 18 % after more than 48 hours exposure, and mortality first seen after 30 hours exposure.

Measurements of dissolved oxygen in the Gordon tailrace have often exceeded 100 % saturation, and at times reached levels approaching 120 % (Hydro Tasmania 2004). Concerns over the potential for raised TDG concentrations under such conditions prompted an initial investigation in 2003-04 into the relationship between supersaturated oxygen and TDG concentrations (Hydro Tasmania 2004). The finding from this initial study indicated that there was no clear relationship between high dissolved oxygen and TDG concentrations.

As part of its licence conditions, Hydro Tasmania undertook a second investigation into the TDG concentration in the Gordon tailrace to better define the risk of lethal concentrations of TDG. This investigation involved the continuous monitoring of TDG concentrations between June 2008 and August April 2009 (Figure 4.18).

The maximum TDG concentration in the tailrace, 118.9 % saturation, was measured on 20 October 2008, with the concentration in excess of 115 % saturation during this increase for a total of three hours. The cause of this peak in TDG is uncertain; however it corresponded with the start of low flow from the power station following an outage. On the basis of the measurements taken during 2008–09, it is concluded that there were no conditions when TDG was at high enough levels for sufficient periods of time to be harmful to fish. The occurrence in October 2008 would have required a substantially longer period of raised concentrations to cause harm. It is therefore concluded that there is a low risk of harm occurring to aquatic biota as a result of raised TDG concentrations in the Gordon tailrace.

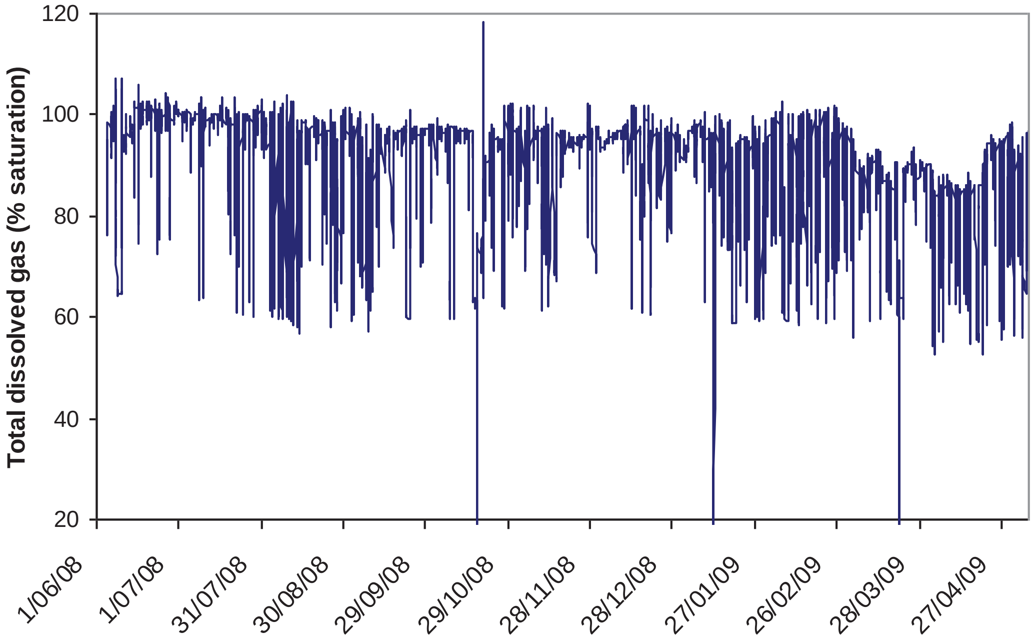


Figure 4.18: Total dissolved gas concentration in site 77 (Gordon Power Station tailrace) from June 2008–April 2009.

4.5 Evaluation of the monitoring program

The capacity of the Basslink Monitoring Program to measure water quality in Lake Gordon and the Gordon River has been good. Water quality measurements taken in Lake Gordon and Lake Pedder and the Gordon River have provided an overall picture of the drivers of water quality in the Gordon River. It has been possible to identify that the main drivers of water quality in the Gordon River are seasonal stratification and water depth in Lake Gordon, as well as the power station operational pattern (i.e. low loading which results in the entrainment of air to the turbine). These drivers primarily impact upon the dissolved oxygen and water temperature in the Gordon River and can all be detected in the Gordon River via continuous *in situ* monitoring.

There have been periods where *in situ* water quality instruments have failed and/or provided data of poor quality. As a result, there are varying proportions of fair or good quality data from the available continuous records. The large majority of sites and parameters have fair or good quality data in excess of 75% of the total record (Table 4.1).

The quarterly lake monitoring program has shown little indication of potential for poor water quality in Lakes Gordon and Pedder over a 13 year period. This component of the program is unlikely to add significant understanding or warning of poor water quality in future. The continuous monitoring of dissolved oxygen and water temperature near the tailrace may continue to be useful to provide indication of the impacts on these parameters. However, of these, the most important measurement will be dissolved oxygen which continues to have some potential to reach harmful lower concentrations during high water levels and stratified conditions.

4.6 Conclusions

Water quality in Lake Gordon and Lake Pedder was good and has not significantly changed since Basslink was commissioned. Water quality, in particularly temperature, in the Gordon River below the dam is largely influenced by the level of Lake Gordon and its influence on thermal stratification at the power station intake. Water released from the power station reflects thermal conditions at the power station intake in Lake Gordon, with water temperatures generally lower than ambient river conditions. Dissolved oxygen concentrations fluctuate on a seasonal, daily and hourly basis in response to stratification and operational factors. Of these, operational factors are the most influential in affecting the concentration of dissolved oxygen immediately below the tailrace. At locations further downstream at site 65, the impact of operational factors on dissolved oxygen is insignificant.

The mitigation measures have had a limited impact on water quality, with only the minimum environmental flow having any detectable effect on water temperature downstream of the power station. The flows provided by the minimum environmental flow are sufficient to influence the temperature of the Gordon River between the dam and the Denison confluence.

4.7 Recommendations

The ongoing requirement for water quality monitoring in Lake Gordon and the Gordon River is not considered critical to the understanding of the impacts of Basslink on the Gordon River. As the risks to water quality in the Gordon River are low, future water quality monitoring should no longer include monitoring of Lake Gordon or Lake Pedder and be limited to monitoring of the water temperature and dissolved oxygen near the Gordon tailrace.

The removal of Lake Gordon and Lake Pedder monitoring from the current program will have little impact on the operational management of Lake Gordon or the power station. This monitoring has been undertaken on only four occasions a year, and while it has been useful in defining the regular patterns within Lake Gordon, it is not useful for determining immediate impacts downstream that might require operational responses.

Despite the continuous record having periods of no or poor data, this record is more comprehensive and relevant than the lake monitoring for use in analysing and understanding the impacts of operation in future, and in responding to events if necessary.

5. Fluvial geomorphology

5.1 Summary

The results from the 11 years of Basslink monitoring have been analysed to establish the relationships between power station discharge and flow patterns in the Gordon River, and the fluvial geomorphic response of the river banks. The results of these analyses have been evaluated to assess whether they were related to operational changes due to Basslink.

Pre- and post-Basslink results show similar relationships between the flow regime and erosional processes in the middle Gordon River. Changes at erosion pins were governed primarily by the magnitude, duration and draw down frequency of flows in the river, which translate into scour and seepage erosion on the banks. Bank toes were predominantly affected by scour erosion, at rates that correlate with sediment transport modelling results. The 1 to 2 and 2 to 3 turbine bank levels were affected by a combination of scour and seepage processes.

The combined results of the geomorphological monitoring program reveal how alluvial banks have responded to flow regulation at the 'bank' and 'zone' scale. A progression of bank forms have been identified which relate to the progression of erosion processes associated with the adjustment to regulated flow. The varying rate of bank adjustment with distance from the power station accounts for the erosional 'wave' apparent in the erosion pin results when grouped at a zone level. No changes to these erosion processes have been identified which were attributable to the implementation of Basslink.

The first two years of post-Basslink power station operation were characterised by moderate to high power station discharge volumes with periods of full-range and 2-3 turbine hydro-peaking. The last four years of the post-Basslink monitoring period have been characterised by low power station discharge volumes, while the last two of these years had some defined periods of hydro-peaking. The observed flow volume and patterns have resulted in a substantial reduction in erosion on the bank toes, and limited change in the 1 to 2 and 2 to 3 turbine bank levels. Post-Basslink rates of net erosion were lower, which was attributable to the large reduction in total flow in the river combined with the increased deposition associated with seepage processes resulting from periods of hydro-peaking.

The erosion rates in the geomorphic zone 1 have remained within the range of projected net erosion rates compiled from pre-Basslink results, with values for zones 2, 3 and 4 falling below the projected range, and zone 5 values being slightly above projected. The difference in post-Basslink erosion rates relative to pre-Basslink were directly attributable to changes in the flow regime, however, most of these changes cannot be solely attributable to Basslink.

Geomorphic photo monitoring results over the six years of post-Basslink monitoring showed no change at the larger bank or river reach scale which can be attributed to the implementation of Basslink.

5.2 Introduction

The aims of geomorphology monitoring in the Gordon River include:

- Documenting fluvial geomorphological processes and changes in the Gordon River between the power station tailrace and the mouth of the Franklin River (defined as the middle Gordon River).
- Relating the observed changes in geomorphology to power station operations, or other factors, where possible.
- Comparing results collected since the operation of Basslink with pre-Basslink results to determine whether observed changes in the river are consistent with the understanding of the conceptual model of the river and are within 'limits of acceptable change'. A multiple lines of evidence approach, rather than 'trigger values' were used to assess the geomorphic results as it is recognised that the river is continuing to adjust to initial flow regulation, with Basslink representing an additional change to the system.

The geomorphology monitoring program included field observations, erosion pin measurements, repeat photo monitoring, repeat bank profiling, and the continuous collection of piezometer data as described in the methods.

5.3 Method

The methods used in the geomorphology monitoring program are described in detail in the first pre-Basslink fluvial geomorphology monitoring report (Koehnken and Locher 2002) and the Basslink Baseline Report (BBR) (Hydro Tasmania 2005a). These documents provide a detailed description of the methods and background material pertaining to the monitoring program. Descriptions of the zones, bank types and processes operating in the middle Gordon River are contained in the initial Basslink Integrated Impact Assessment Study report (Koehnken et al. 2001) and the BBR (Hydro Tasmania 2005a), and are included in Appendix 2 as part of the conceptual model. In summary, geomorphology monitoring included:

- field observations
- the measurement of approximately 250 erosion pins and 25 scour chains located at 47 monitoring sites in the middle Gordon River twice per year (October and March); and
- annual photo monitoring of an additional 54 sites in March each year.

The monitoring activities are summarised in Table 5.1 and Table 5.2.

The monitoring sites are distributed over five geomorphic zones in the river, which have been located based on hydrologic and hydraulic attributes and are shown in Figure 5.1 to Figure 5.6. These zones are as follows:

- Zone 1 extends from the Serpentine confluence to Abel Gorge;
- Zone 2 extends from the Albert River confluence to the Splits;
- Zone 3 includes the reach between Snake Rapids and the Denison River confluence;
- Zone 4 covers from the Denison confluence to Sunshine Gorge; and
- Zone 5 extends from downstream of Sunshine Gorge to the Franklin confluence.

Erosion pins have been placed in sandy alluvial banks along the middle Gordon River with most pins located within the height range typically affected by power station operation. A few pins are situated upslope of the power station controlled river level. The pin locations at each site have also been classified according to the turbine discharge required for inundation:

- <1 turbine indicates that the operation equivalent to the discharge from one turbine is likely to inundate the pin;
- 1–2 turbine bank level requires the equivalent of discharge from the operation of two turbines for inundation; and
- 2–3 turbine bank is inundated when all three turbines are in operation.

These levels are approximate and are based on field observations under low-flow conditions only. This ‘turbine’ nomenclature is based on the assumption that one turbine reaches full discharge prior to a second turbine coming on line. It is recognised that this is not how the Gordon Power Station is operated.

Observations, photos and erosion pin measurements were collected by two boat-based teams during the monitoring trips. Additional field observations were collected opportunistically when access to the middle Gordon River was possible. Repeat surveys of the Gordon River in a number of locations, and bank profiles at the erosion pin monitoring sites, have been carried out periodically during the Basslink investigations and monitoring period.

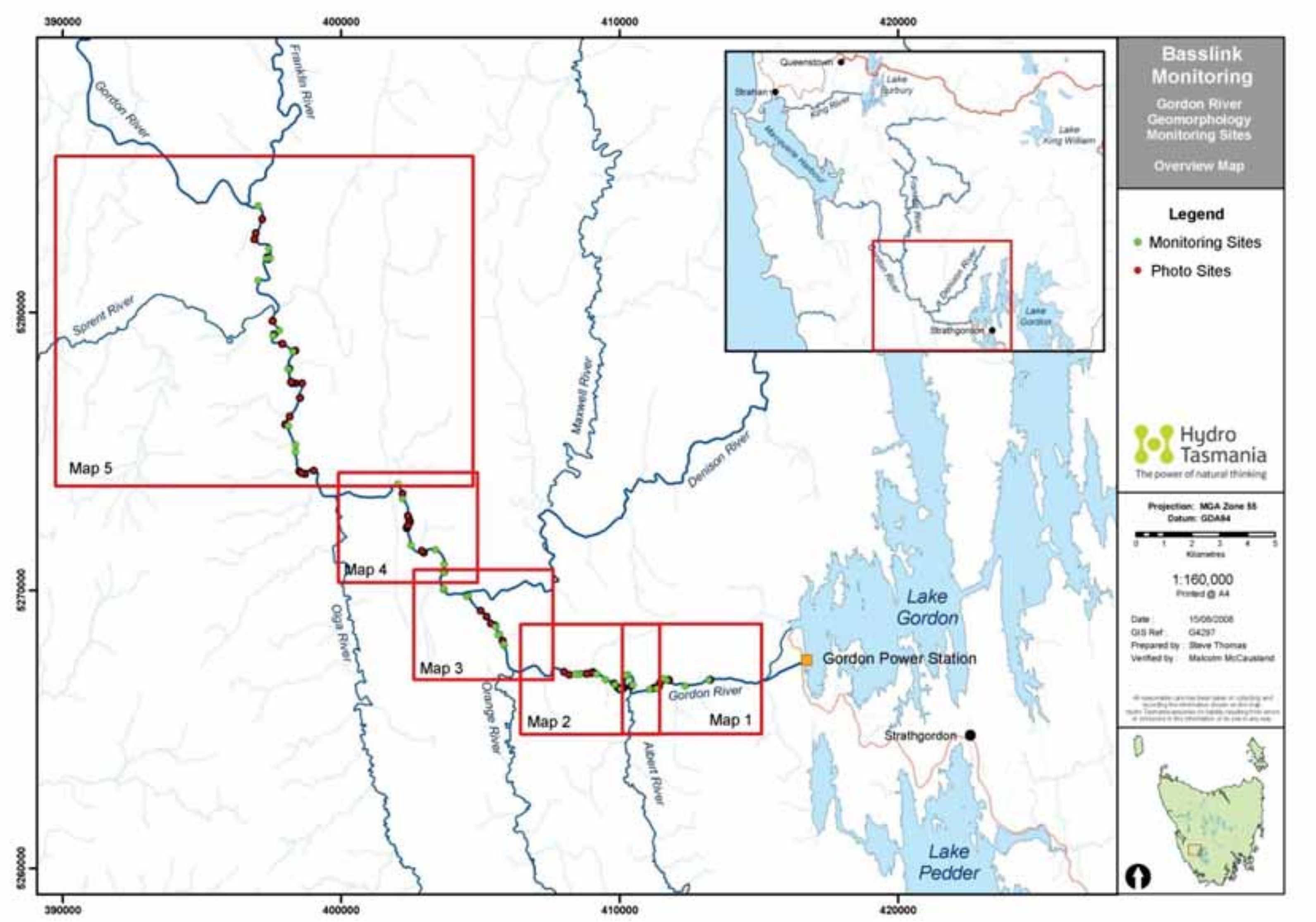


Figure 5.1: Overview of Gordon River geomorphology monitoring sites.

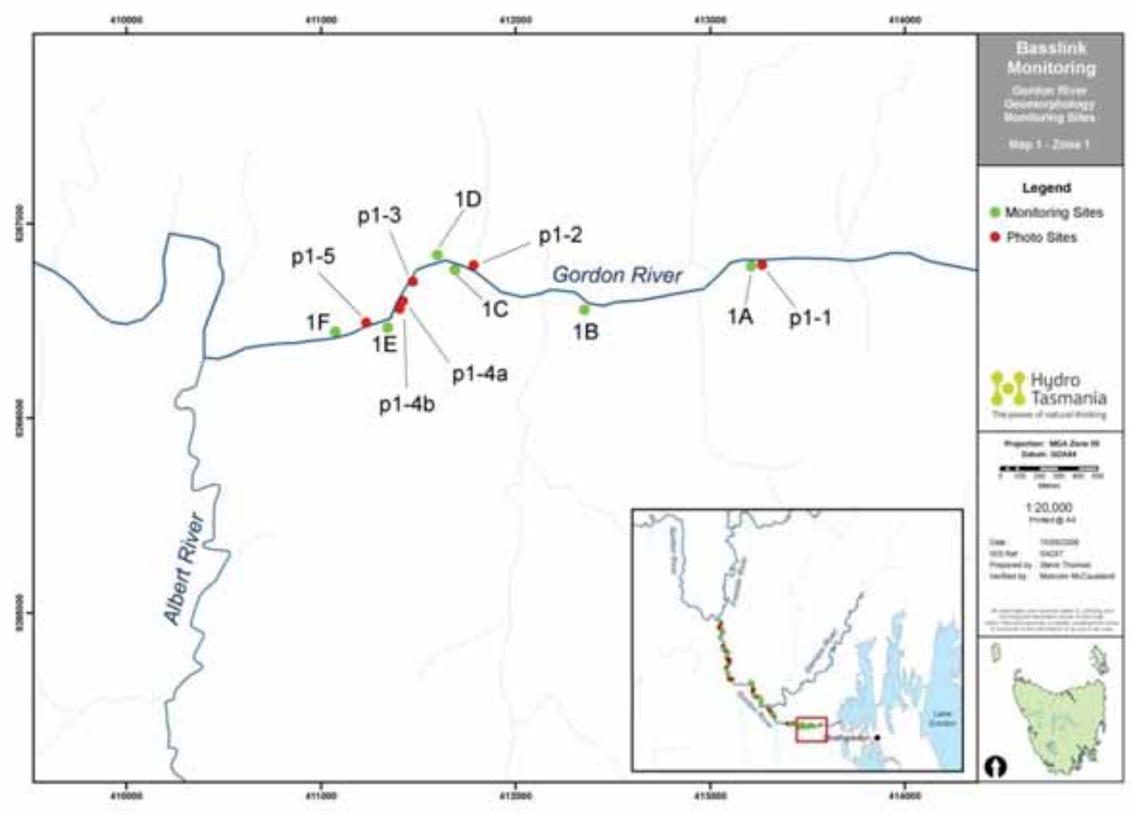


Figure 5.2: Gordon River geomorphology monitoring sites, zone 1.

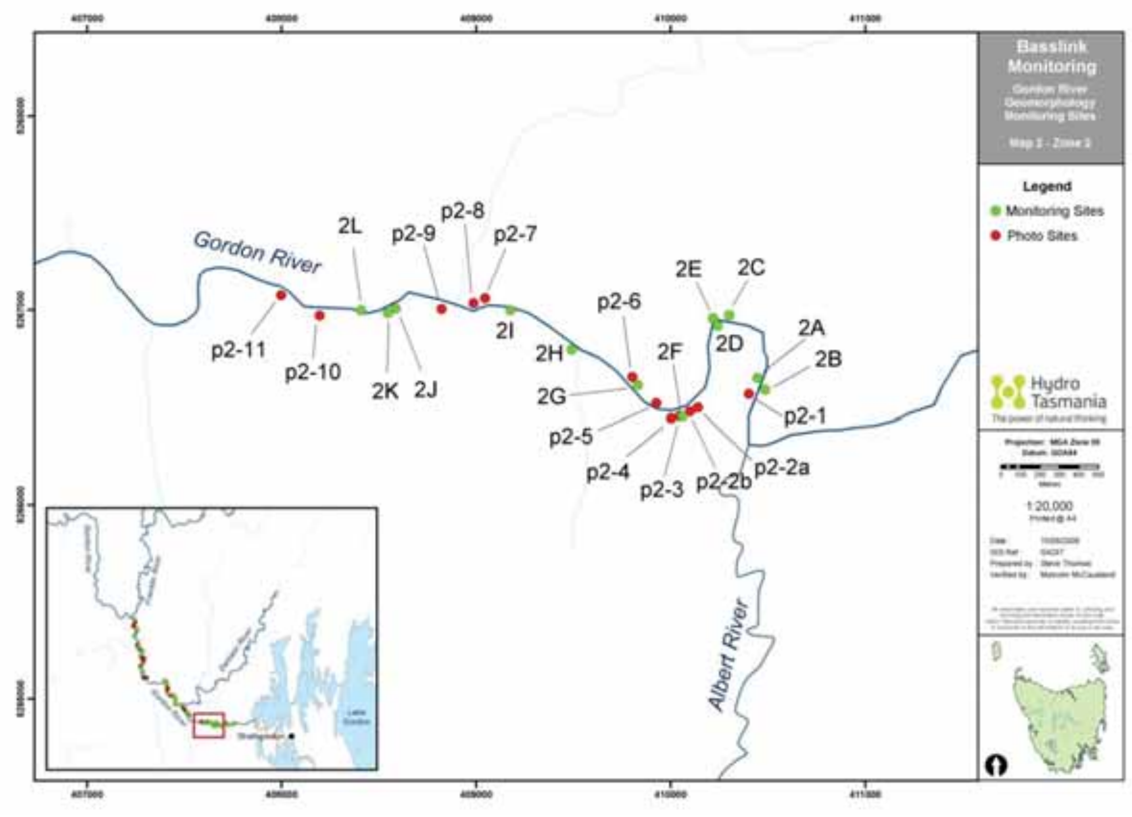


Figure 5.3: Gordon River geomorphology monitoring sites, zone 2.

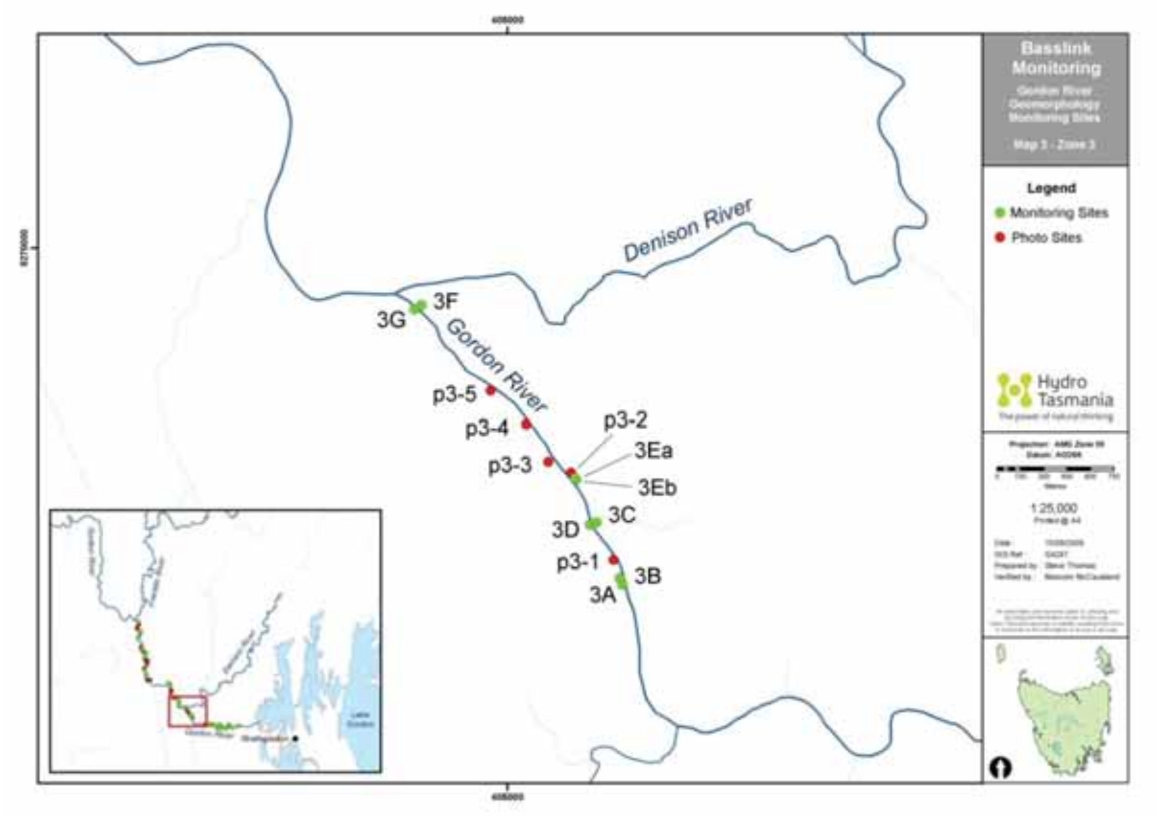


Figure 5.4: Gordon River geomorphology monitoring sites, zone 3.

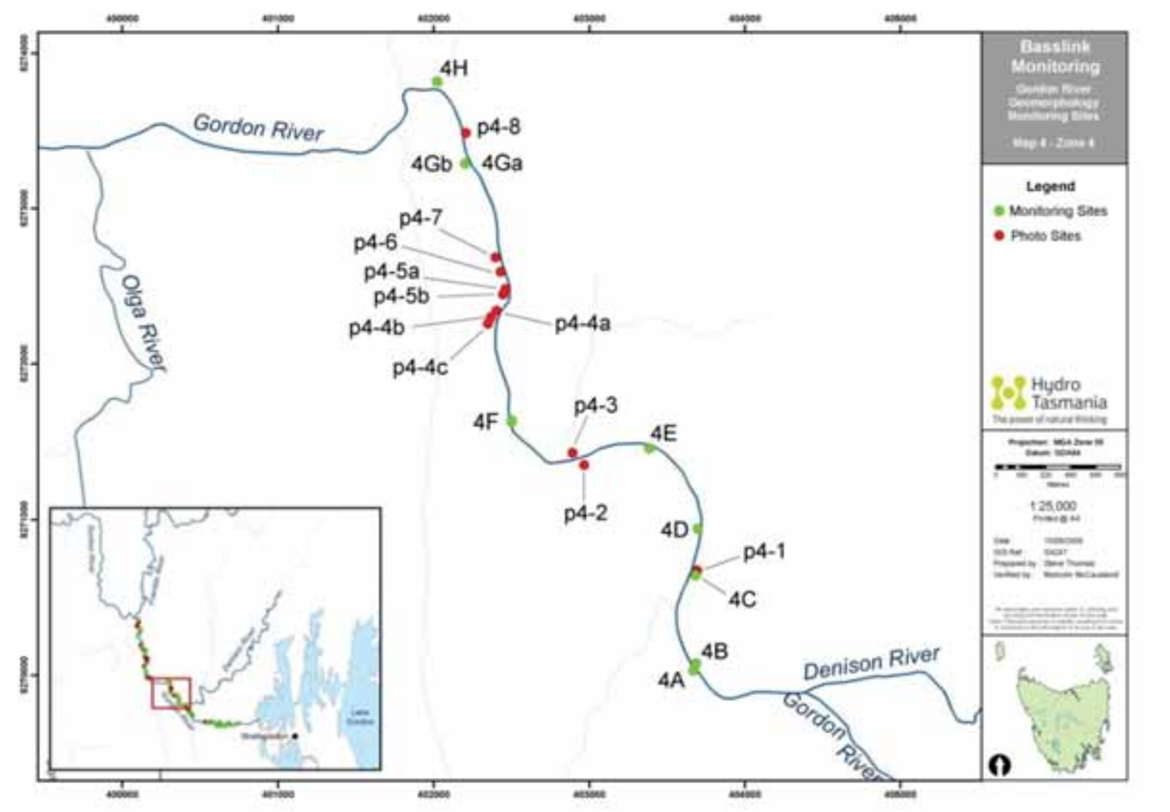


Figure 5.5: Gordon River geomorphology monitoring sites, zone 4.

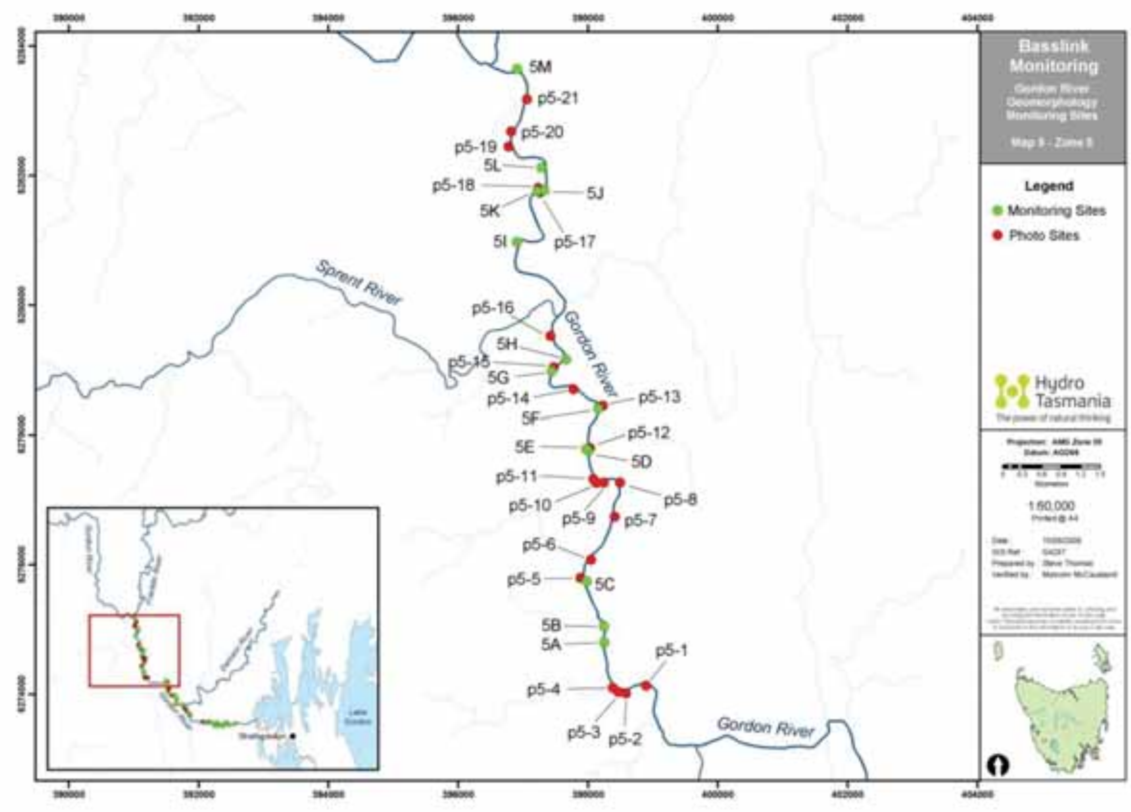


Figure 5.6: Gordon River geomorphology monitoring sites, zone 5.

Table 5.1: Number of monitoring sites and erosion pins in each geomorphology zone.

Zone	#Sites	#Erosion Pins
Zone 1	6	35
Zone 2	12	63
Zone 3	8	47
Zone 4	8	39
Zone 5	13	63
Total	**47**	**247**

Table 5.2: Summary of geomorphology monitoring activities in the middle Gordon River between 1999 and present. 'Derivation' indicates that the data was used in the formulation of trigger values, 'test' indicates that the erosion pin results from that monitoring period have been compared with the trigger values.

Monitoring Type	Triggers: derivation or test	Season	Dates	Monitoring completed
Historical	Initial investigations		11 Dec 99 18 Dec 99 4 Mar 00 25 Mar 00 22 Jul 00 2 Sep 00 4 Aug 01	▪ Investigations for IIAS: ▪ Field observations ▪ Erosion pin measurements ▪ Photo-monitoring ▪ Scour chains ▪ Painted cobbles
Pre-Basslink	Derivation	Spring 01	23 Nov 01 9 Dec 01	▪ Field observations ▪ Erosion pin measurements
		Autumn 02	10 Feb 02 9 Mar 02	▪ Field observations ▪ Erosion pin measurements ▪ Photo-monitoring
		Spring 02	5 Oct 02 16 Dec 02	▪ Field observations ▪ Erosion pin measurements
		Autumn 03	29 Mar 03	▪ Field observations ▪ Erosion pin measurements ▪ Photo-monitoring
		Spring 03	18 Oct 03	▪ Field observations ▪ Erosion pin measurements
		Autumn 04	6 Mar 04	▪ Field observations ▪ Erosion pin measurements ▪ Photo-monitoring
		Spring 04	9 Oct 04	▪ Field observations ▪ Erosion pin measurements ▪ Bank profiling
		Autumn 05	2 Apr 05	▪ Field observations ▪ Erosion pin measurements ▪ Photo-monitoring
		Spring 05	15 Oct 05	▪ Field observations ▪ Erosion pin measurements

Table 5.2 continued next page

Monitoring Type	Triggers: derivation or test	Season	Dates	Monitoring completed
Transition	Test	Autumn 06	11 Mar 06	▪ Field observations ▪ Erosion pin measurements ▪ Photo-monitoring
Post-Basslink	Test	Spring 06	17 Oct 06	▪ Field observations ▪ Erosion pin measurements
		Autumn 07	17 Mar 07	▪ Field observations ▪ Erosion pin measurements ▪ Photo-monitoring
		Spring 07	20 Oct 07	▪ Field observations ▪ Erosion pin measurements
		Spring 07	1 Dec 07	▪ Field observations
		Autumn 08	1 Mar 08	▪ Field observations ▪ Erosion pin measurements ▪ Photo-monitoring
		Spring 08	17–19 Oct 08	▪ Field observations ▪ Erosion pin measurements
		Autumn 08	20–22 Mar 09	▪ Field observations ▪ Erosion pin measurements ▪ Photo-monitoring
Post-Basslink	Test	Spring 08	17-19 Oct-08	• Field observations • Erosion pin measurements
		Autumn 09	21-22 Mar-09	• Field observations • Erosion pin measurements • Photo monitoring
		Spring 09	17 Oct 09 (zones 3&4) 31 Oct 09 (zones 1,2,5)	• Field observations • Erosion pin measurements
		Autumn 10	12-14 Mar 10	• Field observations • Erosion pin measurements • Photo monitoring
		Spring 10	19-20 Oct 10	• Field observations • Erosion pin measurements
		Autumn 11	26-27 Feb 11	• Field observations • Erosion pin measurements • Photo monitoring
		Spring 11	5-6 Nov 11	• Field observations • Erosion pin measurements
		Autumn 12	25-26 Feb 12	• Field observations • Erosion pin measurements • Photo monitoring

Table 5.2 continued

5.4 Trends of consolidated data

The fluvial geomorphology post-Basslink monitoring results were analysed and interpreted after each monitoring event and annually with respect to the flow regime of the river (Hydro Tasmania 2007, 2008, 2009, 2010c, 2011, 2012). The annual reports provide detailed information about the results of the individual monitoring events. The annual reports also include all field data and photos.

The purpose of this section is to consider the post-Basslink monitoring data across the entire monitoring period, rather than in annual 'packages' as is done each year, and where possible, identify linkages between the flow regime and the long-term data set. The results of these analyses have been used to test and refine the conceptual model.

The pre-Basslink period included monitoring results from March 2002 to March 2005, and the post-Basslink period included results from October 2006 to March 2012. The March to September 2006 period was considered transitional, but because the erosion pin results are a time-series, it was not possible to omit the results from consideration or analysis. All data was included in the time-series plots, and the statistical analyses.

This section includes a description of the components of the flow regime relevant to the geomorphic monitoring, including theoretical sediment transport modelling based on the hydrologic results, which provides a means of comparing potential erosion between years. The hydrologic information was followed by repeat channel cross-section surveys to provide an indication of large-scale channel stability over the monitoring period. The section covering the analysis of erosion pin data includes interpretation of the results with respect to the flow regime, distance from the power station and bank level. The final data analysis section describes the findings of the photo monitoring investigations.

Lastly, a summary of the observed trends is provided, together with an assessment of the adequacy of the monitoring program.

5.4.1 Flow regime

A detailed discussion of hydrology and power station operating patterns is provided in Section 2 – Hydrology and water management, with the following section limited to discussing hydrological parameters which are relevant to the interpretation of the geomorphic results. These flow parameters for March 2002 to March 2012 are presented in Figure 5.7 and Figure 5.8. The data is for the 12 months prior to each spring (October) and autumn (February / March) sampling trip. The post-Basslink time period is shown in the blue shaded area of each graph, with the transitional period highlighted in orange.

The hydrologic parameters which in the past have been found to be related to geomorphic response include:

- total power station or river flow;
- the number of high flow events;
- the duration of high flow events; and
- the period of time the power station decreases flow at rates in excess of 30 m^3s^{-1} hr^{-1} when the power station is discharging in excess of 180 m^3s^{-1}.

The hydrologic parameters showed greater variability post-Basslink as compared to pre-Basslink, with both the highest and lowest annual flow volumes recorded at the Gordon Power Station, and at the Gordon above Denison gauging site during the post-Basslink period. The post-Basslink period was characterised by a sharp increase in total flow between 2006 and 2008, followed by a decline in total flow from 2008 until March 2009, after which time flow rates have remained relatively low. The number of hours of high flow (flow > 200 m^3s^{-1}) showed a similar pattern to total flow in the Basslink period through to October 2009, and then increases, indicating that a higher proportion of flow released from the power station was at higher flow rates during the final three years of monitoring.

The highest number of hours during which flow reduction exceeded 30 m^3s^{-1} hr^{-1}, when the power station was discharging greater than 180 m^3s^{-1}, also occurred during the post-Basslink period, with six of the Basslink years having a higher number of hours of high flow change as compared to the pre-Basslink period. The highest number of hours occurred during the October 2007 to March 2008 period, and coincided with the period of highest total discharge from the station. The second highest number of hours occurred during the last year of Basslink monitoring, which coincided with a period of relatively low total power station discharge. The Basslink flow patterns were distinctly different, and the relationship between these flows and Basslink, and whether they represent a Basslink 'change' is discussed in Section 2 – Hydrology and water management.

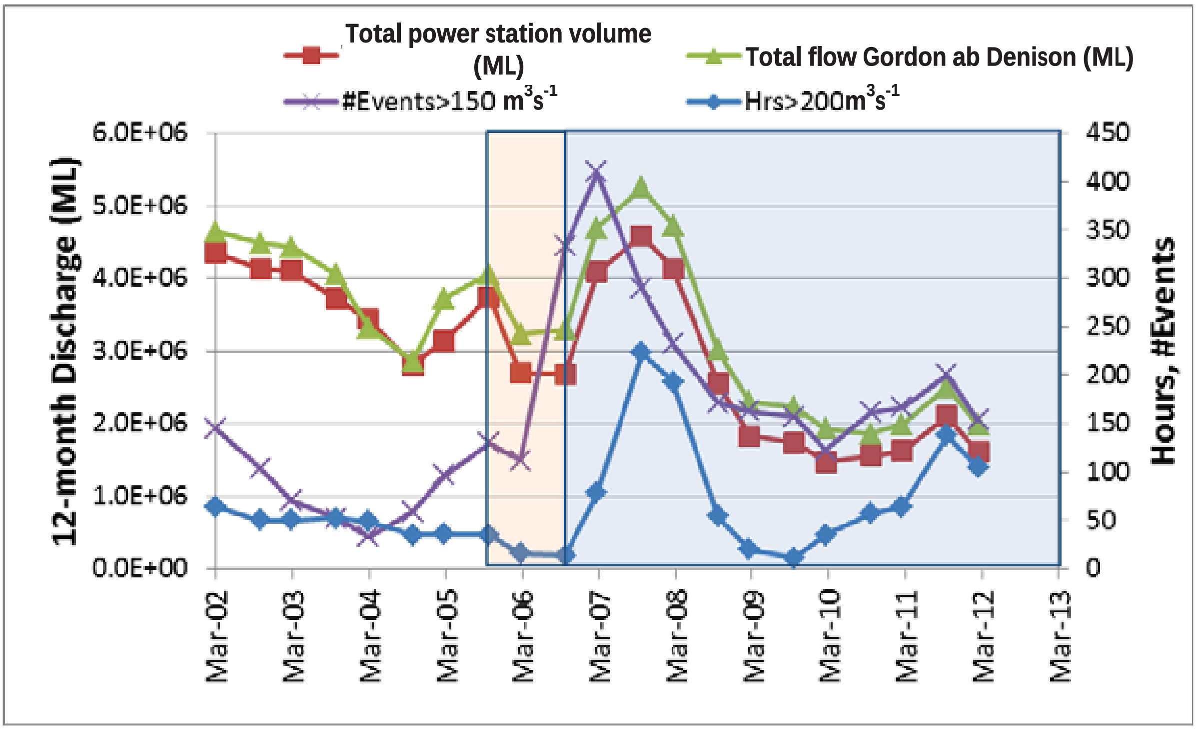


Figure 5.7: Hydrologic parameters used in erosion pin analysis.

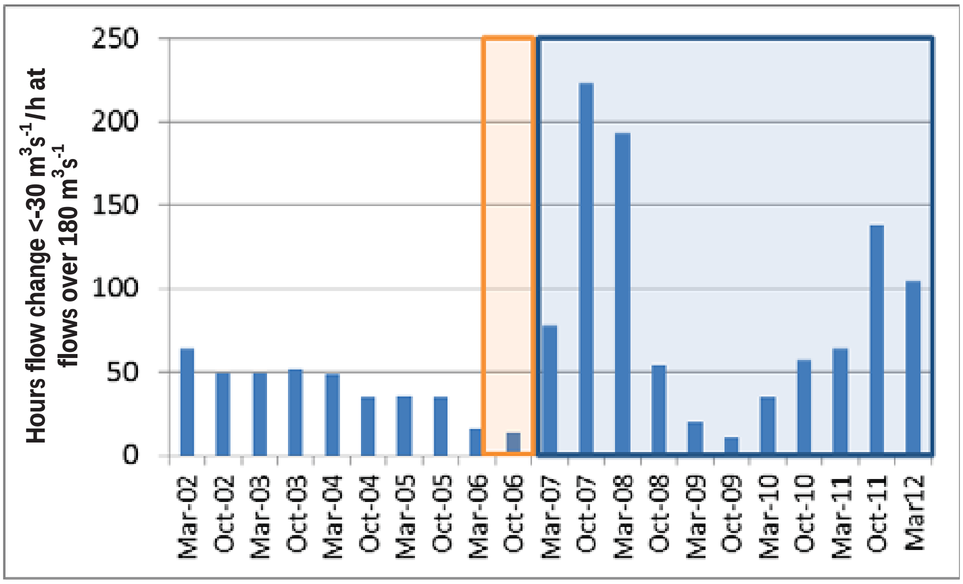


Figure 5.8: Hydrologic parameters used in erosion pin analysis. Number of hours flow reduction exceeded 30 m^3s^{-1} when the Gordon Power Station had been discharging at rates higher than 180 m^3s^{-1} during the previous 12 months.

The data shown in Figure 5.7 includes:

- total discharge from the Gordon Power Station during preceding 12 months (Total flow GPS);
- total flow at the Gordon above Denison gauging site in the previous 12 months;
- the number of flow events which exceeded 150 m^3s^{-1} at the Gordon Power Station during the preceding 12 months (Events>150 12 months); and
- the total hours that flow change exceeded 30 m^3s^{-1} hr^{-1} when the power station was discharging >180 m^3s^{-1} during the preceding 12 months.

The post-Basslink period is highlighted in blue and the transitional period is highlighted in orange in Figure 5.7 and Figure 5.8.

5.4.2 Sediment transport modelling

The modelled sediment transport of the river is related to the hydrology of the river, and is important for the interpretation of the geomorphology monitoring results. This sediment transport model estimates the theoretical transport of sediment from a bank toe based on the flow duration curve, assuming an unlimited amount of sediment available for transport. The model calculates shear stress on the bank toe as a function of water level as a means of evaluating scour potential. The model does not include other erosional processes such as seepage or sub-aerial erosion from rainfall. The model was originally developed for zone 1, and actual numbers are not particularly meaningful, but the results provide a way of comparing the scour potential of each monitoring year. The model was originally developed by S. Wilkinson and I. Rutherfurd during the IIAS investigations (Koehnken et al., 2001).

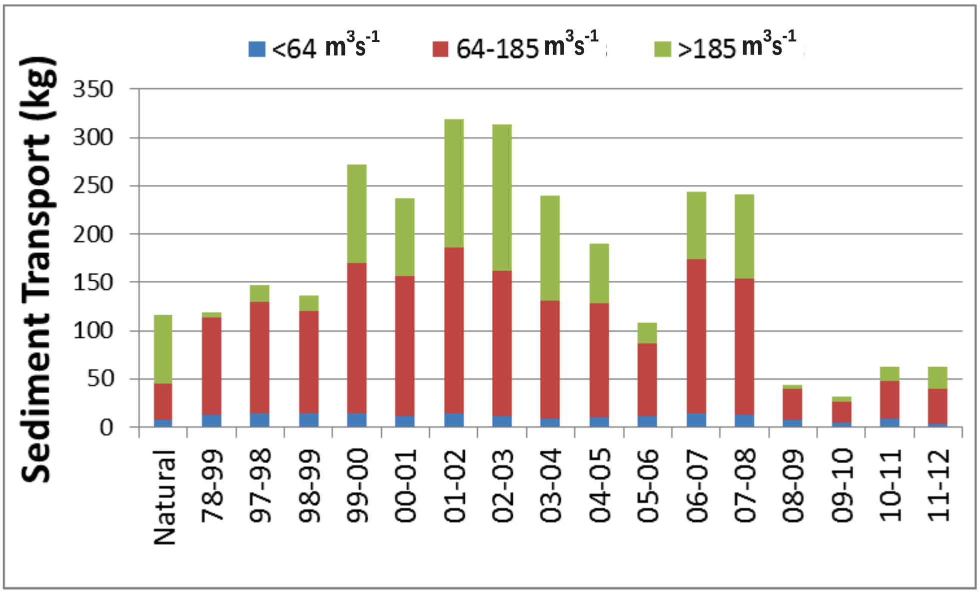


Figure 5.9: Theoretical sediment transport modelling based on discharge from the Gordon Power Station. Graph shows proportion of sediment transported by flow class in kg hr-1. Flow classes roughly correspond to 1, 2 and 3 turbine power station discharge. Model adapted from S. Wilkinson and I. Rutherfurd in Koehnken et al. (2001).Years were based on April to April which roughly coincides with the monitoring year.

The model output (Figure 5.9) includes results based on the natural flow regime, the combined 'historic' period (used in this instance to describe the period 1978 to 1999, which contained predominantly 2-turbine power station operation), and individual years between 1997 and 1998 and the present. The results show that beginning in 1999-2000, there was a large increase in total sediment transport capacity in the river, with the majority of the increase associated with 3-turbine power station operation. This is consistent with the findings of the IIAS investigations which found substantial bank erosion and attributed it to the increase in 3-turbine discharge. The period captured by the pre-Basslink monitoring results (2001 to 2005) was characterised by high total sediment transport rates and a large contribution from 3-turbine power station operation. The Basslink transition period (2005–2006) showed low transport rates associated with the lower power station use which was the result of a long term outage whilst the turbines were being refurbished.

Post-Basslink operations showed a return to high potential scour rates in the first two years, but not as high as the period from 2001 to 2003. The last four monitoring years, 2008 to 2012, have recorded the lowest calculated sediment transport capacity of the entire period, with the values below 'natural' rates. The results also showed that over the past four years the majority of scour (e.g. shear stress) on the banks has been associated with the equivalent of 2-turbine power station operation (64 to 185 m^3s^{-1}), and that 1-turbine operation which includes the minimum environmental flow, contributes little to theoretical sediment transport.

5.4.3 Repeat channel cross-sections

Channel cross sections have been periodically surveyed in the Gordon River between 2000 and 2012 at biological and geomorphological monitoring sites in each of the geomorphic monitoring zones. The surveys were completed using standard field surveying techniques (theodolite, dumpy level). The cross-sections were completed without the aid of a boat, so gaps occur where the river was too deep to safely wade.

The results of the surveys are plotted in Figure 5.10 to Figure 5.17, and show few changes between surveys when the following is taken into consideration:

- at Geo zone 1 site, the location of the tail peg was shifted after 2000 due to access difficulties;
- at Geo zone 3 site, the head peg was lost after 2000 due to bank erosion so a new one was established; and
- at Geo zone 4 site there is uncertainty about the location of the tail peg, so each transect is slightly different.

With the exception of the loss of the head peg at the zone 3 site due to erosion, the profiles showed little change over the 2000 to 2012 time period. The profiles obtained upstream of Sunshine Gorge and upstream of the Sprent River may show some infilling on the left side of the channel in 2012 relative to previous surveys, but the observed changes are likely within the errors of the survey. If they are actual changes, then it may reflect increased deposition in the channel due to the low flows in the river associated with low power station usage.

The stability observed in the channel was consistent with the observed characteristics of the bed and cobble bars. The bars (and bed) of the river tend to be composed of cobbles and boulders, which are too large to be transported by the power station discharge, overlain by small mobile sand and gravel deposits derived from the tributaries as shown in Figure 5.18. Larger quantities of sand and gravel have been observed in zones 3, 4 and 5 where there was a larger component of unregulated tributary inflow.

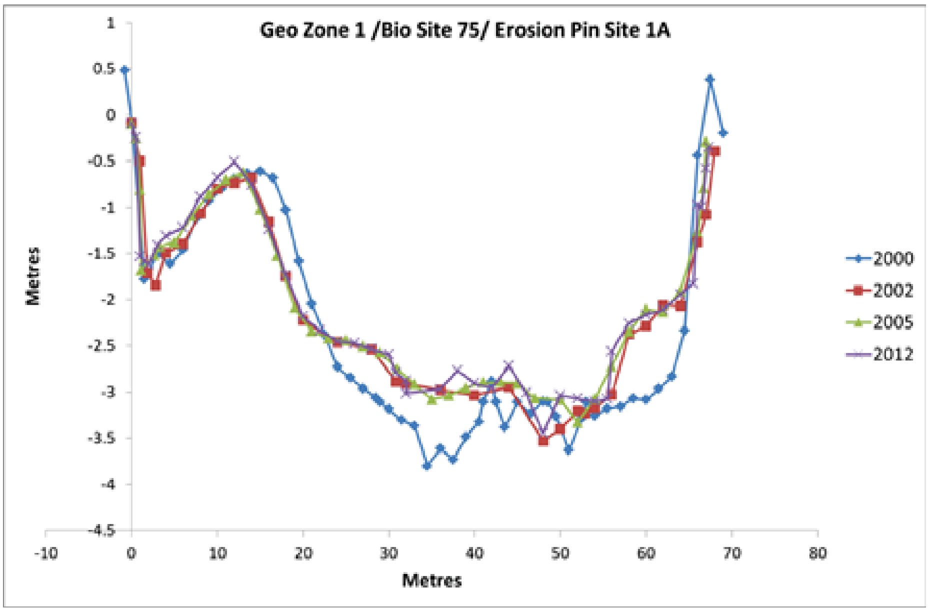


Figure 5.10. Surveyed cross-sections of erosion pin site 1A. Note vertical exaggeration.

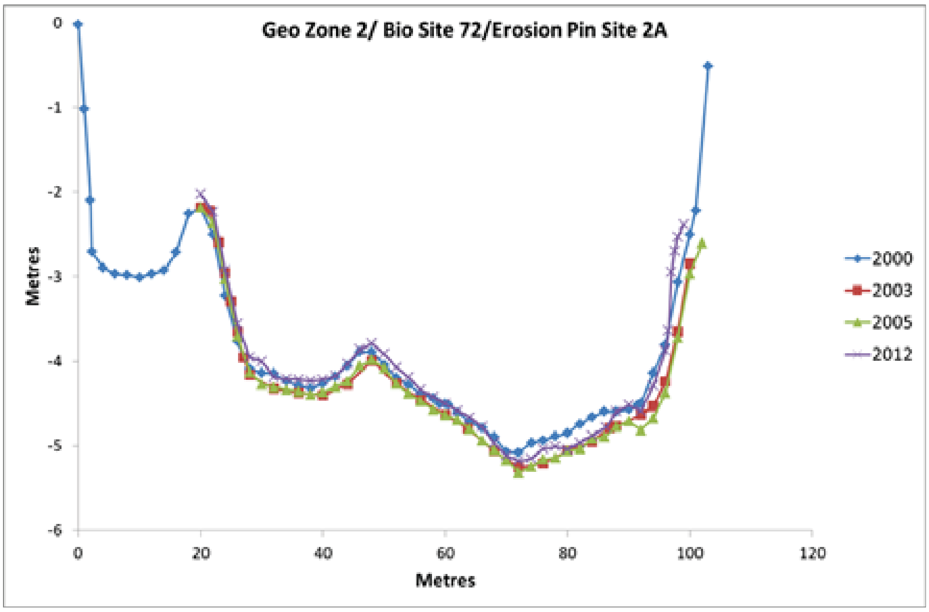


Figure 5.11. Surveyed cross-sections of erosion pin site 2A. Note vertical exaggeration.

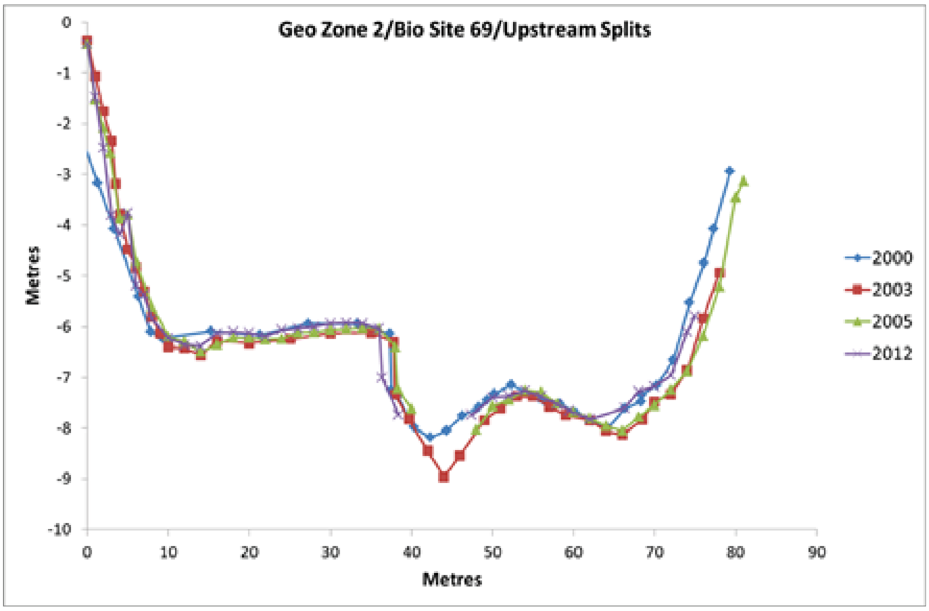


Figure 5.12: Surveyed cross-section in zone 2 upstream of splits near erosion pin site 2L.

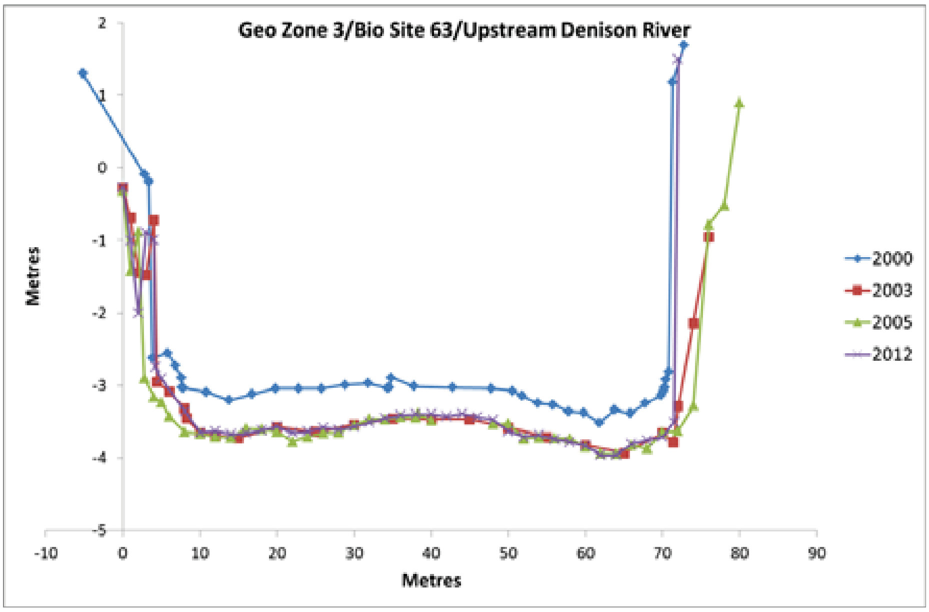


Figure 5.13: Denison River, near erosion pin site 3F and 3G. Note vertical exaggeration.

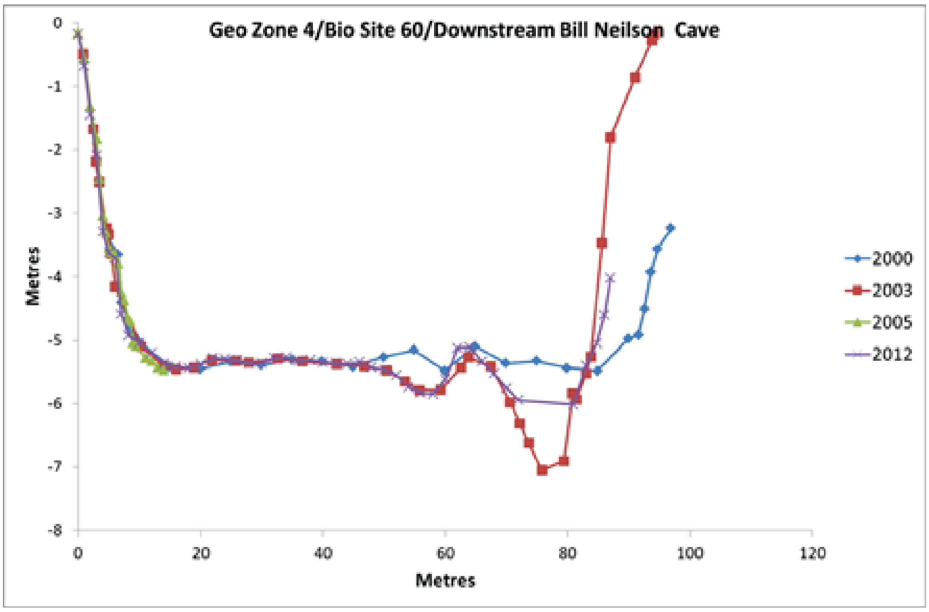


Figure 5.14. Surveyed cross-sections in zone 4, between erosion pin sites 4E and 4F.

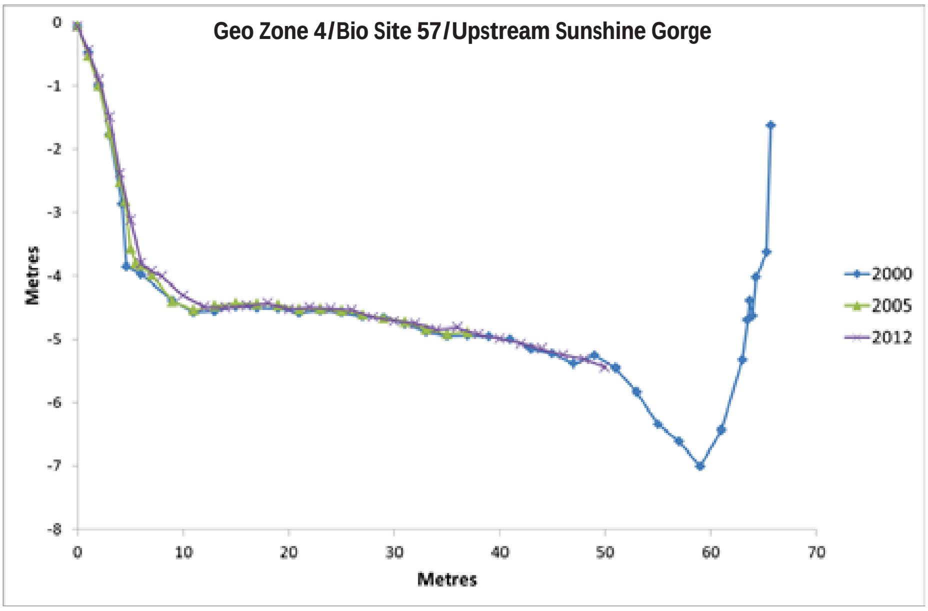


Figure 5.15: Surveyed cross-sections near erosion pin site 4H, upstream of Sunshine Gorge.

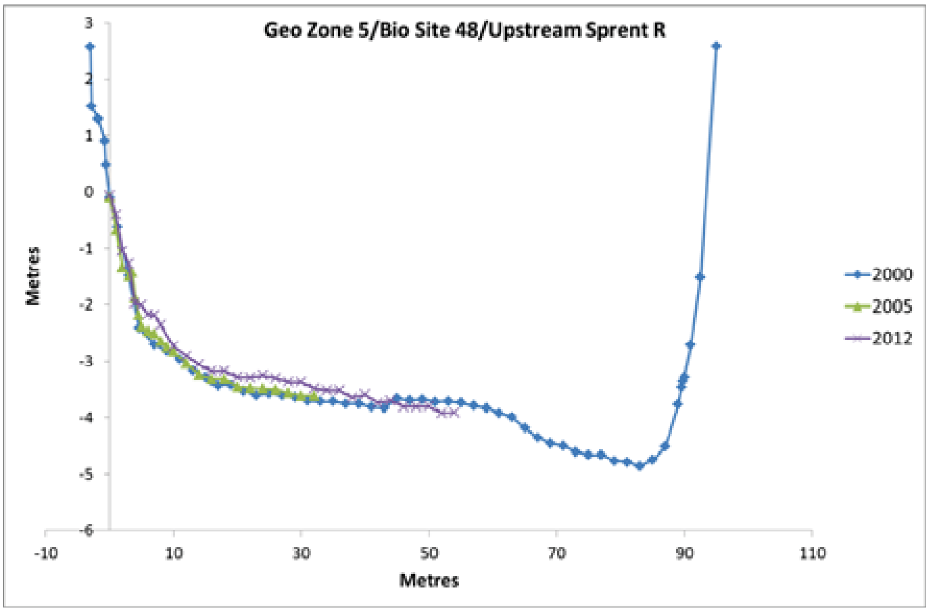


Figure 5.16: Surveyed cross-sections in zone 5, upstream of the Sprent River near erosion pin site 5H.

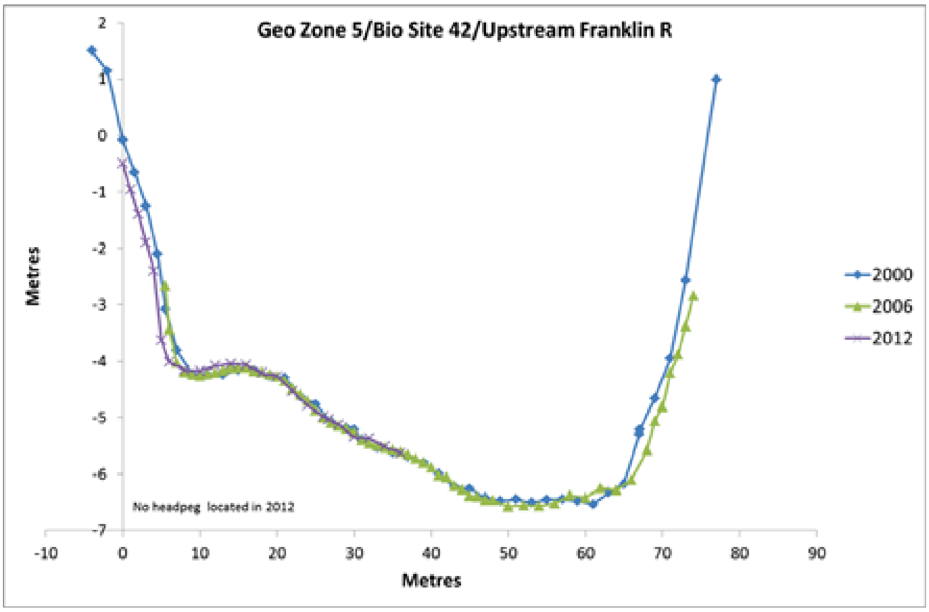


Figure 5.17: Surveyed cross-sections in zone 5, upstream of the Franklin River near erosion pin site 5M.

Figure 5.18: Photo of cobble bar at erosion pin site 3B showing shadow sand deposits on top of armoured and locked cobble bar.

5.4.4 Statistical analysis of erosion pin results

Erosion pin measurements were analysed in a variety of ways to provide information about spatial and temporal changes in the Gordon River. The erosion pin results from each monitoring period were compared to the initial measurements obtained in spring 2001 to provide a cumulative change in the pins, and the results were also compared to the measurements from the previous monitoring period to provide an indication of shorter term seasonal changes. The results from individual pins were then averaged in a range of ways, by zones, by turbine level, and by zones and turbine level, to provide an assessment of the changes with distance downstream of the power station, and with distance up the river bank. The following sections discuss the cumulative erosion pin results (compared to spring 2001). Erosion pin results relative to the previous season are discussed in Section 5.4.6, where they are also presented as annualised erosion rates. Descriptions of each erosion pin site and results from individual erosion pin are presented in Appendix 4.

5.4.4.1 Erosion pins grouped by zones

Following each monitoring event, the erosion pin results were grouped by zones, and the average values were compared to the predicted range (Figure 5.19). The pins from zones or turbine levels (or zones and turbine levels) recording erosion, and the pins recording deposition were also grouped and averaged for each monitoring period. An apparent decrease in the 'pins showing erosion' indicates that the group had a lower average erosion change (since last monitoring or since spring 2001) than in the preceding period. All the pins averaged to obtain the results still recorded erosion, but the average value was lower than the previous monitoring period. Comparing the erosion and depositional contributions is useful for identifying differences (and similarities) between zones (see Figure 5.19).

The graphs also show the predicted range of Basslink erosion pin results based on the pre-Basslink erosion pin measurements. These projections were derived at the conclusion of the pre-Basslink Monitoring Program using a linear regression and 95th percentile confidence limit. At the initiation of Basslink, these values were intended to be used as 'Trigger values' to identify post-Basslink change. The projections have been found to be inappropriate for assessing geomorphic monitoring results without considering other lines of evidence, and have been incorporated into a multiple lines of evidence approach. The projections are included on the graphs as a means of identifying how post-Basslink results have varied from pre-Basslink results.

Only erosion pin results from zone 1 (Figure 5.19a) have consistently remained within the projected range based on the pre-Basslink results. Erosion pin results for zones 2, 3 and 4 (Figure 5.19 b, c and d) have been lower than predicted, and the results for zone 5 have been slightly higher than predicted. The average results from the pins recording erosion, and the pins recording deposition showed a general trend of greater variability with distance downstream. That is, although the average rate of erosion in zone 5 overall was quite low, the erosional and depositional data, which contribute to the final value, were high relative to the upstream zone. It is considered that this was the result of the natural variability of the river increasing due to the inputs from unregulated tributaries. Most zones showed a substantial change in the spring 2007 period, which was attributable to a large flood event.

The ratio of pins recording erosion to those recording deposition is shown in Figure 5.20, and showed that in zones 2, 3, 4 and 5, more pins generally record erosion than deposition, with zones 3 and 4 having the highest ratios. The higher number of pins recording erosion accounts for the net change in the zones (black symbols, Figure 5.19) being closer to the erosional component (blue triangles), as compared to the depositional component (orange circles).

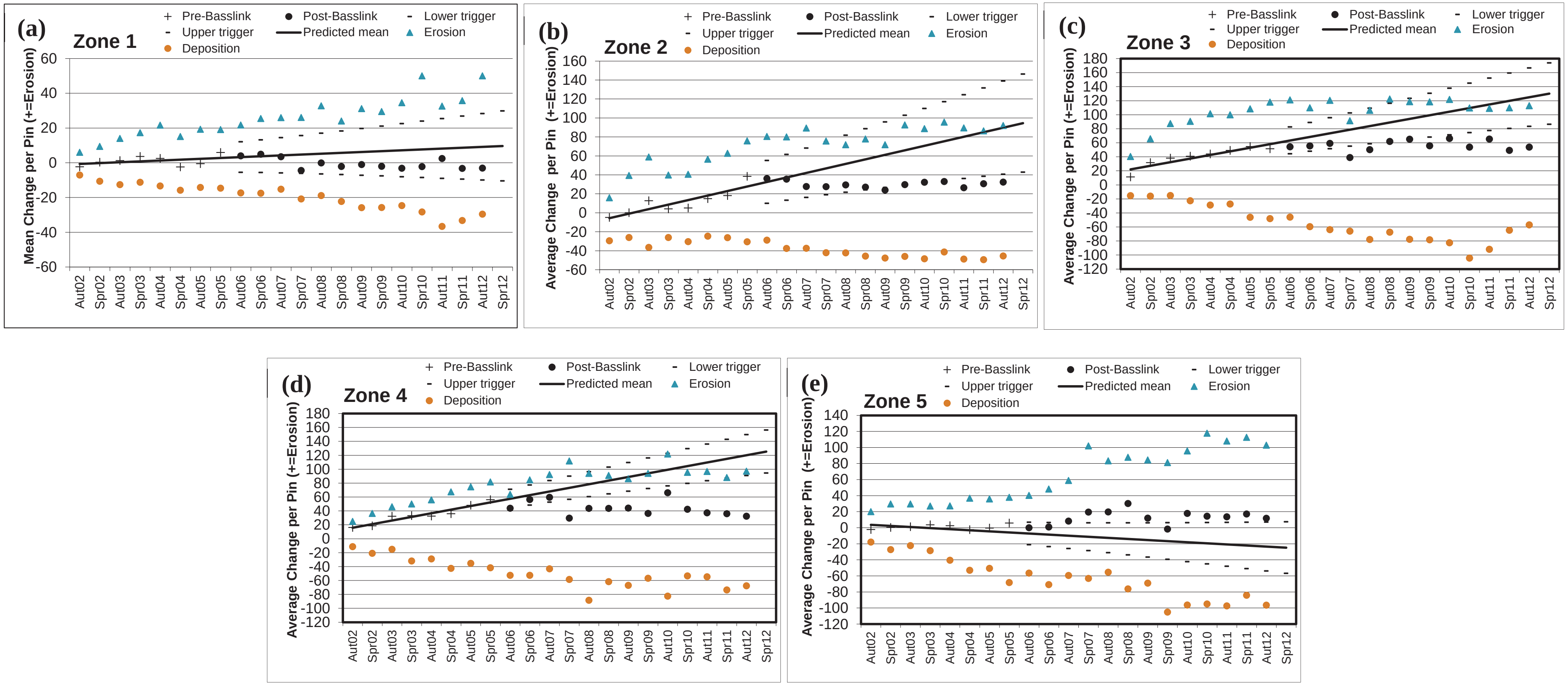


Figure 5.19: Erosion pin results grouped by zones compared to projections of pre-Basslink monitoring results. The erosion pin results show net changes compared to spring 2002.

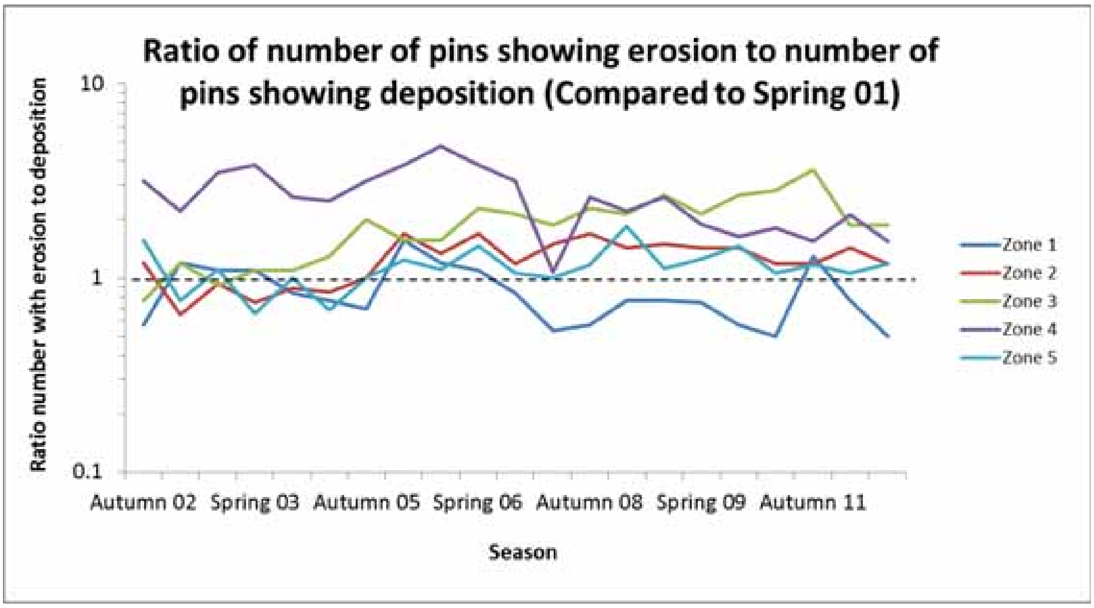


Figure 5.20: Ratio of erosion pins recording erosion to the number of erosion pins recording deposition (relative to spring 2001) in each zone. Log scale used to provide visual clarity over the range of ratio values shown in the graph.

A comparison of the erosion pin results grouped by zones is shown in Figure 5.21, and demonstrates that the results have been relatively consistent over the post-Basslink monitoring period, with zone 3 having the highest net change compared to spring 2002, and zone 1 the lowest. The increase in erosional processes evident in the pre-Basslink data sets for zones 2, 3 and 4 was not evident post-Basslink.

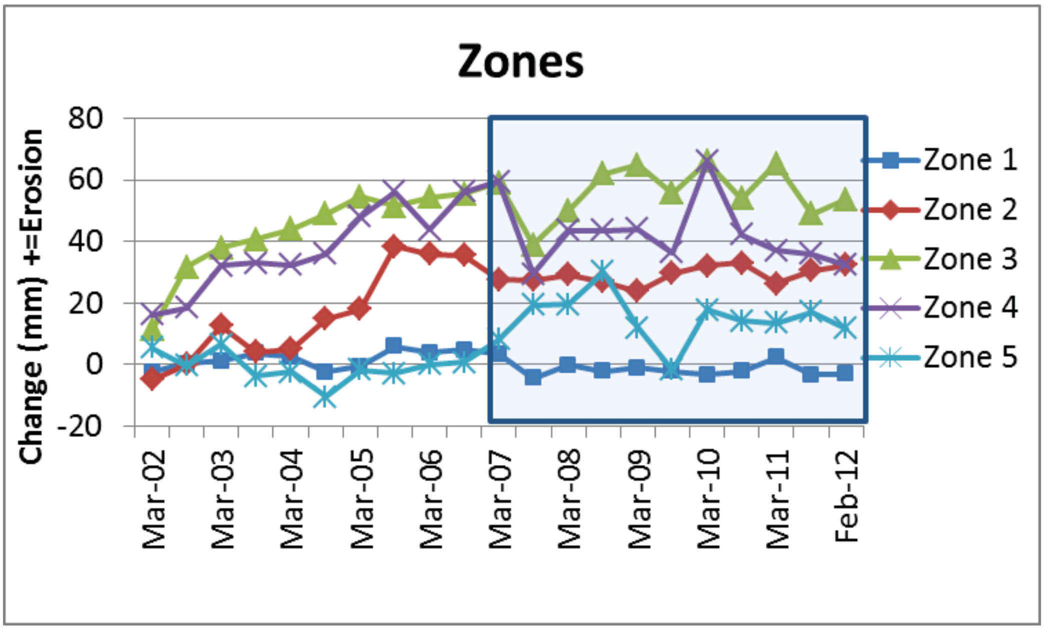
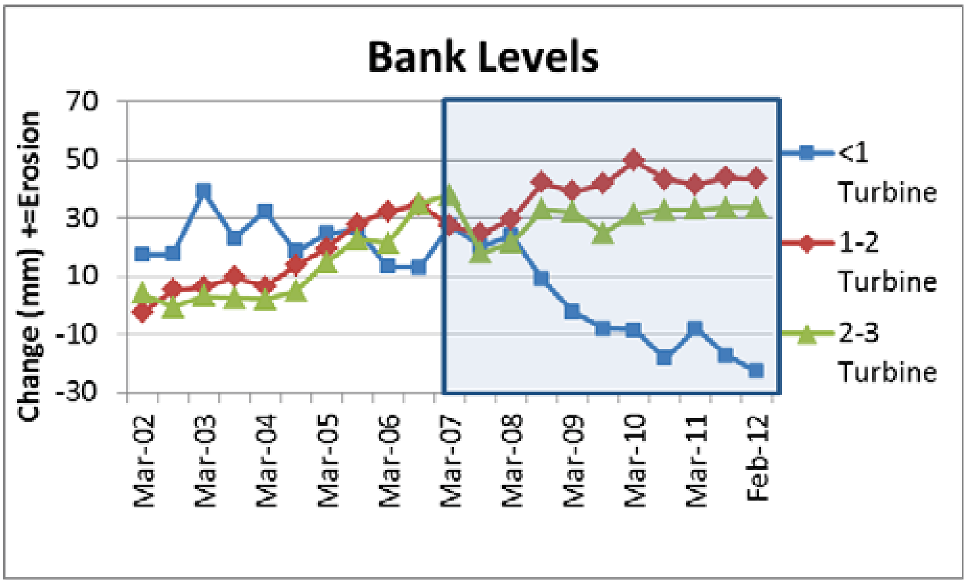


Figure 5.21: Comparison of erosion pin results for each zone during the post-Basslink monitoring period. Results are net change relative to spring 2002.

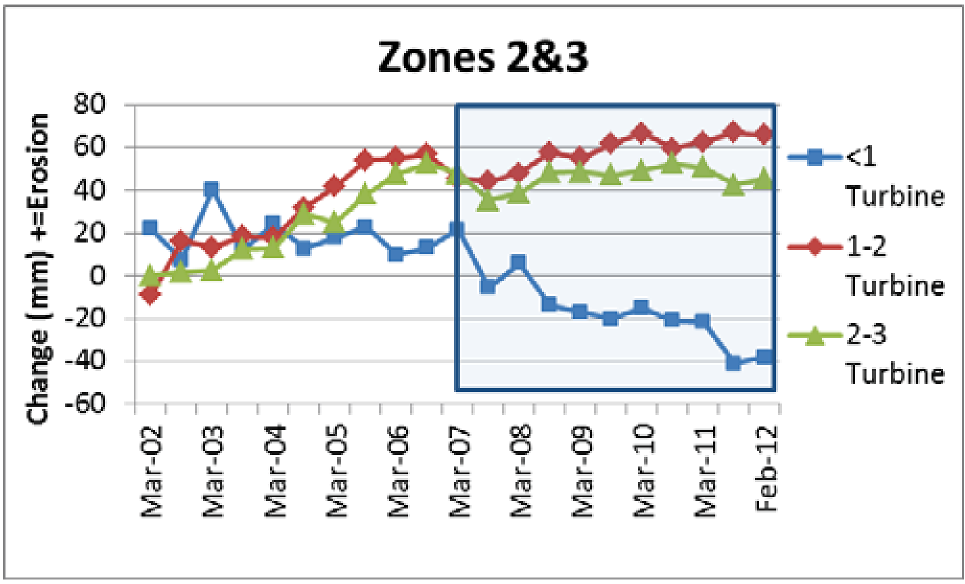
5.4.4.2 Erosion pins grouped by bank level and zones

The results of erosion pin measurements grouped by approximate bank levels for all zones, and by bank level for zones 2 and 3, and zones 4 and 5, are presented in Figure 5.22. Each grouping shows the average results for each monitoring period compared to October 2001 (when monitoring began) therefore trends reflect the cumulative change since the start of monitoring. The post-Basslink period is highlighted in blue shading in each graph.

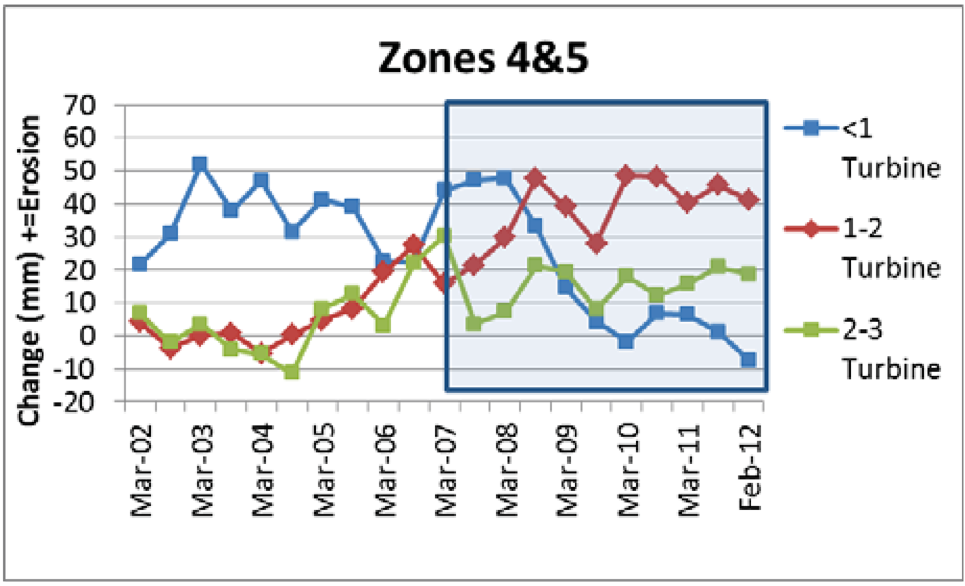
There were clear post-Basslink trends in the turbine levels, with bank toes (<1 turbine) showing deposition in all zones, the 2-3 turbine levels showing erosion, and the 1-2 turbine level showing little change over the post-Basslink period. The zone 4 and 5 results showed greater variability in the results, consistent with greater variability in the flow rate and sediment input in these zones.



(a)



(b)



(c)

Figure 5.22: Erosion pin results grouped by bank levels for all zones (a), by bank level in zones 2 and 3 (b) and by bank level in zones 4 and 5 (c).

5.4.5 Flow and erosion pin correlation analysis

In each of the annual reports, the erosion pin results have been discussed with respect to the flow regime of the monitoring period, and how the flows promote different erosion pin responses. The major findings include:

- scour was the predominant erosion process affecting bank toes and was actively removing remnant root-mats in the 1-2 and 2-3 turbine bank level;
- seepage erosion, resulting from rapid river drawdown during periods of high bank saturation, was most active in the 1-2 and 2-3 turbine bank levels and leads to down-slope deposition on the banks; and
- sub-aerial processes occur when river levels were low and banks were exposed leading to net erosion through raindrop impact and rilling from water flowing over the exposed bank toe.

These results are presented in the post-Basslink conceptual model (see Section 3).

The remainder of this section integrates the hydrologic results presented in Section 2 - Hydrology and water management, and Section 3 - Post-Basslink conceptual models, where the results long-term erosion pin measurements identify the hydrologic drivers of erosion in the Gordon River, and determine if erosional processes have changed post-Basslink.

In the Basslink Baseline Report (Hydro Tasmania 2005a) the erosion pin results between March 2002 and March 2005 were presented and correlated with hydrological parameters to identify potential links between components of flow and bank response. The analysis found little or no correlation between flow parameters and erosion pin results grouped by zone or bank placement (<1, 1-2, 2-3 turbine level on the banks), but correlations increased when data were grouped by bank placement and zones (zones 2 and 3, zones 4 and 5). Generally, there were negative correlations between net erosion on the banks above 1-turbine level and hydrologic parameters associated with high power station discharge and were postulated as being indicative of seepage processes. Positive correlations between high power station discharge or inflows and erosion were suggested as indicating scour.

A similar analysis has been completed using erosion pin results and the flow parameters listed in Table 5.3:

Table 5.3: Flow volumes and erosion pin results used in correlation analyses. Graphs of hydrologic parameters and erosion pin results are contained in previous sections of this chapter.

Flow statistics for 1, 3 and 12-months prior to monitoring	Erosion pin results
Flow volumes & flow hours $<2\ m^3s^{-1}$ $<10/20\ m^3s^{-1}$ (seasonal basis) $<15\ m^3s^{-1}$ $>10/20\ m^3s^{-1}$& $<40\ m^3s^{-1}$ $>40\ m^3s^{-1}$& $<100\ m^3s^{-1}$ $>100\ m^3s^{-1}$& $<200\ m^3s^{-1}$ $>200\ m^3s^{-1}$ $>10/20\ m^3s^{-1}$ (seasonal basis) **# Flow events** $<10\ m^3s^{-1}$ $>150\ m^3s^{-1}$ **Rate of flow change** # of hours rate of flow reduction exceeded 30 m^3s^{1}/h at Gordon Power Station while discharge >180 m^3s^{1}	1. Net erosion by zone 2. Net erosion <1, 1-2 & 2-3 turbine level 3. Net erosion by turbine level grouping zones 2&3 and zones 4&5. **Each dataset considered 3-ways:** ▪ Results compared to Oct 01 ▪ Results compared to previous season ▪ Results compared to previous year

The correlation analysis was completed using the entire erosion pin data set (from October 2001 to March 2012) and the resulting correlations where r exceeds 0.70 are presented in Table 5.4 and Table 5.5. Strong correlations do not necessarily signify cause and effect. However, the correlations are consistent with the understanding of the relationship between flow and bank response in the river as described in the conceptual model, and provide an additional line of evidence for these relationships.

Stronger correlations were found in the comparison between flow results from the previous 12 months as compared to the previous 1 or 3 months, suggesting that the total flow volume is a dominant driver of change. It is notable that in the Basslink three year review (Hydro Tasmania 2010a); few correlations emerged when the entire data set (2001 to 2009) was used in the analysis. Strong correlations were only evident when the analysis was confined to the post-Basslink period. In contrast, good correlations have been found in the present analysis which includes the pre-Basslink and post-Basslink period (2001 to 2012). In the following discussion, positive correlations indicate that the flow parameter is associated with erosion, whereas a negative correlation indicates the parameter is associated with deposition.

Within the context of the conceptual model of erosion in the middle Gordon River, the results can be explained by a combination of scour, seepage erosion and sedimentation from unregulated inflows:

- Zones – few correlations were found between the erosion pin results grouped by zones and flow parameters. This was attributable to each level of the bank being affected by different periods of inundation and flow components; with no one flow component controlling overall erosion rates.

- Strong correlations were found between factors associated with high flow or total flow rates, and erosion in the <1-turbine bank level, suggesting scour was contributing to erosion under these conditions. The results from the sediment transport model (which is based on theoretical scour rates) are compared to the autumn erosion pin results which are shown as change since the previous monitoring (see Figure 5.23). Both data sets show similar erosional patterns throughout the Basslink period. The absence of correlations with the other bank levels is consistent with the understanding of erosion in the middle Gordon, with toes predominantly affected by scour, and the other bank levels affected by a combination of scour and seepage processes. The strong correlation between high flow or total flow rates and erosion also supports use of the sediment transport model as a method of comparing and evaluating annual hydrographs with respect to potential scour in the river.

- There was also a strong negative correlation between the <1-turbine bank level erosion pin results compared to 2001 and low flows (<40 m^3s-^{1}). This can be interpreted as low discharges from the power station translating into low shear stress on bank toes, thus limiting erosion due to scour, and possibly allowing the deposition and accumulation of sediment derived from unregulated tributaries, and or the deposition of sediment derived from rilling of the exposed bank following rainfall events.
- The positive correlations between low (20-40 m^3s^{-1}) flows (Figure 5.24) and erosion in the 1-2 turbine bank level (0.72 – 0.89) was possibly related to erosion of the bank face by catchment inflows under conditions of low power station discharge, and / or through sub-aerial processes (raindrop impact and rilling). The similar but negative correlations between high flow characteristics and erosion in the 1-2 turbine bank level could be showing the impact of seepage erosion on the bank, with material deposited in the 1-2 turbine bank level following seepage movements induced by draw down following high flows. A similar interpretation can be made for the negative correlations between erosion in the 2-3 turbine bank level and high flow characteristics, including the short duration ‘peaking’ events as indicated in Table 5.5.
- Zones 2 and 3 by bank levels – the <1-turbine bank level in zones 2 and 3 show similar correlations as the combined <1-turbine level, with erosion negatively correlated with low flows, and positively correlated with high flows. The strong negative correlations between flows >200 m^3s^{-1}, and the 1-2 and 2-3 turbine zone erosion results were also consistent with seepage processes affecting erosion pin results at these flow levels. The differences between the correlations for the <1 and 2-3 turbine zones underscore the change in erosional processes which occur as high flow events increase;
- Zones 4 and 5 by bank level – the negative correlation between low flows and erosion and positive correlation between high flows and erosion in the <1 turbine zone was consistent with the results from the other groupings, and supports a model in which low flows limit scour and allows deposition on bank toes, whereas high flows lead to toe scour. The negative correlations between high flow and the number of high flow events in the 1-2 turbine level were again consistent with seepage erosion processes;
- No strong correlations were found between the changes in flow <-30 m^3s^{-1} hr^{-1} (i.e. reductions in flow exceeding 30 m^3s^{-1} hr^{-1}) and any of the erosion results. However, erosion results in the 2-3 turbine zone decrease considerably when the duration of rapid flow change was high, as shown in Figure 5.25 and Figure 5.26. It is possible that there is a ‘threshold’ above which the net erosion results are affected when rapid drawdowns occur frequently, but more likely, bank saturation needs to be high at the time of drawdown for seepage processes to occur. The long duration of rapid drawdowns in 2007 and 2008 coincided with a period of high overall power station discharge, resulting in high bank saturation levels (see Figure 5.25). In contrast, overall discharge from the power station and hence bank saturation has been low in 2011 and 2012, leading to little change in net erosion rates during a period of increased drawdowns. Figure 5.26 suggests that a threshold of approximately 50 hours of rapid flow reduction is required before impacts on

> erosion rates are observed. These 50 hours also represent many more hours of elevated flows which contribute to bank saturation. This understanding of seepage processes is reflected in the revised ramp-rule, implemented in April 2012, which allows unrestricted drawdowns under conditions of low bank saturation, but requires ramping of all drawdowns once the banks are saturated.

Correlations between erosion pin results and the number of flow events >200 m^3s^{-1} suggests that flow events of <3 hours in duration show a positive correlation with bank toe changes, indicating erosion, and a negative correlation with the other turbine levels, consistent with deposition. These results suggest that seepage processes in the 1-2 and 2-3 turbine levels were associated with the short duration events. Because a large proportion of the flow events in the Gordon were associated with short-duration events, the positive correlations with scour in the <1 turbine bank level may be reflecting the total volume of water discharged, which is associated with scour, rather than the pattern of power station operations.

Table 5.4: Summary of correlation coefficients between hydrologic parameters and erosion pin results for post-Basslink period. Correlations which exceed 0.7 (or are <-0.7) are shown. Negative correlations highlighted in red. r>0.9 are highlighted in bold and green shading.

Erosion pin grouping	Total flow released from Gordon Power Station at 20-40 m^3s^{-1} in previous 12 months	Total flow released from Gordon Power Station at >200 m^3s^{-1} in previous 12 months	Total flow released from Gordon Power in previous 12 months	Median flow at Gordon above Franklin in previous 12 months	Hours flow>200 m^3s^{-1}at Gordon above Franklin in previous 12 months	#of events >210 m^3s^{-1} in preceding 12 months	#of events >210 m^3s^{-1} of duration<3 hours in preceding 12 months
Zone 1 (all pins)							
Zone 2 (all pins)							
Zone 3 (all pins)						-0.84	-0.72
Zone 4 (all pins)							
Zone 5 (all pins)							
<1 Turbine bank level (all zones)	-0.86	0.74	0.81	0.88	**0.91**		0.86
1–2 Turbine bank level (all zones)	0.82	-0.81	-0.79	-0.85	-0.81	-0.74	-0.86
2–3 Turbine bank level (all zones)		-0.80		-0.76	-0.77		
Zones 2 and 3 <1 turbine bank level	-0.86		0.74	0.81	0.72		0.80
Zones 2 and 3 1-2 turbine bank level	0.72	-0.75	-0.73	-0.76	-0.73		-0.80
Zones 2 and 3 2-3 turbine bank level		-0.81		-0.76	-0.76	-0.78	-0.70
Zones 4 and 5 <1 turbine bank level	-0.73	0.71	0.74	0.81	0.77	0.73	0.89
Zones 4 and 5 1-2 turbine bank level	0.89	-0.78	-0.79	-0.87	-0.83	-0.79	**-0.91**
Zones 4 and 5 2-3 turbine bank level							

Table 5.5: Correlations between number of flow events >150 m^3s^{-1} and erosion pin results, grouped by zone and turbine level.

Bank level	**Number events >200 m^3s^{-1} in the following duration classes**			
All zones	Sum all events	<3 hours	4–24	>72
<1 turbine		0.86		
1-2 turbine		-0.86		
2-3 turbine				-0.70
Zones 2 and 3				
<1 turbine		0.79		
1-2 turbine		-0.80		
2-3 turbine	-0.78	-0.70	-0.79	
Zones 4 and 5				
<1 turbine	0.73	0.88		
1-2 turbine	-0.79	-0.91		
2-3 turbine				-0.86

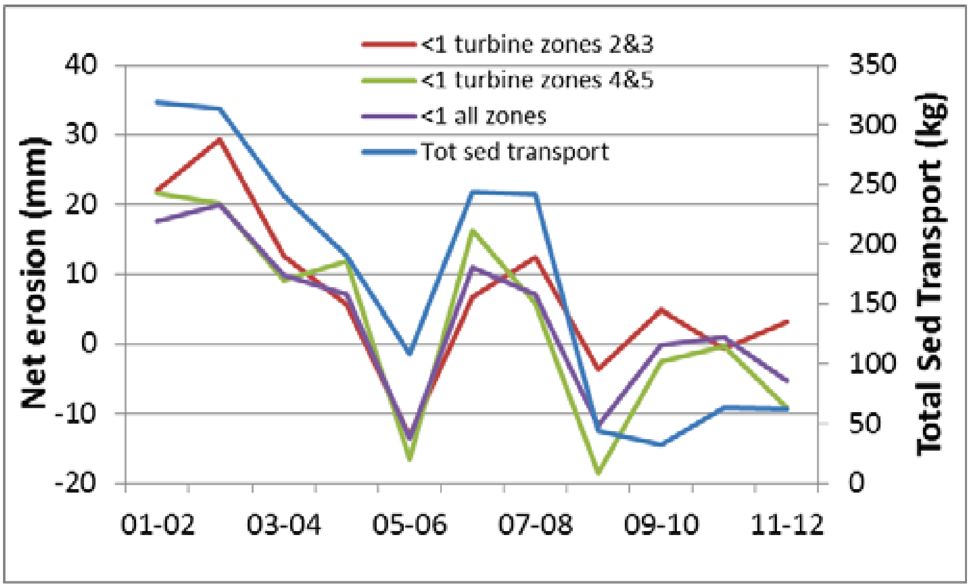


Figure 5.23: Net erosion results from <1 turbine bank level in all zones, zones 2 and 3 and zones 4 and 5 compared to total sediment transport as estimated by model for the entire monitoring period.

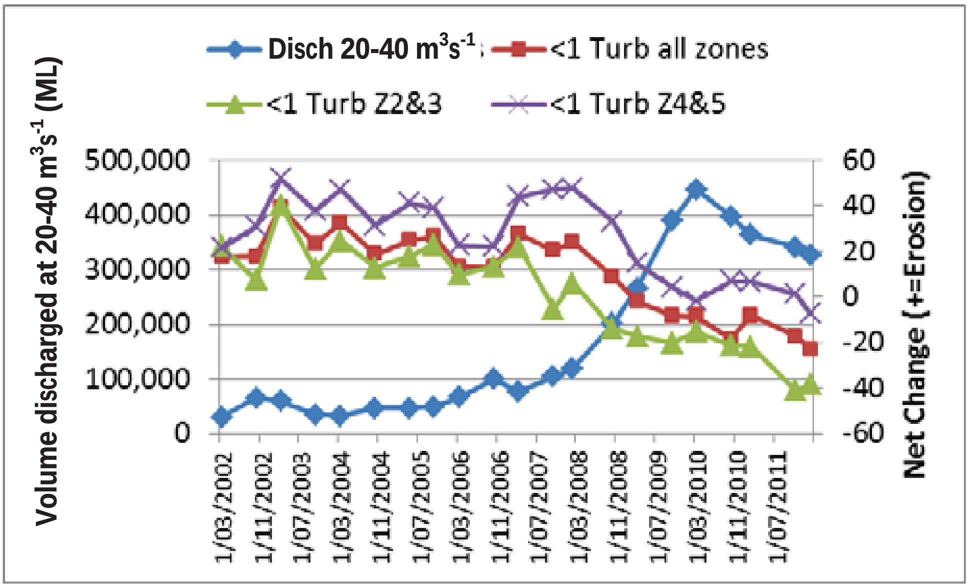


Figure 5.24: Comparison of the flow volume discharge by the power station in the 20-40 m^3s^{-1} range.

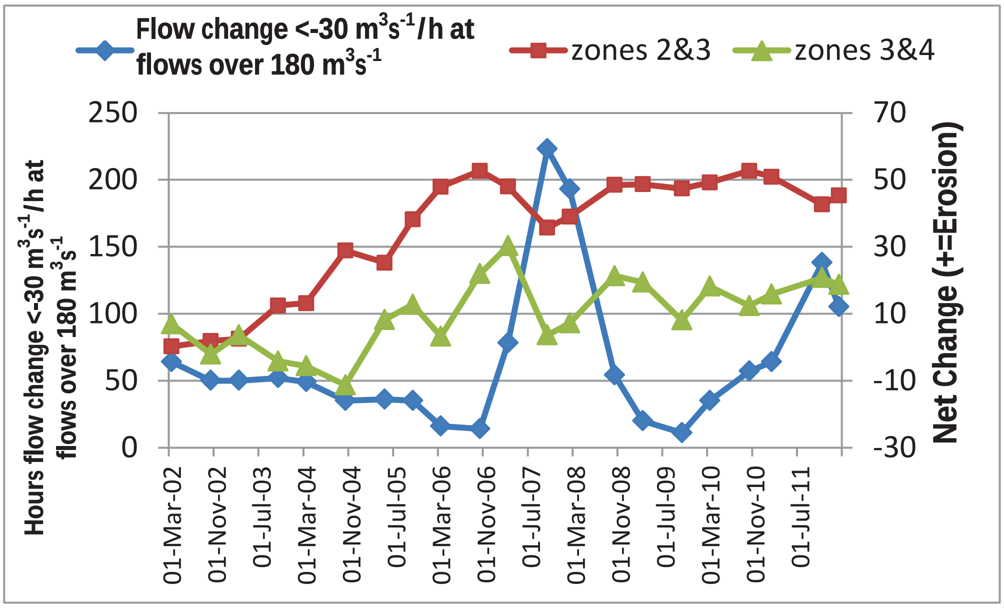


Figure 5.25: Net erosion in zones 2 and 3 and 4 and 5 in the 2-3 turbine bank levels compared to hours at which flow reductions exceeded 30 m^3s^{-1} while the power station was discharging in excess of 180 m^3s^{-1}.

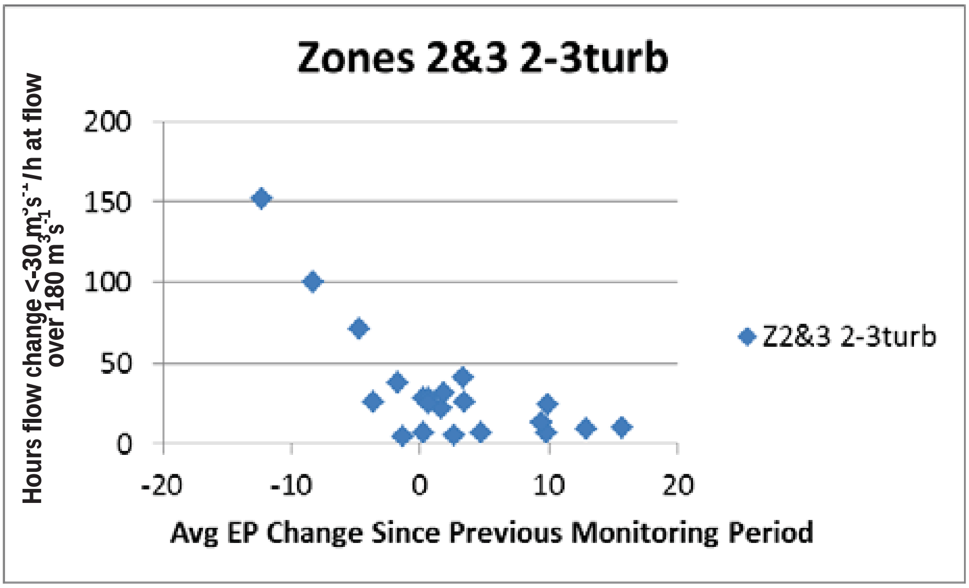


Figure 5.26. Average change in erosion pins in the 2-3 turbine bank zone in zones 2 and 3 compared to the number of hours flow reductions exceeded 30 m^3s^{-1} per hour, since the previous monitoring period, while the station was discharging >180 m^3s^{-1} for the period 2001-12.

5.4.6 Comparison of pre- and post-Basslink results compared to previous season

The erosion pin results discussed in the previous section reflect changes relative to October 2001, when monitoring began. Erosion pin results were also analysed relative to results from the previous season, providing an indication of the magnitude and direction (erosion or deposition) of changes between seasons. The results for the zones are presented in Figure 5.27 and turbine levels in Figure 5.28. The graphs show that the direction of change (erosion or deposition) frequently varies within a grouping, and no trends are evident between groupings.

Results have been divided into pre-Basslink (March 2002 to October 2005) and post-Basslink (October 2006 to March 2012) for each of the erosion pin groupings. The results are presented as box and whisker charts in Figure 5.29 through to Figure 5.36. Also shown are the ratios of pins recording erosion to pins recording deposition for the same groupings over the same time periods.

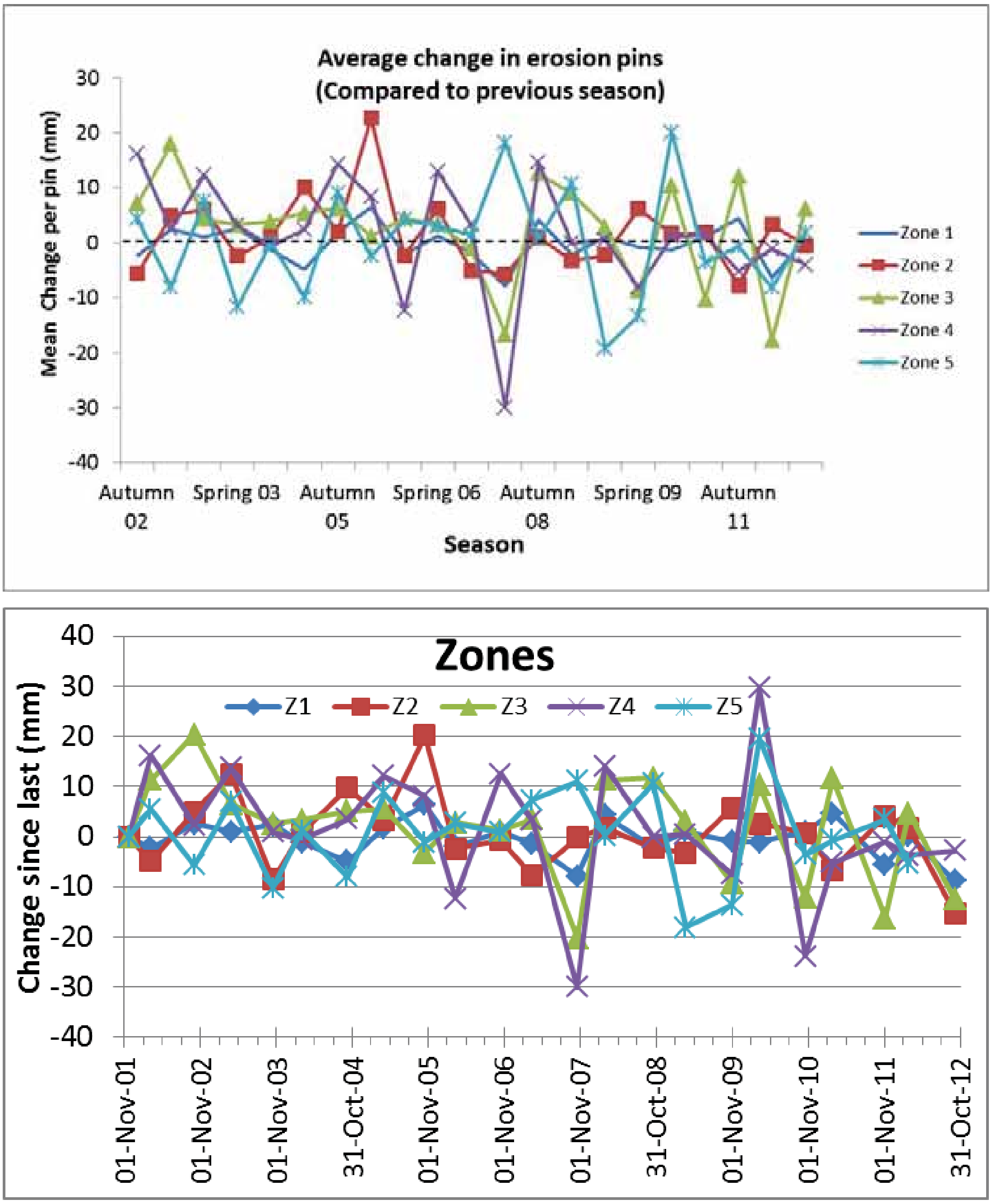


Figure 5.27: Erosion pin results compared to results from previous season grouped by zone.

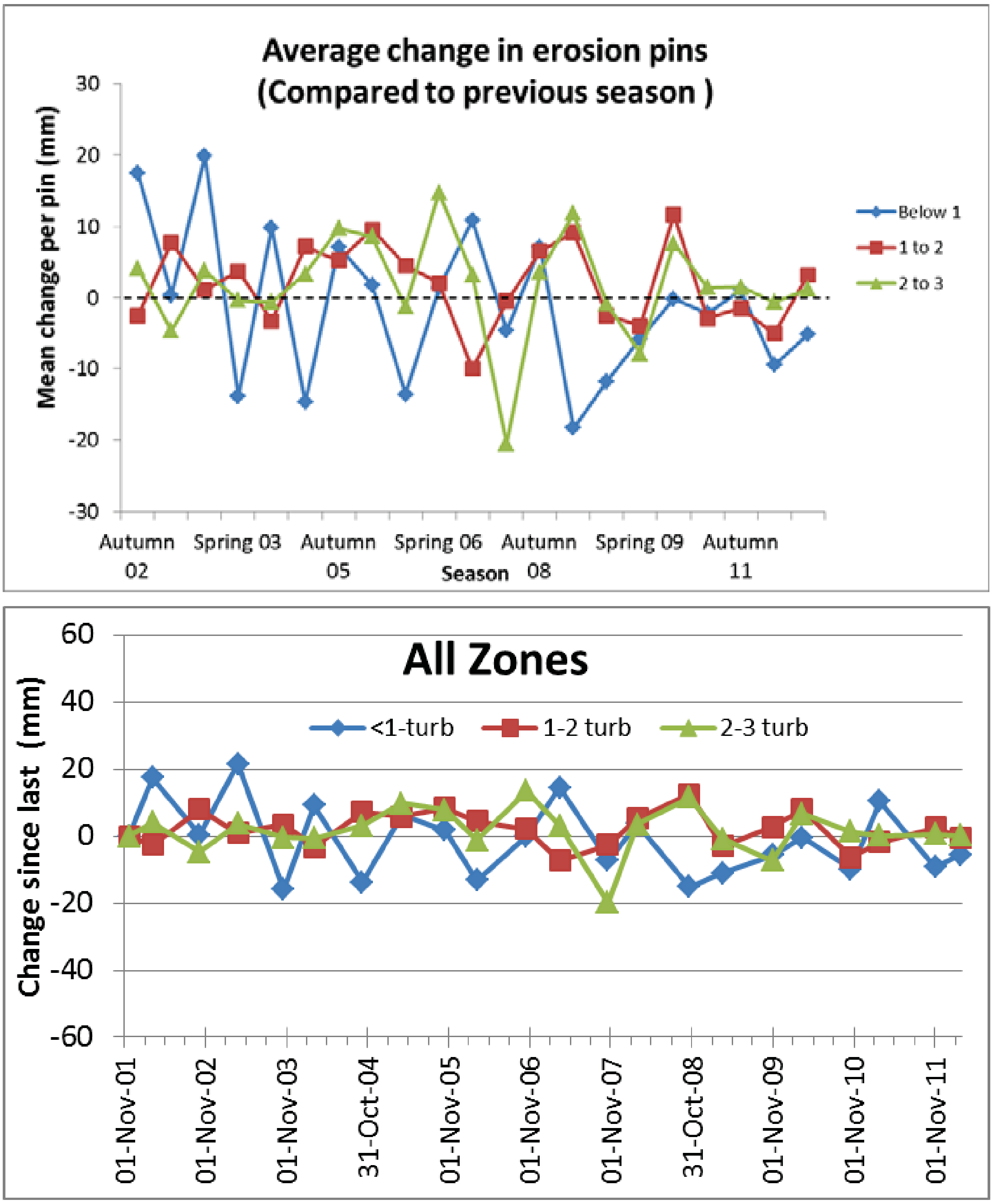


Figure 5.28: Erosion pin results compared to results from previous season grouped by bank level.

Average (median) results for the zones (Figure 5.29) have remained similar pre- and post-Basslink with the exception of zone 4, where median erosion has decreased. The range of results in zones 3, 4 and 5 have increased in the post-Basslink period, but this period also includes more results (14 monitoring events compared to 8) which may account for some of the increased variability. The ratio of pins recording erosion to those showing deposition has decreased since the introduction of Basslink in all zones except zone 3 (Figure 5.30). This apparent reduction in erosion post-Basslink is most likely related to the lower discharge volumes released from the power station in the last four years.

In the turbine zone groupings (Figure 5.31 and Figure 5.32), the <1 turbine bank level showed a change in median values from erosion to deposition. The 1-2 turbine level also shows a reduction, with the median being marginally depositional. A smaller reduction was also apparent in the 2-3 turbine bank level, although the post-Basslink results remain depositional. The decrease in erosion in the <1 turbine zone is consistent with the reduction in the ratio of pins recording erosion to those recording deposition. The pin ratios have remained similar for the other groupings pre- and post-Basslink.

The final two groupings, of pins by zones and turbine levels (Figure 5.33 through Figure 5.36), generally show similar trends to the turbine groupings, with the <1 turbine bank level showing a change from erosion to deposition. The results for the zone 2 and 3, 1-2 and 2-3 turbine levels show a reduction in the post-Basslink period, which may be attributable to a lower discharge from the power station during this period. In contrast, the results for zones 4 and 5 show an increase in the range of results for the 2-3 turbine level, possibly reflecting greater flow variability due to unregulated tributary inflows.

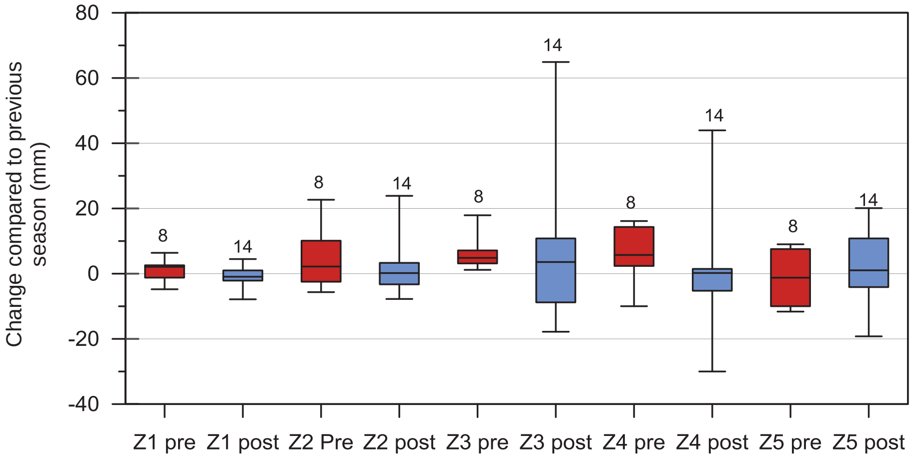


Figure 5.29: Erosion pin results grouped by zones with the results expressed as change since previous season. First (red) box and whisker plot in each pair shows range of pre-Basslink values, with second plot of each pair showing range of post-Basslink results. The box in each plot encompasses the 25th to 75th percentile results, with the median indicated. The 'whiskers' show minimum and maximum values.

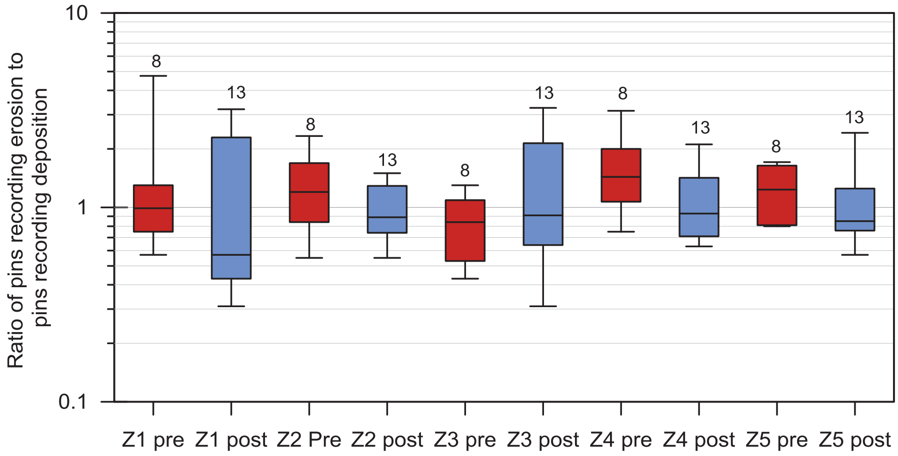


Figure 5.30: Box and whisker plot showing range of ratio of pins recording erosion to pins recording deposition for pre- and post-Basslink results grouped by zones. Z1 pre= zone 1, pre-Basslink = <1 turbine bank level, pre-Basslink. Log plot used for ease of reading ratios.

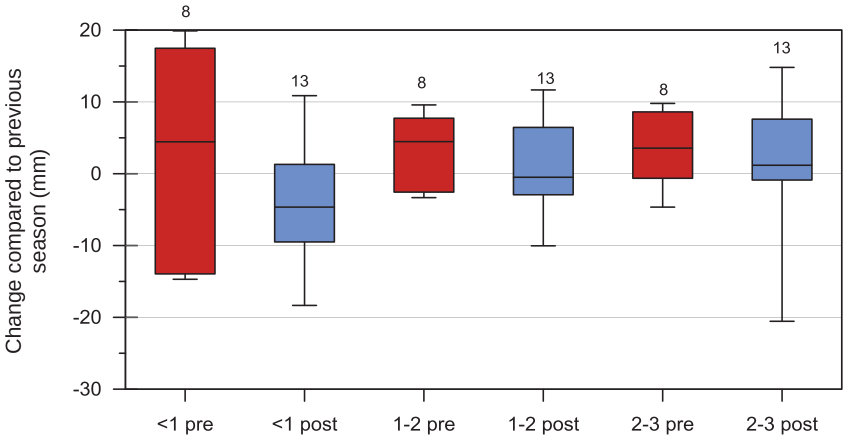


Figure 5.31: Box and whisker plot showing erosion pin results grouped by turbine levels with results expressed as change since previous season. <1 pre = <1 turbine bank level, pre-Basslink.

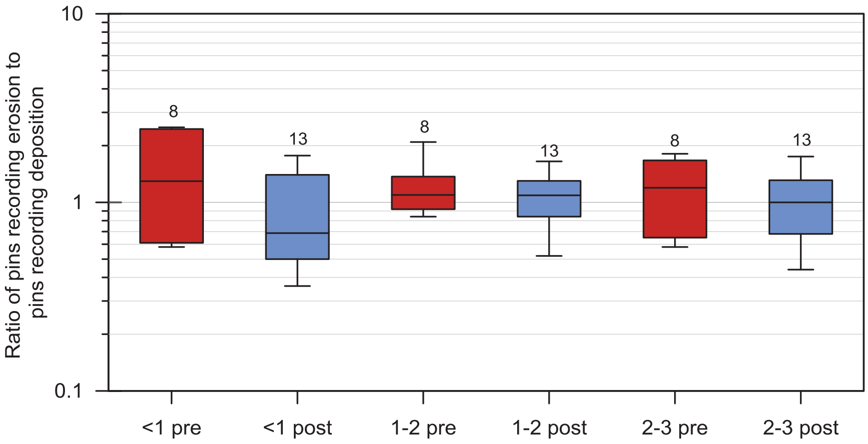


Figure 5.32: Box and whisker plot showing range of ratio of pins recording erosion to pins recording deposition for pre- and post-Basslink results grouped by turbine level. <1 pre = <1 turbine bank level, pre-Basslink. Log plot used for ease of reading ratios.

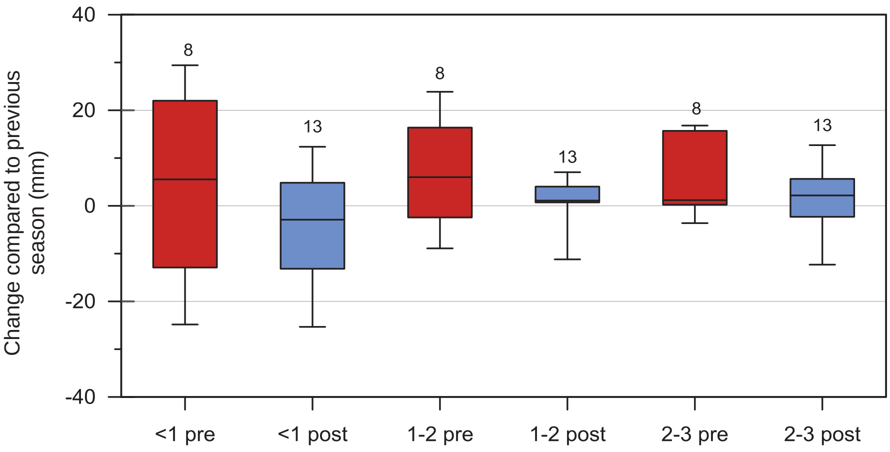


Figure 5.33: Box and whisker plot showing erosion pin results for zone 2 and 3 grouped by turbine levels with results expressed as change since previous season. E.g.<1 pre = <1 turbine bank level, pre-Basslink.

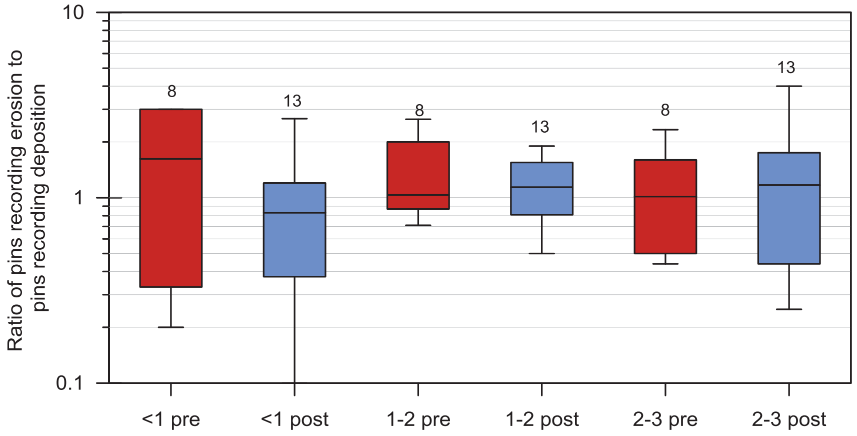


Figure 5.34 Box and whisker plot showing range of ratio of pins recording erosion to pins recording deposition for pre- and post-Basslink results for zones 2 and 3 by turbine level. <1 pre = <1 turbine bank level, pre-Basslink. Log plot used for ease of reading ratios.

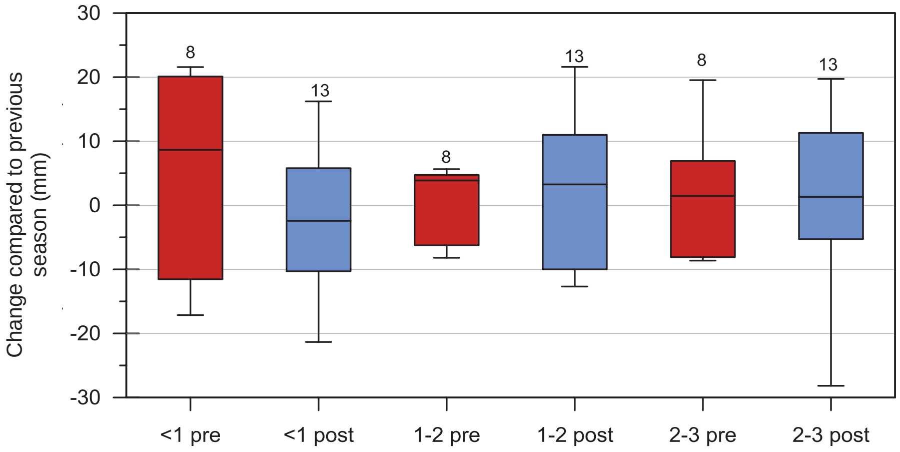


Figure 5.35: Box and whisker plot showing erosion pin results for zone 4 and 5 grouped by turbine levels with results expressed as change since previous season. E.g.<1 pre = <1 turbine bank level, pre-Basslink.

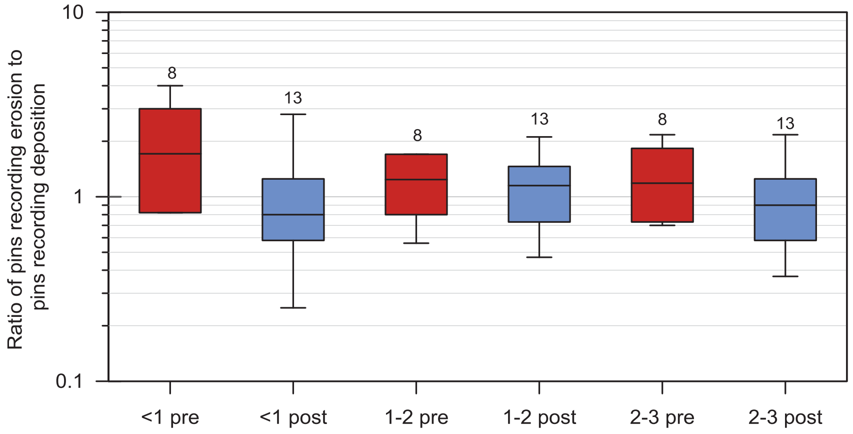


Figure 5.36: Box and whisker plot showing range of ratio of pins recording erosion to pins recording deposition for pre- and post-Basslink results for zones 4 and 5 by turbine level. <1 pre = <1 turbine bank level, pre-Basslink. Log plot used for ease of reading ratios.

5.4.7 Review of erosion pin results by combining erosion and deposition

Typically, erosion pins record erosion, deposition or no change, with deposition reflecting fluvial deposition. In the Gordon River, where there was little fluvial sediment transport due to river regulation and the decoupling of the flow regime and sediment supply, fluvial deposition was limited, especially in zones 1 and 2. Deposition on the bank toes does occur, however, the material was frequently sourced from a higher level on the same bank (rather than upstream).The deposition on bank toes was associated with seepage processes involving entrained sediment being transported down the bank in water draining from the banks following a power station draw down event. Deposition of this sediment typically occurs on the lower bank as the water velocity decreases, leading to sediments dropping out onto banks. The rate of erosion of the higher bank was rarely captured using erosion pins due to the source of the sediment frequently being under the vegetation / root mat which drapes over the sandy alluvial banks. Seepage process were most active in zones upstream of the Denison River, and in zones 4 and 5 alluvial deposition was observed on the banks during periods of low power station discharge. Figure 5.37 shows the erosional and depositional components for each monitoring period for each zone.

In the 3-year Basslink review, the erosional and depositional components were combined to provide an overall indication of total change (erosion plus seepage plus alluvial deposition), and this analysis has been extended to include all post-Basslink results in Figure 5.38.

Zones 1 and 5 showed a linear trend in total change over the pre- and post-Basslink monitoring periods, with the other zones showing a decrease in total activity over the final few years of monitoring. The relative uniformity of the curves is notable given the wide range of flow patterns experienced by the river over the study period, and may reflect the underlying stability of each zone.

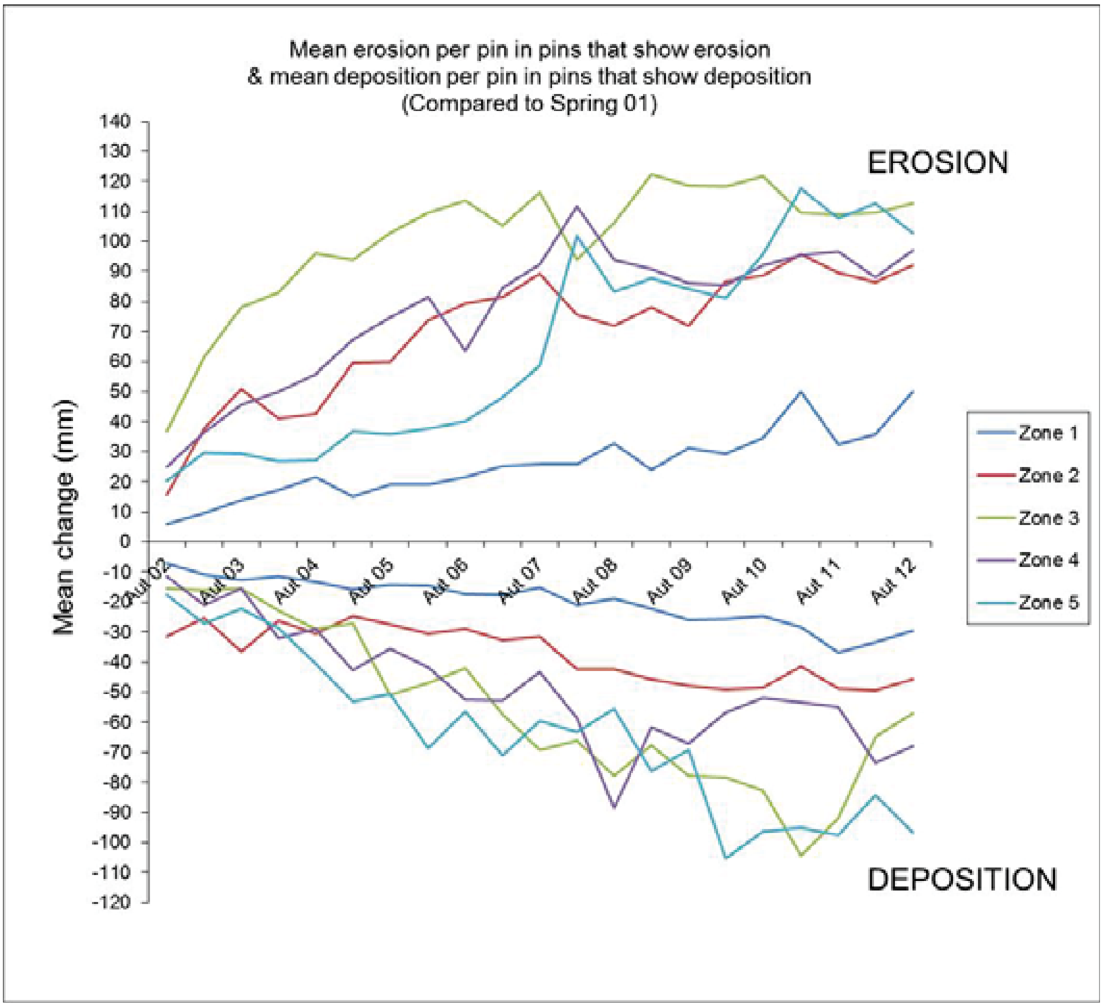


Figure 5.37: Erosion pin results for pins showing erosion and pins showing deposition for each zone. Each monitoring periods, all pins showing erosion are grouped together and averaged, and all pins showing deposition are grouped together and averaged.

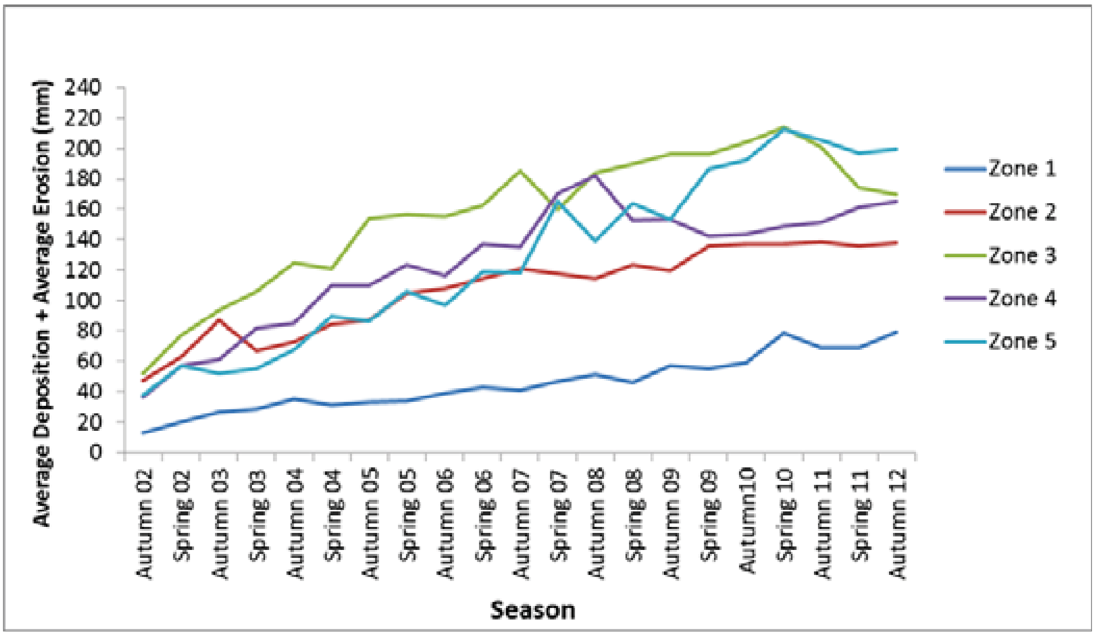


Figure 5.38: Erosion pin results showing sum of erosion and deposition for each zone.

5.4.8 Erosion pin results expressed as annual rates of change

The March erosion pin results from each monitoring year have been used to calculate annual rates of change for each zone, and for the pre- and post-Basslink periods (Figure 5.39). As expected, zone 1 showed the lowest rates, with zones 3 and 4 the highest. Zones 1 through 4 all recorded erosion during the pre-Basslink period, with a change to deposition post-Basslink. Zone 5 recorded the opposite trends, with deposition recorded during the pre-Basslink monitoring phase, and erosion following the introduction of Basslink. Whether the reduction in deposition in the most downstream zone was related to the decrease in erosion in the upstream zones remains unknown.

Maximum annual erosion rates of 22 mm yr^{-1} were recorded in zone 4 in the 2009-10 monitoring year. The following year, this same zone recorded a net depositional rate of 30 mm yr^{-1}.

Annualised rates of change based on the change in erosion pin measurements compared to the previous monitoring period are shown in Figure 5.40 for all zones, all turbine levels, and for zones and turbine levels. Zone 4 also showed the highest rates of change based on ‘zone’ results, consistent with the March to March annual analysis. The turbine level results show that the highest annualised rates of change occurred on the toes of banks (<1 turbine level) during the initial Basslink IIAS investigations which coincided with prolonged 3-turbine high flow. The groupings by zone and turbine level show that zones 4 and 5 recorded lower rates of change compared to the upstream zones, with annualised rates of change generally between ±20 mm.

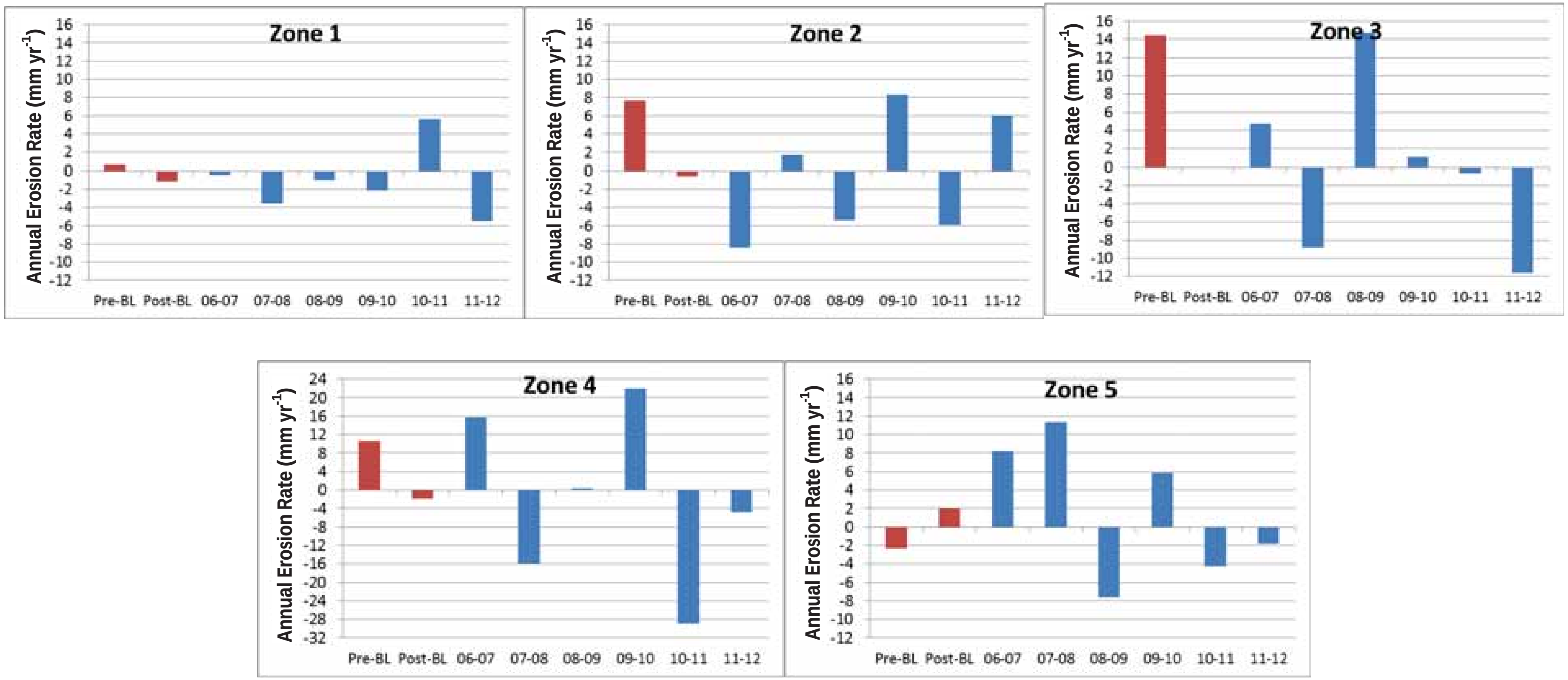


Figure 5.39: Annualised rates of change for each zone based on the March (autumn) results. The pre- and post-Basslink averages are shown as the red bars in each graph. The post-Basslink average result for zone 3 is -0.1 mm/year which is too low to be visible on graph. Note the scale for zone 4 is different from the other zones.

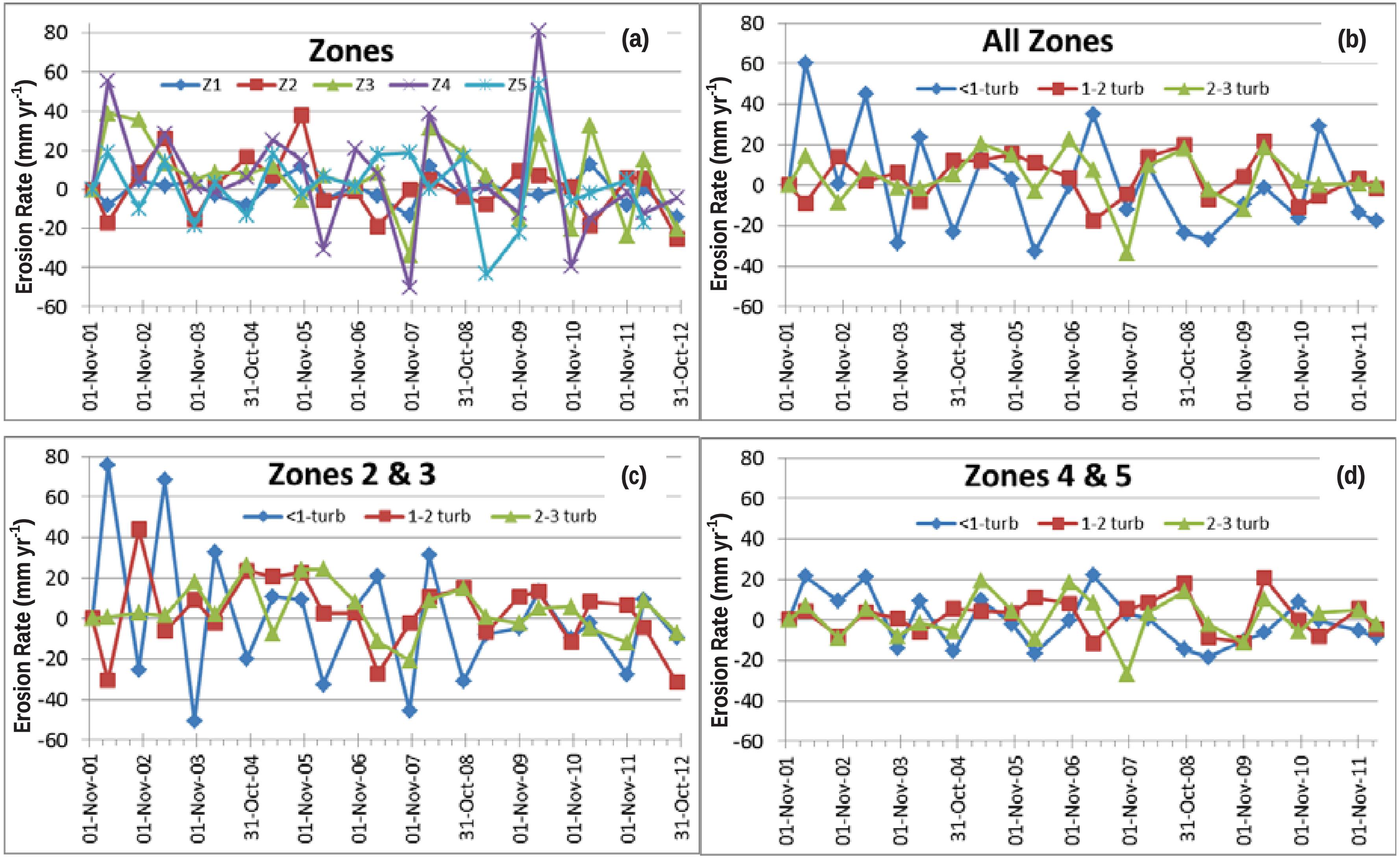


Figure 5.40. Annualised rates of erosion based on monitoring results from each monitoring period for (a) all zones (b) all zone by turbine levels (c) zones 1 and 2 by turbine level (d) zones 4 and 5 by turbine level.

5.4.9 Photo monitoring

Repeat photo monitoring of 54 large scale features in the middle Gordon River (landslips, tree falls, cobble banks, cobble bars) was completed each year in March. Each year the photos were compared with the previous years' and changes were tallied into eight categories. All photos are presented in Appendix 5 of the 2011-12 Annual Report (Hydro Tasmania 2012).

For both the pre- and post-Basslink monitoring periods, the majority of sites have shown no change in successive photos (e.g. recognising limitations of light conditions, different water levels, Figure 5.41). The sites selected to be included in the photo monitoring program showed signs of recent activity when the monitoring began in 2002. Thus the increase in the percentage of photos showing no change post-Basslink may be reflecting increased stability with time.

Post-Basslink, most changes have been associated with the changes to vegetation rather than erosion of banks (Figure 5.42 and Figure 5.43). Vegetation has been lost from banks above the power station controlled high water level, and is frequently associated with root-mats that remained as overhangs following the initial bank disturbance. The single largest post-Basslink change has been a substantial increase in vegetation on the banks within the power station controlled operating level. These changes were reflected in the 'Other' category as they were not observed pre-Basslink. The increase in vegetation is attributable to the consistently low power station discharge during the past three years, which has reduced inundation and water logging of the banks, thus promoting regrowth.

Overall, the photo monitoring sites have demonstrated that large-scale disturbances tend to be localised events, which do not result in prolonged ongoing bank erosion at the initial site, or at adjoining bank locations.

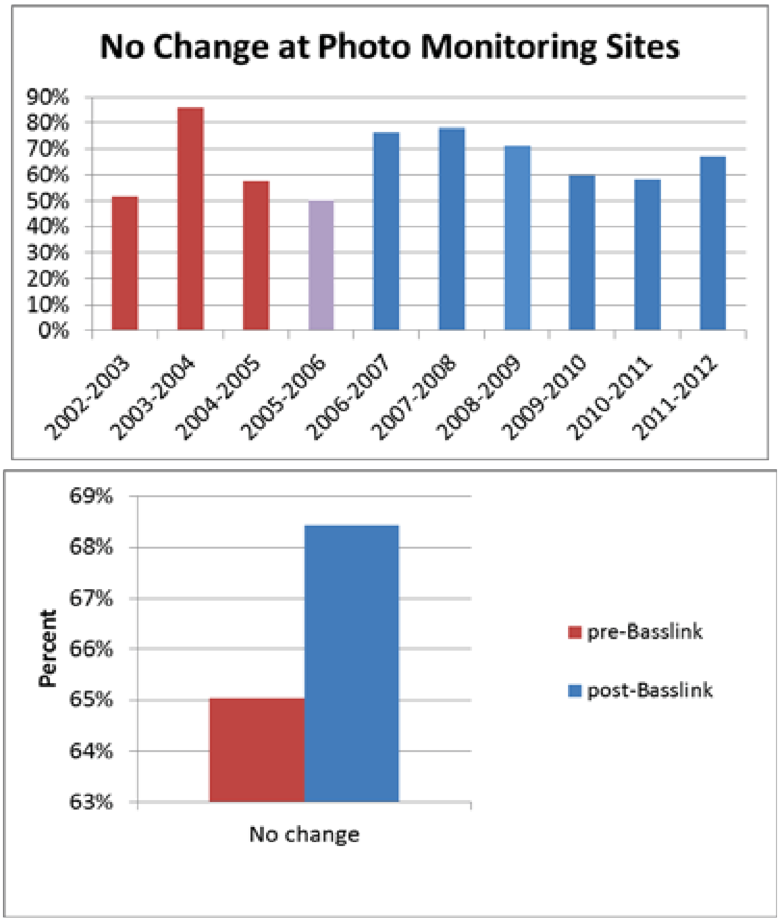


Figure 5.41. Percentage of photo monitoring sites showing no change relative to previous season (top) for each monitoring year, and averaged over the pre- and post-Basslink periods (bottom). The year 2005-06 was excluded from the averages as it was considered a transitional period.

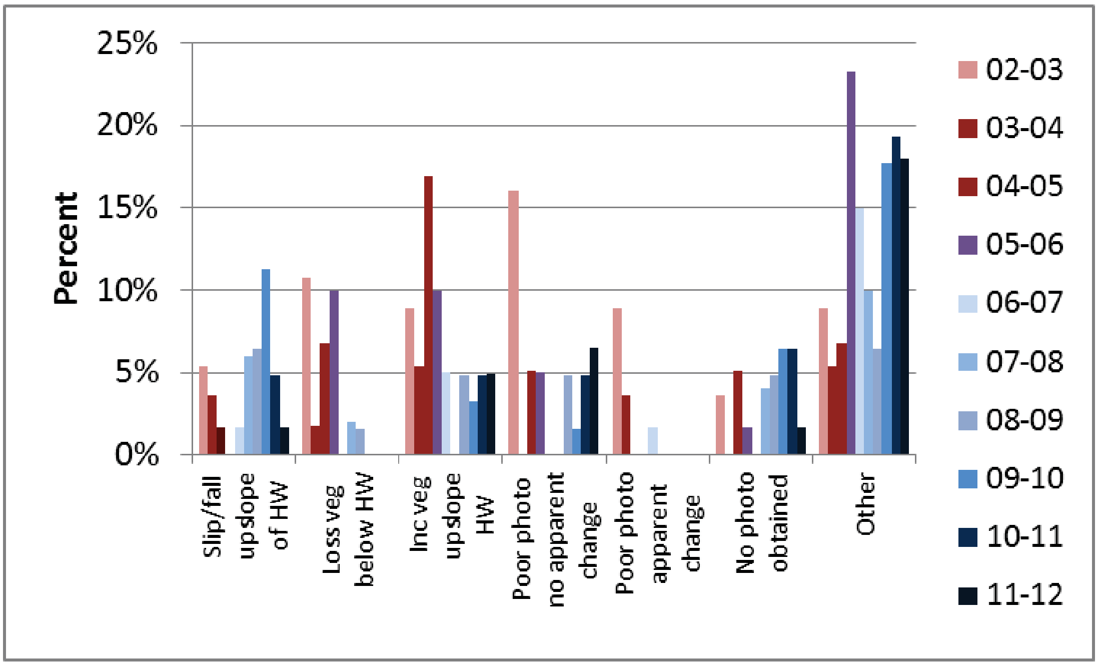


Figure 5.42: Summary of photo monitoring results for 2002-12. The percentage of sites recorded each type of change for each monitoring year. (HW = high water).

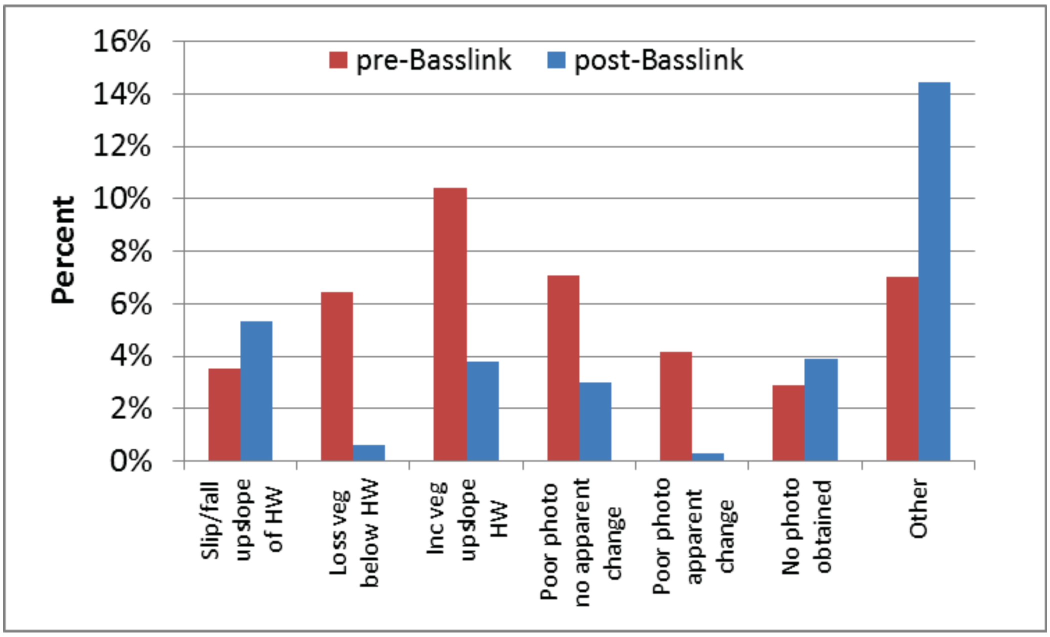


Figure 5.43: Summary of photo monitoring results for 2002-12. The averages percentage change for the pre- and post-Basslink periods. (HW = high water.

5.4.10 Summary of monitoring trends

The erosion pin results for the 2002-12 period show clear relationships to the flow in the river. The post-Basslink flow regime has differed considerably from that predicted during the IIAS-process, and has been characterised by a reduction in total flow, and a relative increase in limited 'hydro-peaking', with much of the peaking coinciding with periods of low bank saturation. The overall reduction in total flow was probably the largest causal factor in post-Basslink trends, as described in the following dot points:

- A reduction in total flow has decreased shear stress on bank toes, and lead to a substantial reduction in scour of the toes. A clear trend in the erosion results was a reduction in erosion and an associated increase in deposition in erosion pins located on the bank toes.
- Results from measurements at erosion pins located in the 1-2 and 2-3 turbine zones have shown little net change following the implementation of Basslink, which is also likely attributable to the overall reduction in flows. A reduction in net erosion in these zones has corresponded to periods when the power station was operated in hydro-peaking mode, and reflects deposition due to local seepage processes.
- Compared to pre-Basslink monitoring results, net erosion rates in zone 1 have remained constant. This result reflects the adjustment of this zone to the power station flow regime. Zones 2, 3 and 4 have shown a reduction in net erosion, which is attributable to the decrease in net flows, and zone 5 has shown a small increase in net erosion. Zone 5 had shown low net deposition pre-Basslink, and it is plausible that the shift to net erosion post-Basslink is linked to the net decrease in erosion in the upstream zones, which is probably associated with the reduction in flow volumes.
- Overall, the erosion pin results continue to reflect an 'erosion wave' progressing downstream, with zone 1 showing stability, and erosion increasing through zones 2, 3 and 4. Zone 5 showed the highest variability of erosion and deposition, which probably reflects the higher level of unregulated inflows to this part of the river. The 'wave' has not appeared to migrate downstream during the post-Basslink period, which may be due to:

- the lack of flow in the river, and/or;
- the progression of the 'wave' is slow compared to the duration of the monitoring program and/or;
- the inflows from unregulated tributaries and associated sediment impeded the progression of the impacts associated with flow regulation.

Photo monitoring results were consistent with the erosion pin findings, and suggest that rates of change were low in the river, and that large scale disturbances, such as land slips and tree falls, do not generally propagate from the initial disturbance site. Over the past three years of photo monitoring, the increase of vegetation within the power station controlled operating level of the banks has been the main change, which is attributable to the low discharge volumes in the river during the post-Basslink period.

5.5 Evaluation of the monitoring program

The Basslink Monitoring Program has provided insights into how discharge patterns at the Gordon Power Station are translated into bank erosion and deposition within the river. The monitoring program has also clearly demonstrated that the robustness of the vegetation on the banks of the Gordon River, including the degraded root-mats and slumped vegetation, exert a stabilizing effect on the river banks. Although erosion pin results and vegetation monitoring results have not been successfully integrated to demonstrate these linkages, field observations clearly indicate the close linkage between vegetation and bank stability.

The monitoring program has enhanced the understanding of spatial changes on the banks, both at the individual bank scale, and at the zone scale. Longitudinally, the monitoring results show the effect inflows from unregulated tributaries have on the banks, through increased flow and sediment variability. At an individual bank scale, the monitoring results have been used to formulate a bank erosion 'model', in which banks progress from low erosion rates where scour is countered by resilient vegetation, through to denuded banks on which seepage processes lead to a lowering of bank slope.

The monitoring results have not been as successful in identifying 'Basslink' changes because the operation of the Gordon Power Station is dependent on many co-related and co-varying factors from which Basslink operations cannot be distinguished. In addition, the power station was not run in the projected 'Basslink' pattern upon which the design of the monitoring program was based. Despite this 'Basslink' short-coming, the results have provided a good understanding of how flow regulation has affected the Gordon River at a large scale. Specifically, the monitoring program has provided a consistent picture of how the flow regime determines the relative contributions of erosional processes in the river, and how these processes are shaping the banks over time frames of months to years.

5.6 Review of triggers

As identified in the Basslink Review Report (Hydro Tasmania 2010a) the present trigger values are not useful as indicators of Basslink change in isolation, and should not be the main focus of reporting. Instead, the grouped erosion pin results (present triggers) should be used as one of the multiple lines of evidence, along with field observations, hydrologic parameters, photo monitoring results, piezometer results, vegetation results, etc. In practice this has been the case since the implementation of Basslink, with the trigger values integrated with other monitoring results in each monitoring report. In the future it is recommended that the grouped erosion pin are no longer referred to as ‘triggers’, with a more holistic approach adopted to identifying change, based on the conceptual model.

The multiple lines of evidence approach adopted for understanding geomorphic changes in the river has proved valuable, with field observations providing insights into the processes which most recently affected the banks (previous days to weeks), and the erosion pin results reflecting impacts from the flow regime over the previous months or year. The piezometer results capture short-term bank saturation changes to flow conditions, and how the power station operations combined with natural inflows affect bank saturation. The photo monitoring results have been most useful for understanding how the river is changing at larger spatial and temporal scales, including the processes and time-scale associated with the revegetation of landslips and slumps.

5.7 Conceptual model

The geomorphic response to the flow patterns identified in the conceptual models (see Section 3) are summarised in Table 5.6 .This summary describes the most typical response of banks in the absence of other inflows or influences, such as the presence or absence of vegetation. In general, the influence of the power station operating patterns decreases with distance from the power station, however, during periods of low inflows, and high discharge from the power station, the impact of power station operating patterns can be considerable throughout the length of the river.

Table 5.6: Summary of bank response to flow-patterns in the Gordon River.

Flow pattern	Geomorphic response
Low flow dominant- minimum flow with occasional peaks to 1-2 turbine level	Deposition on bank toes due to deposition of fluvially derived sediment. Some flattening (deposition) of bank toes may be associated with deposition of sand transported by rainfall or bank draining during periods of the environmental flow discharge.
Daily hydro-peaking to 1 or 2 turbines	Scour of the 1-2 turbine bank level combined with deposition in the <1 turbine level as described above
Daily hydro-peaking to 3 turbine level – rapid, regular alternation between minimum flow and 3 turbine discharge – with and without mitigation	**With mitigation -** Under conditions of low bank saturation, scour of the 1-2 bank level and deposition in the <1 turbine level; **Without mitigation -** Under conditions of high bank saturation, seepage erosion in the 2-3 turbine bank level combined with deposition in the 1-2 and <1 turbine bank level.
Daily hydro-peaking in 2-3 turbine level - rapid, regular alternation between flow at 2 and 3 turbine flow levels	Generally coincides with periods of high bank saturation, and induces seepage erosion in the 2-3 bank level accompanied by deposition in the 1-2 turbine bank level. Seepage deposition tends to exceed scour under this flow pattern.
Base load utilising 3 turbines	Scour in all turbine levels associated with prolonged periods of high flow leading to high shear stress. Following drawdown, seepage erosion in the 2-3 turbine bank level and deposition in 1-2 and <1 turbine bank level is prevalent in zones 1 & 2, with scour dominant process in zones 3-5.

5.8 Conclusions

Changes at erosion pins were governed primarily by the magnitude, duration and draw down frequency of flows in the river, which translate into scour and seepage erosion on the banks.

Bank toes were predominantly affected by scour erosion, at rates that correlate with sediment transport modelling results. The 1 to 2 and 2 to 3 turbine bank levels were affected by a combination of scour and seepage processes.

The results from the combined six-years of post-Basslink monitoring reinforce the findings of the Basslink Baseline Report (Hydro Tasmania 2005a) and the Basslink Review Report, 2006-09 (Hydro Tasmania 2010a), with post-Basslink monitoring results showing similar relationships between the flow regime and erosional processes in the middle Gordon River as documented during the IIAS and pre-Basslink period. Although the processes have not changed pre- or post-Basslink, the flow regime has been substantially different post-Basslink leading to a change in the results of the geomorphic monitoring program.

The results are consistent with the premise that the alluvial sections of the bank are widening in response to sediment deprivation, the removal of overlying vegetation, and increased median flows. Because the river channel is largely bedrock controlled, there has been no change to the planform of the river. Over the time scale of Basslink monitoring, channel cross-sections have remained constant, suggesting that channel infilling or deepening is not actively occurring within the river under the present flow regime. Changes to the alluvial ‘pockets’ in the river include the loss of vegetation, and erosion of material leading to a reduction in bank slope which extends to the limit of power station controlled high water level.

Geomorphic photo monitoring results over the six years of post-Basslink monitoring showed no change at the larger bank or river reach scale which can be attributed to the implementation of Basslink.

5.9 Recommendations

Ongoing monitoring associated with implementation of the revised ramp-rule will obtain additional observations, erosion pin measurements and photo monitoring for a period of two years from 2012 to 2014. This monitoring will involve the measurement of erosion pins and photo monitoring in all zones. The monitoring is to be undertaken once per year in zones 1 and 5, and twice per year in zones 2, 3 and 4. In addition, the piezometer installation in zone 2 will continue to be maintained until 2014 and utilised to interpret the results of the monitoring program.

This will continue to extend the understanding of geomorphic processes in the Gordon, especially if discharge from the Gordon Power Station substantially increases in the near future.

It is recommended to review geomorphic monitoring in the Gordon River at the end of the interim monitoring period.

6. Karst geomorphology

6.1 Summary

The aim of the post-Basslink karst monitoring program is to identify changes to the sediment transfer processes in the karst areas downstream of the Gordon PowerStation, with reference to the pre-Basslink monitoring period, and to relate those changes to any changes in the hydrological regime in the Gordon River, specifically changes in power station operations. Three main indicator variables and associated informal triggers have been monitored: sediment changes at erosion pins, inundation of the dry sediment bank in Bill Neilson Cave, and structural change in the dolines.

Less sediment changes have occurred at the upper and lower parts of the wet sediment banks in Bill Neilson Cave than pre-Basslink as there has been less deposition at the upper parts and less erosion at the lower parts. There has been less erosion in the lower parts of GA-X1 Cave and a greater accumulation of sediment in Kayak Kavern. The most significant power station operation changes contributing to these sediment changes are:

- the reduction in high power station discharges, especially in summer;
- the decrease in frequency of mid range discharges between 50 and 150 m^3s^{-1}; and
- the increase in daily hydro-peaking between 0 and 3 turbines, and less operation in mid-range discharge.

Despite these changes, there were no exceedances of the informal triggers for sediment change:

- The dry sediment bank in Bill Neilson Cave was inundated to a higher level and for longer during the post-Basslink period than in previous years.
- There were no significant structural changes recorded in the dolines throughout the program and it has been concluded that Channel Cam is not a karst feature.

The post-Basslink Monitoring Program is considered to have met its objectives and worked well within its limitations. The informal triggers were found to be a useful tool for highlighting changes to existing trends, which were then assessed for their relationships with hydrological change due to power station operations.

All the evidence suggests that the sediments in the caves are more protected and buffered from the effects of the power station operations than the sediments in the river channel, and that the caves are relatively robust. The recorded sediment changes are also small, of the order of a few mm, and irrespective of the hydrological driver of change, whether Basslink related or not, they are considered to be of little significance from an ecological, geomorphological or conservation perspective. This is supported by comparisons of the 1976 and 2000 cave surveys in Bill Neilson Cave and Kayak Kavern which show that there has been considerably more accumulation of sediment in the caves as a result of the commissioning of the power station, than there has been change between the pre- and post-Basslink operating scenarios (Deakin et al. 2001).

It is considered that Basslink has not had a significant impact on the Gordon River karst. The notable sediment changes that have been detected are still within the ranges of change experienced during the pre-Basslink monitoring period, and are negligible in comparison with the changes that have taken place since the power station was originally commissioned. At all sites, but in GA-X1 in particular which has the highest conservation value, there are more impacts being caused by the visits to carry out the monitoring than would otherwise take place.

It is therefore recommended that the karst monitoring program be ceased and that all monitoring equipment be removed in a sensitive manner in consultation with a local karst specialist.

6.2 Introduction

The post-Basslink Karst monitoring program incorporates analyses and interpretation of data collected over a 6-year period during the spring and autumn of each monitoring year, typically in October and March respectively (Table 6.1).

Table 6.1: Post-Basslink Karst monitoring program sampling dates.

		Spring	Autumn
Year 1	2006-07	17 Oct 2006	17 Mar 2007
Year 2	2007-08	20 Oct 2007	1 Mar 2008
Year 3	2008-09	18 Oct 2008	21 Mar 2009
Year 4	2009-10	17 Oct 2009	14 Mar 2010
Year 5	2010-11	20 Oct 2010	27 Feb 2011
Year 6	2011-12	5 Nov 2011	25 Feb 2012

The program was based on the initial karst investigations carried out as part of the Basslink Integrated Impact Assessment Statement (IIAS), the findings and recommendations of the Basslink Baseline Report (BBR), (Hydro Tasmania 2005a), and a review of the karst program's informal triggers as proposed in the BBR, following collection of the October 2005 dataset (Hydro Tasmania 2006). A brief summary of the locations of the karst monitoring sites and the purpose of the monitoring being carried out is provided in the following sections. Further details can be found in Hydro Tasmania 2001 and 2005a.

6.2.1 Location of study sites

The Gordon–Albert Karst area and the Nicholl's Range Karst area (Figure 6.1) were targeted in the karst monitoring program as the area's most likely to be affected by the Basslink regime. Within the Gordon-Albert Karst area, which is located within Zone 2, the program is focused on the newly discovered cave GA-X1, two dolines[2] (Sites 3 and 4) and a backwater channel, Channel Cam. Within the Nicholl's Range Karst Area in Zone 4, the primary monitoring sites are Bill Neilson Cave, which is the biggest known cave to date in this part of the Gordon River catchment, and the nearby smaller cave, Kayak Kavern. With the exception of the dolines, all karst features are regularly inundated by the Gordon River.

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[2] Dolines are karst features which present as depressions or collapses of the land surface. They are of variable size and can reach up to 10s of metres in diameter. Dolines are formed when a solution cavity in the underlying rock becomes enlarged enough for overlying sediment to collapse into it.

6.3 Program objectives and monitoring strategies

The BBR identified that the key karst ecosystem component likely to be affected by Basslink was the sediment transfer processes in the caves which are driven by the hydrological regime in the Gordon River. Changes to the regime could affect the trends and rates of sediment transfer that could in turn impact on the habitats of the species present and their food sources, and change the geomorphological development of the caves. In the dolines, it was considered that there was potential for increased transfer of sediment from underneath the base of the dolines, due to the increased number of wetting and draining events associated with the anticipated increase in the number of on-off sequences in power station operations. This could lead to further collapse of the dolines and destabilisation of the surrounding vegetation. While doline collapse is a normal karst process, it was considered that there was potential for the operations of the river to increase the rate at which the process occurs. Channel Cam was included in the original investigations in an effort to determine whether there were potential connections to the seepage erosion features in the banks of the adjacent Gordon River through the underlying karst. The channels and seepage erosion features are common in Zone 2 and the hypothesis was that if there was a karst connection, the sediment transfer processes between the channels and the river banks would likely be relatively rapid.

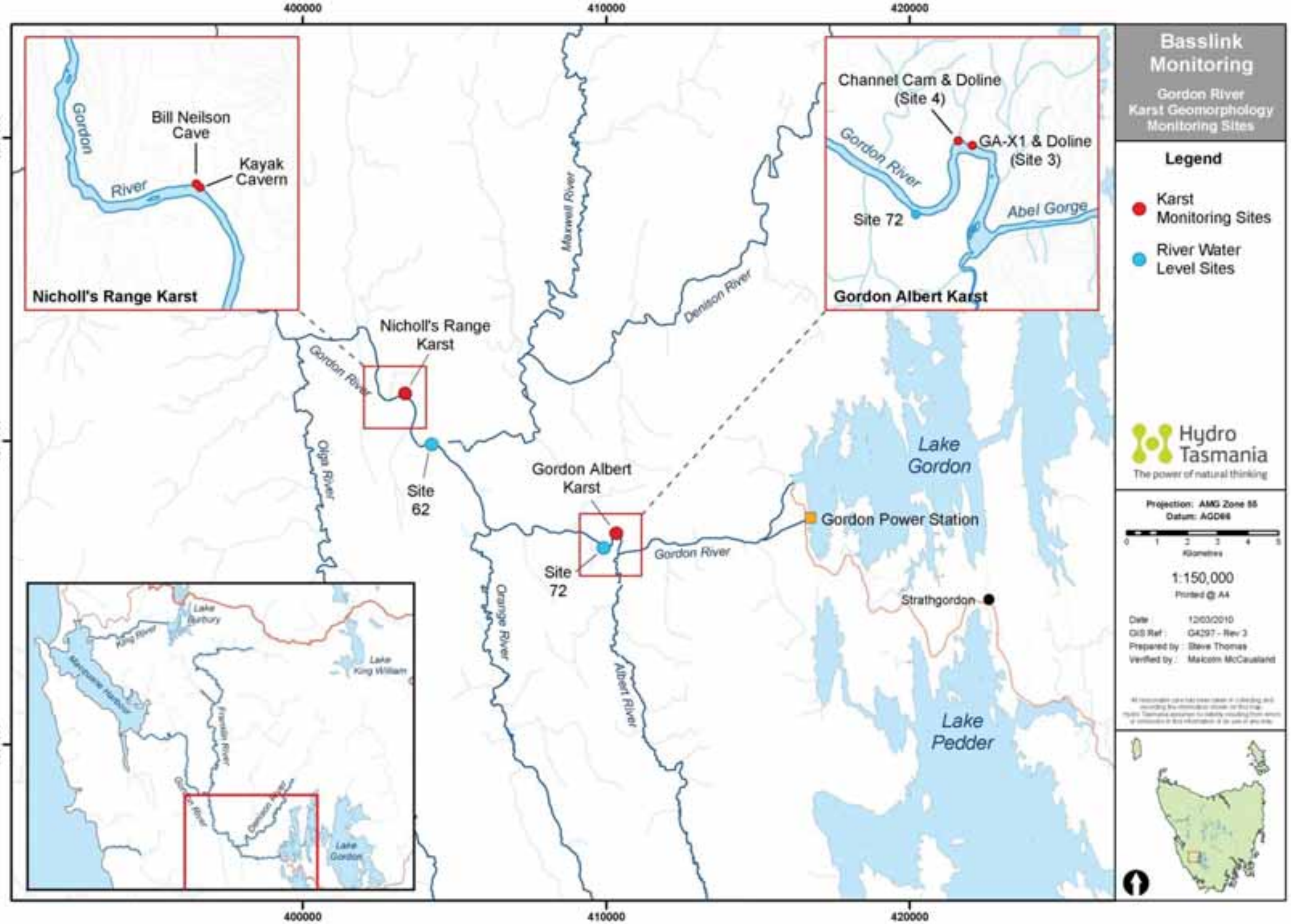

Figure 6.1: Location of the karst monitoring sites.

The aim of the post-Basslink karst monitoring program was therefore to identify any post-Basslink changes to the sediment transfer processes in the karst areas, and to relate those changes to post-Basslink changes in the hydrological regime in the Gordon River, specifically to changes in power station operations.

The objectives of the post-Basslink karst monitoring program were threefold:

- Monitor sediment changes within the three major caves (GA-X1, Bill Neilson Cave and Kayak Kavern) and in Channel Cam, and monitor structural changes driven by sediment transfer processes in the dolines in the Gordon-Albert Karst area.
- Relate the sediment and structural changes, if any, to changes in the hydrological regime in the Gordon River.
- Identify which hydrological changes, and associated sediment changes, can be attributed to the operations of the power station, and if possible to Basslink.

Three sediment monitoring sites were identified in Bill Neilson Cave: two wet sediment banks near the cave entrance and a dry sediment bank located 175 m into the cave. Erosion pins have been installed in each of the sediment banks at different heights corresponding to inundation associated with different levels of power station operations. The water inundation regime in the cave is measured by three temporary water level recorders and a nearby permanent water level recorder in the Gordon River (Gordon below Denison; Site 72). Erosion pins have also been installed in the adjacent Kayak Kavern. In GA-X1, there are erosion pins and a dedicated cave water level recorder which is supported by data from the nearby permanent hydrometric stations at G5 and G5a (Site 72). The structure and integrity of the two dolines at Sites 3 and 4 are being monitored by surveying the distances between the tops of a number of erosion pins inserted in a transect from the bases to the tops of the features. Data collected are complimented by photo monitoring at all sites as well as biannual observations by an experienced karst hydrogeologist.

Karst environments are often pristine and are highly sensitive to disturbances. GA-X1 Cave for instance, was newly discovered during the course of the initial IIAS investigations and is relatively unique as caves in the dolomite rocks in this area had not previously been recorded. Care was taken during the course of the monitoring program therefore, to balance the need to monitor the caves with conservation objectives. The team were cognisant that in environments such as these, the physical processes of monitoring the sites can in themselves cause more change than would otherwise have taken place had the site been left alone. The number of erosion pins used in the program, and the number of people accessing the caves, was therefore kept to a minimum.

6.3.1 Indicator variables and informal trigger values

The primary indicator variables for assessing potential Basslink effects, as recommended in the BBR (Hydro Tasmania 2005a) and in the subsequent Basslink Review Report 2006-09 (Hydro Tasmania 2010a), can be divided into three groups:

1. sediment changes at erosion pins;
2. inundation of the dry sediment bank in Bill Neilson Cave; and
3. structural change in the dolines.

Within each group, there are a number of different indicators which are used to assess whether there is change occurring that is outside the range of change observed during the pre-Basslink period. A series of informal trigger values have been determined for each of the indicator variables which are used to detect any change. Should change be detected, the next step is then to determine whether the cause of the change is power station related or due to one of the other potential drivers of change in the system.

Based on the predicted post-Basslink power station operating regime developed using the TEMSIM model, the main threats to the karst environment were anticipated to be:

1. A higher probability of high power station discharges occurring at the same time as high rainfall and high tributary flow. This would mean higher levels of inundation in the caves and possible new impacts to the dry sediment bank in Bill Neilson Cave.
2. A higher frequency of short duration hydro-peaking from 0 to 3 turbines, separated by periods with no discharge. This would mean more dewatering of the sediment banks creating possible instability, slumping and collapse. There could also be potential for increased mobilisation of the sediments in the base of dolines, at or below, the high water level mark which could lead to further collapse and destabilisation of the area just behind the river banks.
3. A slight increase in the duration of peak discharge events. This could lead to additional sediment deposition at higher levels in the caves.

The post-Basslink karst monitoring program and informal trigger values were developed in the context of these predictions and were centred around assessing the extent of the increased rates of change that were anticipated to occur. This was to ensure consistency with the aim of the mitigation measures of ‘no net Basslink environmental impact’, or in other words, ‘impact that remained within the present boundaries, recognising inherent variability in the environmental indicators as well as long-term’ (Hydro Tasmania 2007).

The BBR identified two important steps in utilising the karst informal trigger values. Firstly the indicator variables and their associated informal trigger values were to be used to highlight incidences in the karst regime where potentially significant change was occurring. Change was considered to be significant if it was greater than the range of change experienced during the pre-Basslink period. Minimum acceptable rates of change thresholds were not determined for the karst sites because the rates of normal change are already low anyway (see next section). Secondly, that change was then to be assessed in the context of the hydrology of the system to determine which of the potential six drivers of hydrological and/or sediment change was responsible for effecting that change. Those drivers included the following:

- natural changes that always occur in dynamic hydrologic environments;
- climate change;
- changes due to the sediment transfer processes in the river having not yet reached equilibrium since the dam was constructed and power station operations commenced;
- changes that occur in the caves due to isolated events in the power station operating regime in the weeks immediately prior to the sampling trips which have an influence on the data;
- changes in power station operations for reasons other than for Basslink (e.g. maintenance, drought); and
- Basslink change.

A third step was therefore recommended in the Basslink Review Report 2006-09 (Hydro Tasmania 2010a) to review the relevant power station operations and determine which if any, could be attributed to Basslink. It is considered that the most probable Basslink-specific changes of relevance to the Karst Monitoring Program have been the changes to the hydro-peaking regimes and the reduction in the high summer baseload discharges.

Further discussion on the indicator variables and the informal trigger values can be found in the BBR, the Basslink Review Report 2006-09 (Hydro Tasmania 2010a), and in each of the post-Basslink Annual Reports (Hydro Tasmania 2007, 2008, 2009, 2010b, 2011 and 2012).

6.4 Trends in the consolidated data

In general terms, the flows in the Gordon River have been much lower during the post-Basslink Monitoring Program than during the pre-Basslink period. This is primarily due to significantly reduced discharge through the power station, especially during the summer, although there has also been a slight reduction in rainfall over the catchment of approximately 10 %, based on the Strathgordon records. These lower flows have resulted in less inundation of the karst features than during the pre-Basslink years, and there has consequently been a general reduction in sediment changes across the majority of sites.

The trends in the monitoring data for each site are described in detail for each monitoring year in the annual reports where each season’s data is also discussed in the context of all the data collected over the course of the Basslink Monitoring Program. The findings for each of the sites in this report will not be reported on. Rather, this report focuses on describing the changes in trends between the pre- and post-Basslink operating periods. The trends are presented below under each of the three indicator variable groups. A brief section on the key elements of the hydrology of the system of relevance to the karst monitoring is presented first to provide some context. A more detailed discussion on the hydrology can be found in Section 2.

6.4.1 Key elements of the hydrology of the system

The karst regime is heavily dependent on the power station discharge and the hydrology of the Gordon River and its tributaries. While there have been various changes to the hydrological regime since the monitoring program began (see Section 2 − Hydrology and water management chapter for details), from a karst monitoring perspective, the most significant are the following post-Basslink changes to the power station operations:

- Decrease in power station discharge;
- Change in frequency in mid-range flows;
- Reduction in three-turbine base load flows in summer;
- Increased hydro-peaking; and
- Implementation of the minimum environmental flow.

6.4.2 Sediment changes at erosion pins

In the karst monitoring program, sediment change assessments are made based on individual erosion pins at each site, rather than by comparing multiple pins from different sites in different zones as in the geomorphology assessment. This is because the karst features are located away from the river channel and are being influenced by a unique range of hydrological impacts specific to that site (e.g. rainfall, power station, tributaries, cave stream etc). Direct comparisons between pins at different sites are not possible.

Considering the pins individually however, means that the dataset can be heavily influenced by single extreme events that may not necessarily be representative of general sediment change trends. For example, the pins in the caves can be moved by pieces of floating debris as the waters in the caves rise and fall which can give the impression that there has been significantly more or less erosion than has actually occurred. A grouping in the analyses is therefore required to increase the likelihood of the informal trigger values identifying actual changes rather than extreme events.

Three indicator variables ‘maximum range of change’, ‘average rate of change’ and ‘the long term trend since the pins were installed’ are considered as subcomponents of the one indicator variable group, ‘sediment change at erosion pins’. An exceedance of an informal trigger value for one of these subcomponents is not considered significant unless (a) it is accompanied by exceedances for the other subcomponents of the group, and/or (b) it is consistently repeated over subsequent monitoring seasons. Changes between sampling periods, and since sampling began, are both considered.

6.4.2.1 Bill Neilson Cave

The erosion pins in the sediment banks in Bill Neilson Cave are positioned at different heights and are inundated under a range of flow conditions. When the Denison River is low, the lowest pins in the two wet sediment banks near the cave entrance (Pins 20 and 25) are not inundated until the power station is operating with at least 2-turbines. The mid level of pins (Pins 21 and 26) require 3-turbine operations before they are inundated. The highest pin in the second wet sediment bank (Pin 27) needs maximum power station discharge, while the equivalent pin in the first wet sediment bank (Pin 22) remains dry unless there is also some tributary contribution to the flow. The two pins in the dry sediment bank (Pins 23 and 24) are only inundated when the tributary flows are high. All pins can be inundated when the power station is off if there are high flows in the Denison River and other tributaries.

When the Gordon River is high, a backwater environment is created in the mouth of the cave and sediment being transported by the river and the cave stream is deposited on the banks. The amount of sediment deposited is related to power station activity and rainfall in the catchment: sediment is prevalent with the higher flows. Erosion in the cave occurs when the water levels are reduced, particularly when there is rapid dewatering due to hydro-peaking over a large discharge range in otherwise dry conditions. The cave stream also influences the sediments at the lower levels of the banks: when the Gordon levels are low and there is high rainfall in the catchment, the high velocities in the cave stream can cause erosion of the banks.

Pre-Basslink, the lower levels of the first wet sediment bank showed a relatively strong seasonal trend of winter erosion and summer deposition, with a net loss of 12 mm of sediment (Figure 6.2a). This summer/winter pattern has substantially weakened post-Basslink, and there was no net sediment change. At the lower levels of the second wet sediment bank (Figure 6.2b), there was a steady reduction in sediment with a net loss of 10 mm, and this trend continued until October 2008, after which the trend switched to deposition and a much reduced net loss of 3 mm. These changes are due to a combination of factors: firstly, the lack of inundation at the three turbine level in summer which previously encouraged summer deposition; and secondly, the significant reduction in two-turbine, mid-range flows, particularly from October 2008 onwards, that had previously facilitated erosion. The introduction of the minimum environmental flow may also have increased the base flow level in the river, decreased the gradient of the cave stream in the lower reaches of the cave, and therefore reduced the stream velocities and its erosive power. Finally, the overall reduction in rainfall, and therefore volume of flow in the cave stream is also a factor but is likely to be less significant.

During the pre-Basslink period, the dominant trend at the mid-levels of the wet sediment banks, that is representative of three-turbine flow, was a small net loss in sediment over time which occurred when high power station discharges were being reduced to lower flows. Higher losses were evident in the first sediment bank in the large entrance chamber as it is closer to the river and is less influenced by the dynamics in the constricted cave channel. During the post-Basslink period, this trend continued but was more muted, particularly in the first wet sediment bank over the last four years of the program, due to the significant reduction in the percentage of time that the station has operated at the three-turbine level.

At the upper levels of the sediment banks, Pin 27 typically experienced an increase in sediment in pre-Basslink times as power station discharges were frequently above 250 m^3s^{-1} and there was sufficient water depth above the pin to allow for deposition of the fine sediment. In the later years of the pre-Basslink period, and continuing into the post-Basslink regime, discharges above 250 m^3s^{-1} were rare and hence the trends at the pin changed to follow those of normal three-turbine operations at the mid-level pins. The trend at Pin 22 at the highest level in the first wet sediment bank continued unchanged as the pin is somewhat independent of the power station operations.

Further back into the cave, inundation of the dry sediment bank happens infrequently — typically <2 % of the time throughout the sampling program. Contrary to the initial hypothesis, it has been found that despite the pins being inundated at times by these high flow events, there has been little change to the sediment throughout the program (Figure 6.2c). Apart from an apparent large sediment increase at Pin 24 in October 2002, which was attributed to the pin being knocked by a floating branch at high flows, the biggest change of –2 to –3 mm took place in the 2011–12 summer period when the pins were not inundated at all. This suggests that sediment transfer at the dry sediment bank can also be controlled by other processes not related to the power station, such as a change in personnel reading the pins or drips from the roof.

While there were some changes compared to the pre-Basslink ranges of change at some of the pins in the cave, especially at the lower levels in the wet sediment bank, there were no changes across all of the change criteria at any of the pins, and therefore there were no exceedances of the informal triggers.

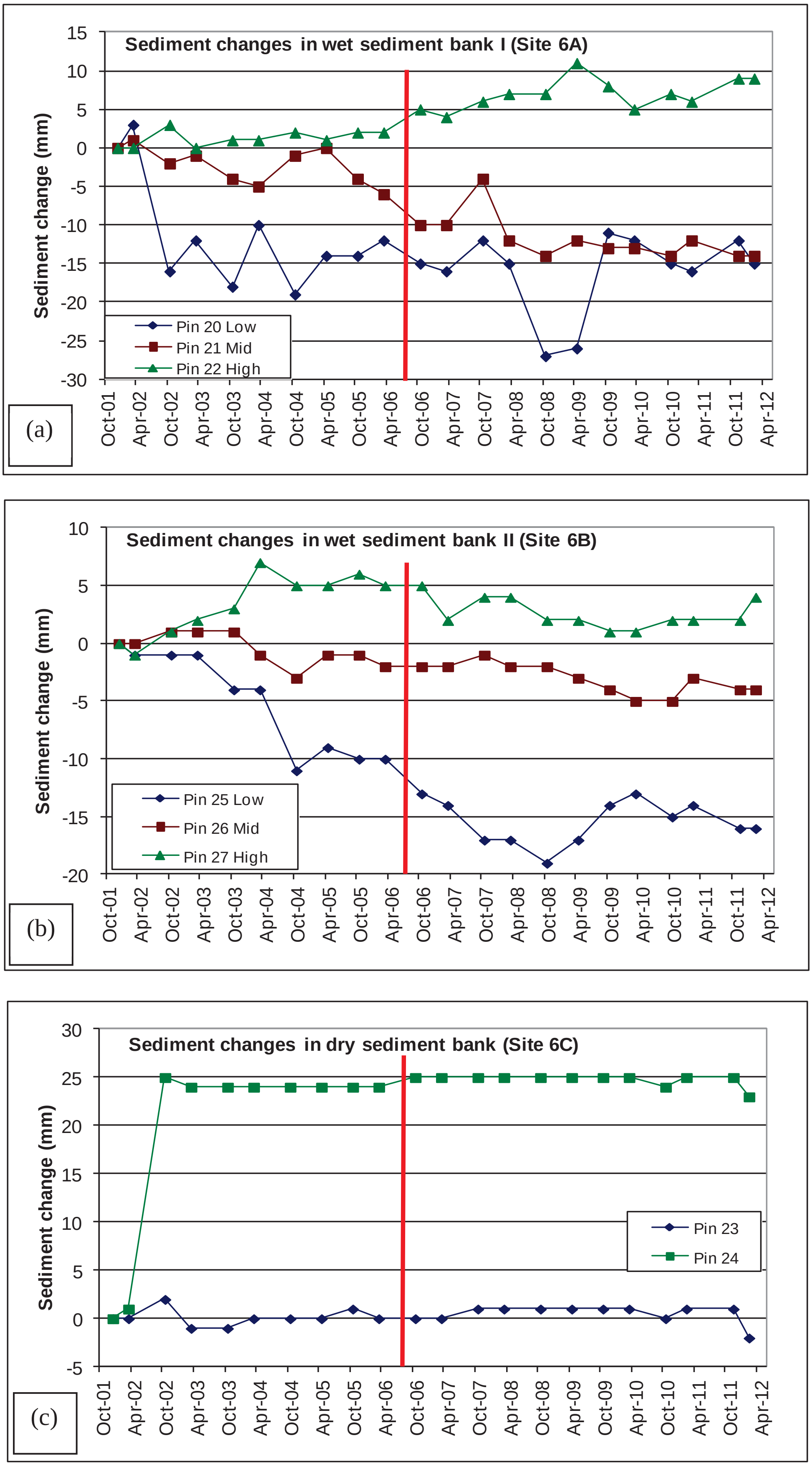

Figure 6.2: Sediment changes in Bill Neilson Cave (a–c). The red line separates pre- and post-Basslink monitoring.

6.4.2.2 Kayak Kavern

The sediment bank in Kayak Kavern has an active slope to the front which plateaus out on top to a primarily horizontal surface that fills the base of the cave. There are four erosion pins located on the active slope (Pins 17, 29, 30 and 33) which, in the absence of flow from the Denison River, are inundated when the power station is operating in the mid flow range between 100 and 140 m^3s^{-1}. Pin 19 is located in an area subjected to eddy currents from the river when the station is at the upper end of this range, while Pin 18 on top of the sediment bank is inundated when there are three turbines operating. As is the case in Bill Neilson Cave, all pins can also be inundated by the tributary flow when the power station is off.

The erosion pin data highlight that the scale of sediment change in Kayak Kavern was much larger than in the other caves (Figure 6.3a). For example the sediment at Pin 33 on the active slope has increased by 188 mm since the pin was emplaced in April 2004, and seasonal changes of 40 to 50 mm at individual pins were not uncommon. This is because the inundation regime in Kayak Kavern is akin to that of a large eddy in the river channel, rather than one of discrete filling and emptying through a restricted cavity as occurs in the other caves. Different erosion and deposition patterns also occur on different parts of the sediment bank due to the localised effects of the swirling Gordon River waters in the eddy and in the cave. The changes at Pin 18 on top of the sediment mound are thought to be the most representative of general sediment transport conditions in the cave.

Sediment is typically deposited in Kayak Kavern during high flow conditions. Sediment is mobilised in the Gordon River catchment and tributaries with the high flow velocities and deposited in the slow moving backwaters within the cave. Single large rain or power station events can have a significant effect. Removal of sediment then occurs over the longer term with the fluctuations in Gordon River levels due to power station operations. The fluctuations in the two to three turbine flow range (>110 m^3s^{-1}) appear to be having the most effect on the sediment in the cave.

Pre-Basslink, erosion and deposition occurred in the cave at various times but there was a general net balancing of sediment change with most pin levels being within ±30 mm of the level when they were emplaced (Figure 6.3a). The exceptions to this were Pins 16, 17 and 19, all of which are (or were, as Pin 16 was eroded out) located at the extremities of the active slope and are thought to be heavily influenced by the circulating eddy currents. Since Basslink was commissioned, there has been significant net deposition occurring at the majority of the pins. The rate of sediment accumulation has also increased in the latter half of the post-Basslink monitoring period at three of the six pins, including the most representative pin, Pin 18 on the top flat. It is probable that the sediment increases are due to:

(a) the significant reduction in the duration of mid-range flows in recent years; and

(b) the reduction in hydro-peaking between the two and three turbine levels; which together have reduced erosion in the cave and tipped the balance in favour of deposition.

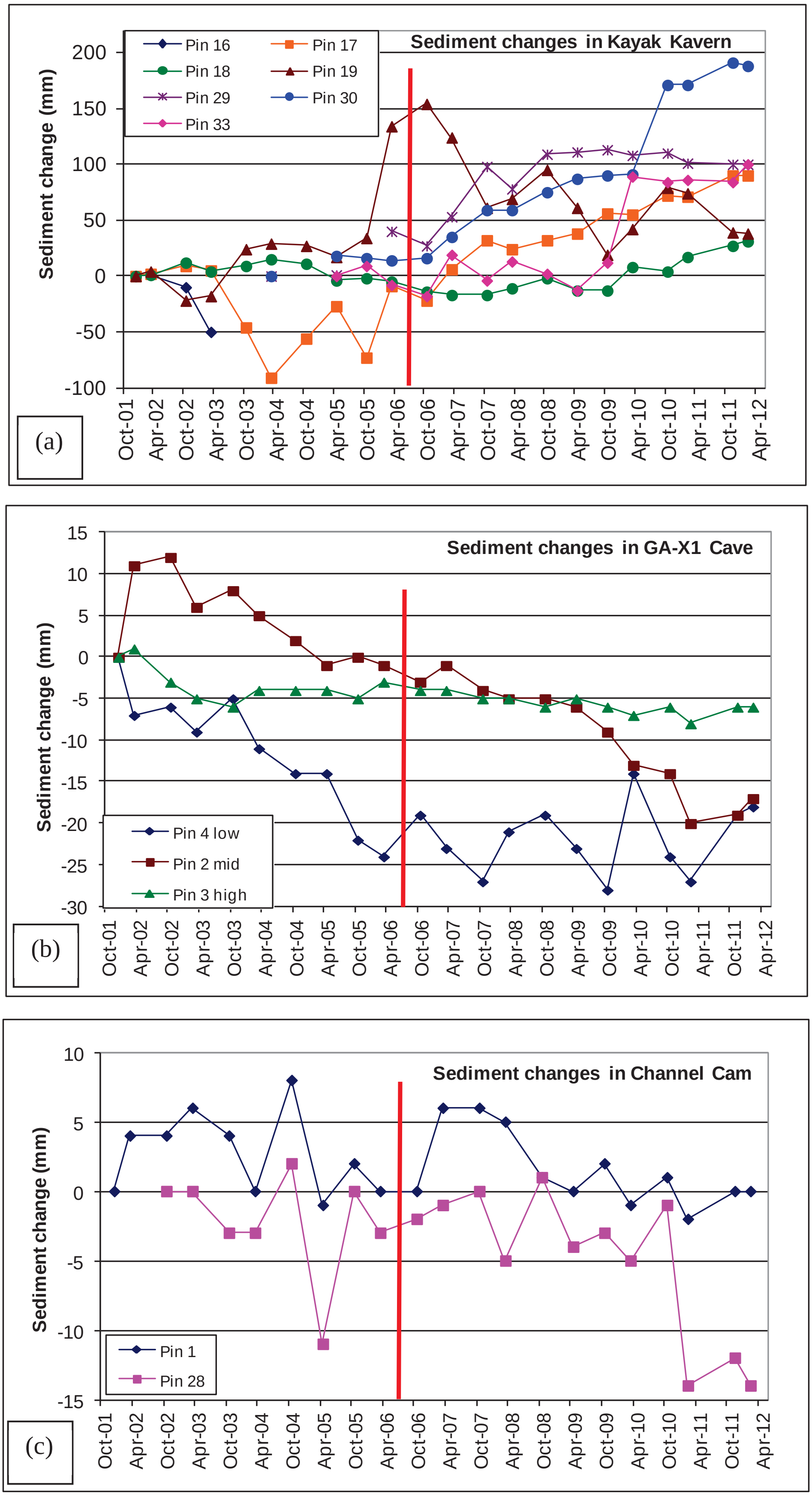

Figure 6.3: Sediment changes in Kayak Kavern, GA-X1 and Channel Cam (a–c). The red line separates pre- and post-Basslink monitoring.

6.4.2.3 GA-X1 Cave

There are three erosion pins in GA-X1 cave and a water level recorder which are being used to measure sediment transfer in the cave under different flow conditions. Pin 4, at the lowest measured level, is inundated under one turbine operations when the power station is discharging at >50 m^3s^{-1}. The pin is located just above, but as close as possible to the sump of the cave which was surveyed during the initial investigations to be at, or about, the level of the bed of the Gordon River. The bottom of the cave is therefore influenced by flows at all levels. Pin 2 is located at the mid-level in the cave and is inundated when the station is operating at the two-turbine discharge level. The water level recorder is also predominantly measuring flows within this range. Pin 3 is higher up in the cave and is only affected when the power station is operating at full gate operations. It is located beneath a second smaller entrance hole to the cave and may also be be influenced by a direct influx of surface sediment being delivered into the cave by rain.

The power station discharge is the dominant hydrological control in GA-X1 as the cave is located in Zone 2 upstream of the major tributaries. There is just a brief lag time between changes in water levels in the river and in the cave which suggests that the hydraulic connection between them is relatively good, potentially a rock channel loosely filled with sediment. Erosion in the cave typically takes place when the sediments have been inundated for a period and are water logged, and the river water level then sharply declines with a reduction in discharge from the power station. The drawdown increases the groundwater gradient and dewaters the sediments causing them to move downwards towards the sump of the cave. Deposition takes place with an influx of sediment from nearer the surface, either with rainfall or from the collapse of the wall of the doline adjacent to the cave. There is also likely to be some recycling of sediment within the cave and resident crayfish have been observed which may be contributing with their burrowing activity. The closer the erosion pin is to the base of the cave, and therefore the greater the influence from the Gordon River, the larger the changes in sediment.

Pre-Basslink, the trend in the cave was for a gradual net erosion at all levels with larger changes at Pin 4 at the base of the cave than at Pin 3 which is above the level of impact of the majority of power station operations (Figure 6.3b). Following the introduction of Basslink, the sediment activity at Pin 3 has been minimal due to the general reduction in power station discharge. The sediment processes at Pin 2, at the two-turbine flow level, were similar until the latter half of the post-monitoring program when the rate of erosion increased. This is likely due to the reduction in mid-range flows and the increases in large range hydro-peaking from three turbines to low flows during this period, which means that the groundwater gradients between the cave and the river remain relatively steep for longer. At the lowest level at Pin 4, there was no longer net erosion of sediments and the sediment transfer processes appeared to be in balance. This is likely because there has been a decrease in hydro-peaking between the 0 to 1 turbine levels which typically removes the sediment from the cave. The base water level in the cave has also increased with the minimum environmental flow in the river, which has resulted in slightly decreased gradients at the cave sump and therefore, potentially a slight decrease in sediment removal from the cave.

While there has not technically been an exceedance of the informal trigger values in GA-X1 Cave, over the course of the post-Basslink Monitoring Program there has been a change to the sediment transfer processes at Pin 4, at the lowest level in the cave. There have been new maximum seasonal and long term changes, a new average seasonal change and a trend change from net erosion to a net balancing, or marginal increase, of sediment within the cave.

6.4.2.4 Channel Cam

Surveys to the nearby gauging station at Site 72 and analysis of the water level data, show that Channel Cam is inundated by Gordon River water when the power station is operating with three turbines, at a flow greater than 230 m^3s^{-1}. The channel flows out into a small tributary and then into the river and so back flooding from the tributary will also have an impact when there is significant rainfall in the catchment. The depth of water in the channel when inundated is typically less than 0.2 m. Two erosion pins (Pin 1 and Pin 28) are located at, or about, the level that the relatively horizontal channel is first inundated with the back flooding from the Gordon. Pin 28 is closer to the river.

Sediment changes in Channel Cam appear to be most highly correlated with the percentage of time that the channel is inundated and the type of inundation, whether continuous and steady or fluctuating levels. In general, the less the channel is inundated, the greater the deposition. This would suggest that the deposition mechanism is transport of sediment from the surrounding area with rainfall. Fluctuating water levels appear to remove the sediment, while continuous and steady inundation either has little effect or causes slight deposition.

Pre-Basslink, there were some large erosion and deposition events in the channel with high power station discharges and high rainfall events, but overall there was no net change at Pin 1 furthest from the river, and a slight net reduction in sediment at Pin 28 (Figure 6.3c). Since Basslink, the trends have remained broadly the same despite Pin 28 currently showing a net loss overall. In the last 3 years of the program, changes at Pin 1 have been relatively minor and both pins are gradually being covered with a layer of thick fine mud and moss, reflecting the general lack of inundation in recent years.

There have been no exceedances of the informal trigger values in Channel Cam, due principally to the lack of inundation with lower power station output.

6.4.3 Inundation of the dry sediment bank

The purpose of monitoring the inundation regime of the dry sediment bank, located 175 m into Bill Neilson Cave, is to determine whether under Basslink there is a higher frequency of high power station discharges coinciding with high natural flows in the catchment, such that the sediment could be inundated and dewatered more often which could lead to destabilisation. The dry sediment bank is monitored in two ways; the duration of inundation caused by backflooding of the Gordon River and the maximum height of inundation in the cave.

6.4.3.1 Duration of inundation

It has been estimated, based on detailed surveys of Bill Neilson Cave and the Gordon River channel between the cave and the Gordon below Denison gauging station at Site 61, that the pins in the dry sediment bank were inundated when the Gordon River level was above 4.4 m on the Gordon below Denison gauge. The percentage of time the pins were inundated was assessed on a seasonal basis and over the course of the pre- and post-Basslink Monitoring Program.

Prior to the introduction of Basslink, the greatest extent of inundation at the dry sediment bank occurred in winter 2002 (2.9 %) when heavy rainfall coincided with two to three turbine flows at the power station (Table 6.3). This resulted in apparent increases in sediment at both the pins, although it is considered likely that the largest increase on record at Pin 24 (+24 mm) was due to the displacement of the pin by floating debris. Overall, the pins were inundated just 1.2 % of the time and this was considered to be the informal trigger value for this indicator variable.

Table 6.2: Percentage of the time the dry sediment bank was inundated.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Winters	1.8	2.3	2.9	1.4	1.1	0.5	0.7	3.1	0.0	1.6	0.0	1.2
Summers*	1.2	0.2	0.0	0.2	0.1	0.1	0.6	0.0	0.8	0.0	0.0	0.0

Pre-Basslink	1.2	(1 Mar 2000 to 28 Feb 2006)
Post-Basslink	0.8	(1 Mar 2006 to 29 Feb 2012)

*For the purposes of this analysis, summer refers to the period from 1 November in the year indicated to the end of February the following year. Note that these statistics are based on 2 hourly average flow data and differ slightly from the figures presented in the annual reports which are based on 15 minute data. The outcome is nevertheless the same with one exceedance of the informal trigger value in winter 2007.

During the post-Basslink period, the pins were inundated for slightly less time overall (0.8 %). The seasonal informal trigger value was exceeded just once, in the winter of 2007. However, when the nature of the high winter flow events were assessed in more detail, it became apparent that almost half of the total duration of inundation occurred when there was less than 150 m^3s^{-1} discharge from the power station coincident with a high daily rainfall of more than 58 mm/day. This shows that the inundation during the 2007 winter was heavily influenced by high rainfall events and was not dictated by power station operations. Review of the erosion pin data for the same period shows that there was just 0–1 mm of sediment change simultaneously recorded at the two erosions pins, which is smaller than the margins of error associated with reading the pins. This exceedance of the informal trigger is therefore not considered to be significant.

6.4.3.2 Maximum inundation

During the pre-Basslink monitoring period, the peak flow at the Gordon below Denison gauge was 6.1 m which occurred during the wet 2002 winter period when the power station was operating at three turbines. During the post-Basslink period, there were four peak flow events that surpassed that maximum level: two in the winter of 2007 when the river reached 6.2 m (July) and 7.3 m (August), and one each during the 2009 winter and the 2011 winter when the maximum levels were 6.4 m and 6.5 m, respectively (Table 6.3). It is therefore considered that there were four exceedances of the informal trigger for maximum inundation.

During the July 2007 and June 2011 events, the power station was operating at 3 turbines and so the station outflows contributed to the high flow in the river. During the August 2007 event however, the power station was operating at less than 10 m^3s^{-1}, so the very high flow in the river, the highest flow on record, was completely independent of power station operations. The power station discharge during the 2009 winter event was 160 m^3s^{-1}.

Despite the four brief periods of higher inundation, the only change recorded at the erosion pins in the dry sediment bank was 0 to +1 mm in 2007 which is within the level of accuracy of the method of analysis. The exceedances of the informal triggers for inundation of the dry sediment bank are therefore not considered to be significant in terms of impacts on the bank due to power station, and ultimately Basslink operations.

Table 6.3: Peak seasonal flow levels (m) at the Gordon below Denison gauging station.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Winters	5.4	5.7	6.1	5.1	5.8	5.4	5.4	7.3	3.5	6.4	4.4	6.5
Summers*	4.9	4.7	3.8	4.7	4.4	4.5	5.1	3.6	5.7	3.3	2.2	3.1

*For the purposes of this analysis, summer refers to the period commencing 1 Nov in the year indicated and ending on 28 or 29 Feb the following year. There were four exceedances of the informal trigger value in winter 2007 (twice), Winter 2009 and winter 2011.

6.4.4 Structural change in the dolines

Structural change in the dolines was monitored using erosion pins as survey markers placed in a transect from the base of the features up to the surface. Each season, the sum of the distances between the erosion pins was compared with the average sum of the distances over the pre-Basslink monitoring period, with an allowance for the level of accuracy of the measuring technique. The average sum of the distances between the pins at Site 3 is 4.25 m and the informal trigger value is therefore 4.25 ± 0.02 m. The average sum of the distances between the pins at Site 4 is 2.95 m and the informal trigger value is 2.95 ± 0.02 m. It was identified in the early years of monitoring that the wildlife were attracted to the fluoro tape used to identify the pins so consideration needs to be given in the results to whether the pins have been interfered with.

During the post-Basslink Monitoring Program, the sums of the distances between the erosion pin markers in the two dolines each year remained well within the ranges of the informal trigger values at each site (Figure 6.4). The data showed that there has been no significant structural change in the dolines since the monitoring program began and there have been no exceedances of the informal triggers.

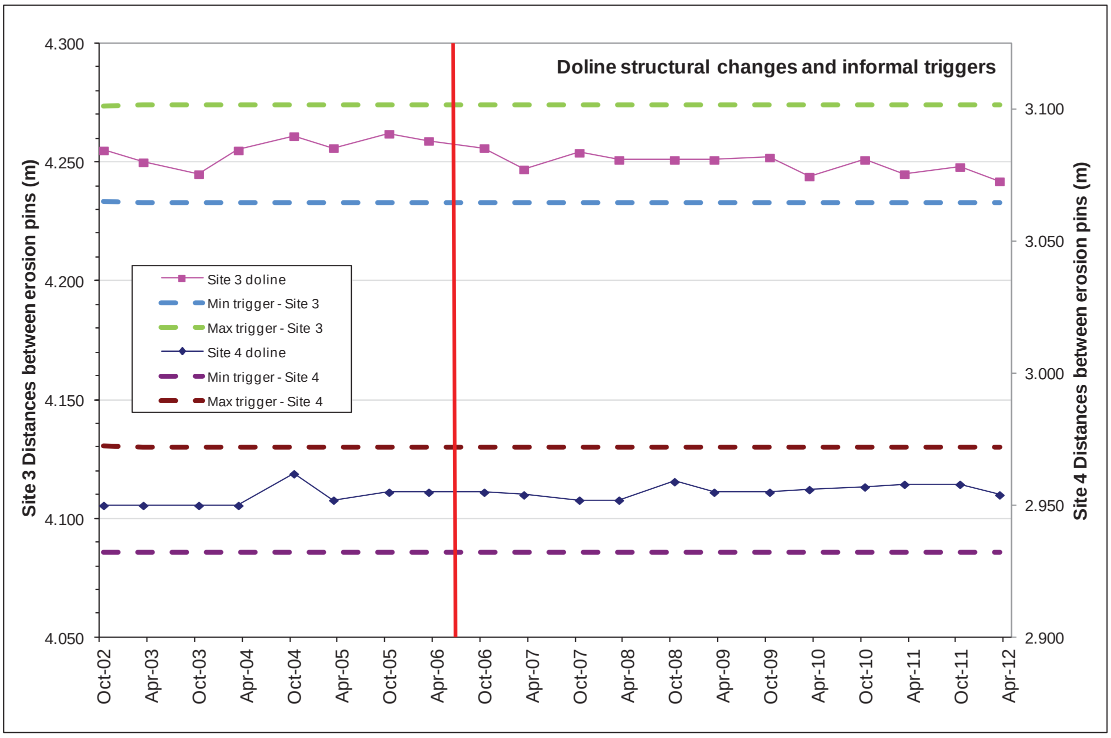

Figure 6.4: Pre- and post-Basslink survey data for the dolines. Results show there has been no significant structural change since the monitoring program began.

6.4.5 Summary of sediment changes in the karst system

The sediment changes in the karst system and associated hydrological changes are summarised in Table 6.4.

Table 6.4: Summary of the key hydrological changes and their impacts on the karst system.

Site	Post-Basslink sediment changes	Hydrological changes	Informal Trigger Exceeded?
Bill Neilson Cave	Net rate of sediment loss reduced to zero, or close to zero, at the mid and lower levels of the wet sediment banks. Change from deposition at the upper level in the second bank to erosion similar to the mid level pins.	Reduction in three turbine power station discharges leading to reduced water levels in the river and cave. Reduction in the percentage of time the power station was operating at mid-range flows, especially from 2008 onwards. Possibly the introduction of the environmental flow raising baseflow levels in the river. Lower rainfall and less cave stream flow.	No. Rainfall and cave stream also a factor
Kayak Kavern	Increase in sediment deposition at most levels in the cave, especially during the latter half of the post-Basslink Monitoring Program.	Reduction in mid-range flows. Reduction in hydro-peaking between the 2 and 3 turbine levels leading to less erosion.	No. Localised impacts in the eddy apparent.
GA-X1	Rate of sediment erosion reduced at lower levels in the cave and a change from net erosion to net balance or slight deposition. At mid-levels, the rate of erosion has increased in the latter half of the post-Basslink program	Reduction in hydro-peaking at the 0 to 1 turbine level. Reduction in mid range flows and increases in 3-0 turbine hydro-peaking causing increased groundwater gradients in the cave sediments. Reduction in high power station discharges. High rainfall in summer 07/08 which brought fresh sediment from the wall of the adjacent doline into the cave.	No. Rainfall and external sediment source also a factor
Channel Cam	Little change overall	Reduction in high power station discharges.	No.

Results also show that rainfall, and consequently the flows in the Bill Neilson cave stream and the Gordon tributaries, has played a role in some of the changes in hydrology and sediment transfer in the caves during the post-Basslink Monitoring Program, as have external factors such as the collapse of the sediment wall in the doline adjacent to GA-X1.

6.5 Evaluation of the monitoring program

The investigative and pre- and post-Basslink phases of the karst monitoring program have provided 11 years of data that have allowed us to develop relationships between sediment transport processes in the caves and dolines, and the hydrology of the Gordon River. There are a limited number of sites in the karst monitoring program which has helped the team to achieve a high degree of familiarity with each and ensured good repeatability in the observations. The understanding is now considered to be reasonably sound within the constraints of the available data.

A detailed discussion of the adequacy of the Karst Monitoring Program has previously been presented in the BBR (Hydro Tasmania 2005a). That report focused on the nature of the design of the program, including the strengths and weaknesses of each of the monitoring elements, and the limitations the program had in terms of what it was trying to achieve. As the post-Basslink karst monitoring program is a continuation of the pre-Basslink program, and has changed little since then, the same issues are therefore pertinent and are not repeated here. The overall conclusion in the BBR was that whilst there were a number of limitations with the monitoring program (such as six-month gaps between sampling trips and reliability of water level monitoring data in the caves), positive steps had been taken to reduce their impacts and optimise the strengths of the techniques being used, and the program was generally considered to be working well within its objectives. This report builds on the BBR and addresses at some of the other issues that have become apparent following six years of post-Basslink monitoring data.

6.5.1 Scale of change

The scale of the sediment changes being measured in the caves on a seasonal basis is small, particularly when the accuracy of the method of measurement (reading the length of the exposed pin with a 300 mm steel ruler) is taken into consideration. Analysis of the average seasonal and net changes during the monitoring program is presented in Table 6.5.

Table 6.5: Average sediment changes (mm) in karst erosion pins throughout the monitoring program.

	Average seasonal change[1] (mm)			**Average net seasonal change[2] (mm)**		
	Pre-Basslink[3]	**Post-Basslink**	**All years**	**Pre-Basslink[3]**	**Post-Basslink**	**All years**
Bill Neilson Cave pins	2.2	1.6	1.8	0	–0.2	–0.1
GA-X1 pins	2.9	2.9	2.9	–1.0	–0.4	–0.7
Bill Neilson and GA-X1 pins	2.4	1.9	2.1	–0.3	1.7	–0.2
Kayak Kavern pins	18.5	15.8	16.7	1.7	5.3	4.1
All cave pins	6.5	6.8	6.7	0.2	1.7	1.1

[1] Seasonal change is the scale of change only and does not differentiate between erosion and deposition

[2] Net seasonal change incorporates erosion and deposition. Negative values represent erosion, positive is deposition

[3] The pre-Basslink changes are slightly different to those reported in Hydro Tasmania (2010a) because in this report, the data collected in 2006, during what was considered to have been a transition period, have been included in the analysis.

The average seasonal change across all pins over the entire monitoring program is 6.7 mm of either erosion or deposition. The vast majority of this has occurred in Kayak Kavern where the average change is 16.7 mm over the course of the whole program. When the Kayak Kavern results are excluded from the analysis, the average seasonal change in Bill Neilson Cave and GA-X1 Cave is just 2.1 mm. The average net change since the program began, across all the pins at all sites over the entire monitoring period is just 1.1 mm, with again the largest net change in Kayak Kavern. The relatively major changes in Kayak Kavern have occurred because the cave is directly connected to the Gordon River and local flow currents from the swirling waters of the river and cave eddies play a significant role. These changes are not apparent across all pins in Kayak Kavern however, and are considered to be a localised effect.

These data highlight that there is little sediment change occurring overall in the caves, and what little changes there are, including those in Kayak Kavern, have tended to balance out over time resulting in an even smaller net change. It is also worth noting that the average seasonal changes at each site were less during the post-Basslink period than they were in pre-Basslink times, which confirms the general reduction in inundation. In view of the sediment changes being so small, it is worth posing the question whether Basslink changes can actually be recognised from changes due to other hydrologic factors, and whether those changes are, in any case, significant.

6.5.2 Significance of change

The results of the monitoring program have shown that the caves are somewhat protected and buffered from the impacts of rapid changes in flow in the Gordon River and that they are also influenced by additional hydrologic and other factors such as rainfall, tributary flows, cave stream flows, sediment influx from the surface, etc. The most significant sediment changes that have occurred are at the lower levels in GA-X1 and at the lower and mid-levels of the wet sediment banks in Bill Neilson Cave, where the rate of erosion has slowed due to the reduction in mid-range flows and low level hydro-peaking, resulting in a net balancing of erosion and deposition during the post-Basslink period. The question remains as to how significant these changes actually are in the context of the cave conservation values.

Comparison of the 1976 cave survey of the Bill Neilson Cave with the 2000 survey carried out by the karst team as part of the early Basslink investigations (Deakin et al. 2001), suggests that there have been some sediment changes in the first 50–60 m of cave passage which is the reach encompassing the two wet sediment bank monitoring sites. The surveys were conducted to equivalent cave survey standard levels (CRG Grade 5C in 1976 and ASF Grade 54 in 2000) and while allowances must always be made for the surveyor’s style and interpretations, the surveys should in theory be directly comparable. The 1976 survey shows that the streamside and streambed were both composed of river gravels, while the 2000 survey shows that while the streambed was still river gravel, the streamside was composed of the fine sediment banks still present in 2012, which were measured in 2000 to be quite thick (~30–40 cm) with evidence of layering parallel to the surface. This suggests that the fine sediment bank only started to accumulate in response to the commissioning of the power station and that the current average net seasonal changes of <1 mm over 11 years, which amount to a cumulative reduction of – 15 mm, are negligible by comparison.

In Kayak Kavern, the rate of sediment deposition has increased due to reduced erosion from the loss of mid-range flows and hydro-peaking at the 2–3 turbine level. The changes are however, considered to be relatively localised reflecting their location in a major eddy of the Gordon River. Kayak Kavern was also surveyed in 1976, and again in 2000. In this case however, the two cave surveys were conducted to different standards (ASF Grade 2 in 1976 and ASF grade 54 in 2000) and so were not directly comparable, but they nevertheless suggest that there was significantly more sediment in the cave in 2000 than there was before the power station was commissioned. The 1976 survey showed the silt mound to extend to approximately 16 m from the constriction at the eastern side of the cave, whereas the 2000 survey shows it to extend to at least 21 m. The mound also supported a growth of ferns in 1976 which was not present in 2000, or at any time throughout the monitoring program. This suggests that the introduction of the dam and power station has greatly increased the amount of sediment in the cave, and that the current average net seasonal increase of 4.1 mm over 12 years, which amounts to a total of 30–90 mm of deposition, is still small by comparison.

In the dolines, the post- Basslink Monitoring Program has confirmed that there is still no appreciable gradual change occurring in the structure of the features, consistent with the findings during the pre-Basslink investigations. This raises a difficulty in the program however, as highlighted in the BBR, that it will now be impossible to distinguish whether any catastrophic events that may occur are related to Basslink, or would have happened anyway. For this reason, the hypothesis and the reason for the monitoring has become less of a priority.

In Channel Cam, given the relatively small changes throughout the entire monitoring period in contrast to the regular flow of sediment from the seepage erosion feature, and the nature of the substrate being more muddy than the sandy material found in the river bank, it is concluded that the channel is not a source of material for the seepages.

In summary, the long term sediment changes within the caves, which are the primary karst features of interest, are generally small (or larger but more localised in the case of Kayak Kavern) and typically almost balance out over time which supports the finding that the caves and their sediments are relatively robust under pre- and post-Basslink operating regimes. The available evidence suggests that these changes are especially small when viewed in the context of the changes since 1976 before the power station was originally commissioned.

6.5.3 Review of the informal triggers

The informal triggers are considered to be relatively robust when they are used in this three step approach. For instance, they successfully highlighted the change in the inundation patterns in the dry sediment bank in Bill Neilson Cave during the winter of 2007. However, assessment of the hydrological influences on the system identified that the above average rainfall in the catchment during that period, which increased flows in the Denison and the cave stream, was responsible for increasing the levels and duration of back flooding in the cave in approximately half of the inundation events. This finding immediately reduced the significance of the exceedance of the informal trigger value.

Similarly, the grouping of the different components of the informal trigger values for sediment change is considered useful to mitigate against the limitations of relying on data from individual erosion pins rather than averaging across sites. This serves to differentiate between sites where significant change, change which is not yet significant, and negligible change is occurring. This was found to be useful for highlighting arising issues.

It has emerged over the course of the post-Basslink monitoring period, that the discharge patterns from the Gordon Power Station have not been dominated by the degree of hydro-peaking that was predicted in the TEMSIM modelling. Specific Basslink changes are difficult to quantifiably determine as there are many other interlinked drivers of change in the system that are not Basslink related such as weather, system inflows and storages, local electricity demand and new generation capacity. In reality, the volume of flow through the power station has decreased since Basslink was commissioned and in general terms, so too have the rates of sediment change.

6.6 Conclusions

In general terms, there have been lower flows in the Gordon River during the post-Basslink Monitoring Program than there were during the pre-Basslink period due to lower power station discharges and below average rainfall in the catchment, particularly during the winter months. The lower flows have resulted in less inundation of the karst features than during the pre-Basslink years, and there has consequently been a general reduction in sediment changes across the majority of sites, particularly at the lower to mid-levels in the caves.

There were no significant structural changes recorded in the dolines throughout the program.

The post-Basslink Monitoring Program is considered to have worked well within its objectives and limitations. The informal triggers were found to be a useful tool for highlighting changes to existing trends, which were then assessed for their relationships with hydrological change due to power station operations.

All the evidence suggests that the sediments in the caves are more protected and buffered from the effects of the power station operations than the sediments in the river channel, and that the caves are relatively robust. This is because of the caves' connections with the river and the influences of other non-power station hydrological processes. The recorded sediment changes are also small, of the order of a few mm, and irrespective of the hydrological driver of change, whether Basslink related or not, they are considered to be of little significance from an ecological, geomorphological or conservation perspective. This is supported by comparisons of the 1976 and 2000 cave surveys in Bill Neilson Cave and Kayak Kavern which show that there has been considerably more accumulation of sediment in the caves as a result of the commissioning of the power station, than there has been change between the pre- and post-Basslink operating scenarios.

Finally, the conclusion has been drawn that Channel Cam is not connected to the adjacent seepage erosion feature in the river channel via a buried karst feature.

It is considered that Basslink has not had a significant impact on the Gordon River karst. The notable sediment changes that have been detected are still within the ranges of change experienced during the pre-Basslink monitoring period, and are negligible in comparison with the changes that have taken place since the power station was originally commissioned.

6.7 Recommendations

At all sites, but in GA-X1 in particular, there are more impacts being caused by the visits to carry out the monitoring than is otherwise taking place. It is therefore recommended that the karst monitoring program cease and that all monitoring equipment be removed in a sensitive manner in consultation with a local karst specialist.

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7. Riparian vegetation

7.1 Summary

In the post-Basslink period there has been a net recovery of vegetation on the banks of the Gordon River. There has been a measurable increase in total vegetation cover at all bank levels; however it is most pronounced in the ‘above’ quadrat levels and is seen in all zones.

The major change in post-Basslink riparian vegetation metrics was an overall measured increase in species richness over the monitoring period. The trend was most apparent at ‘high’ quadrat sites since 2006, but was also seen in ‘low’ quadrat sites since 2008. This pattern is consistent with the increase in rate of colonisation and the persistence of vegetation in the ‘high’ and ‘low’ quadrat types under low discharge regimes that have occurred over the past 4 years.

The increase in vegetation cover and associated increase in species richness in the past 4-6 years have been promoted by the low flows observed over this period. Correspondence analysis identifed that the key environmental variables explaining the differences observed in species richness were zone, year and annual flow volume for the year preceeding the monitoring event. The correspondence analysis identifed that the ‘high’ quadrats demonstrated a significant correlation with annual flow over time. These results are consistent with a reduction in power station use that first affected the ‘high’ quadrats as a result of reduced duration and frequency of inundation that allowed recovery of these quadrats. As flows became dominated by the minimum environmental flow, ‘low’ quadrats also began to recover.

Changes in vegetation occur in response to major changes in annual flow volume; however several years following the flow change are required before changes are able to be detected. Changes in vegetation in response to small changes in annual flow patterns are difficult to determine due to the lack of statistical power in the experimental design. Total annual flow volume from the power station has decreased over the monitoring period meaning that the relationship between total annual flow and the recovery of vegetation is hard to distinguish independent of time.

Photo monitoring results confirm the link between extended periods of low flow and the recovery of the ground layer on the lower banks. Significant expansion of the ground layer occurred in 2007-08 following a reduction in cover recorded in the preceding year due to high total annual flow volume and the long duration of high flows. Expansion of the ground layer continued in photo monitoring plots in 2008-09 as well as in 2010-11 and 2011-12 with more variable results in 2009-10.

7.2 Introduction

Monitoring of riparian vegetation along the banks of the Gordon River was undertaken to characterise the vegetation and determine if Basslink operations were resulting in changes outside of those expected from the pre-Basslink period. Vegetation monitoring sites were located in four zones of the Gordon River downstream of the dam. These zones correspond to geomorphic zones 2-5. These monitoring sites are shown in Figure 7.2 through to Figure 7.6.

The aims of the riparian vegetation monitoring program were to:

- characterise and monitor the abundance and composition of vegetation at permanent plots along the river;

- relate changes in vegetation abundance and composition to changes in water regime if appropriate; and
- assess these results against a set of pre-Basslink baseline condition metrics (i.e. triggers).

Vegetation and floristic data were collected for five years prior to the operation of Basslink (known as pre-Basslink) to determine a baseline for the system. These data have subsequently been used to develop a set of quantitative and qualitative trigger values (see Hydro Tasmania 2006) to detect changes in the post-Basslink period. Data has been collected annually and assessed against the trigger values over a period of six years (2006 to 2012). It was recommended that this approach be used cautiously due to the nature of the data. The low replication, paucity of data points, lack of long term data to characterise natural variability and the ongoing adjustment of the river to the third turbine were seen as factors which would limit the interpretation of the data. The evaluation of the effectiveness of the monitoring program presented in Hydro Tasmania (2005a) concluded that whilst the monitoring program was successful in developing a greater understanding of vegetation processes in the river, the program was limited by the high degree of variation in the system and the low number of sites and frequency of monitoring.

The current review follows the Basslink Review Report 2006-09 (Hydro Tasmania 2010a) in assessing the riparian vegetation monitoring program. This section reviews the results to date and incorporates additional data analysis to better describe the processes of vegetation change and response along the river. This section also includes an exploration and analyses of the data to discover if there are any quantitative relationships between the results of the vegetation, geomorphology and hydrology monitoring. The monitoring program and triggers are also evaluated.

7.3 Methods

The riparian vegetation monitoring program comprised two methods of assessment: quantitative monitoring consisting of permanent quadrat and transect sites, and photo monitoring sites. Permanent quadrat studies involved the assessment of ground species cover, seedling numbers and ground conditions. These quadrat studies were undertaken annually in autumn in the Gordon River and at reference river sites. The position of the quadrat was designed to approximately correspond with river heights under the operation of two and three turbines and above the level of 3-turbine operation. The bank location was used to label the quadrats; ‘low’ , ‘high’ and ‘above’ respectively. Quadrats were located with reference to the high–water mark, as shown in Figure 7.1, and offset by 0.5 m from the transect line to avoid trampling impacts. Sampling within the Gordon River was stratified longitudinally by zones delineated by tributary confluences and inflows . Seedling recruitment monitoring was undertaken twice yearly, in summer and autumn, to determine seasonal recruitment patterns. Monitoring was also undertaken at reference sites in the Franklin and Denison Rivers.

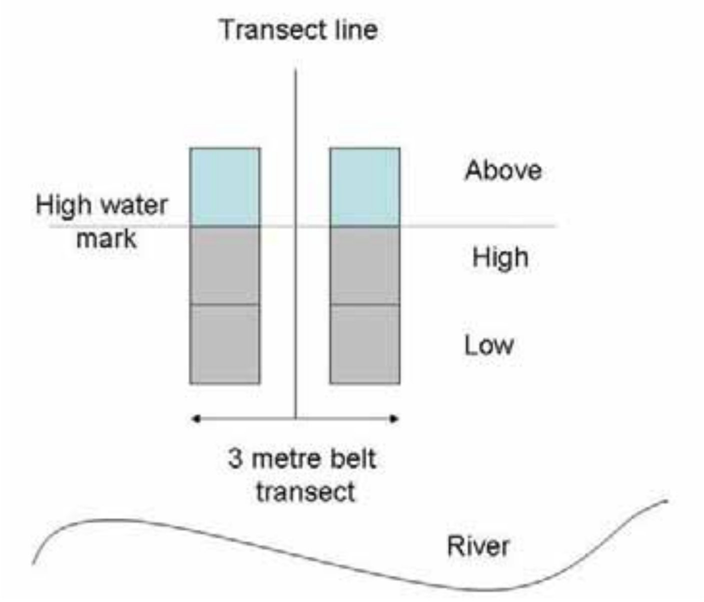

Figure 7.1: Diagrammatic representation of quadrat positions along transects in Gordon, Franklin and Denison Rivers.

7.3.1 Photo monitoring

Photo monitoring sites were established at the 35 representative sites covering all substrate types within each major river reach to obtain representative data on vegetation patterns and processes within the rivers (Figure 7.2 to Figure 7.5). These photo monitoring sites enable accurate, objective measurements of canopies of shrub and tree species, presence/absence of ground layer species and assessment of vegetation health indicators.

Site photographs were compared between concurrent years to identify trends between the years (e.g. the 2007 photograph is compared with 2008). The results are summarised as the proportion of photograph pairs showing: canopy expansion or contraction and/or ground cover expansion or contraction, no discernible change or no data (no photograph to compare). It should be noted that the results show the number of sites showing changes and do not detail the magnitude of changes. A change of 10 % or more in any variable is recorded for the comparison.

7.3.2 Data Analysis

The monitoring results for riparian vegetation were assessed annually against the trigger values that were calculated from data obtained in the pre-Basslink monitoring period. This section does not aim to repeat these analyses or results; rather, it describes overall trends in the data collected between 2002 and 2012. Due to the high degree of variation present in the data and the limited statistical power of the experimental design, the autumn data set was the only one analysed because a more comprehensive set of variables was measured during this monitoring event.

The monitoring program employs a stratified approach to sampling, where data is grouped into zones, sites and bank level for analysis. In addition, the vegetation structure in the riparian zone can be a complex system where natural changes may mask (or mimic) the potential changes resulting from altered flow regime. These complexities mean that care is required when interpreting the data to understand changes and causal effects. To lessen the risk of misinterpreting the data, multiple indicator variables were used to assess different aspects of the measured changes in vegetation structure. A combination of the species composition and the ecological distance between different measurements, the total vegetation cover, the arrangement of ground cover variables and the species richness was used to measure and analyse different aspects of the riparian ecosystem of the Gordon River.

This section reviews the drivers of vegetation change along the river and how they may be impacted by changes in power station operations. Specific questions addressed in this section include:

- How do the processes of bank change such as deposition and erosion interact with vegetation and ground cover conditions?
- Have patterns of vegetation abundance or structure changed over the monitoring period?
- Is vegetation showing sustained differentiation along the river between the zones in response to the varying degrees of river regulation impacts?
- How do hydrological factors interact with vegetation changes? and
- Has there been a Basslink affect?

7.3.2.1 Comparison of species composition and ground cover variables between zones

The variation between zones was investigated by using multi-dimensional scaling to cluster sites according to the similarity of the species composition or ground cover classes at each site. The ecological distance, specifically the Bray-Curtis similarity index of ground cover variables between zones and sites was used as an indicator of change in community structure. This enabled changes in species composition to be identified, even if they did not result in a significant change in diversity.

All ordination of data was carried out with the assistance of the *vegan* package (Oksanen et al. 2012) in the R statistical programming environment (R Development Core Team 2010).

7.3.2.2 Key differentiating species

As with previous reports, a similarity percentages (SIMPER) analysis (Clarke 1993) was carried out to identify which species and taxa account for the majority of the variation between zones. It uses the Bray Curtis measure of similarity and breaks down the contribution of each species to the observed similarity (or dissimilarity) between zones.

7.3.2.3 Quantifying vegetation changes over time

Time series charts were prepared to understand how key indicators had changed over time. The total vegetation cover, the distribution of the ground cover groups and the species richness were plotted over time for each zone and quadrat location. Mixed effects modelling using linear models was used to test whether there were any significant changes in total vegetation, total ground cover or species richness in response to time period, flow or the commencement of Basslink operations. All linear models were fitted and tested using the statistical package *nlme* library (Pinheiro et al. 2012) in the R statistical programming environment.

The graphical data displays were underpinned with a formal assessment of trend, using linear modelling, where the significance and predictive ability of different variables (x_i) to predict the value of the indicator variable was tested.

7.3.2.4 Changes in response to flow regime over time

The effect of the hydrology of the Gordon River on the riparian vegetation was investigated in the following ways:

- the seasonality of the flows;
- the duration of high flows; and
- persistence of low flows;

Total flows, mean, median and maximum flow (m^3s^{-1}) in the 7, 30, 90 and 365 days, as well as analysis of hours of flow across a range of flow ranges preceding a monitoring trip were investigated as potentially affecting the riparian vegetation. The flow parameters determined to be most relevant to the interpretation of the riparian vegetation data were determined by a preliminary ordination.

The most relevant flow parameters were then analysed by Correspondence Analysis (CA) (McGarigal et al. 2000). These parameters were the frequency of high flows and the total flow and were used to assess whether changes in species composition were related to changes in flow regime over time. Correspondence Analysis provided a visual and statistical tool to determine how causal factors (time, flow, zone etc.) related to changes in the species composition between measurements. The causal factors (or vectors) were fitted along the gradient of the axes of MDS ordination of species composition to determine relationships.

7.3.2.5 Interactions between vegetation, ground cover and bank processes

It is recognised that vegetation, ground cover and geomorphology interact as both cause and effect within the riparian zone. Therefore, to assess the interactions between vegetation variables and geomorphology, analysis was undertaken to compare the changes in erosion pins with those of ground cover variables. The geomorphology data set used in the analysis was reduced to include only those sites where there also were vegetation sites because of the high variability in data between sites.

Erosion pin data was collected in spring and autumn (see Section 5.3). Pins are occasionally lost, so the data set contains a number of null values where pins have been unable to be located, and a number of sites where pins have been added. This limited the ability to apply formal tests of correlation or prediction, so the data was analysed graphically (Appendix 4). It should be noted that the geomorphology monitoring was generally undertaken one to two months before the vegetation monitoring and this time difference may be reflected in vegetation results.

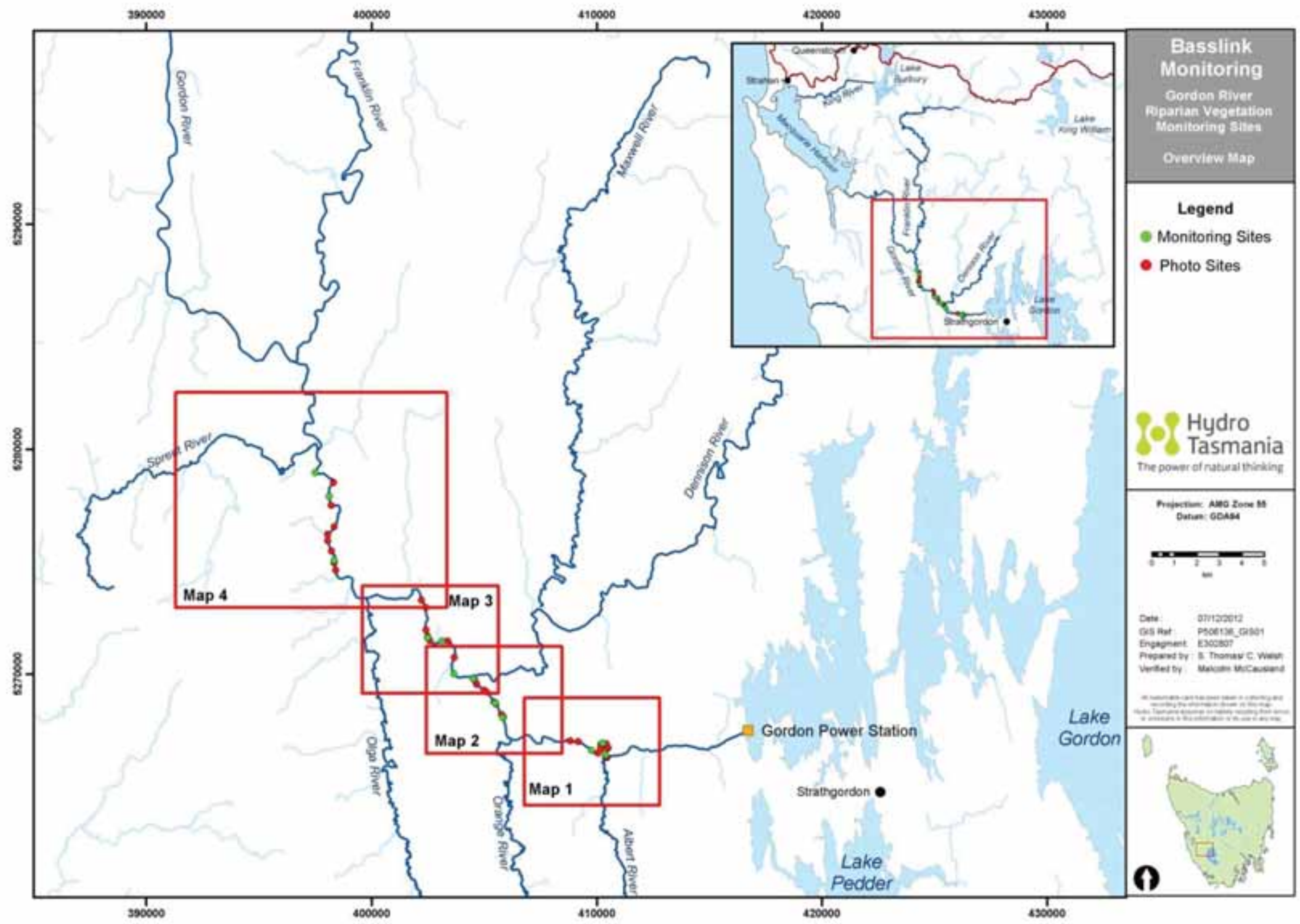

Figure 7.2: Gordon River riparian vegetation quadrat sites and photo monitoring sites.

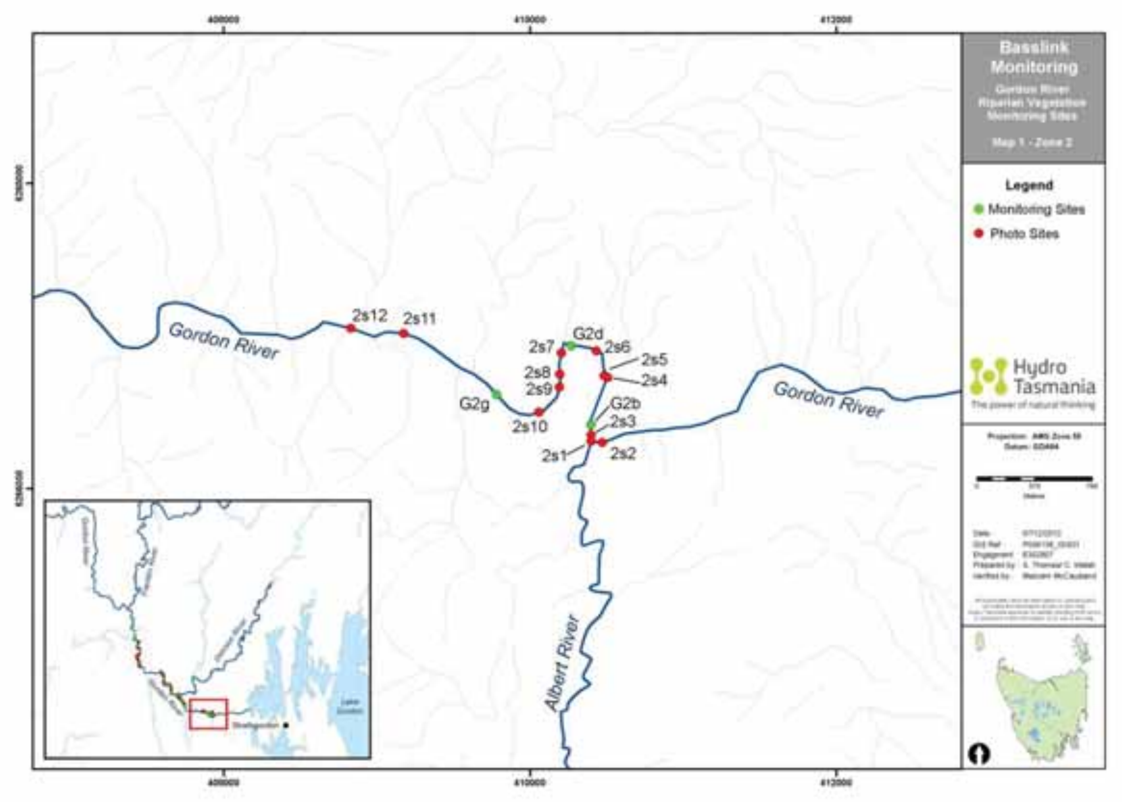

Figure 7.3: Gordon River riparian vegetation quadrat sites and and photo monitoring sites in Zone 2.

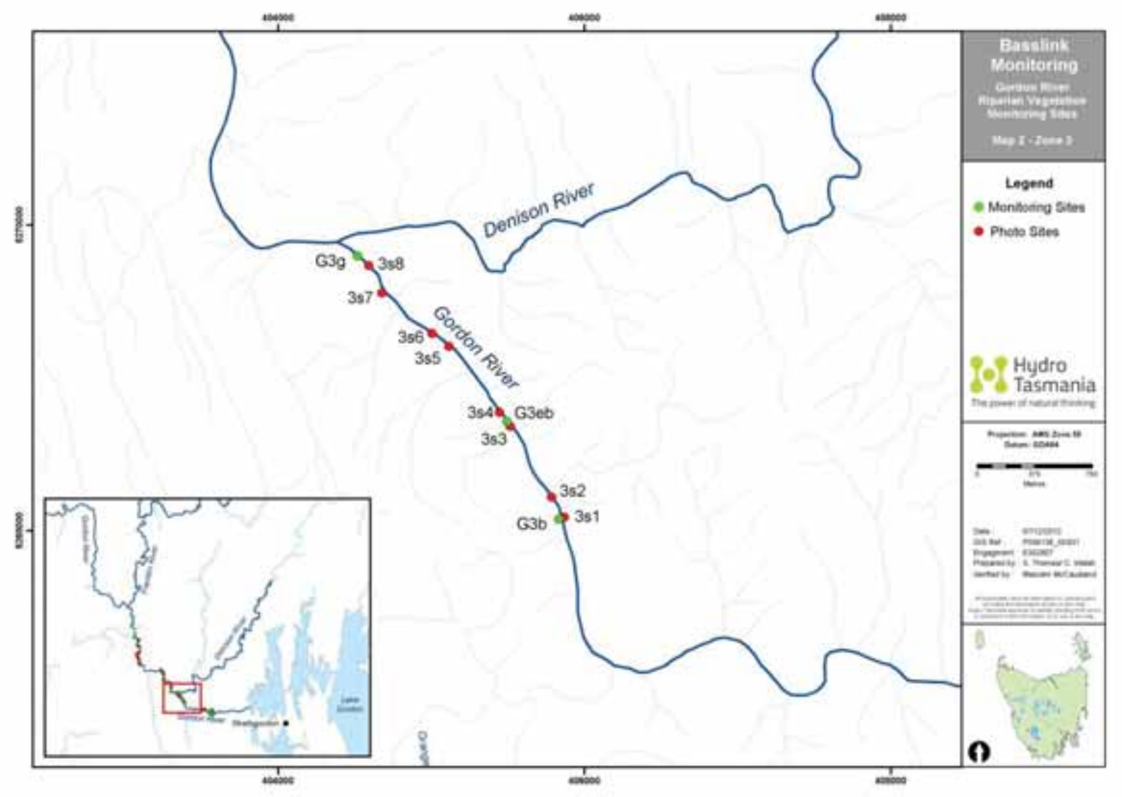

Figure 7.4: Gordon River riparian vegetation quadrat sites and and photo monitoring sites in Zone 3.

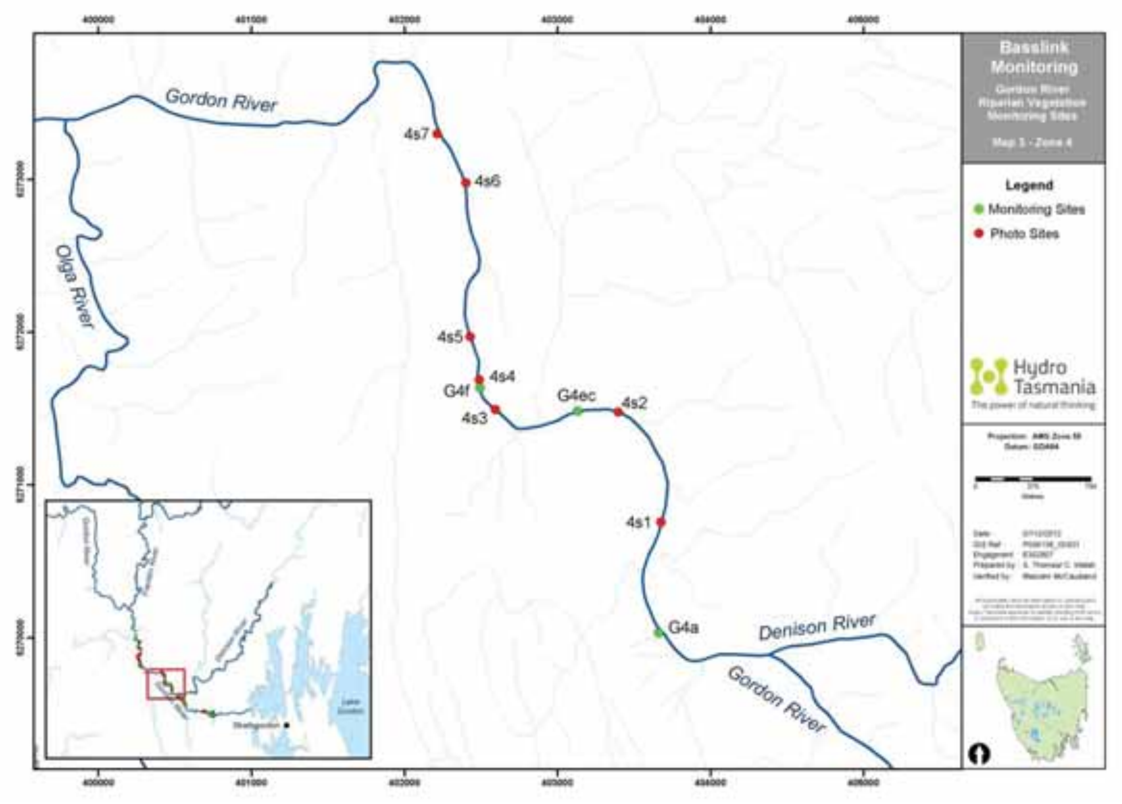

Figure 7.5: Gordon River riparian vegetation quadrat sites and and photo monitoring sites in Zone 4.

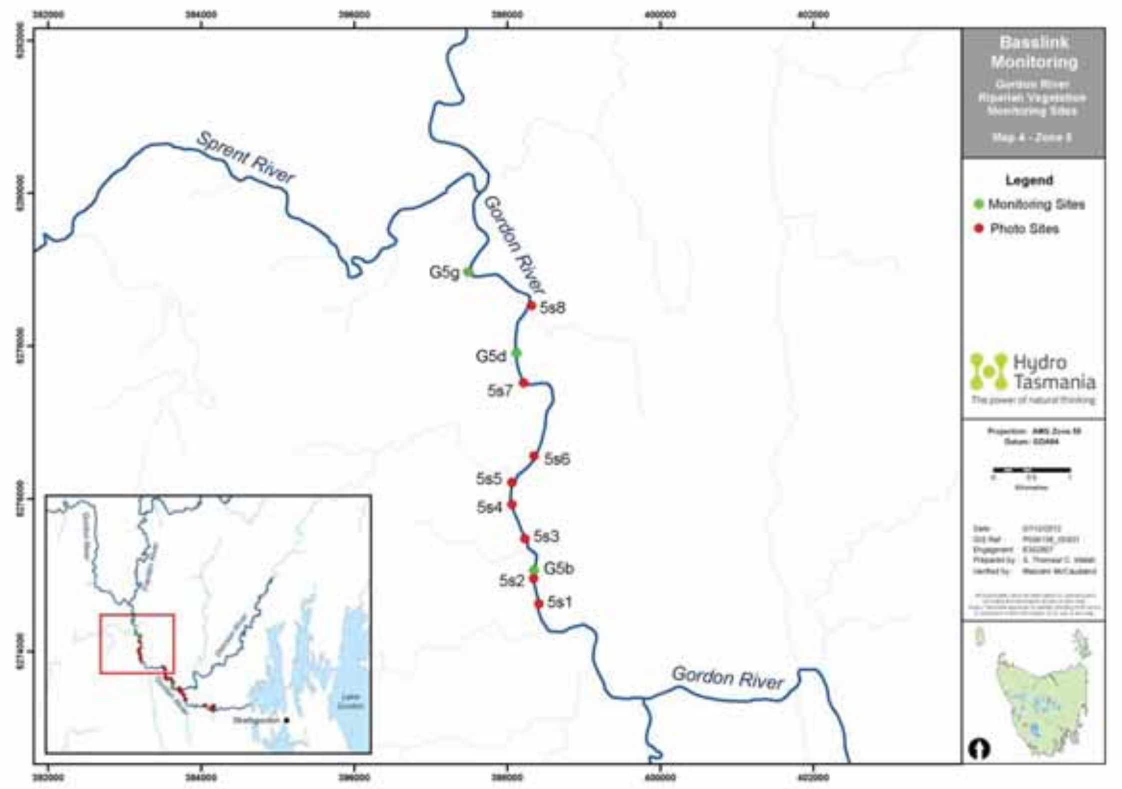

Figure 7.6: Gordon River riparian vegetation quadrat sites and and photo monitoring sites in Zone 5.

7.4 Trends of consolidated data

7.4.1 Comparison of species composition between zones

The similarity between the average species composition for each year at each site is shown in Figure 7.7 to Figure 7.9. The MDS ordination was explored in both two and three dimensions. The standardised stress value in two dimensions was always less than 0.2, which can be considered a reasonable fit given the number of data points (Clarke 1993). The MDS ordination in three dimensions showed a slightly lower stress value (<0.15 for all heights) but the group clustering showed the same general patterns.

Only two dimensional ordination plots are displayed as they are easier to interpret given the large number of data values. Although measurements from the same site each year tend to group, there is a degree of overlap in the species composition between sites and zones for 'low' and 'high' quadrats. At the 'above' quadrat sites, the vegetation was more characteristically distinct which suggests that species are more influenced by other site factors (such slope, aspect, substrate, etc.) rather than their riparian position. There is some indication in the ordinations that zones 2 and 3 were more similar, whilst the species composition at sites in zones 4 and 5 had greater variability. This is consistent with results noted in the previous Basslink Review Report 2006-09 (Hydro Tasmania 2010a).

Site 5g was found to be different from other sites at all levels. This was a site with a low slope behind a cobble bar which supported gallery rainforest with a shaded understory. Consequently it had little in the way of successional species that were common in the higher light environment of the river banks with a relatively more open vegetation structure. The results of the analysis of species composition between zones showed that there is no real pattern in the composition in vegetation at sites based on the zones within the river. The sites selected within zones may be different but they are not necessarily representative of the zones and so do not represent broad scale differences between the zones. This leads to a high degree of variability in the data and makes interpretation of any impacts on composition difficult.

7.4.2 Key differentiating species between zones

The results of the Simper analysis indicated that the fern *Blechnum wattsii* was a key differentiating species between zones. *Blechnum wattsii* accounts for much of the variation within zone 2, particularly at the 'high' and 'above' levels. It is much less abundant in the other zones, and rarely recorded in zone 5. The shrub *Bauera rubioides* and small tree *Leptospermum riparium* were key differentiators for zone 4. They were both recorded in higher abundances in zone 4 than in other zones. *B. rubioides* was mainly found at the 'high' and 'above' levels in zone 4 while, *L. riparium* was found at all levels. This is similar to the previous three year review analysis and is the major difference between the sites in the four zones.

7.4.3 Change in species composition over time

At all quadrat levels there was little evidence of a sustained trend in species composition over time (beyond the existing variation between sites and zones). This is evidenced by there being little difference between site measurements taken recently with those taken near the beginning of the monitoring program (Figure 7.7 to Figure 7.9). In addition, the pre-Basslink measurements are not significantly different from post-Basslink.

The previous Basslink Review Report 2006-09 (Hydro Tasmania 2010a) noted that erosion events in 2007 resulted in some of the ‘above’ quadrats in zone 2 slumping down towards the river. This effectively meant that these quadrats could no longer be considered ‘above’ the inundation level. However, Figure 7.9 shows no evidence of sustained change in the overall species composition at sites in zone 2 after 2007, nor is zone 2 any less similar than other zones. It may be that the structural changes have not noticeably impacted the species composition for these sites. It is also possible that low flow levels in recent years (see Section 2.5.3.3) may have caused lower inundation than was expected for the slipped bank.

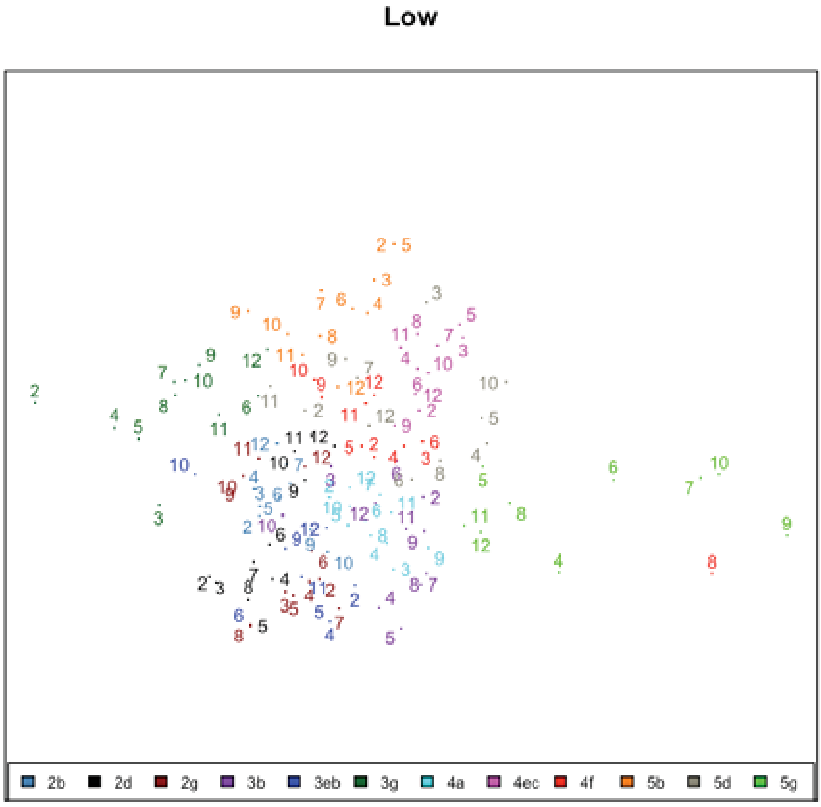

Figure 7.7: Two-dimensional MDS ordination of the average species abundance for 'low' quadrats in each site each year. Points are coloured by site, and the number in each site name represents the zone. The ordination labels denote the year.

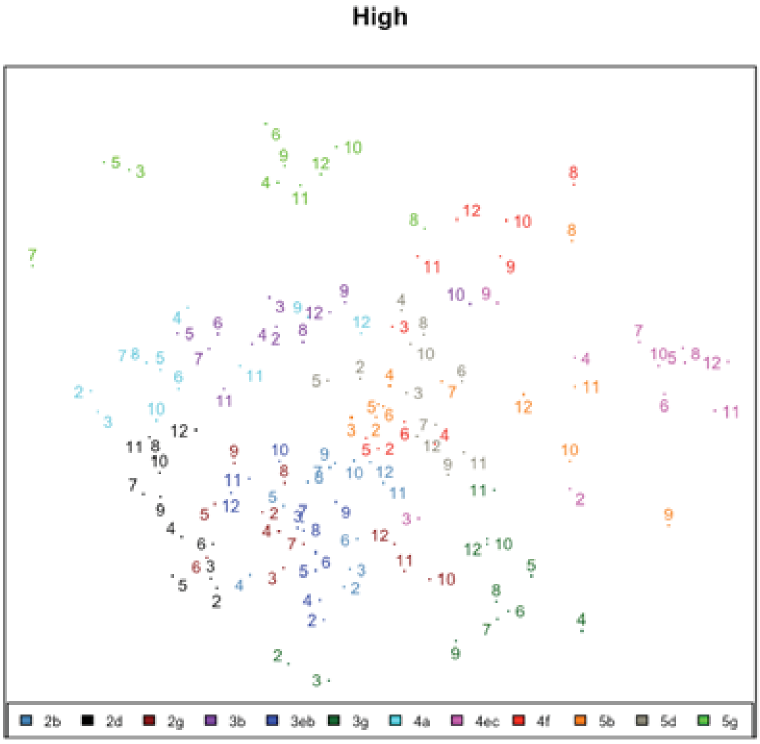

Figure 7.8: Two-dimensional MDS ordination of the average species abundance for 'high' quadrats in each site each year. Points are coloured by site, and the number in each site name represents the zone. The ordination labels denote the year.

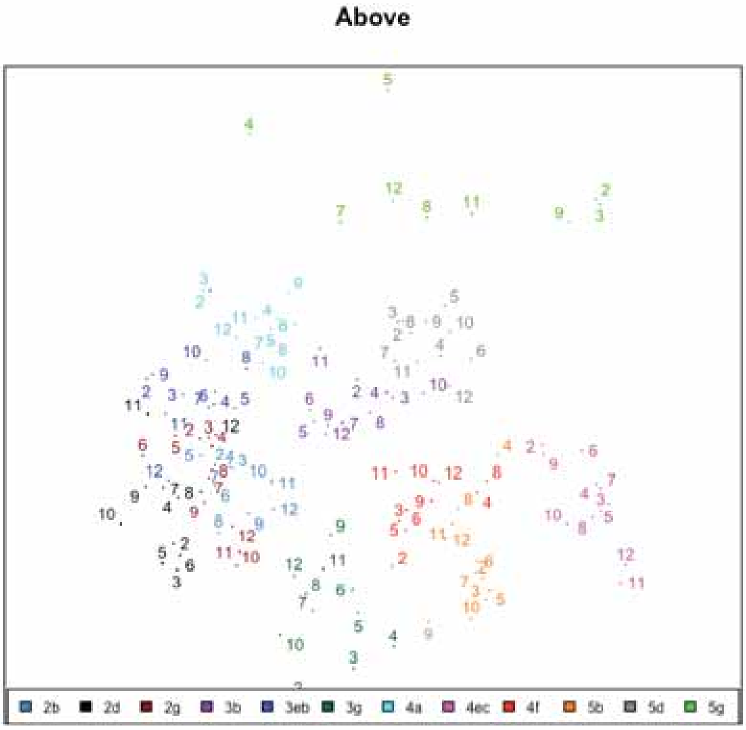

Figure 7.9: Two-dimensional MDS ordination of the average species abundance for 'above' quadrats in each site each year. Points are coloured by site, and the number in each site name represents the zone. The ordination labels denote the year.

7.4.4 Influence of flow regime on species composition

When comparing the hydrology of both pre- and post-Basslink a number of differences are immediately apparent. The median flow for the post-Basslink period is ~35 m^3s^{-1} compared with ~120 m^3s^{-1} pre-Basslink while the duration of high flows has been declining since 2007-08 (Figure 2.11).

The main changes in post-Basslink hydrology affecting the vegetation can be summarised as follows:

- Fewer very low flows (<10 m^3s^{-1}) as a result of the implementation of the minimum environmental flow;
- Significantly fewer periods of high flow (>180 m^3s^{-1}) over protracted periods (72+ hours), i.e. much less base-load operation; and
- Significantly reduced total annual volume of flow.

The change in flow regime can be clearly seen with a greatly reduced total flow annual volume in the year preceding the monitoring event (Figure 7.10). One of the confounding factors is the fact that there has been a general decrease in flows from the power station over the monitoring period (except for 2007 and 2008). This means that there is a link between total annual volume and time. This is further confounded by the fact that there is a time relationship in the vegetation variables that are measured. Vegetation metrics are often responding to time since the last event so that small yearly changes are difficult to pick up and it is only after a number of years of successive recovery that changes can be detected.

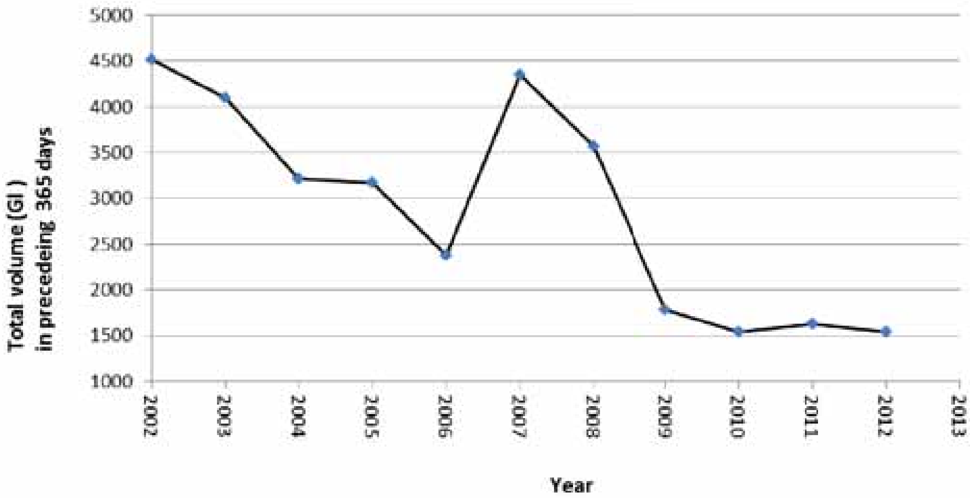

Figure 7.10: Total volume discharged from the power station in the preceding 365 days over the Basslink monitoring period.

A correspondence analysis was done which examined the key environmental factors of zone, year and total flow volume for the year preceeding the monitoring event onto the MDS ordination plots of community composition (Figure 7.11). The analysis highlights the measured variables that are associated with the greater levels of variation in the data. The longer the vector, the stronger the correspondance with the vector. The results showed that zone explains much of the variation between sites however it is not related to any particular environmental factor. The similarity of vegetation at the site level was more related to site selection and the causal factors influencing the general distribution of vegetation in the region (slope, aspect, soil depth, moisture availablility, fire protection etc.) rather than an effect of distance of site from the dam.

The results of this analysis showed a correlation between flow volume and time period which fall along the same axis. For this analysis, only the ‘high’ level quadrats demonstrated a significant correspondence with time (p<0.01) and therefore with total flow volume for the year. The high level of variabilty between zones tends to mask the more subtle changes in community structure over time.

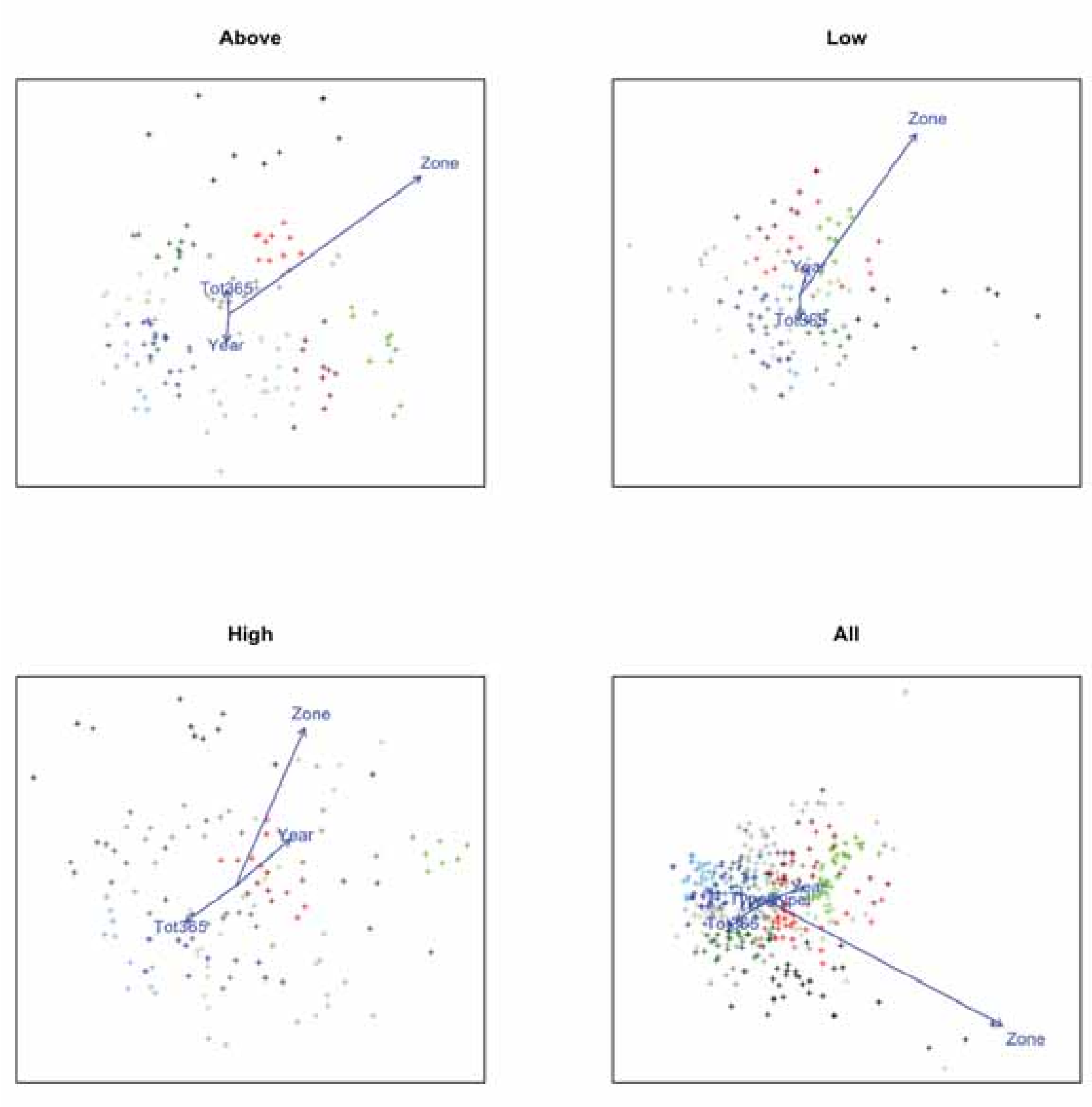

Figure 7.11: Correspondence analysis plots showing the environmental factors that correspond to variation within species assemblages at a site.

7.4.5 Comparison of ground cover classes between zones

The results of the multi-dimension scaling ordination of the ground cover classes (bare ground, moss, litter, coarse woody debris and root exposure) shows none of the differences between zones that were seen in the species composition analysis (Figure 7.12). This means there was no discernible difference between zones in these ground cover variables, and no evidence of any temporal gradient over the monitoring period (2002-12).

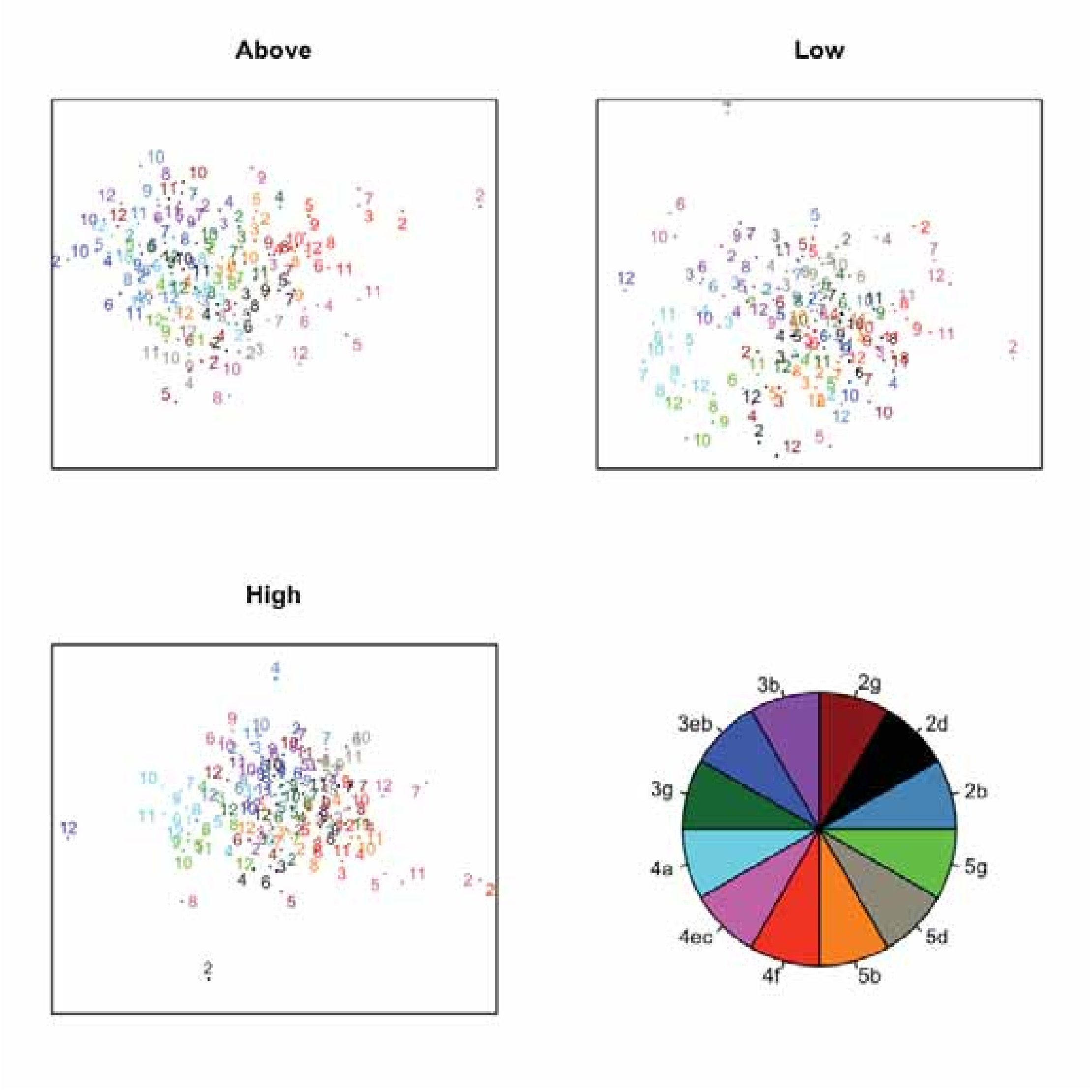

Figure 7.12: Two dimensional MDS ordination of average ground cover per quadrat. Colours represent different sites, and numbers represent different monitoring years.

7.4.6 Trends in specific vegetation indicators over time

Trends in specific vegetation indicators, including total vegetation, species richness, and ground cover were explored to gain an understanding of vegetation responses at the zone and quadrat level. As stated previously, due the fact that vegetation response is linked to total annual volumes and time, it is difficult to separate vegetation response to flow from that of time. The variation in the data is also high, thus identifying small annual changes is difficult. However, with successive years of measured responses to low flow, the trends are more apparent.

7.4.6.1 Total vegetation cover

The averages of the total vegetation cover per site and quadrat type over time are shown in Figure 7.13. Notably, the results for zone 2 in the ‘above’ quadrat reflect the impact of the increased inundation in 2007, with all quadrats at all heights showing a decline in vegetation cover in 2008 following the high flows in the preceding year. This was also noted in the Basslink Review Report 2006-09 (Hydro Tasmania 2010a).

In recent years an overall increase in total vegetation cover has become evident across sites and zones. The increase in vegetation cover can be seen at all levels, though is most noticeable in the ‘above’ quadrats as would be expected as they have not been impacted, although vegetation cover in zone 4 is quite variable at the ‘low’ and ‘high’ levels.

These changes become even more apparent when the annual rate of change in total cover vegetation is plotted against year and total flow volume in the preceding year (Figure **7**.**14**). While the data is highly variable, a consistent trend of increasing vegetation cover is evident in ‘above’ quadrats, particularly when looking at combined data for all zones.

High quadrats can be seen to have a variable response prior to 2008 but undergo consistent increase in vegetation in the low flows occurring after this date. This is consistent with the significant correspondence between community composition and time and total flow volume. These ‘high’ quadrats are most sensitive to changes in flow volumes being impacted by high flow volumes but recovering in periods of low flow with changing species composition occuring as successsion occurs.

The trend in increasing vegetation cover was confirmed using mixed effects modelling, which indicated an overall increase in average cover values of around 13 % per year across all sites and zones ($p<0.01$). There was no evidence of a step change in total vegetation from pre- to post-Basslink ($p>0.8$). A step change is a large difference in vegetation cover before and after a change in operation of the river system (e.g. pre- and post-Basslink), which would be unusual for natural systems of succession and evolution. It would be more likely to expect a gradual change in the rate of colonisation or retreat which is seen in the Basslink vegetation monitoring components of the fitted model.

The mixed effects model suggests that the trend towards increased vegetation cover has occurred post-Basslink (though Figure 7.13 indicates that it began a little later, since 2007-08). This is consistent with an increase in vegetation cover due to the lower flows in the post-Basslink period.

7.4.6.1 Species richness

The analysis of species richness (S) involves the taking the log normal of the number of different species recorded in a quadrat and plotting it over time. The plots of the change in species richness over time for each quadrat type and zone are presented in Figure 7.15. Similar to total vegetation cover, there is an increase in species richness over the Basslink monitoring period. When plotted against total flow volume, no real trends can be ascertained (Figure 7.16) as it is cumulative growth over several years that are becoming evident in the data. Linear modelling however indicates an increase in species richness of around 7 % per year ($p<0.01$), with the trend only becoming evident since 2006 ($p\sim0.1$). The trend is most obvious at ‘high’ quadrats. In contrast the trend at ‘low’ quadrats is most evident after 2008. For quadrats at the ‘above’ level, there is little evidence of a trend, except in zone 2. The trend in increasing species richness is most likely to be as a result of increased colonisation of species and persistence of vegetation in the ‘high’ and ‘low’ quadrat types.

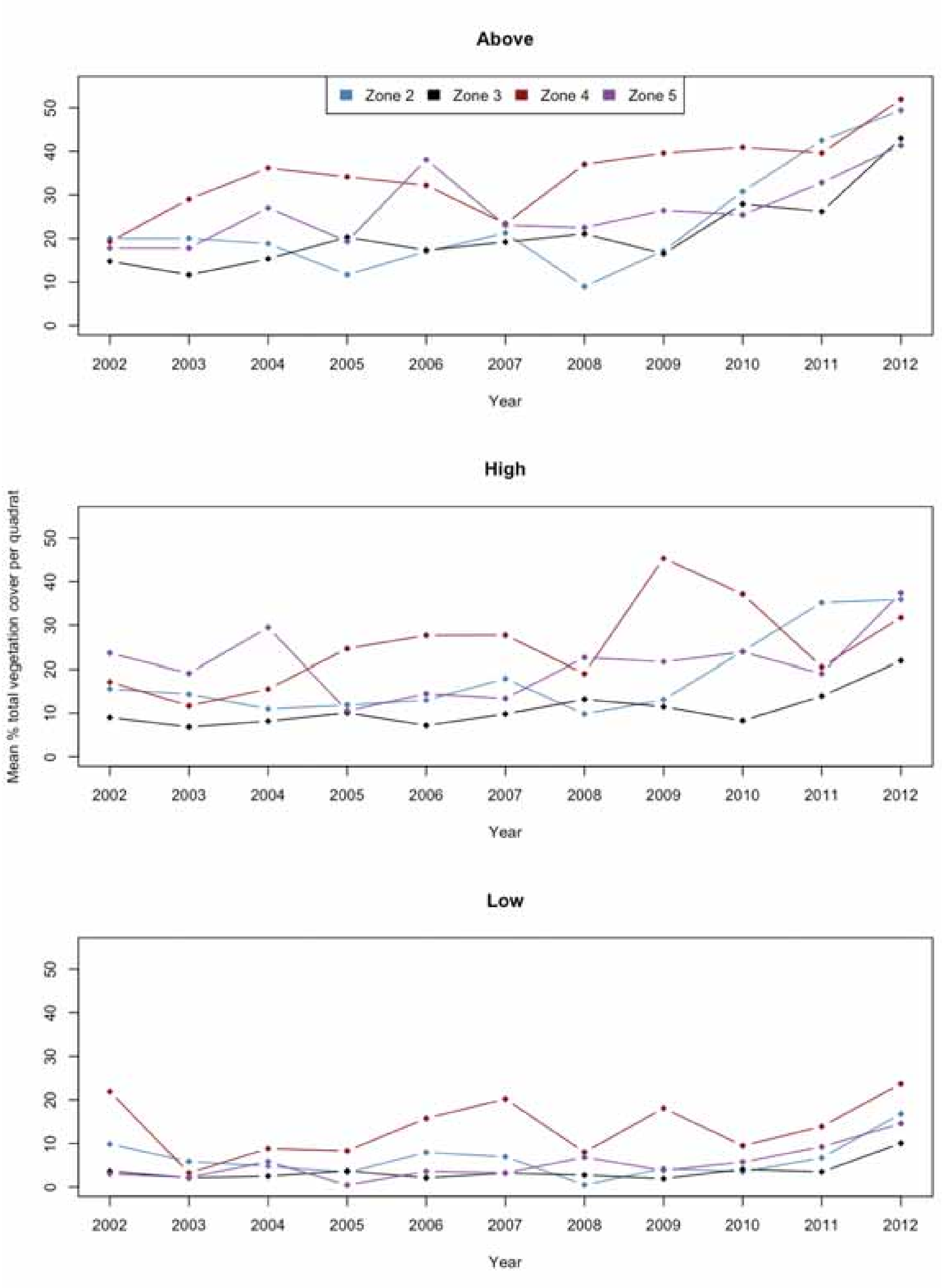

Figure 7.13: Trends in mean percentage of total vegetation cover for each zone and quadrat type.

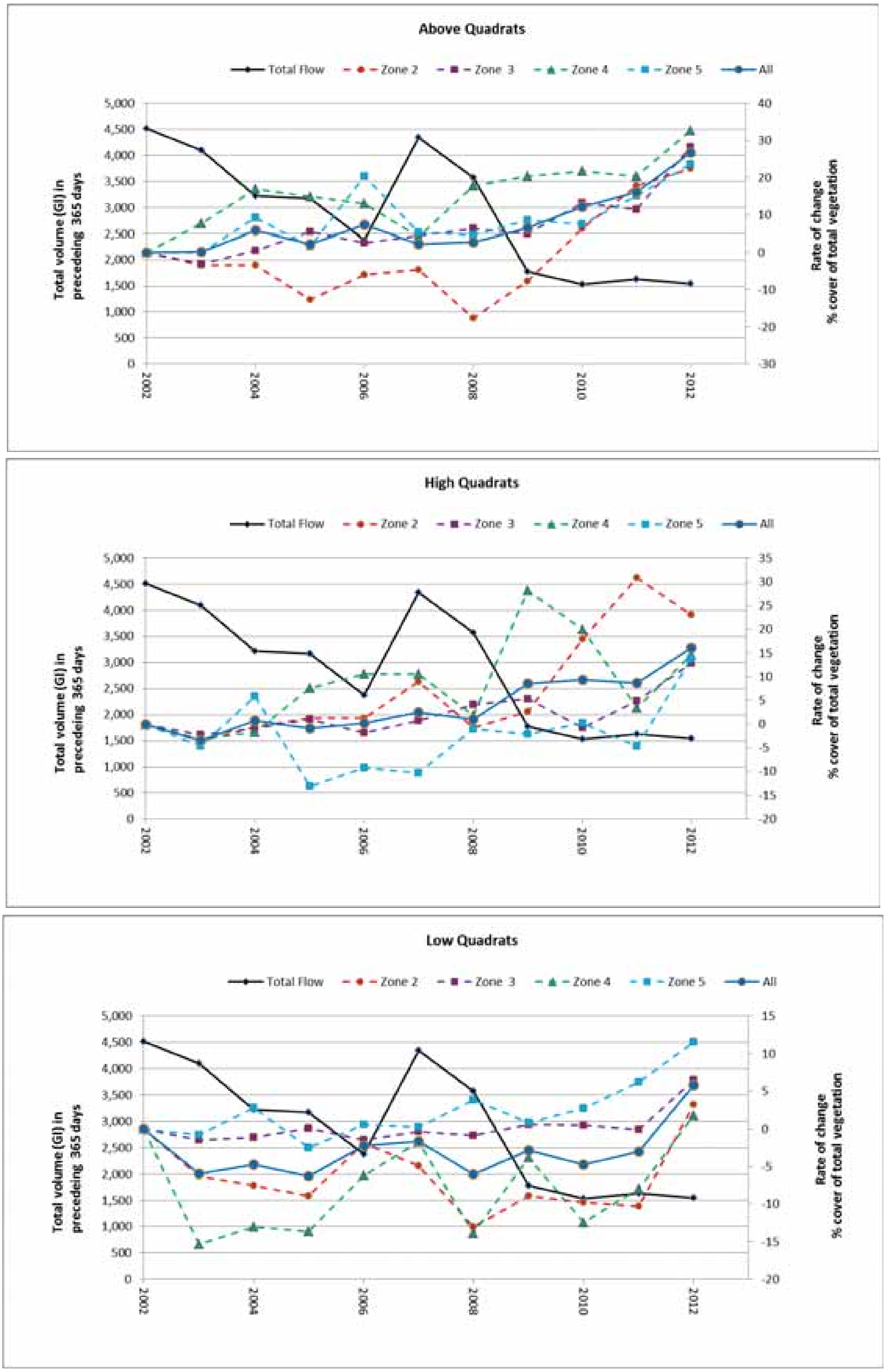

Figure 7.14: Annual rate of change of percentage of total vegetation cover for each zone and combined zones (ALL) and quadrat type compared with total flow volume in the preceding year.

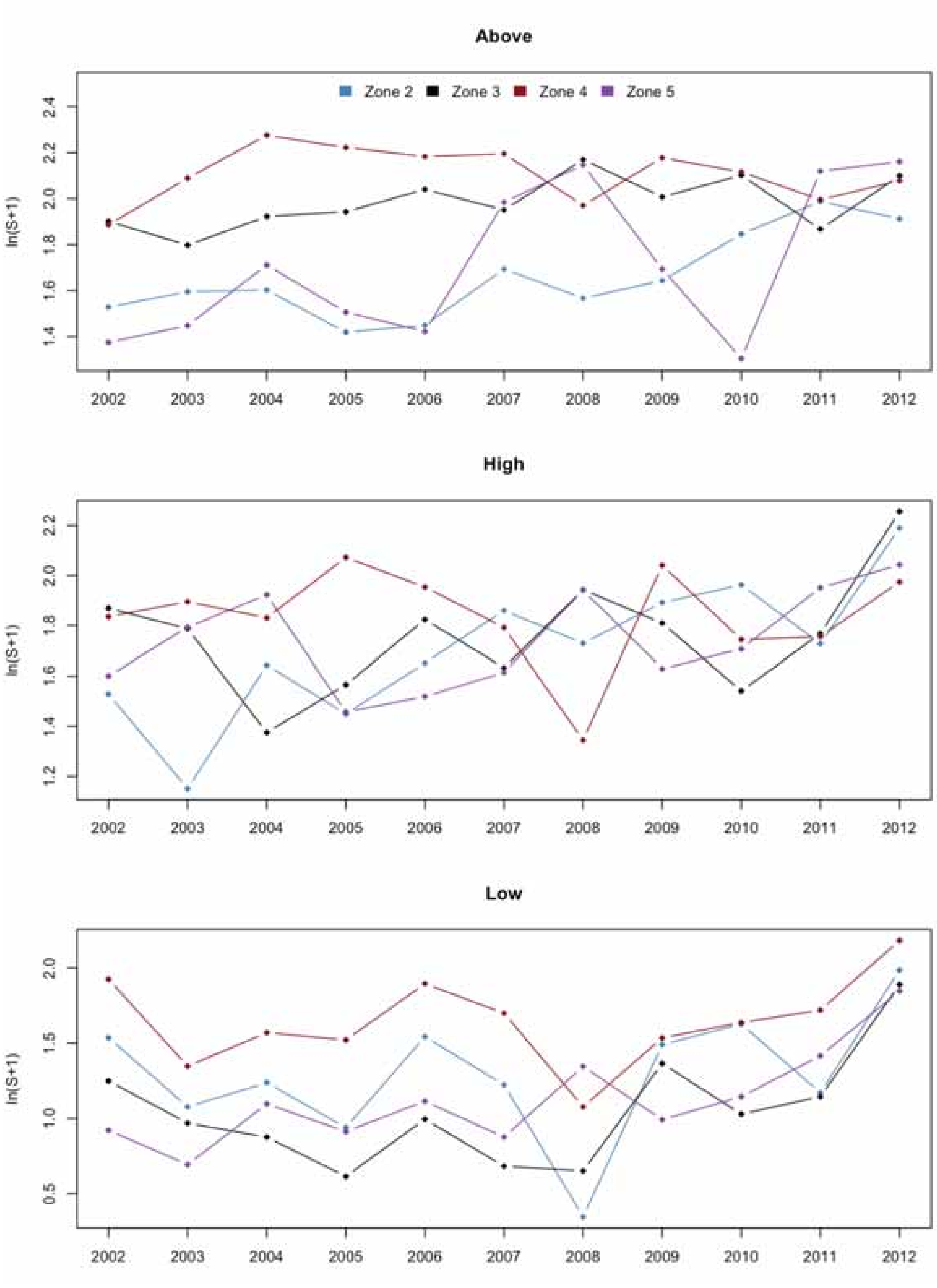

Figure 7.15: The change in species richness (S) over time for each quadrat type and zone.

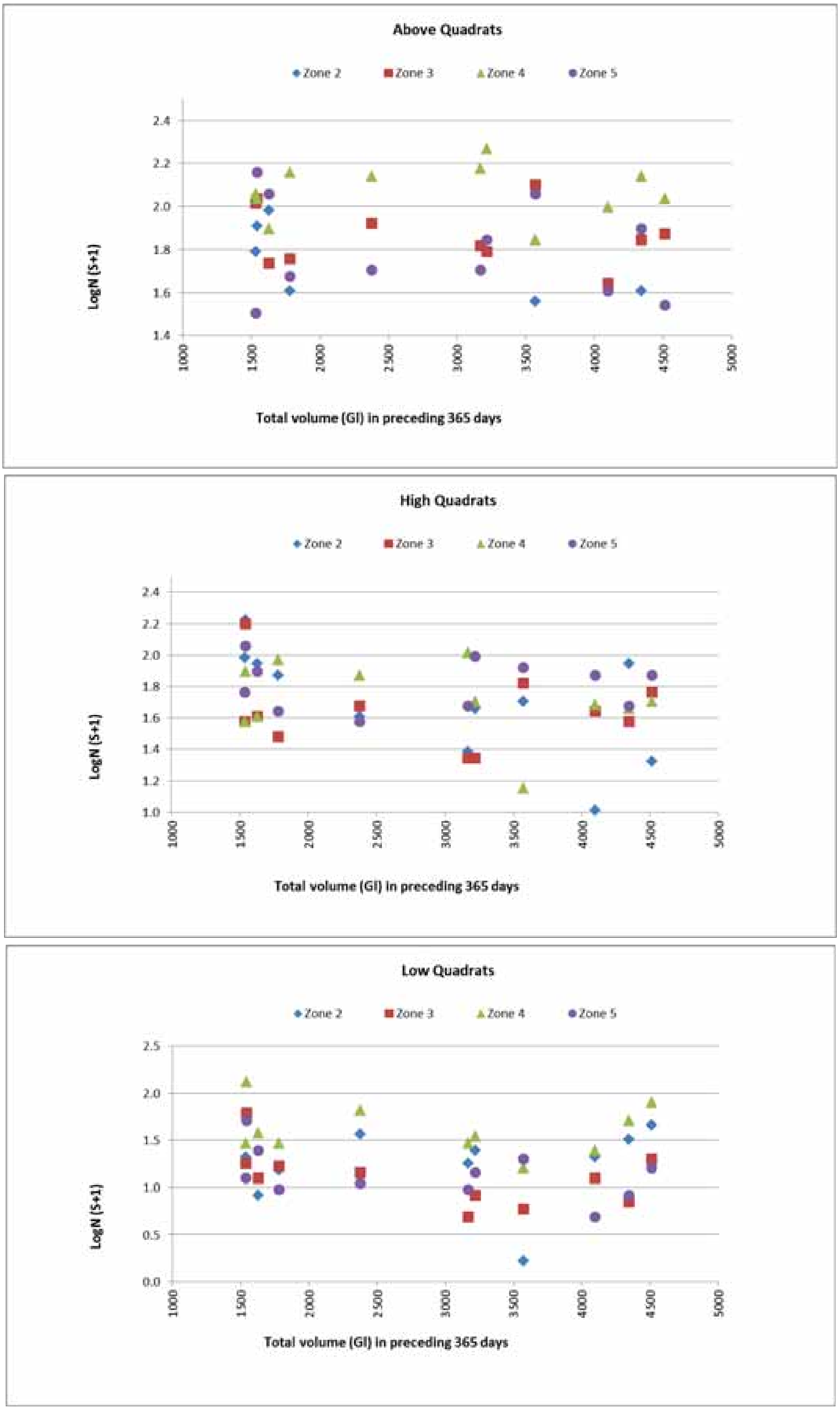

Figure 7.16: Change in species richness (S) for each quadrat type and zone plotted against total flow volume in the preceding year.

7.4.6.2 Ground cover

There have been observable changes in overall ground cover vegetation and number of species. There is also evidence that the character of the ground cover has changed over time (Figure 7.17). The proportion of bare ground above the inundation level has generally declined since 2007, while the proportion of litter and mosses has increased. This trend appears to have been more pronounced in zones 2 and 5 (Figure 7.18). However, the high variability in the recorded measurements of the ground cover categories limits the statistical power to confirm the trends.

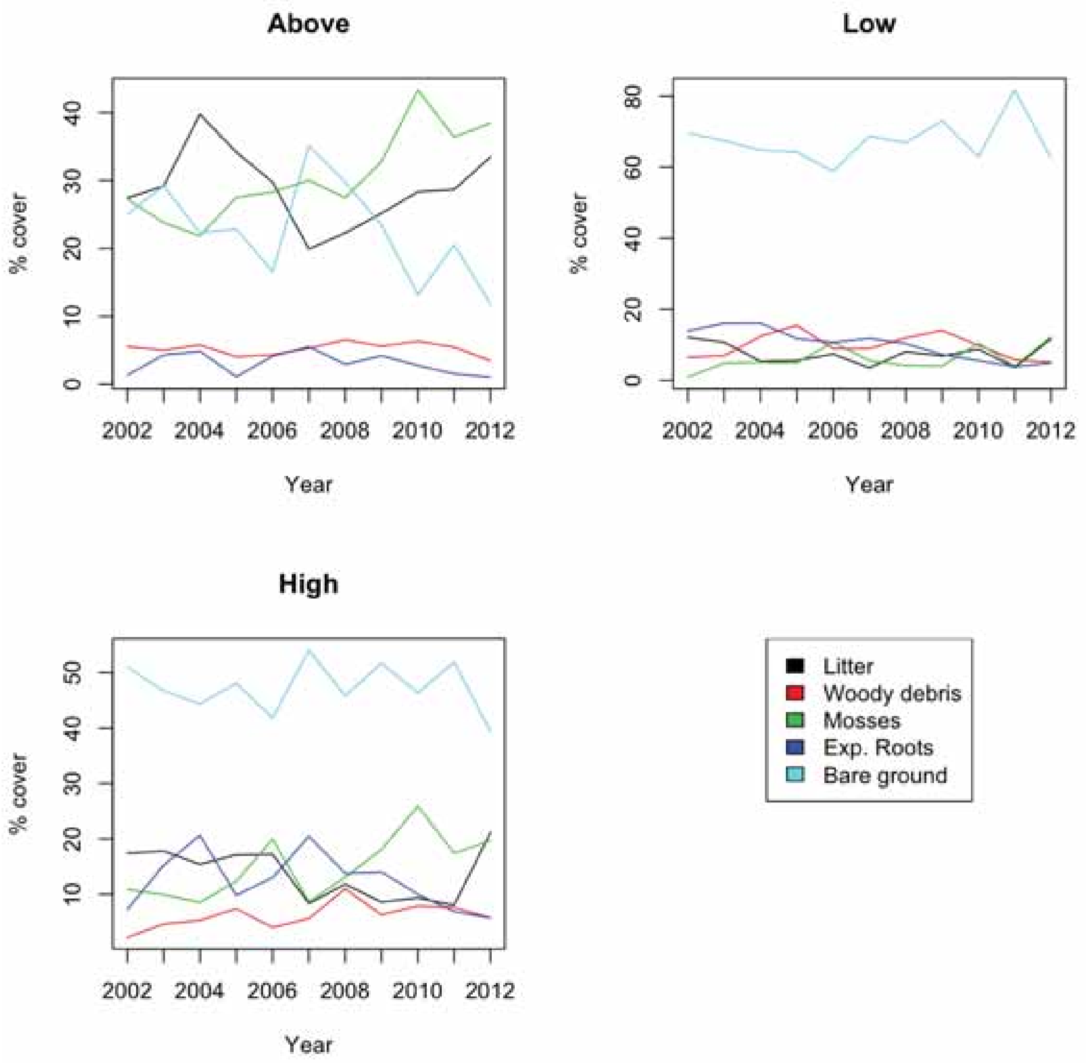

Figure 7.17: Changes in ground cover profile over time, by quadrat type.

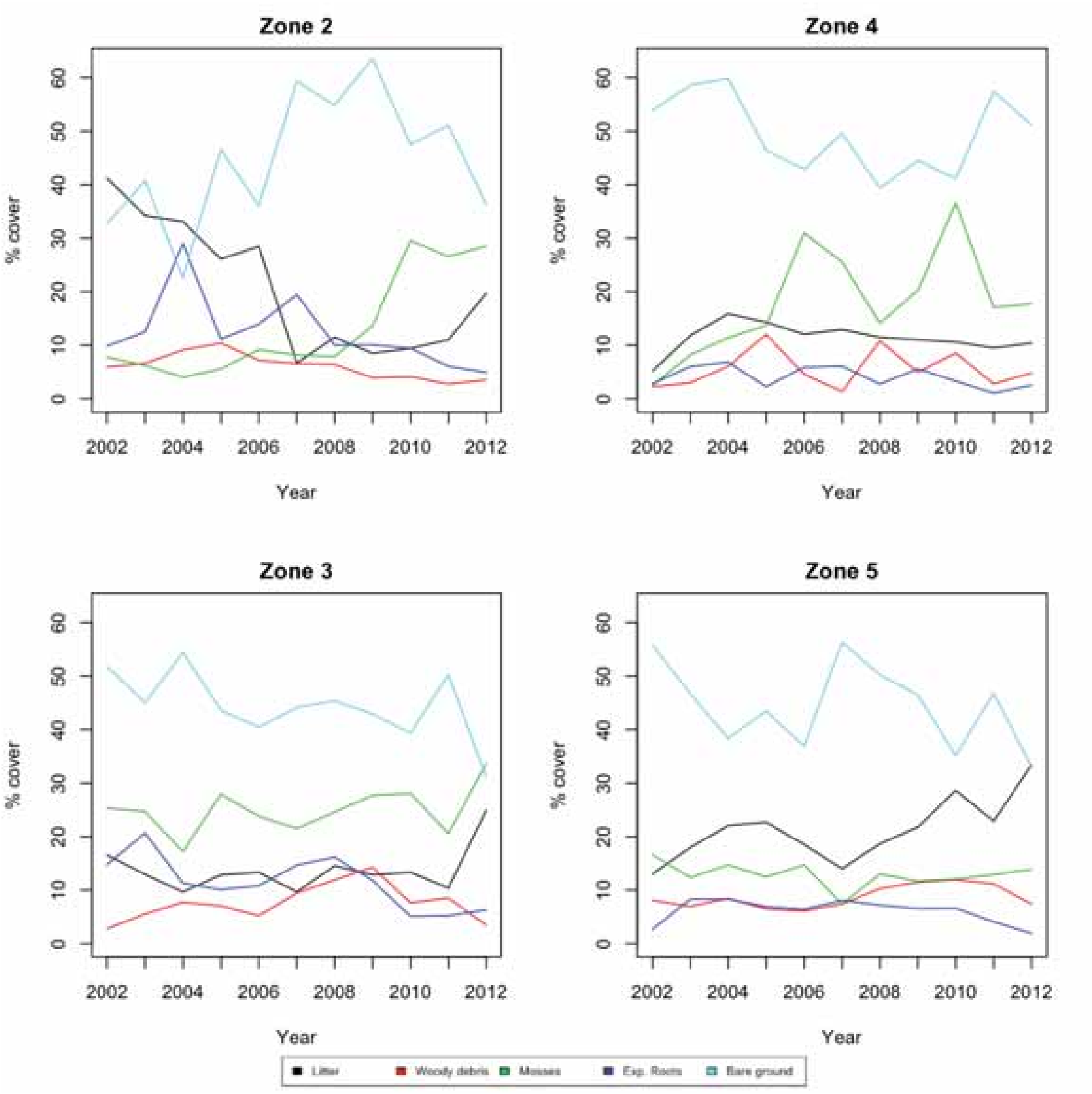

Figure 7.18: Changes in percentage ground cover variable over time and by zone.

7.4.7 Interactions between vegetation, ground cover and bank processes

The cumulative erosion pin measurements and proportion of bare ground were plotted for each site and zone and no correlation patterns in the data were evident[3]. Some sites showed a slight trend towards increased bare ground over time, despite differing erosion profiles. The erosion data was also plotted against the total vegetation, proportion of exposed root and graminoids, but no vegetation measures showed any strong relationship to the erosion data. Any specific correlation between the vegetation and erosion pin data is likely to be subtle even within a site or level, and may include a time lag and/or is likely to be masked by the variability in the data.

The results of the investigation of associations between the vegetation and the erosion data are similar to those reported in the previous Basslink Review Report 2006-09 (Hydro Tasmania 2010a) where many of the sites within the data set were showing conflicting results in both the

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[3] The cumulative erosion pin measurements and proportion of bare ground plots were not incuded in the report because they did not show any correlations.

geomorphology and vegetation data. These issues were also noted in Hydro Tasmania (2005a) and the recommendation to interpret the data cautiously is supported by the results in this report.

7.4.8 Photo monitoring

Photo monitoring was undertaken at the 35 sites across all zones in spring each year since 2002. A complete set of photos is provided in Appendix 7 of the 2011-12 Annual Report (Hydro Tasmania 2012).

The percentage of sites showing expansion or contraction in ground layer or canopy for all photo monitoring sites in all zones over the monitoring period is shown in Figure 7.19. It should be noted that changes in the canopy can be the result of tree/shrub fall or death or die back of the leaves due to drought. Whether these are related to natural thinning or other processes is not established as photos are often taken from a boat and the cause of the fall or death not readily visible or apparent. The recording of expansion of the ground layer was always on the lower areas of the bank that are readily visible.

Analysis of the photo monitoring reveals that results for the 2002-06 are variable with sites showing a variety of responses including both expansion and contraction of ground layers and canopy. However, while the 2002-3 year showed expansion of vegetation at some sites almost 30 % of sites showed contraction of the ground layer. This also coincided with high total flows for the year and a high proportion of high flows in the preceding 365 day period (Figure 2.18).

Also apparent is the high proportion of sites that underwent contraction of both ground layer and canopy between 2006-07 (Figure 7.19). This coincided with two factors:

- a period of high daily hydro-peaking (Figure 2.11 and Figure 2.16) combined with high total yearly flows and a high proportion of total volume > 200 m^3s^{-1} which occurred in the preceding year (Figure 2.18); and
- a major flood that occurred in August 2007 (three months prior to 2007 spring sampling) provided very high flows, particularly at sites downstream of the Denison River.

Significant expansion of the ground layer occurred between 2007-08. Expansion of the ground layer continued between 2008-09 as well as between 2010-11 with more variable results between 2009-10. The expansion of the ground layer coincided with decreasing total flows and decreasing proportion of high flow events since February 2008 (Figure 7.19).

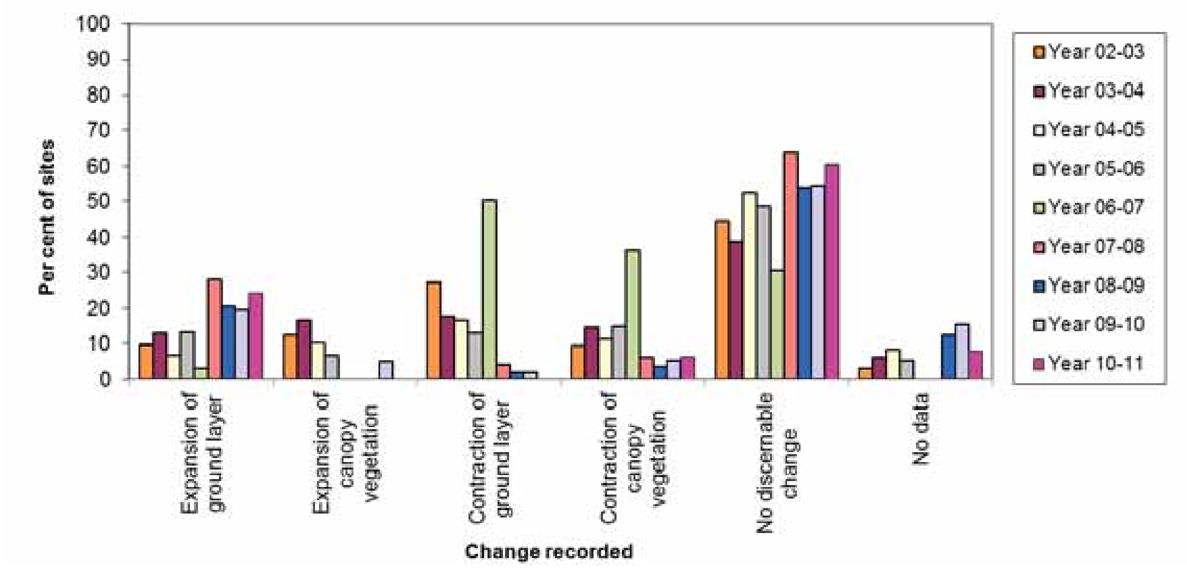

Figure 7.19: Percentage of sites showing contraction or expansion of ground layer or canopy for all photo monitoring sites in all zones over the entire monitoring period.

7.5 Evaluation of monitoring program

The Basslink vegetation monitoring program was designed to gather five years of pre-Basslink data and a further six years post-Basslink data which would allow the effect of the change to power station operation to be accurately quantified rather than relying on comparisons with other rivers. Pre-Basslink monitoring was initiated in April 2002 (Hydro Tasmania 2005b).

The limited number of sampling sites in combination with a range of methods of data collection and vegetation sites which were highly variable in terms of their floristics, slope and aspect resulted in a high degree of variability present in the structure and composition of the vegetation at the monitoring sites.

The limited replication, the small sample size and high degree of variability made it difficult to detect significant vegetation changes in response to changes in power station operation. This was further confounded by the difficulty in determining and defining the change in operation of the power station post-Basslink as the power station was not operated as the modeling predicted. Identifying impacts due to the power station operation in the post-Basslink period was also complicated by natural climatic and hydrological variation including the ending of the drought in the post-Basslink period and its impact on Hydro Tasmania's storage and generation strategies.

Despite the limitations discussed above and in previous reports (Hydro Tasmania 2010a, Hydro Tasmania 2011), the vegetation monitoring program was able to identify trends in species richness as well as vegetation cover, however there is limited statistical power in the data to confirm trends. The monitoring program was able to provide sufficient information to assess whether species composition of sites on the Gordon River have changed in the post-Basslink period and to identify possible causal factors.

Quadrat measures of floristics have proven to be moderately effective in detecting changes on the banks of the Gordon River. Increases in total vegetation and species richness have been detected and most change has occurred post-Basslink. However, variation in the vegetation between zones is high and the small size of the quadrats and minimal replication tends to mask small scale changes occurring at the site level.

Photo monitoring allowed broad-scale assessment of changes in the vegetation that has been valuable in detecting changes particularly to the ground cover vegetation. Changes in shrub and tree canopies are also able to be detected but the cause of these changes is harder to determine. Whether changes in canopy are due to natural thinning, wind fall or impacts on the banks are unclear. Although the photographs do not allow identification of species in all cases, they have provided supporting evidence and allow for investigation on subsequent monitoring trips. Photo monitoring has proven to be a useful and time effective monitoring method.

7.6 Review of triggers

Triggers were developed from an analysis of quantitative quadrat data and the ratio of the ‘above’ quadrats compared with the ‘low’ and ‘high’ quadrats using pre-Basslink data. This ratio analysis was based on the assumption that the ‘above’ quadrats act as a ‘reference’ (un-impacted sites) for the lower quadrats on the bank that are directly impacted by power station discharges.

It should be noted that the trigger values for both types of triggers (quadrat data and ratio data) were based on only five years of pre-Basslink monitoring. Hence, the triggers were frequently exceeded due to sampling a much wider range of variation in measurements than occurred in the pre-Basslink period. Changes to the flow regime were also different from what was predicted due to a number of operational reasons. In addition, community composition triggers particularly Bray Curtis diversity and species richness are highly sensitive to minor changes in measures because of the small scale of the sampling (3 to 4 sites across a zone) and the small quadrat size (1 m x 1 m). Thus, they are regularly exceeded because of the increased recruitment of species that has been recorded over the period of low flows which have occurred between 2008 and 2012. The diversity indices are sensitive to small changes particularly in the lower quadrats where often only two or three species are recorded.

The underlying assumption for the ratio analysis is that the ‘above’ quadrats act as a ‘reference’ for the quadrats that are lower on the bank and thus are more directly impacted by flow changes. This hypothesis is flawed because it relies on the assumption the ‘above’ quadrats are not impacted by flows and therefore are stable and remain unchanged. However, as noted in the previous review (Hydro Tasmania 2010a) some ‘above’ quadrats have been affected by flows and they do not remain unchanged over time. Therefore, by not acting as an effective reference, trigger values can be exceeded due to changes recorded in the ‘above’ quadrat rather than change occurring in the flow impacted ’high’ and ‘low’ quadrats. For example, a 10 % increase in total vegetation cover in an ‘above’ quadrat (containing 70 % total vegetation cover) is a much more observable change than the same percentage change in a ‘low” quadrat (which may typically contain ≤ 5 % total vegetation). Large well established plants (including fern species) located in the ‘above’ quadrats are able to significantly increase leaf area relatively quickly and smaller plants in lower quadrats subject to adverse conditions may be much slower to increase in leaf area.

Whilst the triggers themselves may not be of particular ecological significance in terms of whether they are exceeded or not, they are useful in terms of setting benchmarks against which to explain ecological change and the processes likely to be responsible for it.

7.7 Conceptual model

Since Basslink commissioning the hydrological regime in the Gordon River has been different compared to the pre-Basslink period. Post-Basslink changes have included a number recognisable flow patterns (see Section 2.4.2.3 and Table 7.1).

Vegetation can be immediately impacted by a flow event, but generally will take a much longer period to recover. Therefore, it is difficult to determine whether the vegetation is responding to an individual event occurring in the beginning of the monitoring year or a series of events occurring throughout the monitoring year. What is apparent through the analysis is that it was the total annual volume over several years, rather than any short term flow patterns (e.g. peaking to three turbines), that affected the vegetation.

The seepage erosion which resulted in impacts on vegetation in the 2-3 turbine zone that was reported in Basslink Review Report 2006-09 (Hydro Tasmania 2010a) occurred in a period where there were extended periods of hydro-peaking in the 2-3 turbine zone combined with high total yearly flow volumes. This flow pattern has not been repeated and since 2008, the flow patterns have been dominated by daily hydro peaking (0-1 turbine, 0-2 turbines or 0-3 turbines) and the low flow dominant patterns (10 to 40 m^3s^{-1}) (See Figure 2.16 and Figure 2.17). All of these flow patterns have occurred in years with low annual volume and recovery of bank vegetation was recorded. This would suggest that there is a positive vegetation response during long periods of low annual flow volume. General vegetation responses to prolonged flow patterns are described in Table 7.1.

Table 7.1: Response of vegetation to the dominant flow patterns occurring on the Gordon River.

Flow pattern	Vegetation response
Low flow dominant- minimum flow with occasional peaks to 1-2 turbine level.	Vegetation on the all bank levels is in good condition with plants having aerated roots and seedlings are able to establish in the low flow environment.
Daily peaking to 1 or 2 turbines.	Vegetation on the upper banks is in good condition and roots are well aerated. The vegetation in the 1-2 turbine level can survive individual peaks; however vegetation will not survive under prolonged, repeated hydro-peaking operations. This process is most dominant in the upstream zones.
Daily hydro-peaking to 3 turbine level – rapid, regular alternation between minimum flow and 3 turbine discharge – with and without mitigation.	**With mitigation -** Established vegetation and seedlings can survive individual peaks, however vegetation will not survive under prolonged, repeated, hydro-peaking operations. The vegetation is most likely to disappear in the upstream zones first. Mitigation will slow the speed at which seepage erosion processes occur, and may slow the rate at which vegetation disappears through the maintenance of substrate and bank structure. **Without mitigation -** Established vegetation and seedlings can survive individual peaks, however vegetation will not survive under prolonged, repeated, hydro-peaking operations. The vegetation is most likely to disappear in the upstream zones first. High rates of seepage erosion will act to quicken the rate of decline in vegetation through the removal of substrate and slumping.
Daily hydro-peaking in 2-3 turbine level - rapid, regular alternation between flow at 2 and 3 turbine flow levels.	Seepage processes lead to the loss of sediment in the 2-3 turbine bank level which under cuts vegetation, leading to the formation of 'cavities' and the collapse of over lying vegetation. The vegetation cannot survive in the 1-2 turbine level due to inundation.
Base load utilising 3 turbines.	The vegetation is inundated for extended periods and exposed to high velocities. Both processes leads to loss of vegetation on the banks

7.8 Conclusions

The vegetation monitoring program that has been undertaken on the Gordon River over the past 11 years has used a multiple lines of evidence approach and has provided an understanding of the processes and ecological responses occurring on the river due to changes in power station operation.

There was little evidence of a sustained change in species composition over time, however a significant change was detected in total vegetation cover in the post-Basslink period (2006-12). There was evidence of an overall increase in total vegetation cover at all bank levels. The increase in cover was most evident in the 'above' levels across all zones.

There was an overall increasing trend in species richness that was evident after 2006. The increase in species richness was most obvious at 'high' sites. This was consistent with an increase in species richness associated with the enhanced colonisation of species and persistence of vegetation in the ‘high’ and ‘low’ quadrat types.

Based on the analyses undertaken, the causes of changes in vegetation cover, species richness and ground cover indicate that sustained lower total yearly flows and lower duration of high flows have been key influences on observed changes in vegetation. The low power station discharge over the last four years of the monitoring program have allowed for the colonisation and expansion of vegetation on the banks of the Gordon River. This has resulted in a measurable increase in vegetation cover and also an associated increase in species richness as the low flows have allowed the establishment and expansion of recruited species particularly in ‘high’ and ‘low’ quadrats. The reduction in power station use and consequent low flows have first affected the ‘high’ quadrats with a reduced duration and frequency of inundation allowing earlier recovery of these quadrats.

While changes in vegetation have occured in response to alterations in flow patterns, prolonged exposure to a pattern is required before the response becomes evident in the vegetation. The flow pattern will determine where the changes in bank vegetation occur, however an annual volume threshold is required before vegetation is negatively impacted.

The vegetation monitoring techniques have yielded information of varying usefulness, with the quadrat monitoring of floristics and ground cover, and the photo monitoring, proving most useful in detecting vegetation change. The vegetation monitoring program has supported and confirmed the processes identified in the ecological conceptual model which can be used to predict ecological response to future long-term changes in power station operation.

To date the flow regime experienced since the commissioning of Basslink appears to have had enhanced the recovery of vegetation on the banks of the Gordon River.

7.9 Recommendations

The middle Gordon River has been regulated for many years prior to the implementation of this study, meaning the banks have already been highly impacted and monitoring has only recorded short-term level of recovery to those impacted banks.

It is recommended not to continue the vegetation monitoring as the current design has low statistical power due to the low degree of replication, and high variability present. Given our understanding of the response of the riparian vegetation to changes in power station operation, future impacts to the riparian vegetation can largely be understood using the conceptual model.

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8. Benthic macroinvertebrates, algae and moss

8.1 Summary

Most benthic macroinvertebrate indicators did not show a major change between pre- and post-Basslink periods. There were significant post-Basslink changes in some macroinvertebrate indicators, most of which may be considered positive Basslink-related impacts. The changes identified are consistent with the conceptual model, with trigger exceedances being generally a positive response to the post-Basslink minimum environmental flow mitigation measure.

Lagged responses to post-Basslink minimum flow conditions were detected in several macroinvertebrate indicators, mainly due to increases in abundance of several EPT taxa, which may take several generations (i.e. 2-3 years) to occur. These upward trends have led to exceedances for some triggers with time. These exceedances all represent improvements in overall condition of macroinvertebrate communities.

Filamentous algal and benthic moss cover varied both between zones in the Gordon River and with time. None of these changes are of substantive ecological concern, and no substantive trigger exceedances were observed after Basslink operations commenced.

8.2 Introduction

The aims of macroinvertebrate and aquatic plant monitoring in the Gordon River included:

- Documenting how post-dam and post-Basslink flow conditions continue to influence the in-stream biological condition of macroinvertebrates, algae and aquatic moss.
- Relating the observed changes in community composition and abudandance to power station operations, or other factors, where possible.
- Comparing results collected since the operation of Basslink with pre-Basslink results to determine whether observed changes in the river are consistent with the understanding of the conceptual model of the river and are within 'limits of acceptable change'
- Assessing the effectiveness of the 10/20 environmental flow on the macroinvertebrates, algae and aquatic moss communities of the Gordon River.

8.3 Methods

Benthic macroinvertebrates, filamentous algae and benthic moss have been sampled twice a year, in spring and autumn, for each year of the Basslink Monitoring Program (2001-12). This monitoring has been conducted at nine sites in the Gordon River, downstream of the Gordon dam, and six sites in reference rivers (Figure 8.1 and Figure 8.2). This sampling is both quantitative and semi-quantitative, and provides multivariate and univariate data. For analysis, reporting and some interpretation, the sites have been grouped into the following zones:

- zone 1 (Gordon River sites 75, 74, 72 and 69);
- zone 2 (Gordon River sites 60, 57, 48 and 42); and
- reference rivers (all six reference sites Fr11, Fr21, De7, De35, Ma7 and Ja7).

(Note site 63 has been excluded from all analyses due to its transitional nature i.e. located above the confluence of the Denison River and highly influence by high flows from the Denison River.)

The macroinvertebrate multivariate data consists of matrices of taxon abundance (per unit area of river bed) by site for each sampling occasion. The level of taxonomic identification is at both family level (for all taxa, consistent with the level of identification used in the AUSRIVAS protocol) and at genus/species level (for the insect orders Ephemeroptera, Plecoptera and Trichoptera – referred to as the ‘EPT’ group).

The macroinvertebrate univariate data derived from the multivariate data consists of abundance records for all taxa on each sampling occasion and a set of nine indicators, all of which are derived for each sampling occasion. The values of the nine indicators derived from samples collected during the post-Basslink period are reported against pre-Basslink trigger values developed from the pre-Basslink data.

Filamentous algal and moss monitoring data derived from all Gordon River monitoring sites were used to derive mean percent cover values at site and zone scales. These mean cover figures were used at zone scale to assess compliance with pre-Basslink triggers.

All indicators are listed in Table 8.1, grouped by the key ecological component that they represent. The background and original justification for these indicators is presented in the Basslink Baseline Report (BBR) (Hydro Tasmania 2005a).

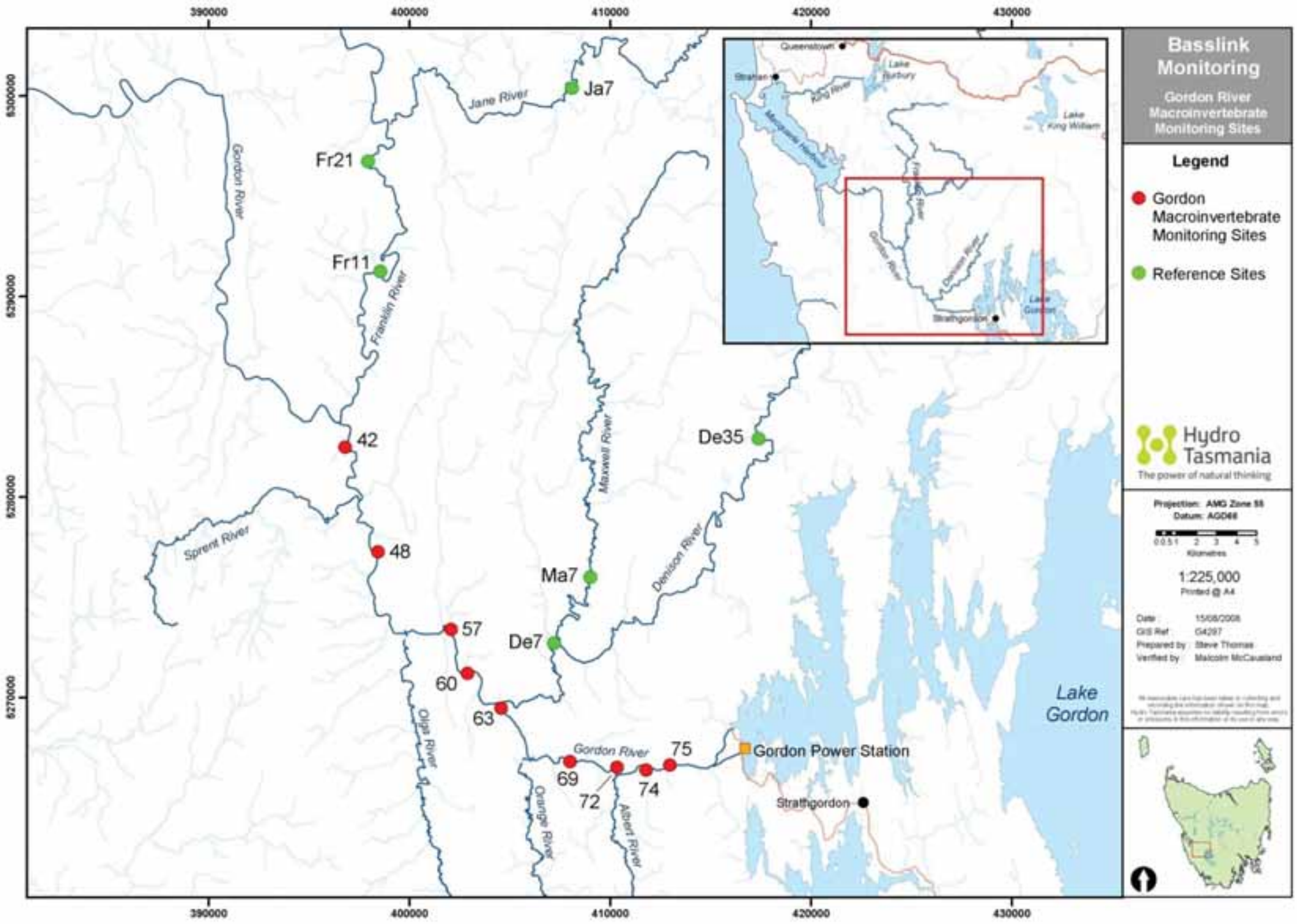


Figure 8.1: Map of the Gordon River catchment showing benthic macroinvertebrate monitoring sites.

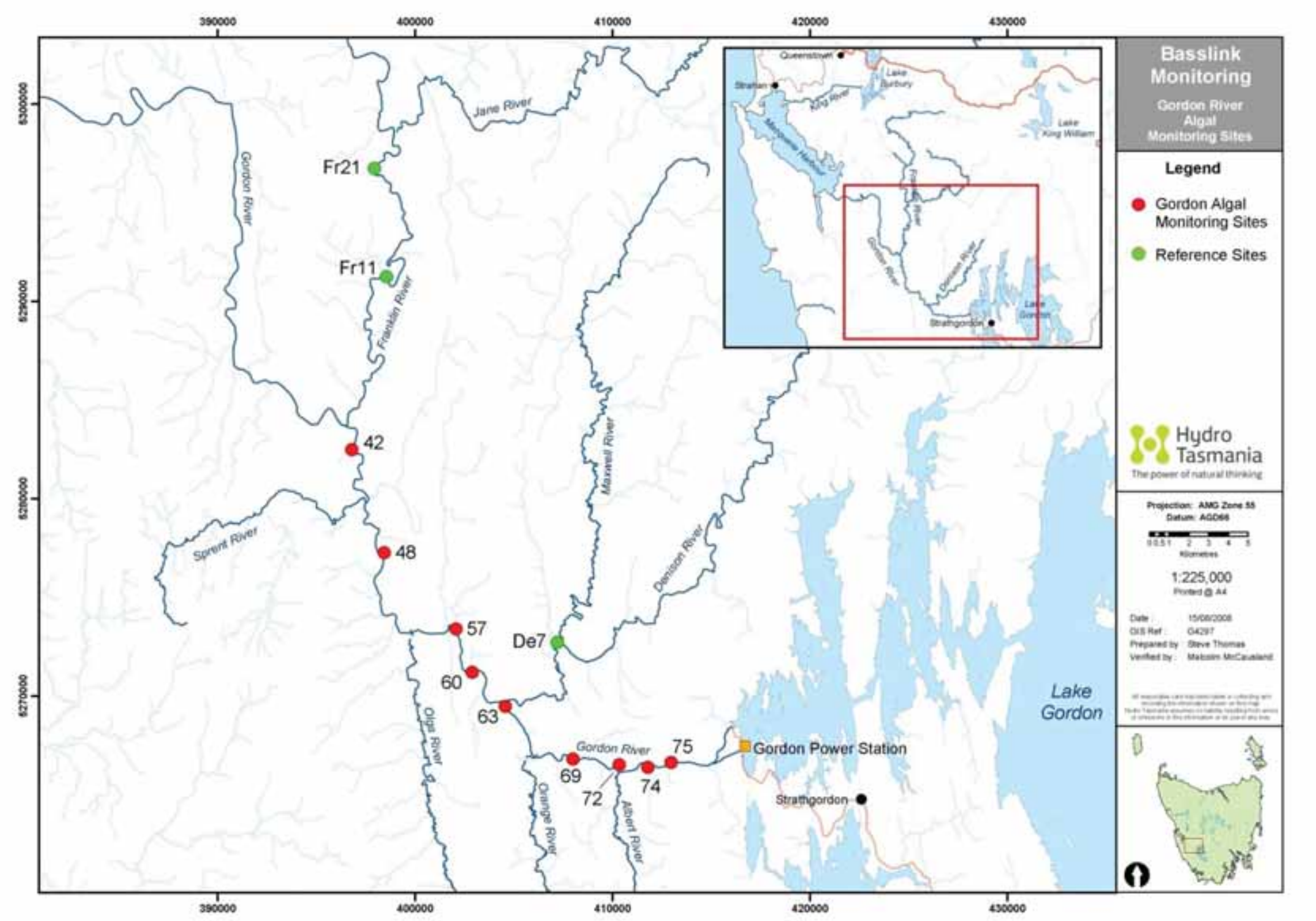


Figure 8.2: Map of the Gordon River catchment showing algae and moss monitoring sites.

Table 8.1: Mapping of key components to the final list of reported variables for which trigger values were derived. * BM = benthic macroinvertebrates; A = filamentous algae; M = moss.

Component	Type *	Indicator	Description
Community structure	BM	BC abundance	Bray Curtis Similarity to Reference (abundance data)
	BM	O/Erk	Observed to expected ratio (rank abundance data)
Community composition	BM	BCpa	Bray Curtis Similarity to Reference (presence/absence data)
	BM	O/Epa	Observed to expected ratio (presence/absence data)
Taxonomic richness	BM	N taxa (family)	Taxon richness (number of families)
	BM	N EPT taxa	Number of genus/species taxa from the EPT group
Ecologically significant species	BM	Proportion EPT taxa	Proportion of total abundance represented by EPT species
	BM	Abundance EPT taxa	Total abundance of the EPT group (number per unit area)
Biomass/productivity	BM	Total abundance (family)	Total abundance of all benthic macroinvertebrates (number per unit area)
	A	Filamentous Algal cover	Mean of % cover of benthic algae
	M	Aquatic Moss cover	Mean of % cover of benthic mosses

8.4 Trends in consolidated data

8.4.1 Univariate indicators

Trends in all metrics are shown in Figure 8.3 to Figure 8.7. Most metrics show no overall trend across the entire sampling period in the Gordon River, and are generally consistent in values with time. The value of all metrics is predominantly highest in reference sites, lowest in zone 1 and intermediate in zone 2. This is consistent with the BBR conceptual model in which the effects of flow regime alteration and changes in sediment and carbon regime are greatest in zone 1, and partially rectified downstream by tributary inputs (especially the Denison River), causing zone 2 values to be higher.

Some metrics show high levels of variability through time – most notably the number and total abundance of EPT species and total abundance. Reference rivers show a decline between 2001 and 2009 in the number of family taxa, the number of EPT species, total abundance and the abundance of EPT species (Figure 8.5 to Figure 8.7). This has also been accompanied by a decline of around 0.2 units in both O/Epa and O/Erk for both seasons (spring and autumn, Figure 8.3). This decline is believed to be related to the increasing dry conditions experienced during the program (refer to Chapter 2, Hydrology and water management), which have led to declining flows in reference rivers. Declines are also observed in the Gordon River in zone 2 for two indicators: O/Erk and the number of EPT species which reflects the fact that this zone is more influenced by inputs from tributaries than zone 1, and hence shows some aspects of biological trends observed in the reference rivers.

Trends in the Gordon which are likely to indicate responses to post-Basslink conditions were:

- an increase in the absolute and proportional abundance of the EPT group in zone 1 since spring 2008 (Figure 8.6); and
- an increase in O/Epa and O/Erk in zone 1 since autumn 2007-08 (Figure 8.3).

These metrics showed a lagged response to post-Basslink conditions, with increases since 2007. The lags in response are believed to be related to the time required for population and diversity increases. These require a mix of increased recruitment and/or immigration. The former may take 1-3 years to become apparent in monitoring data, depending on the life histories of the various taxa. The zone 2 macroinvertebrate community appears to track inter-annual changes in abundance of several dominant taxa, probably reflecting recruitment inputs (larvae, eggs) from the Denison and Olga Rivers combined with this zones more natural flow and carbon food-resource regime.

The trends of increasing proportional abundance of EPT, O/Epa and O/Erk in zone 1 were accompanied by a rise in O/Erk in autumn 2009 in both zone 2 and reference sites. Additional data over the next two years is required to confirm whether this is indicative of a Basslink related effect or driven by naturally higher recruitment of expected families throughout the Gordon-Franklin system (see note below regarding synchrony in abundance of key taxa between zone 2 and the Reference rivers).

Two-way ANOVA of indicator values with period (post- *vs* pre-Basslink) and season (autumn *vs* spring) as factors revealed no differences in any indicator in zone 1 (all p >0.08). Thus there were no statistically significant differences in indicator values between the pre- and post-Basslink period in zone 1. There were lagged changes evident in several indicators (indicated in trend plots) including increased values in 2006–07. However, these results are still similar to pre-Basslink values. This, combined with the small degrees of freedom (3 – 5 samples per factor stratum), precludes statistically significant differences.

In contrast, two-way ANOVA did reveal significant inter-period differences in the following indicators in zone 2:

- the number of EPT species, with pre- and post-Basslink means of 13.5 and 9.7 species respectively (p = 0.008);
- the proportion of EPT taxa, with pre- and post-Basslink means of 0.289 and 0.198, respectively (p = 0.04), also accompanied by a significant inter-seasonal difference (p = 0.03); and
- the abundance of EPT taxa, with pre- and post-Basslink means of 4.32 and 3.75, respectively (p = 0.04), also accompanied by a marginal inter-seasonal difference (p= 0.06).

These differences represent declines in the species richness and abundance of EPT species in the macroinvertebrate community of zone 2 during the post-Basslink period. Examination of the data, and comparison with zone 1 and reference sites, indicates that these declines were likely due to a combination of catchment-wide reductions in natural flows, particularly over the post-Basslink period, and the (albeit transient) effect of the substantial flood sequence in winter-spring 2007. These differences are therefore unlikely to be Basslink effects.

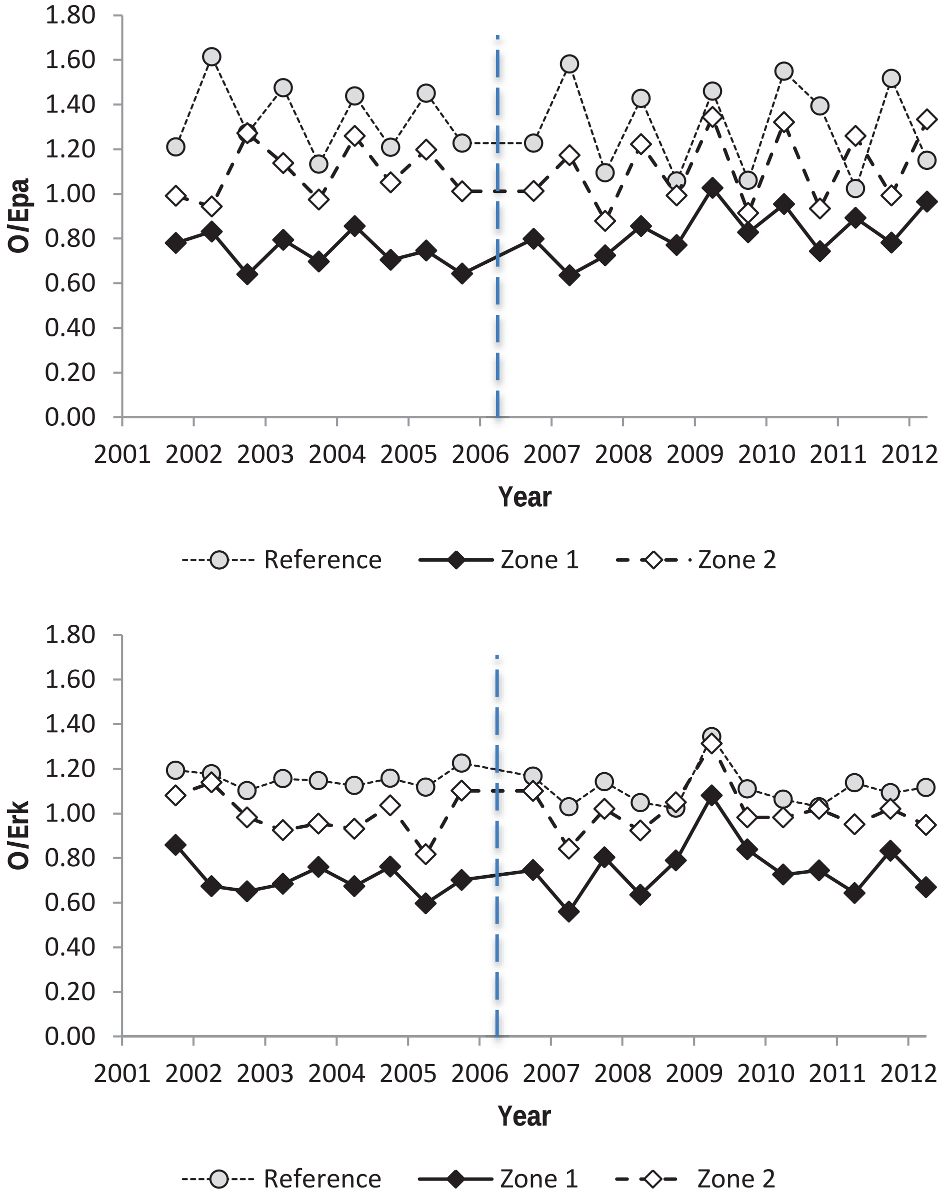


Figure 8.3: Mean O/Epa and O/Erk indicator values for the Gordon River zones and reference sites over the entire Basslink monitoring period. Vertical dashed line indicates initiation of Basslink operations.

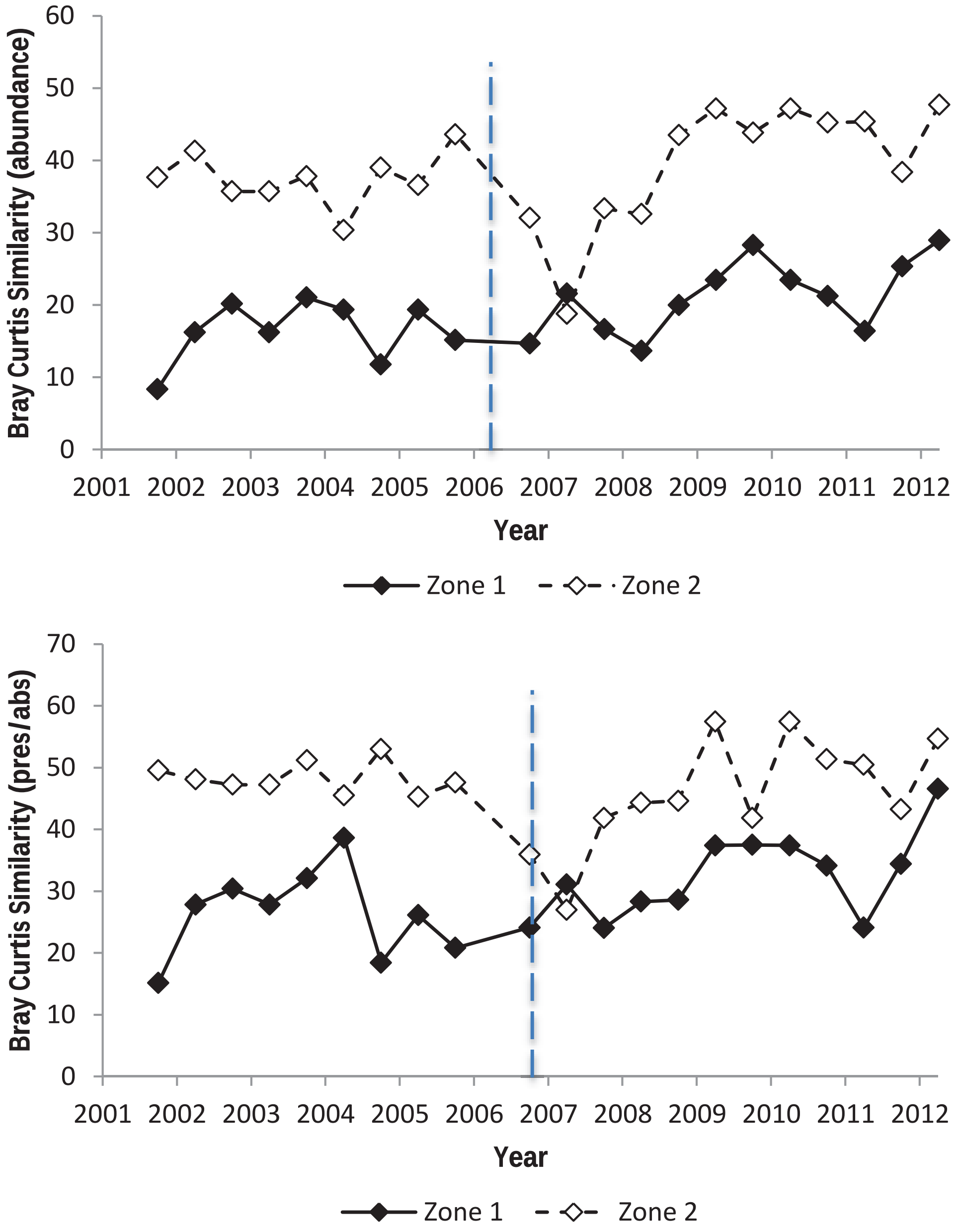


Figure 8.4: Mean Bray Curtis Similarity indicator values for each zone in the Gordon River on each sampling occasion. Vertical dashed line indicates initiation of Basslink operations. Similarity index based on comparison between Gordon and reference rivers.

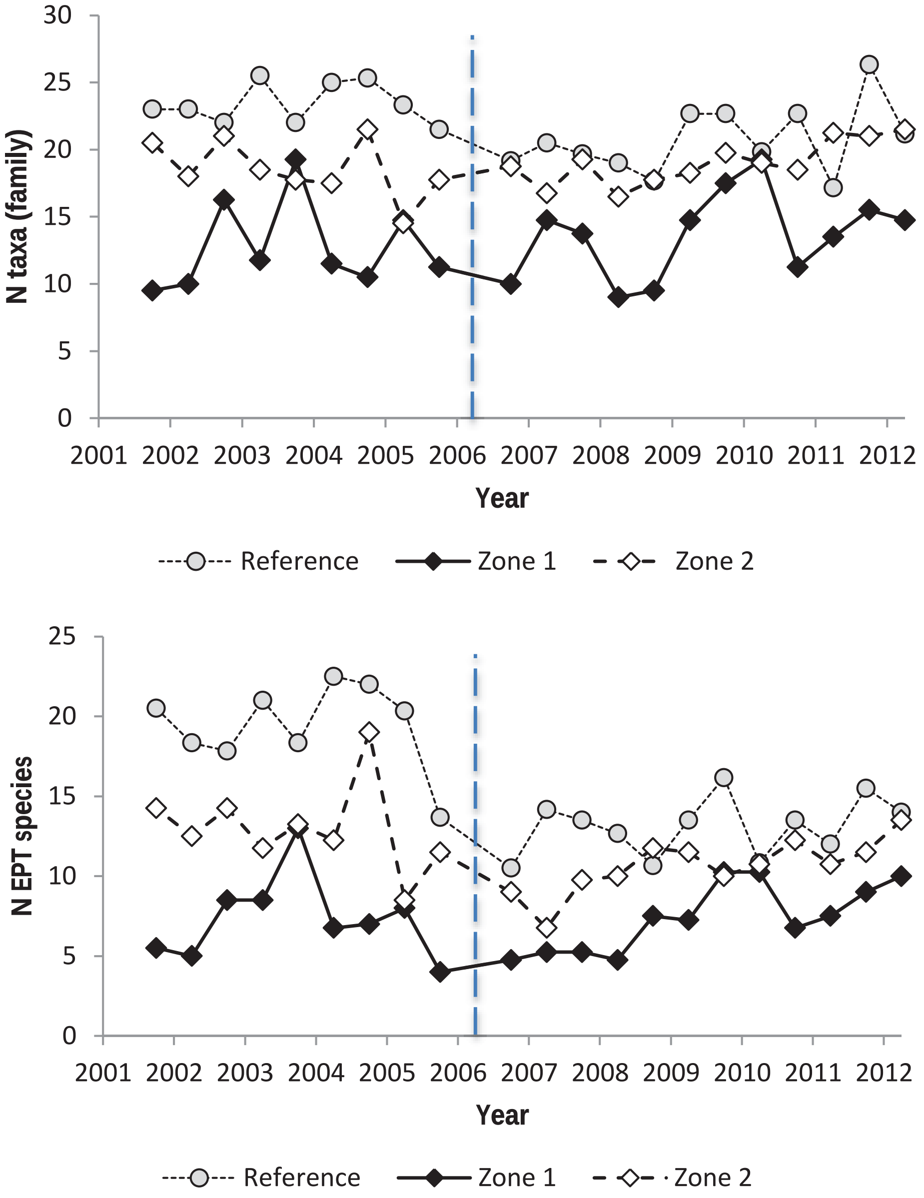
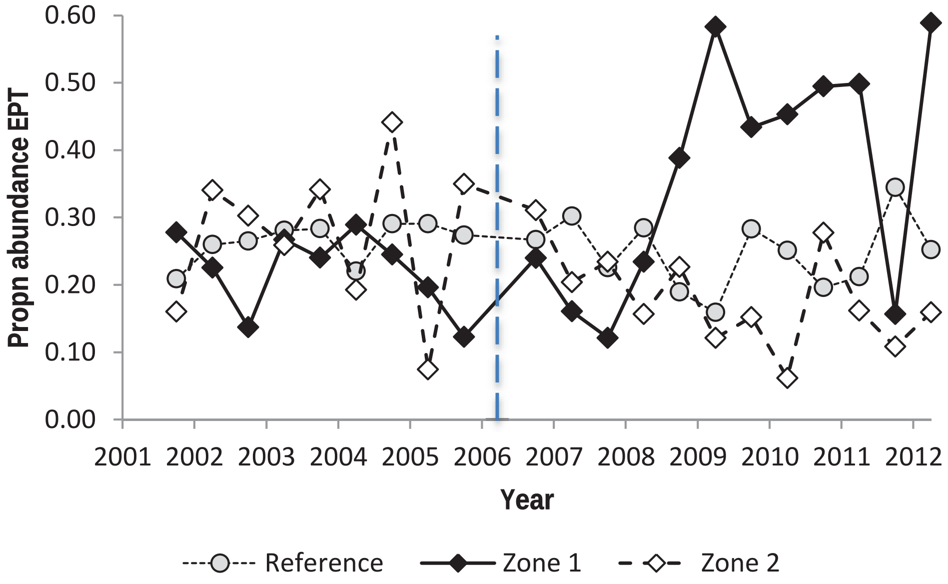


Figure 8.5: Mean N taxa (family) and N EPT species indicator values for each zone in the Gordon and reference rivers on each sampling occasion. Vertical dashed line indicates initiation of Basslink operations.



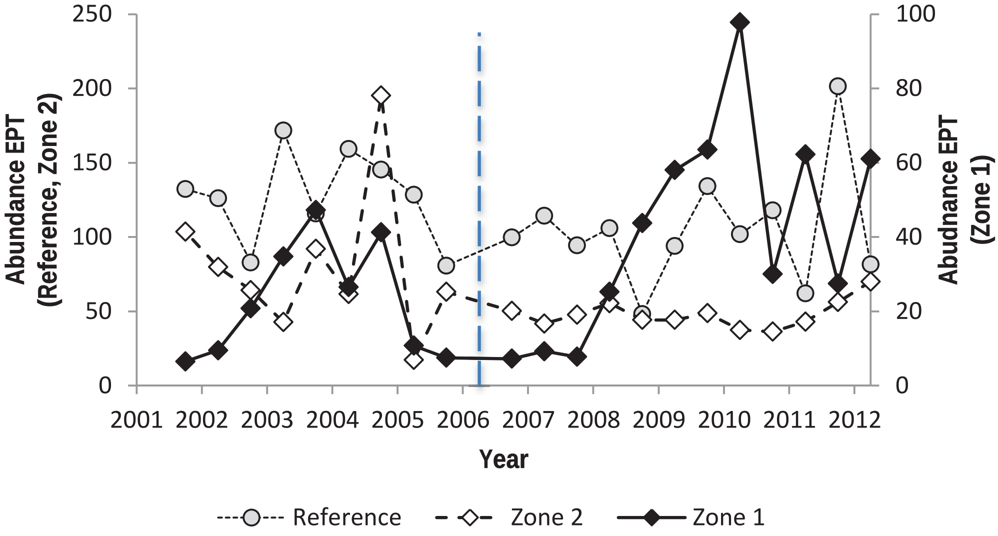


Figure 8.6: Mean proportional abundance and absolute abundance of EPT taxa indicator values for each zone in the Gordon River and reference rivers on each sampling occasion. Vertical dashed line indicates initiation of Basslink operations.

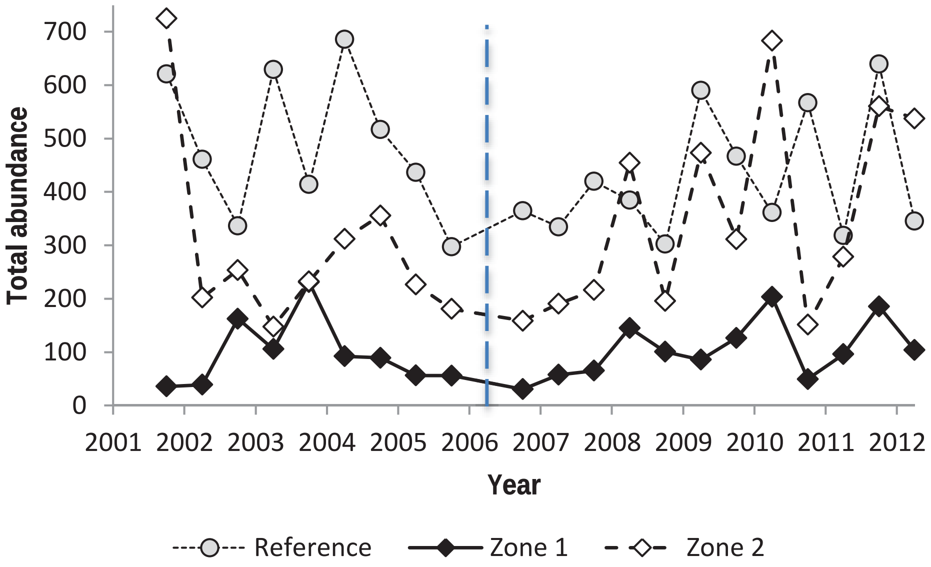


Figure 8.7: Mean total abundance indicator values for each zone in the Gordon and reference rivers on each sampling occasion. Vertical dashed line indicates initiation of Basslink operations.

8.4.2 Individual taxon abundances

Trends were evident over the monitoring period in several numerically dominant taxa in the Gordon River (Figure 8.8 and Figure 8.9). The taxon responsible for the change in the absolute and proportional abundance of EPT taxa indicators in zone 1 is the caddis family Hydropsychidae (especially *Asmicridea*, the snowflake caddis), for which an increasing abundance is observed since spring 2008 in zone 1 (Figure 8.8).

By contrast, hydropsychid numbers have been stable during that period in zone 2 (Figure 8.8). This taxon has been consistently more abundant in zone 2, especially in the vicinity of the Denison confluence (between sites 57 and 63). This taxon favours uninterrupted, steady flow conditions combined with abundant food resources in the form of particulate organic material as it is a net-building filter feeder. Since Basslink operations commenced, these conditions have increasingly been met in zone 1 (upstream of the Denison confluence) due to the presence of a minimum environmental flow.

The abundance of gripopterygid stoneflies post-Basslink has been stable in both zones in comparison with the pre-Basslink period (Figure 8.8). Hydrobiosid caddis, the dominant aquatic insect predator, has been variable throughout the monitoring period in both Gordon River zones. Evidence suggests a post-Basslink but requires more data to be confirmed (Figure 8.8).

For three taxa – gripopterygid stoneflies, Simuliidae (blackflies), and hydrobiosid caddis – abundances in zone 2 appear to ‘track’ abundances in the reference rivers: this is particularly notable for the stoneflies and simuliids (Figure 8.9). For hydrobiosid caddis, some tracking is evident pre-Basslink, but not since spring 2008, when numbers in zone 2 appear to have increased relative to reference rivers. A late post-Basslink increase may also be occurring for simuliids in zone 2.

Overall, there appears to be a post-Basslink increase in abundance of Hydropsychidae in zone 1, with indications of other taxa starting to show a lagged increase in zone 2.

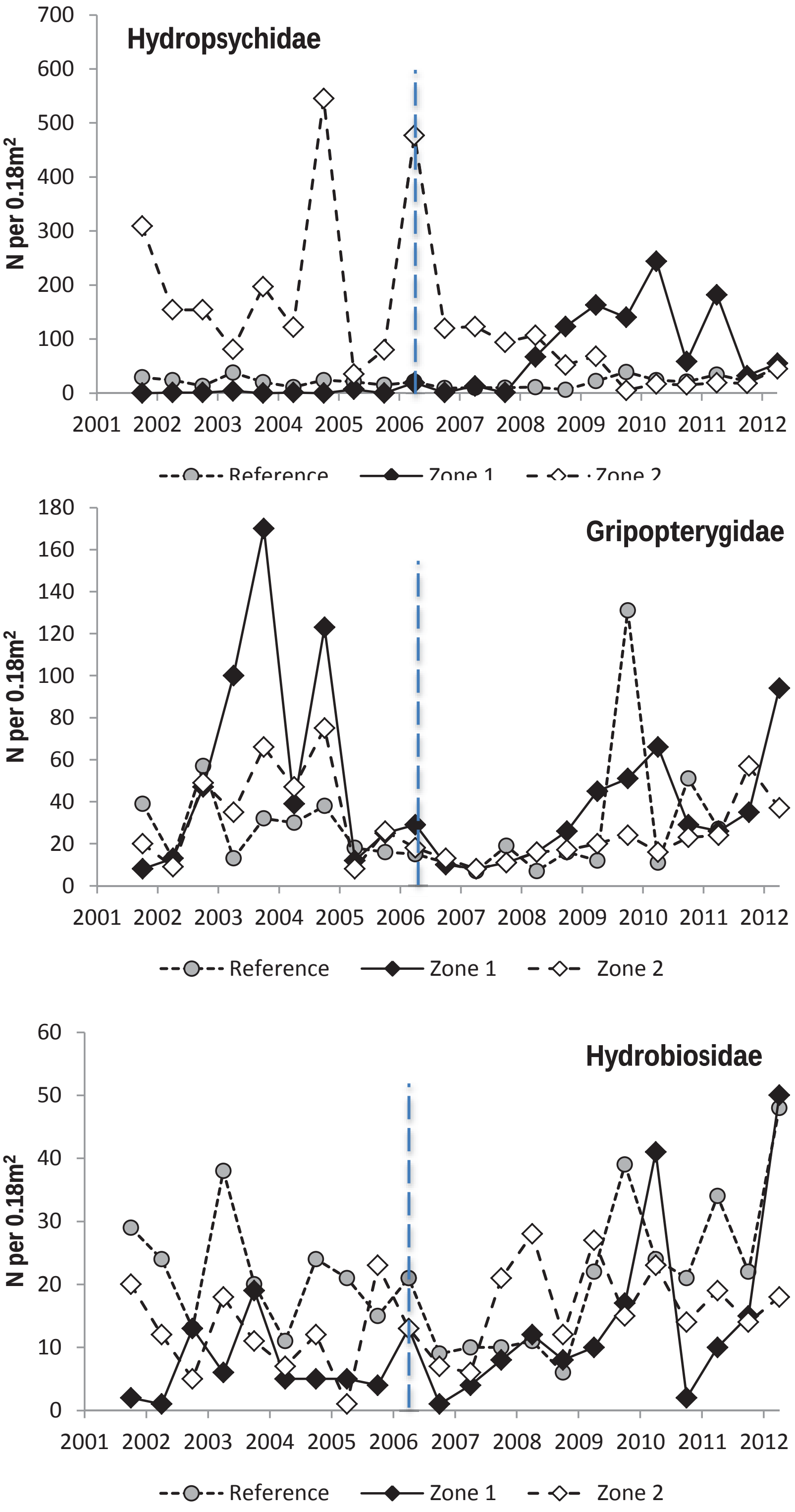


Figure 8.8: Mean abundance of three key taxa for zone 1 and 2 in the Gordon River, and in the reference rivers, against time. Dashed vertical line indicates initiation of Basslink operations.

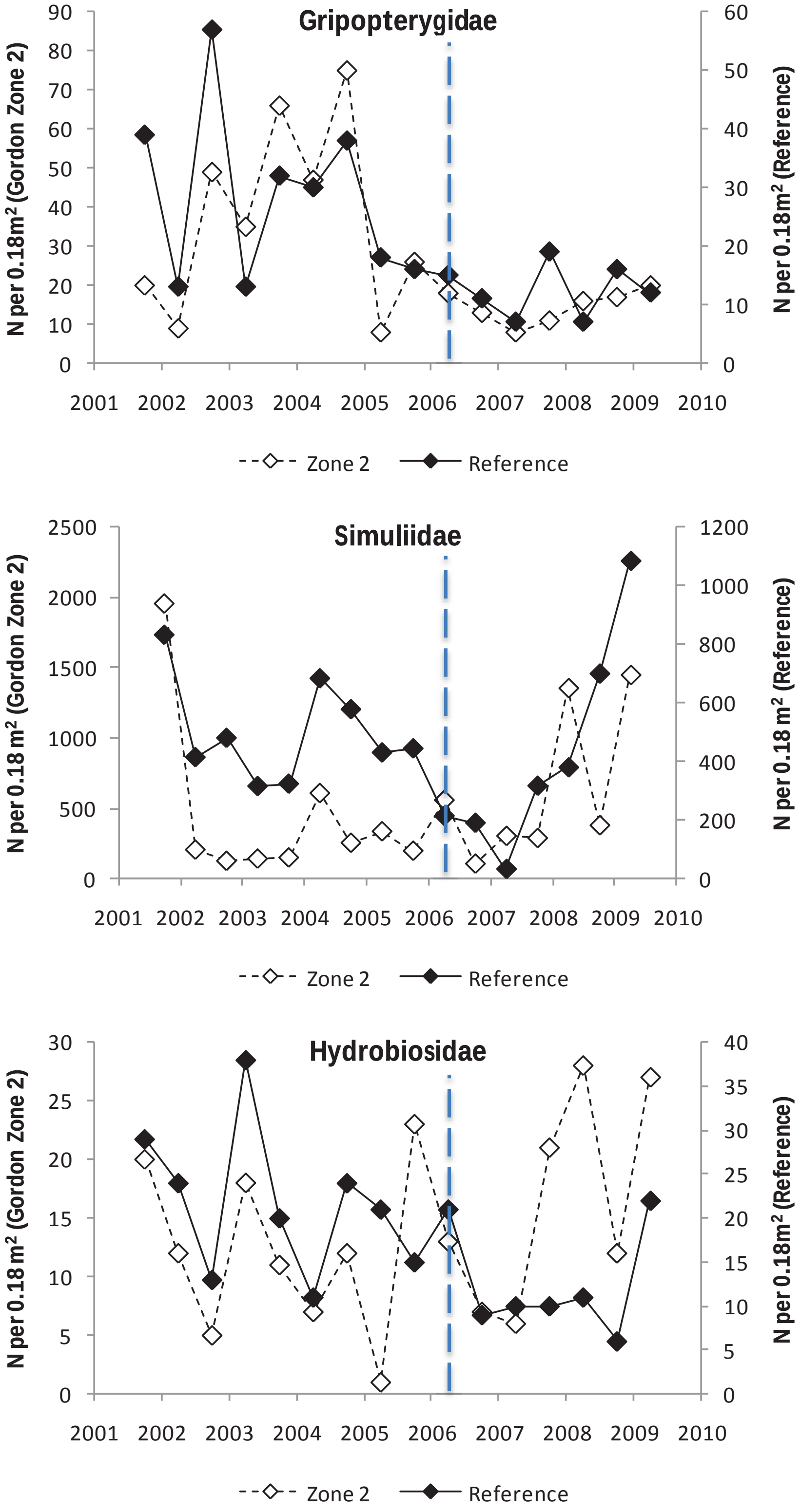


Figure 8.9: Mean abundance of three key taxa for zone 2 in the Gordon River and in reference sites against time. Dashed vertical line indicates initiation of Basslink operations.

8.4.3 Multivariate trends

Community composition relationships between sites were presented in the Basslink Baseline Report (Hydro Tasmania 2005a) by use of multidimensional scaling (MDS) ordination plots. The spatial trends within the Gordon River are broadly consistent throughout the monitoring period, as indicated in Figure 8.10, with a trend in community composition dominated by loss of taxa at sites closer to the Gordon Power Station. This pattern has been broadly consistent since power station releases commenced in 1977, as indicated in Figure 8.10 where data from the Hydro Tasmania investigations in 1977 (Coleman 1978) is plotted alongside Basslink monitoring data.

Presentation of ordinations of repeated site samples for the entire monitoring program is too complex for interpretation and ordination has therefore been conducted on abundance data aggregated to zone level (by summing taxon abundances among sites within a zone). For this analysis, the three zone aggregations are: zone 1 and zone 2 within the Gordon River, and reference rivers. The patterns of similarity between zone samples and their trends through time are illustrated in Figure 8.11 to Figure 8.15.

These ordination plots are ‘maps’ of compositional similarity between zone samples, and are based on a matrix of (Bray Curtis) similarity measures between samples which are fitted as distances in ordination space. Hence samples with highly similar composition are close together, while those with low similarity (in taxonomic composition, abundances or both) are further apart.

Ordination of all zone samples across the entire monitoring period (Figure 8.11) revealed three distinctly separate sample groupings, with reference rivers and zone 2 similar to each other but distinct in composition, and with relatively closely grouped samples. Zone 1 is highly dissimilar from reference rivers and has become more variable in composition through time, especially post-Basslink. Within these dominant inter-zone differences there is also a marked seasonal signal. For example, autumn and spring samples in reference rivers are significantly different (by analysis of similarities, ANOSIM with 999 permutations, $p = 0.008$, Figure 8.12). Note that this analysis revealed no differences in composition between the pre- and post-Basslink periods (ANOSIM with 998 permutations, $p = 0.49$). Formal multivariate analysis of the significance of compositional variation across zone, period and season is described below (using Primer-E PERMANOVA). Individual tests are therefore described here only to illustrate the dominant patterns.

Post-Basslink samples from zone 1 are compositionally distinct from those taken pre-Basslink (Figure 8.12 and Figure 8.13) and this difference is statistically significant (by ANOSIM, $p = 0.001$). Pre- vs. post-Basslink samples from zone 2 are also significantly different across both seasons ($p = 0.04$ by ANOSIM, Figure 8.14).

Identified using the Primer-E package SIMPER routine, changes in zone 1 are a result of pre- vs. post-Basslink differences in abundance of several taxa. In autumn, these taxa were, in order of decreasing importance: Hydropsychidae, Simuliidae, Orthocladiinae, Gripopterygidae, Leptophlebiidae and Hydrobiosidae, accounting for 46 % of the difference in compositional similarity between the two periods. Hydropsychidae, Simuliidae and Hydrobiosidae experienced substantive increases in abundance during the post-Basslink period. In spring the key taxa, in order of decreasing importance, were: Simuliidae, Hydropsychidae, Janiridae, Diamesinae and Gripopterygidae, accounting for 42 % of the difference in compositional similarity between the two periods. The Simuliidae and Hydropsychidae experienced substantive increases in abundance during the post-Basslink period, while Janiridae and Diamesinae experienced decreases.

Hydropsychid caddis abundance (dominated by *Asmicridea*) has been superimposed on the ordination of zone 1 samples in Figure 8.15. A marked shift toward greater abundances post-

Basslink can be clearly seen, particularly in the autumns of 2009–11. The above sequences of taxa showing pre- vs. post-Basslink changes is consistent with their relative flow sensitivity, with Hydropsychidae and Simuliidae being markedly flow dependent in their feeding strategies and physiology. Davies et al. (1999) identified several ‘flow obligate’ taxa which respond markedly to flow alteration downstream of Tasmanian hydroelectric infrastructure, with the above taxa being prominent in macroinvertebrate community responses to altered flows.

Multivariate analysis of variance was conducted on the taxon (abundance x sample) biological data matrix using the PERMANOVA (permutational MANOVA) routine in Primer-E Permanova+ software package. The aim was to assess the degree to which variation in biological composition was related to key factors in the sample, (zones 1, 2 and reference), season (spring and autumn) and period – with the latter differentiating pre- vs. post-Basslink time periods (spring 2001 – spring 2005, and spring 2006 – autumn 2012 respectively).

All three factors were statistically significant (Table 8.2), with zone (i.e. geographic location) accounting for by far the greatest proportion of variance in the data (49 %), followed by season (3 %) and period (2 %). There was a strong interaction between period and zone, unsurprisingly, as there were no major differences in the reference sites between the pre- and post-Basslink periods, in contrast to zones 1 and 2.

Due to the overwhelming influence of zone, pairwise tests were conducted to evaluate the significance of compositional differences between the two periods within each of the three zones. No significant difference was observed for reference sites, as expected ($p > 0.3$). The difference in composition between the two periods was substantially greater for zone 1 than for zone 2 ($p = 0.01$ and 0.026 levels respectively, following 999 permutations each). These results reflect the pattern seen in the ordination in Figure 8.10.

Reference sites were then excluded from the analysis, due to their substantial compositional differences from Gordon samples. All three factors were again statistically significant (Table 8.3), with zone again accounting for by far the greatest proportion of variance in the data (46 %), followed by period (5 %), then season (2.6 %). There was again a strong interaction between period and zone, as there were substantial differences between the pre- and post-Basslink period responses of zones 1 and 2. An interaction term between period and season was also marginally significant ($p = 0.054$). A pairwise test again revealed that zone 1 differed substantially between the pre- and post-Basslink periods ($p = 0.001$), compared to a less significant difference for zone 2 ($p = 0.035$).

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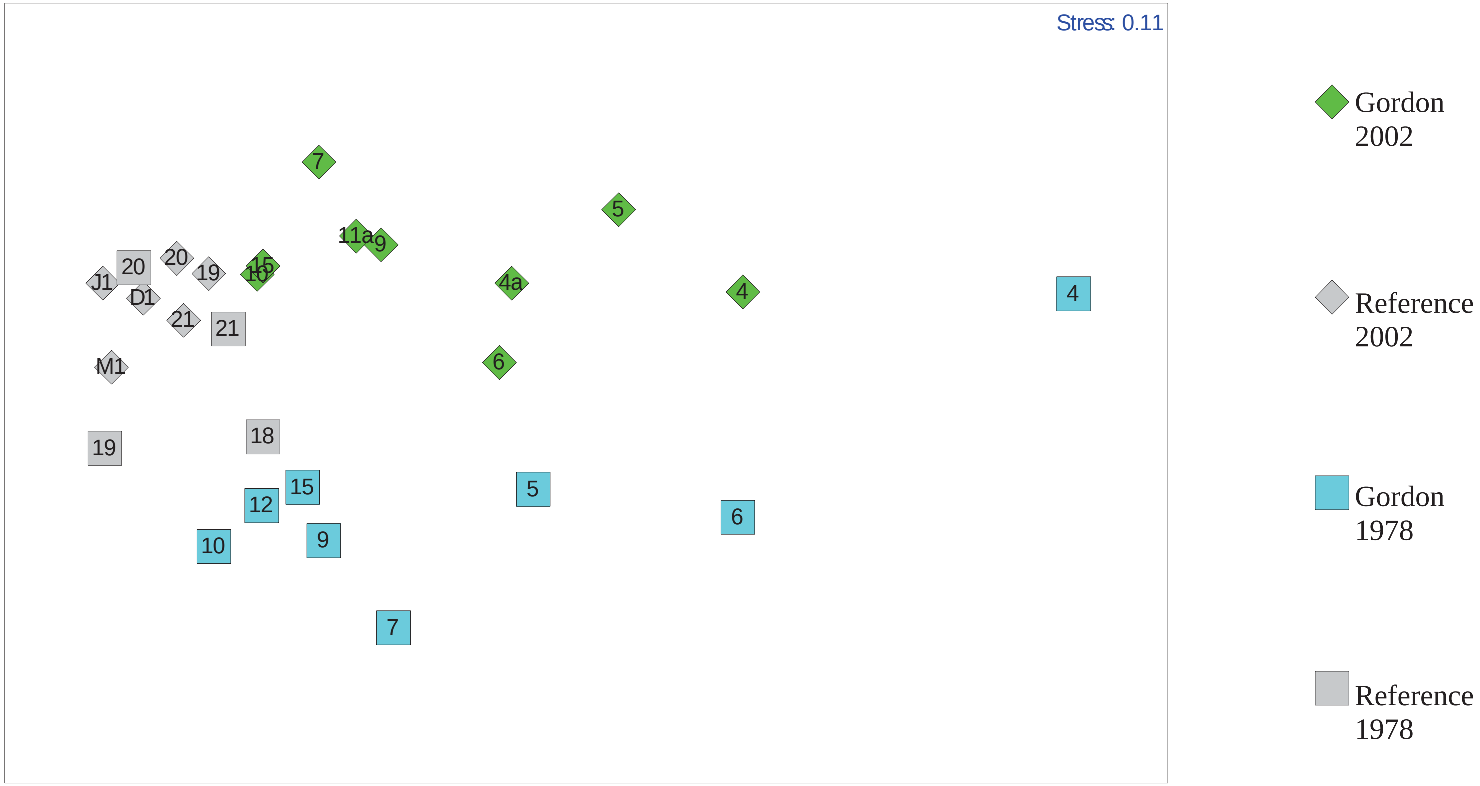


Figure 8.10: Ordination of quantitative (surber) benthic macroinvertebrate data collected in 1978 (Coleman 1978), and during the Basslink Monitoring Program in 2002, scaled to the same sampling effort (unit area). Note same broad spatial pattern between two data sets 25 years apart.

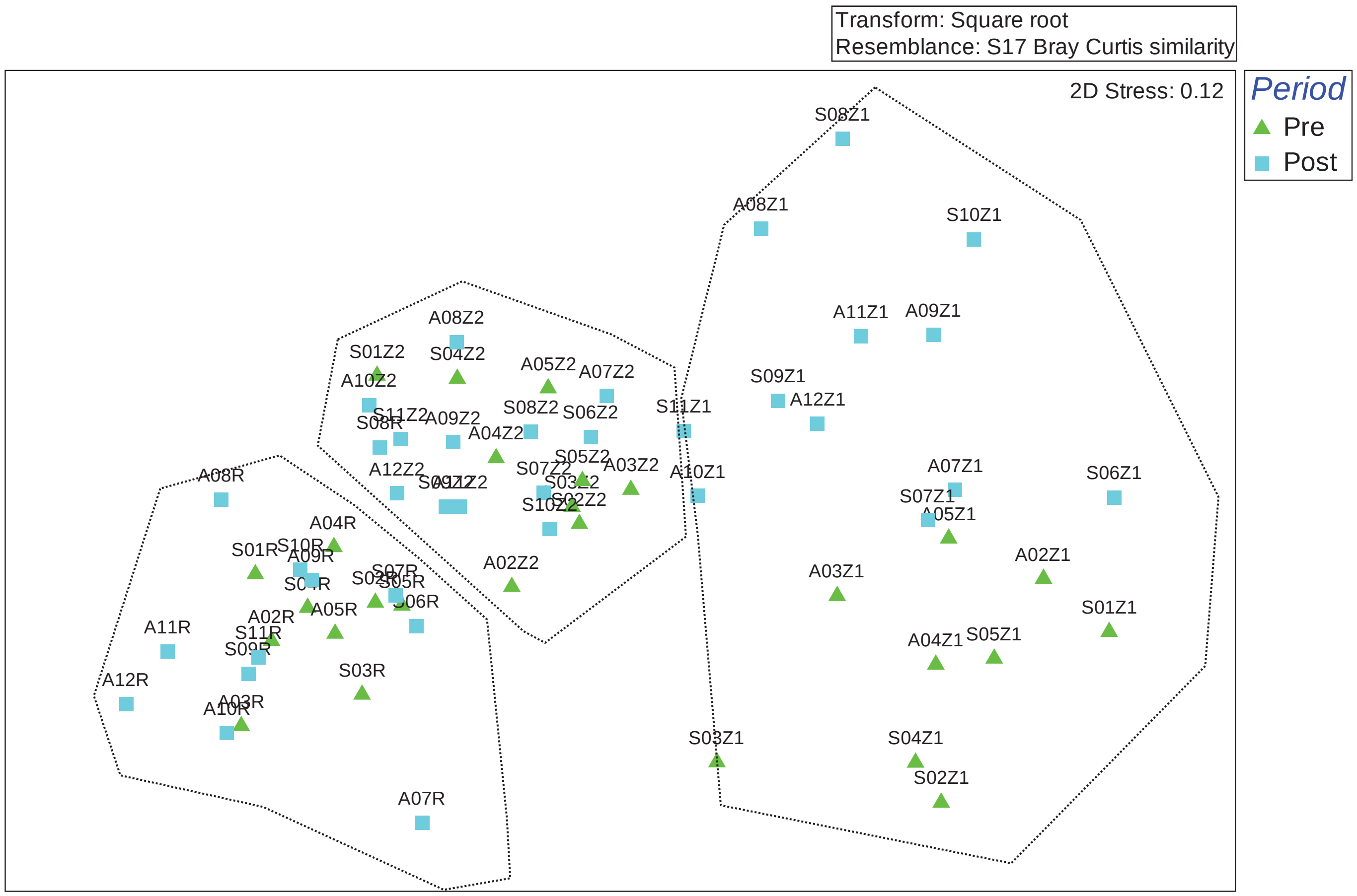


Figure 8.11: MDS ordination of zone-aggregated macroinvertebrate samples for the Gordon River. Symbol indicates period relative to Basslink. Labels indicate sampling season (S = spring, A = autumn), sampling year (2001–12) and zone (Z1 = zone 1, Z2 = zone 2, R = reference rivers). Dashed polygons show zone groupings. Ordination derived from Bray Curtis Similarity matrix of square root transformed family taxonomic abundance data from Surber sampling, using the PrimerE 6 MDS routine.

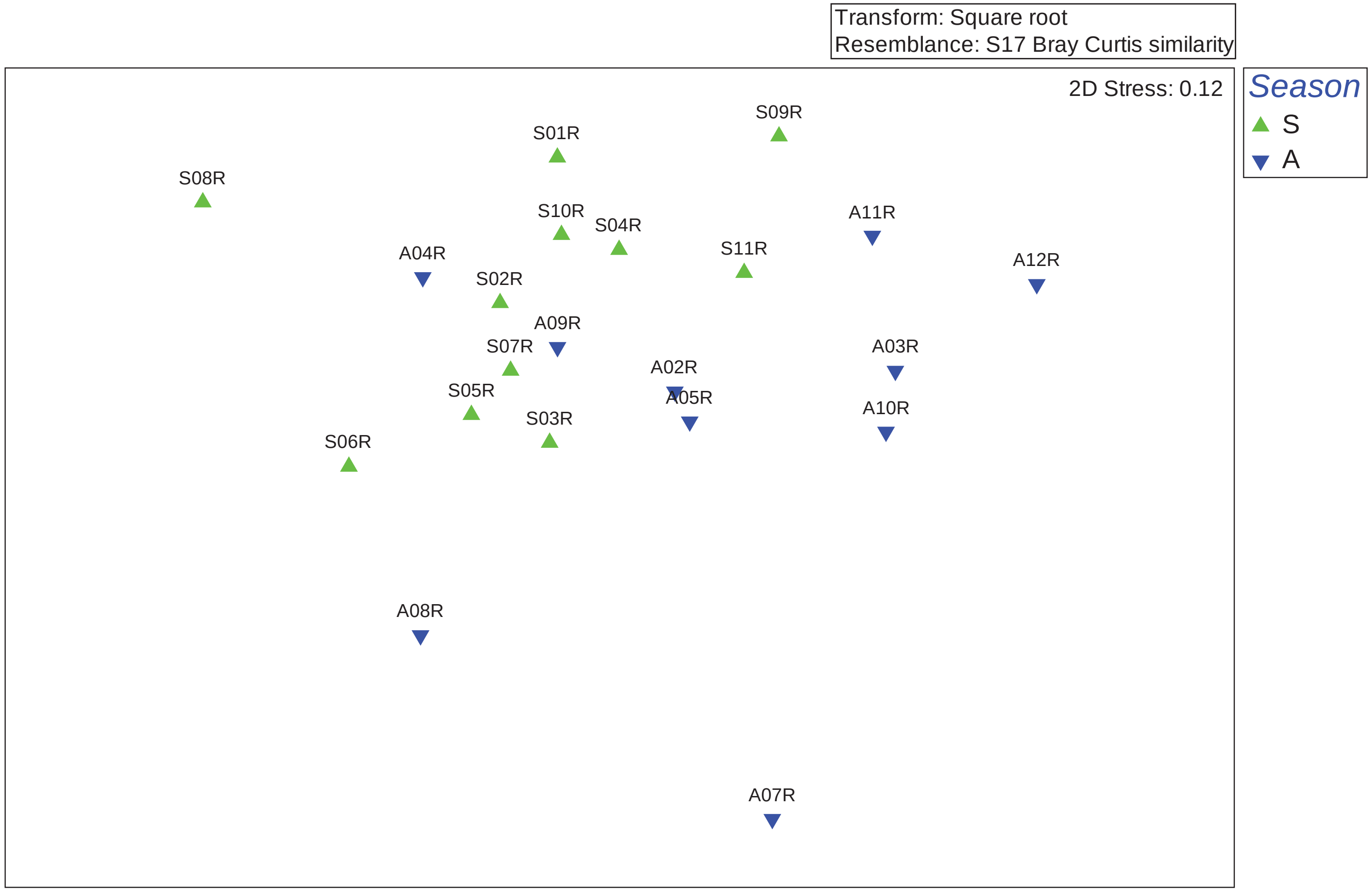


Figure 8.12: MDS ordination of aggregated macroinvertebrate samples for all reference (R) rivers. Symbol indicates season. Labels indicate sampling season (S = spring, A = autumn) and sampling year (2001–12). Ordination derived from Bray Curtis Similarity matrix of square root transformed family taxonomic abundance data from Surber sampling, using the PrimerE 6 MDS routine.

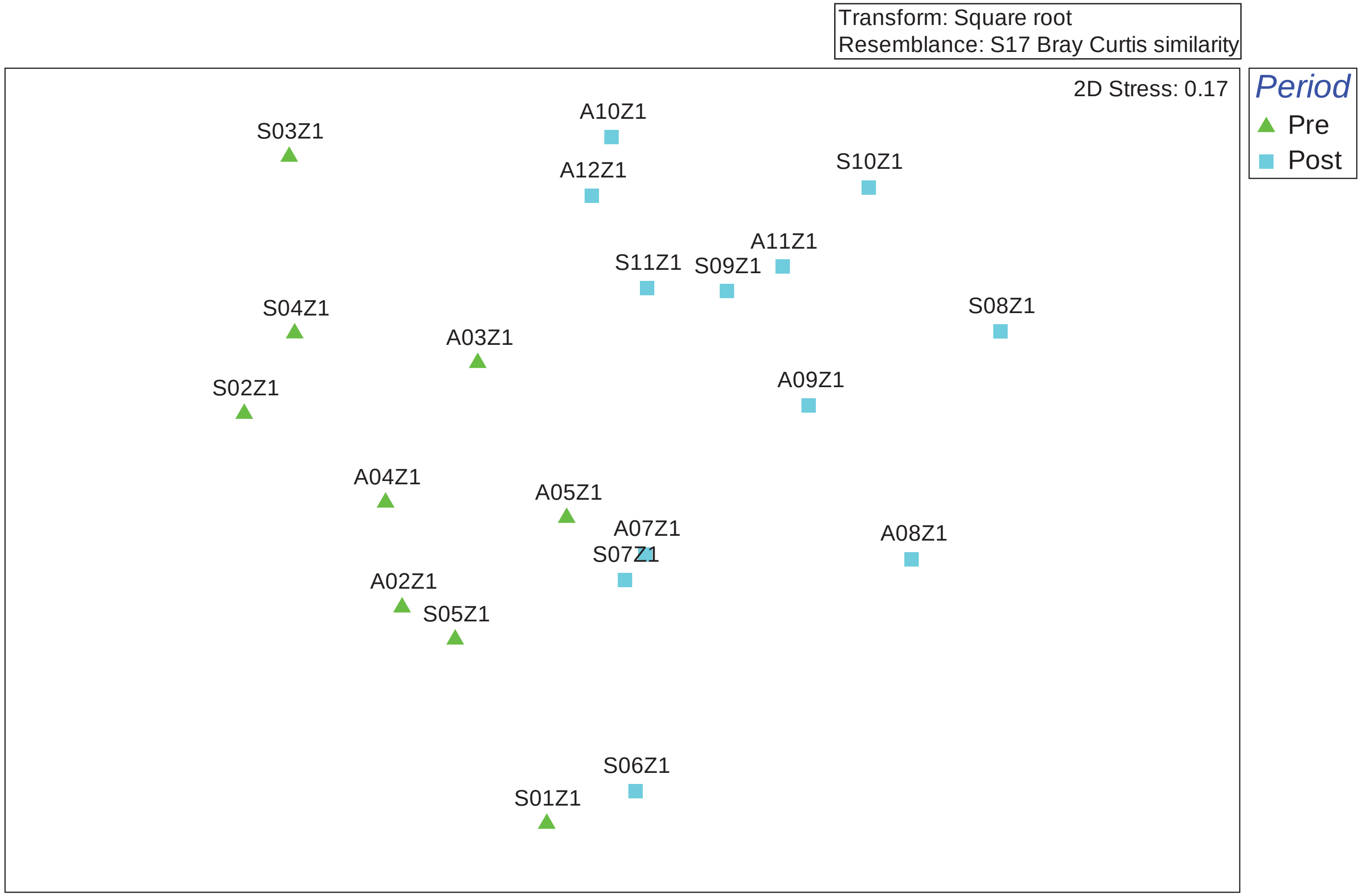


Figure 8.13: MDS ordination of aggregated macroinvertebrate samples for zone 1 in the Gordon River (Z1, upstream of the Denison River). Symbol indicates period relative to Basslink. Labels indicate sampling season (S = spring, A = autumn) and sampling year (2001–12). Ordination derived from Bray Curtis Similarity matrix of square root transformed family taxonomic abundance data from Surber sampling, using the PrimerE 6 MDS routine.

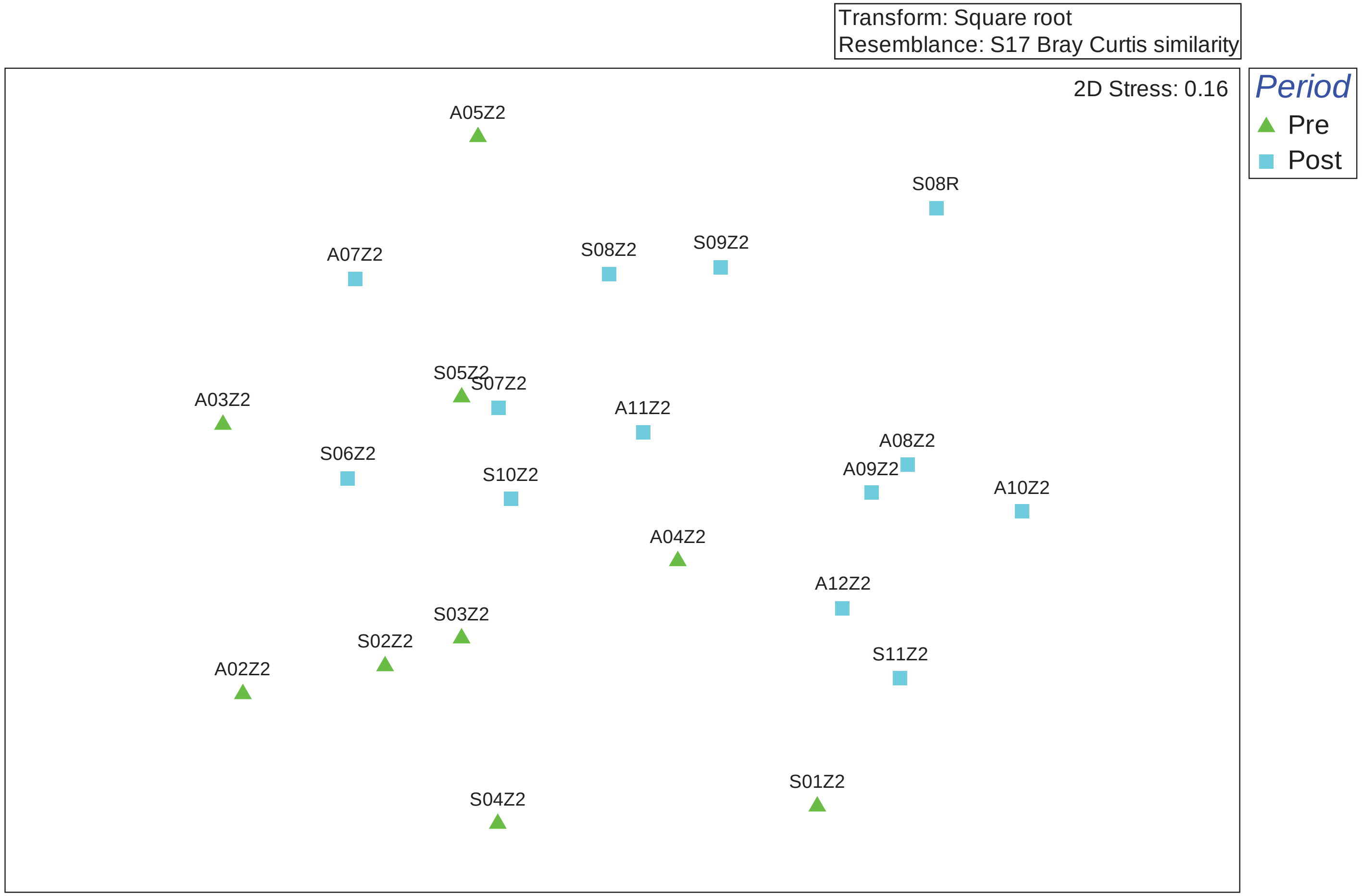


Figure 8.14: MDS ordination of aggregated macroinvertebrate samples for zone 2 in the Gordon River (Z2, downstream of the Denison River). Symbol indicates period relative to Basslink. Labels indicate sampling season (S = spring, A = autumn) and sampling year (2001–12). Ordination derived from Bray Curtis Similarity matrix of square root transformed family taxonomic abundance data from Surber sampling, using the PrimerE 6 MDS routine.

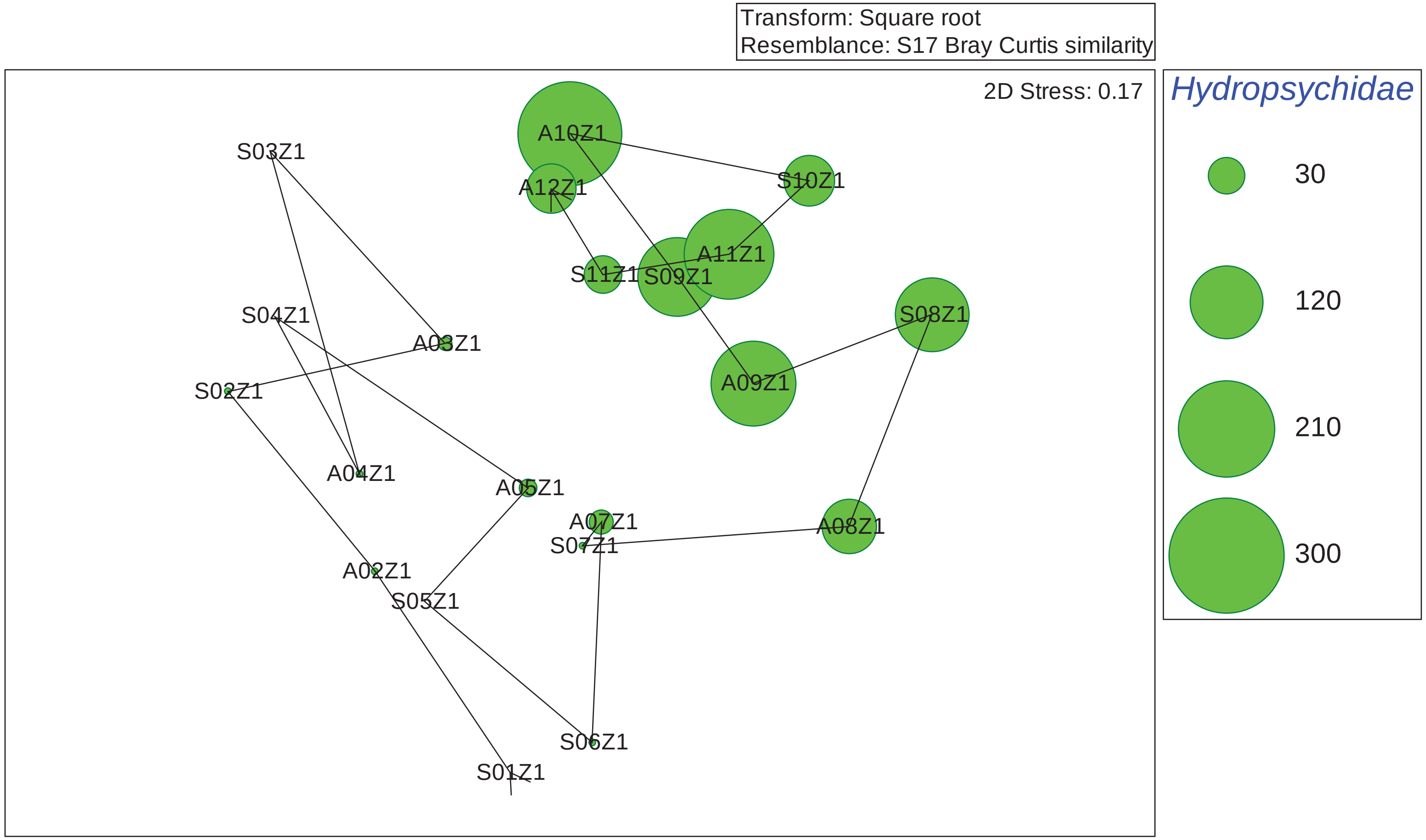


Figure 8.15: MDS ordination of aggregated macroinvertebrate samples for zone 1 in the Gordon River (Z1, upstream of the Denison River). Bubble size indicates abundance of Hydropsychid caddis. Labels indicate sampling season (S = spring, A = autumn) and sampling year (2001–12). Trajectory shown as arrow line linking S01Z1 to A12Z1. Ordination derived from Bray Curtis Similarity matrix of square root transformed family taxonomic abundance data from Surber sampling, using the PrimerE 6 MDS routine.

Table 8.2: Results of Permanova analysis conducted on the full taxon abundance x sample data set across all zones (Gordon zones 1 and 2 and reference) and both seasons for the entire 2001-12 macroinvertebrate sampling program. df = degrees of freedom, SS = sum of squares, Pseudo-F = F statistic analogue, p = probability.

Source	df	SS	MS	Pseudo-F	P	N permutations
Period	1	1315.2	1315.2	2.86	0.001	998
Season	1	1656.8	1656.8	3.60	0.001	999
Zone	2	27109	13554	29.47	0.001	999
Period x Season	1	777.55	777.55	1.69	0.081	998
Period x Zone	2	2533.8	1266.9	2.76	0.001	998
Season x Zone	2	1258.8	629.4	1.37	0.139	999
Period x Season x Zone	2	652.26	326.13	0.71	0.841	996
Res	51	23457	459.93			
Total	**62**	**59256**				

Table 8.3: Results of Permanova analysis conducted on the taxon abundance x sample data set for the two Gordon River zones (but excluding reference sites) and both seasons for the 2001-12 macroinvertebrate sampling program. df = degrees of freedom, SS = sum of squares, Pseudo-F = F statistic analogue, p = probability.

Source	df	SS	MS	Pseudo-F	P	N permutations
Period	1	1807.7	1807.7	3.5539	0.001	999
Season	1	1163.7	1163.7	2.2878	0.01	999
Zone	1	11171	11171	21.962	0.001	997
Period x Season	1	894.18	894.18	1.758	0.054	999
Period x Zone	1	1633.5	1633.5	3.2114	0.001	999
Season x Zone	1	485.98	485.98	0.95543	0.489	999
Period x Season x Zone	1	292.19	292.19	0.57443	0.859	997
Res	34	17294	508.65			
Total	**41**	**34887**				

8.5 Trends and patterns in consolidated instream flora cover data

Mean filamentous algal and benthic moss cover is shown by zone for each sampling occasion between 2001 and 2012 in Figure 8.16. Both algal and moss cover have been consistently higher in zone 1 than zone 2 throughout the monitoring program, and these differences are statistically significant (both $p < 0.02$ by pairwise t-test).

Algal cover appears to be trending upward over the 6 years post-Basslink in zone 1 and for the whole-of-river (WOR), now resulting in minor trigger exceedances (see below). The trend is slow, and considerable inter-site and seasonal variation still exists in cover values.

Moss cover has shown no specific trend for zone 1 or at WOR scale, despite a slight decrease in zone 2 during the post-Basslink period (Figure 8.16).

Overall there have been no substantive changes in plant cover that are of ecological concern during the program. Analysis of variance indicated an absence of any statistically significant differences between the pre- and post-Basslink periods for either algae or moss at either zone or WOR scales, nor any significant and consistent differences in cover between seasons (all $p > 0.2$ by two-way ANOVA).

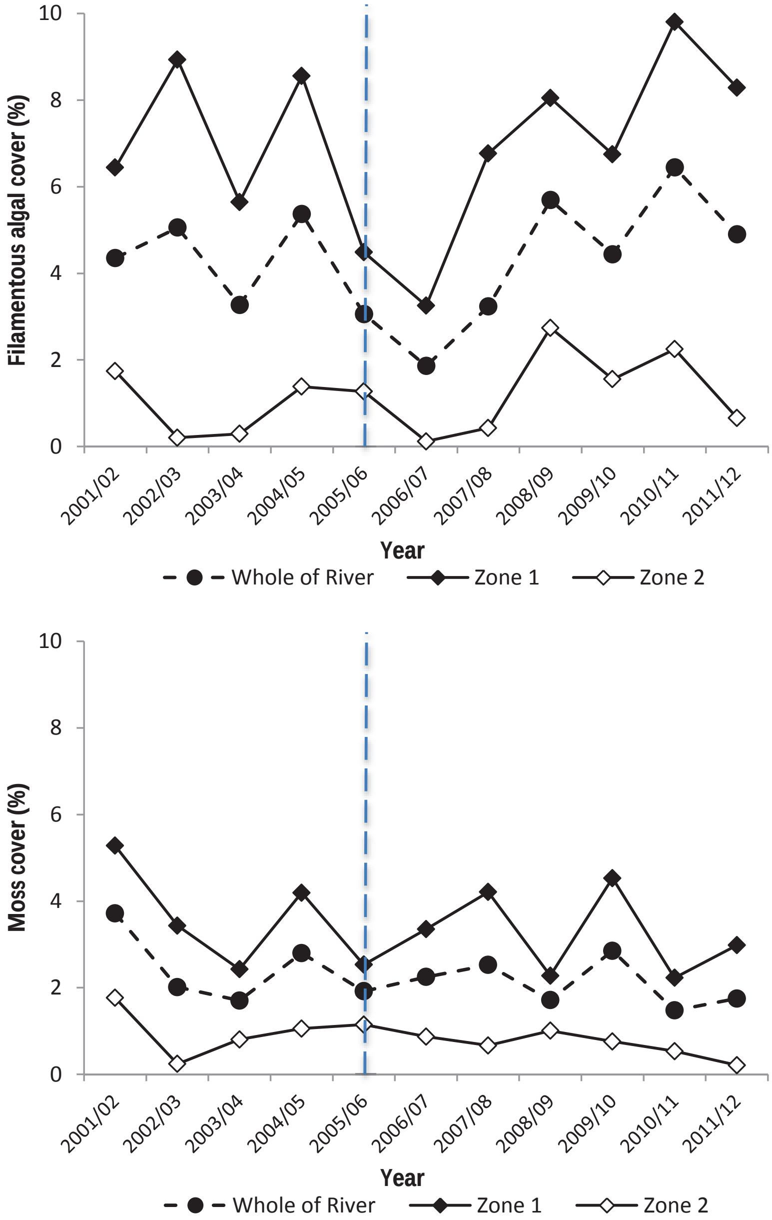


Figure 8.16: Long term trends in percentage cover of benthic filamentous algae and moss in the two zones of the Gordon River and for the WOR from 2001-02 to 2011-12. Vertical dashed line indicates commencement of Basslink operations.

8.6 Performance against triggers

8.6.1 Background

The following components were identified in the BBR (Hydro Tasmania 2005a) as key aspects of the ecological integrity of benthic macroinvertebrates and the instream flora (listed in order of priority):

1. Community structure (taxonomic composition and relative or absolute abundance);
2. Community composition (taxonomic assemblage);
3. Taxon richness (number of taxa);

4. Ecologically significant species (key ecological taxa); and
5. Biomass and productivity (abundance, density and/or cover).

All of these components are addressed by indicators in the Gordon River Basslink Monitoring Program for benthic macroinvertebrates and in-stream flora. Indicator variables have been classified according to:

1. Priority (as above);
2. Ecological significance of changes in variable values;
3. Sensitivity of the variable to Basslink drivers; and
4. Pre-Basslink temporal variance in variable values (at the appropriate spatial scale).

The indicators differ in relation to their ecological significance, their likely sensitivity of response to changes in post-Basslink conditions (flow etc.), and their pre-Basslink magnitude of temporal variation. Each indicator was rated according to these features in the BBR (Hydro Tasmania 2005a). This information is updated below for benthic macroinvertebrates and instream flora as an aid in defining how exceedances in their trigger values may be used in developing management responses.

8.6.1.1 Ecological significance

The movement of indicator values outside trigger and LOAC ranges (particularly decreases below lower trigger values) are considered to be in the following order of decreasing ecological significance (as presented previously in the BBR):

O/Epa ≅ Number of families ≅ NEPT sp > Bray Curtis Similarity to reference ≅ O/Erk > Total Density > Proportional abundance of EPT species > Density EPT taxa.

8.6.1.2 Sensitivity of response

By contrast, the responses of the indicators to declining environmental conditions, especially triggered by changes in flow regime, are considered to be in the following order of sensitivity (as presented previously in the BBR):

Proportional abundance EPT species ≅ Density EPT ≅ Bray Curtis Similarity to reference > NEPT sp ≅ O/Erk ≅ Total abundance > Number of families ≅ Total Density ≅ O/Epa.

The order of ecological significance is essentially opposite to the sensitivity for these variables. This means that the more sensitive indicators with the smallest trigger ranges can be used as early warnings of the potential for more ecologically significant changes.

8.6.1.3 Temporal variance

Following analysis of pre-Basslink data for the period 2001–02 to 2005–06, the variables are considered to fall in the following order of increasing temporal variance or ‘noise’ (as presented previously in the BBR):

Number of families ≅ O/Epa ≅ O/Erk ≅ Bray Curtis Similarity to reference > N EPT Species ≅ Total density ≅ Proportional abundance of EPT species > Total abundance ≅ Density EPT taxa.

This information is summarised in Table 8.3. Indicators with high sensitivity, low temporal variance and moderate to high ecological significance are designated as early warning variables.

Exceedances of trigger values should initiate further investigation. Variables with high ecological significance and low sensitivity often have low to moderate temporal variance and are those for which changes are both ecologically important and frequently difficult to recover from. For these, management interventions should be considered as soon as practicable. Other indicators with intermediate sensitivity and ecological significance, and/or with high temporal variance, are considered to provide useful diagnostic information.

Substantive exceedance of upper trigger bounds for macroinvertebrates indicates increase in diversity, abundance and compositional similarity to reference. While this indicates that the biota have undergone substantial changes post-Basslink, these changes are unlikely to be ecologically negative if they are associated with major increases in certain taxa. Such increases associated with several taxa are likely to represent a 'beneficial' shift toward community compositions observed at reference sites i.e. they represent a less impacted state.

Table 8-3: Characteristics of benthic macroinvertebrate indicators. Relative order (ranked 1-low to 4-high) is shown against four key characteristics, along with role of indicators in decision making when trigger levels are exceeded.

	Key Characteristics				**Indicator Role**		
Variables	**Component priority**	**Ecological significance**	**Response Sensitivity**	**Temporal variance**	**Early warning**	**Supplementary evidence**	**Management intervention**
Macroinvertebrates							
Bray Curtis Similarity to Reference (abundance data)	1	2	1	1	x		
O/Erk	1	2	2	1	x		
Bray Curtis Similarity to Reference (presence/absence data)	1	2	2	1	x		
O/Epa	1	1	3	1			x
Taxon richness (number of families)	1	1	3	1			x
N EPT species	1	1	2	2			x
Proportional abundance of EPT species	2	4	1	2	x		
Abundance of EPT taxa	2	5	1	3		x	
Total abundance (n per unit area)	3	3	3	2			x
Instream Flora							
Filamentous Algal Cover	3	3	3	3	x	x	x
Moss Cover	2	3	2	2		x	

8.6.1.4 Spatial and temporal scales of analysis

The indicators are reported at three spatial scales: as means at 'WOR' and 'zone' scales, and at individual site scale. Zone 1 consists of four sites upstream of the Denison River confluence while zone 2 consists of all four sites downstream of the Denison confluence. Whole of river estimates are derived from observations from all nine Gordon River sites. Note that one site, site 63, though geographically upstream of the Denison confluence, is considered to be highly locally influenced by both Denison River inflows and benthic macroinvertebrate colonisation, since it is hydraulically 'controlled' (with backwater inundation) during high Denison River flows.

Data reporting and trigger value derivation is conducted at three temporal scales: seasonal (summer and autumn), yearly and multi-yearly (two and three years). Not all variables have statistically significant differences between seasonal values of means and/or variances at a particular spatial scale. Where they do, separate trigger values have been derived.

8.6.2 Performance assessment

8.6.2.1 Macroinvertebrates

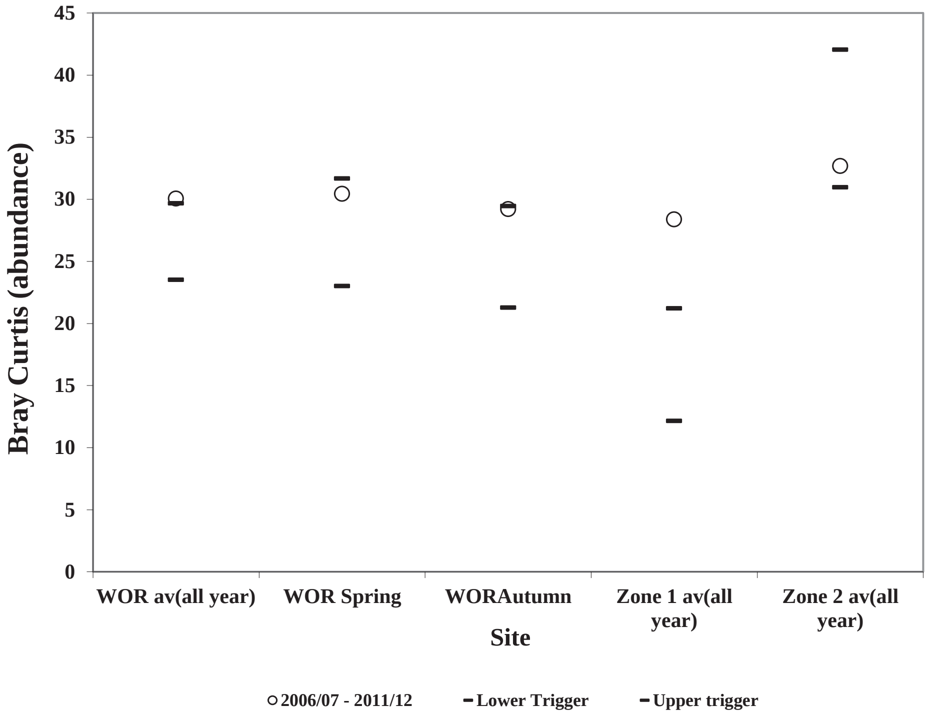
Established trigger bounds for each benthic macroinvertebrate indicator are compared with six-year mean values of the indicators in Figure 8.17 to Figure 8.21.

No substantive negative exceedances were observed for any indicator – i.e. no 6-year mean value of any post-Basslink indicator fell substantively below the lower trigger thresholds. There were three other cases of minor exceedances above the upper or below the lower trigger bounds (Bray Curtis indicator in Figure 8.17, O/Epa in Figure 8.18, and N families and EPT species in Figure 8.19), but these are not considered ecologically significant. Thus in the majority of cases, the macroinvertebrate indicators fell either within or above the pre-Basslink trigger bounds.

Substantive positive exceedances were observed for the following indicators:

- Bray Curtis similarity (abundance and presence/absence) for zone 1 (Figure 8.17, Figure 8.18);
- O/Erk and O/Epa for zone 1, and for O/Epa in the spring season (Figure 8.17, Figure 8.18);
- EPT abundance for WOR (all year), both season and both zones (Figure 8.20);
- Total abundance for WOR (all year and autumn) and zone 1 (Figure 8.21).

All of these positive exceedances were related to increased abundances of EPT taxa relative to pre-Basslink conditions, coupled with shifts in overall community composition toward that of reference sites. The benthic macroinvertebrate community was therefore broadly consistent with its pre-Basslink state, with some improvements due to increases in abundance or diversity of flow-dependent taxa.



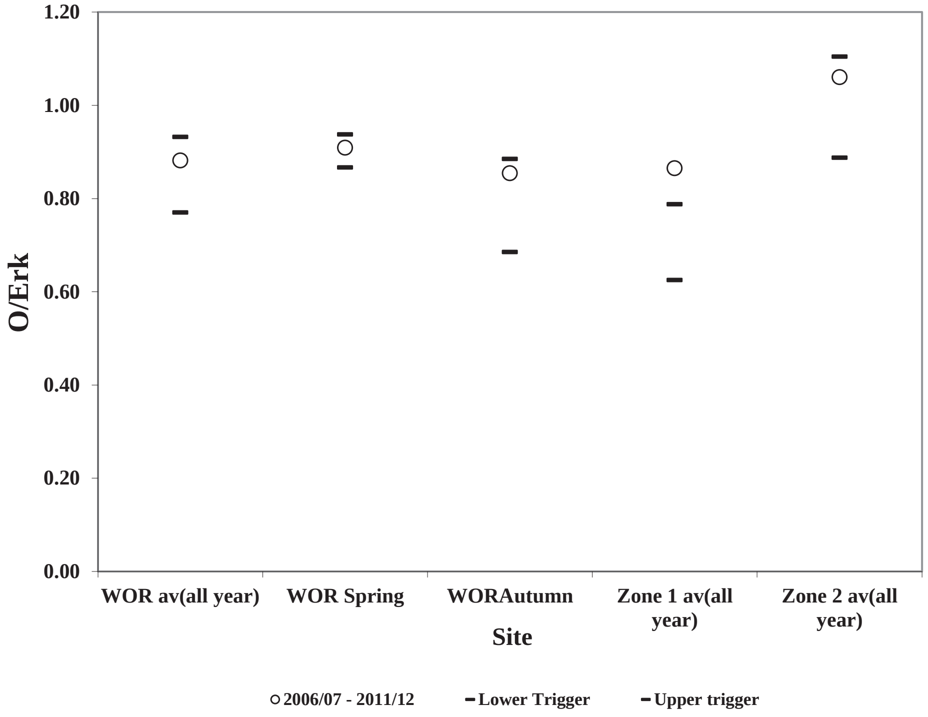
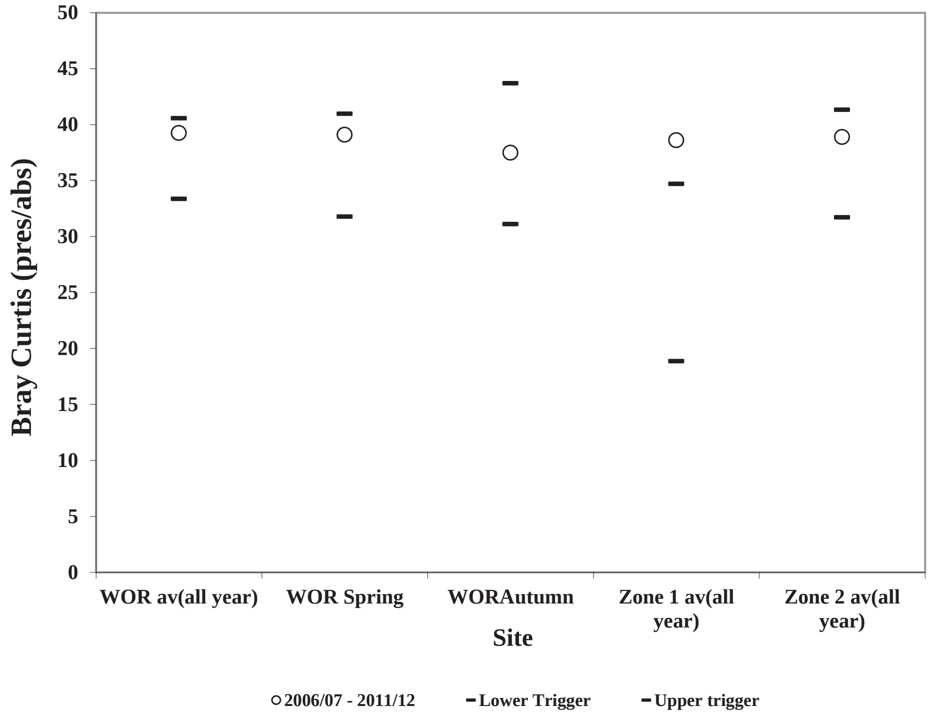


Figure 8.17: Community structure metric values, as means for 2006–07 to 2011–12, compared with upper and lower LOAC 6-year Trigger values in the Gordon River for the following cases: WOR = Whole of River (by year = seasons combined, spring and autumn), zones 1 and 2 (all year). Trigger values based on the 95th percentile of pre-Basslink data.



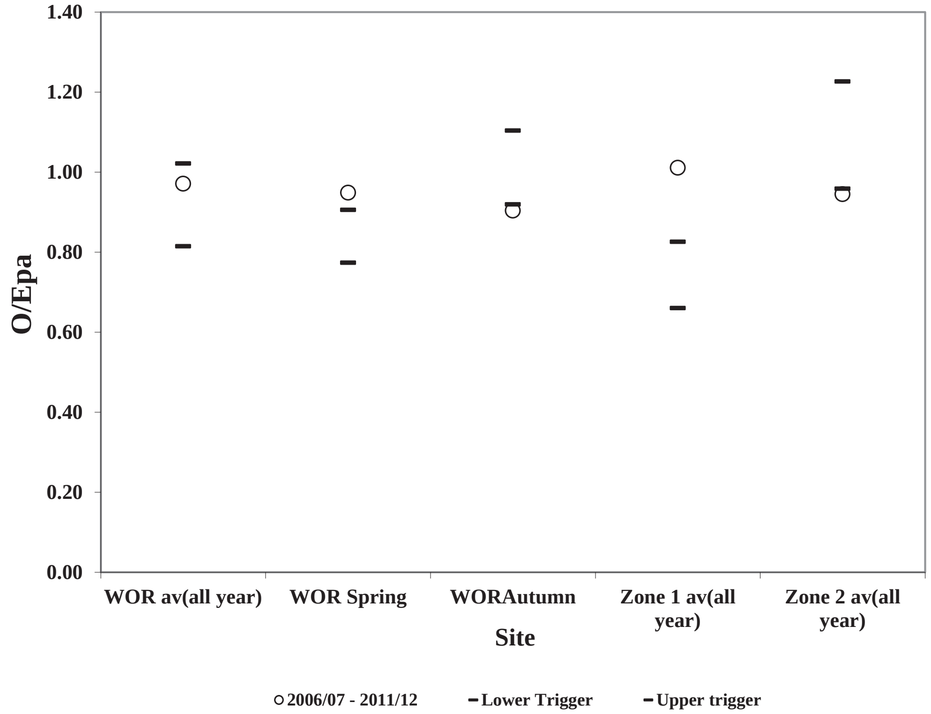
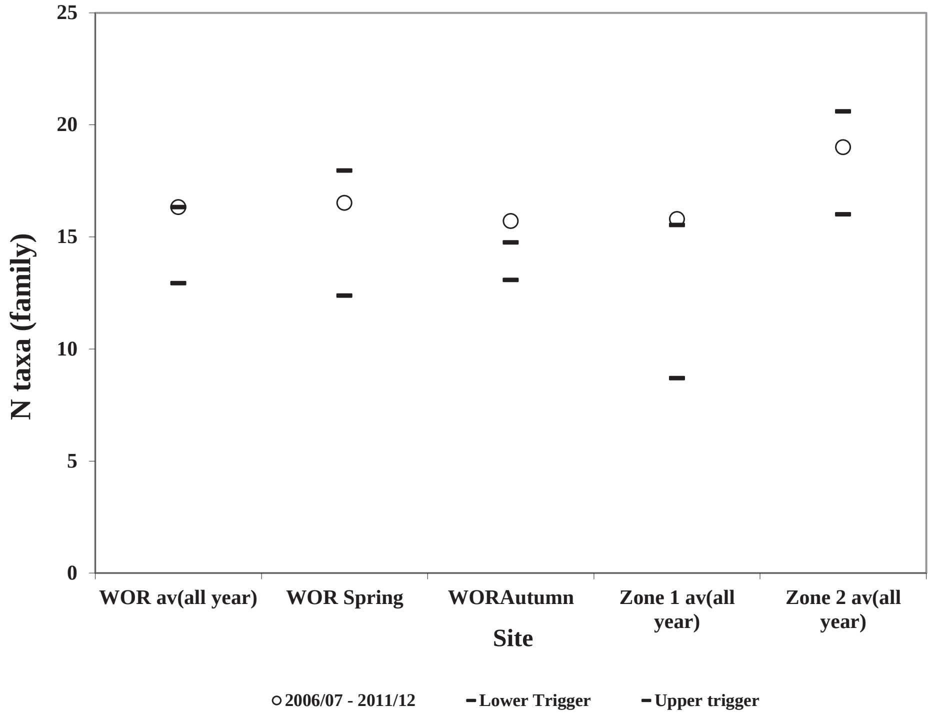


Figure 8.18: Community Composition metric values, as means for 2006–07 to 2011–12, compared with upper and lower LOAC 3-year Trigger values in the Gordon River for the following cases: Whole of River (year = seasons combined, spring and autumn), zones 1 and 2 (all year). Trigger values based on the 95th percentile of pre-Basslink data.



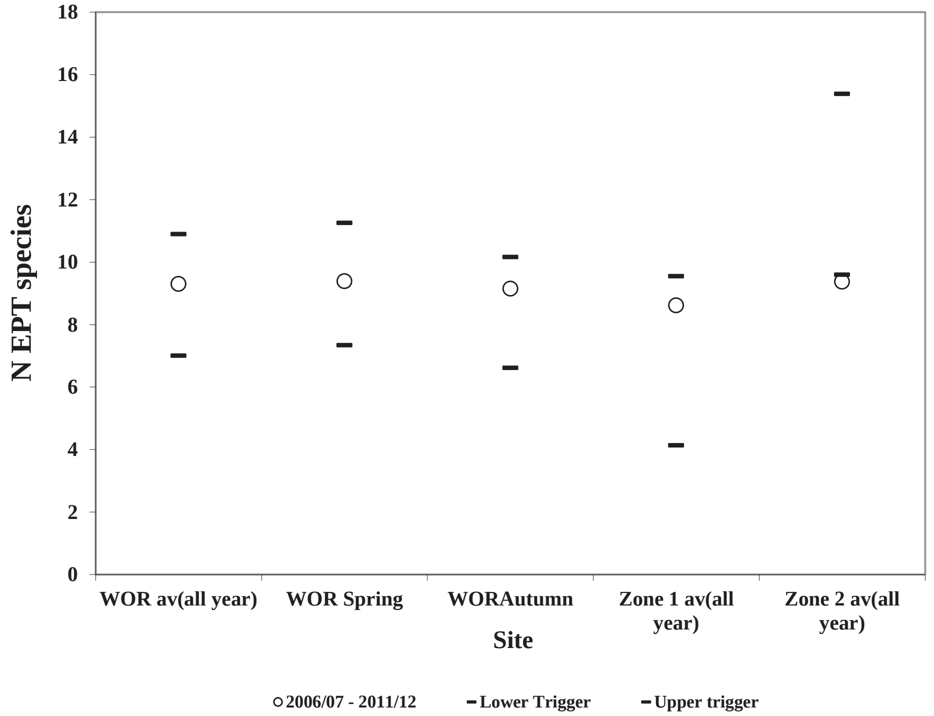
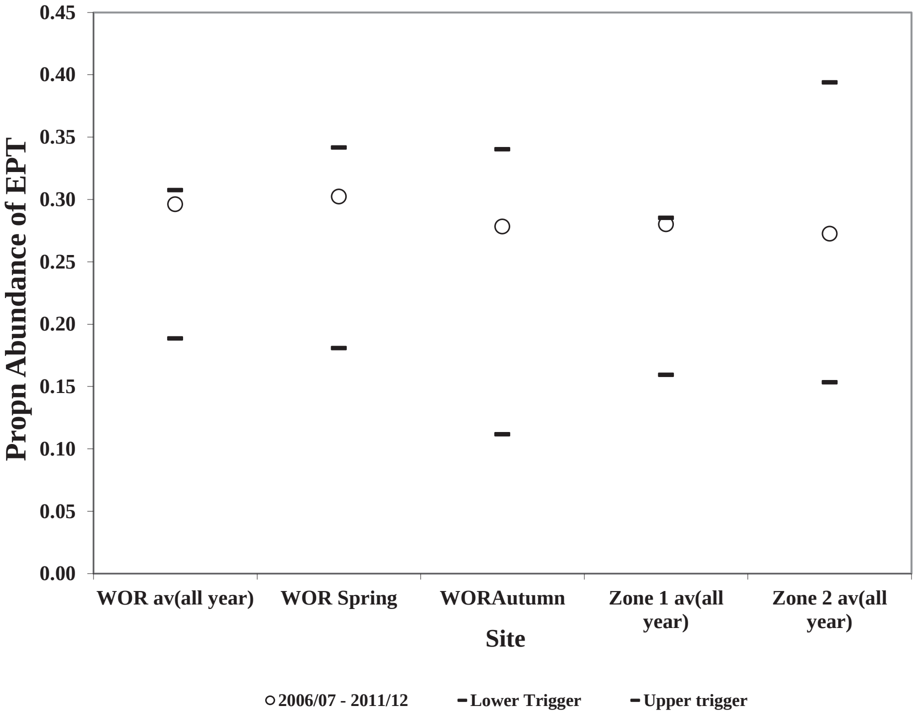


Figure 8.19: Taxonomic Richness metric values, as means for 2006–07 to 2011–12, compared with upper and lower LOAC 3-year Trigger values in the Gordon River for the following cases: Whole of River (year = seasons combined, spring and autumn), zones 1 and 2 (all year). Trigger values based on the 95th percentile of pre-Basslink data.



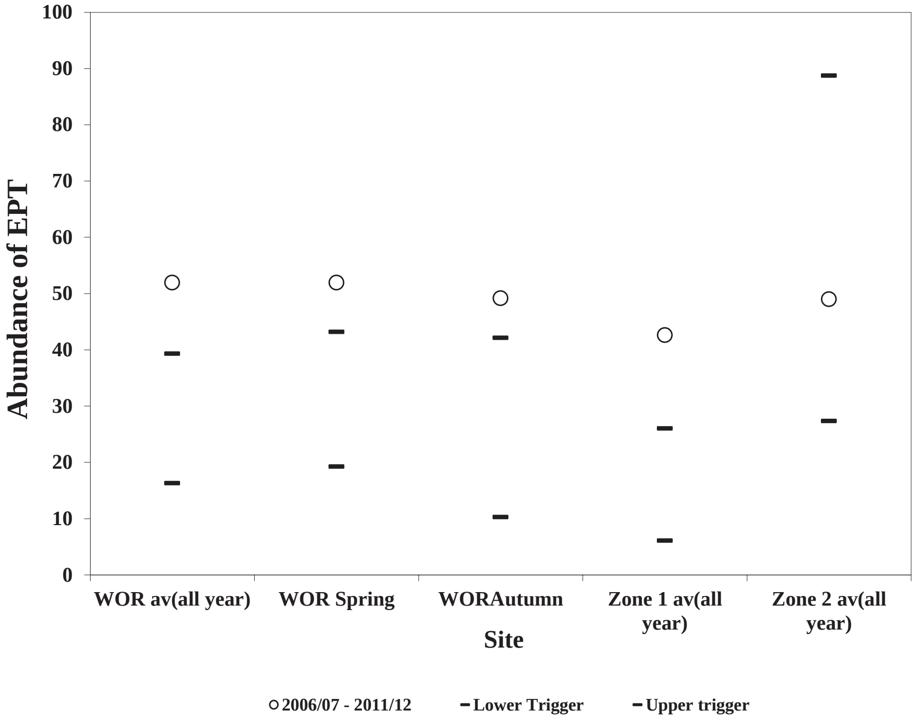


Figure 8.20 Ecologically Significant Species metric values, as means for 2006–07 to 2011–12, compared with upper and lower LOAC 3-year Trigger values in the Gordon River for the following cases: Whole of River (year = seasons combined, spring and autumn), zones 1 and 2 (all year). Trigger values based on the 95th percentile of pre-Basslink data.

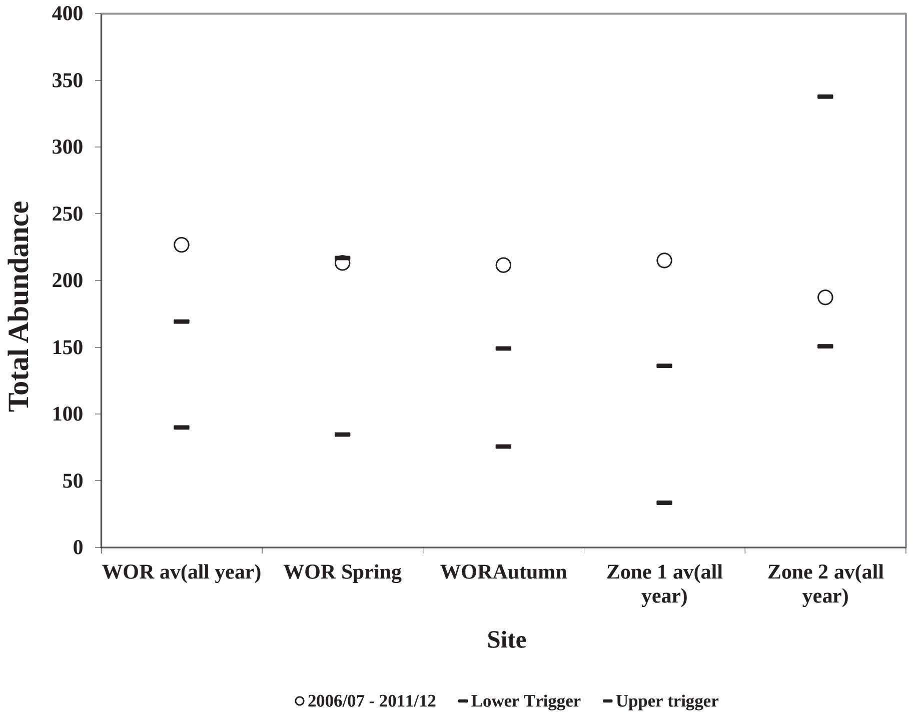


Figure 8.21: Biomass/Productivity metric values, as means for 2006–07 to 2011–12, compared with upper and lower LOAC 3-year Trigger values in the Gordon River for the following cases: Whole of River (year = seasons combined, spring and autumn), zones 1 and 2 (all year). Trigger values based on the 95th percentile of pre-Basslink data.

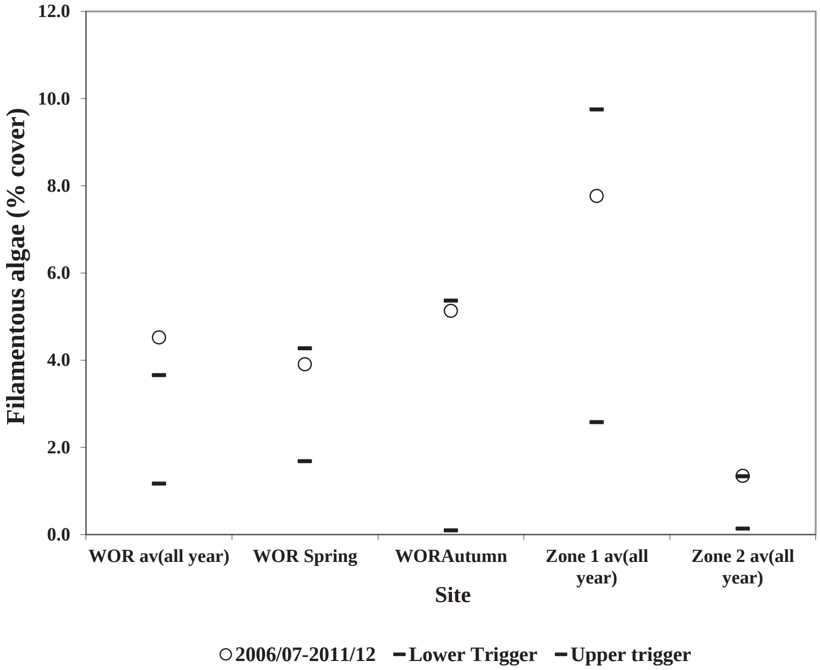
8.6.2.2 In-stream Flora

Established trigger bounds for the benthic filamentous algal and moss indicators are compared with six-year mean values of these indicators in Figure 8.22.

No substantive negative exceedances were observed for either indicator – i.e. no 6-year mean value of any post-Basslink indicator fell substantively below the lower trigger thresholds.

Algal cover values in 2006-07 to 2011-12 for WOR and both zones fall within their trigger bounds with the exception of the WOR all year case which shows a minor exceedance of approximately 0.5 % cover. The pattern of algal cover observed among sites and zones is otherwise consistent with pre-Basslink conditions.

Moss cover values fell within or close to trigger bounds, though the mean value for WOR fell just below the upper trigger bound (Figure 8.22). Cover exceeds the upper trigger bound in spring for the WOR mean, but not by an ecologically significant amount. The pattern of moss cover observed among sites and zones is consistent with pre-Basslink conditions.



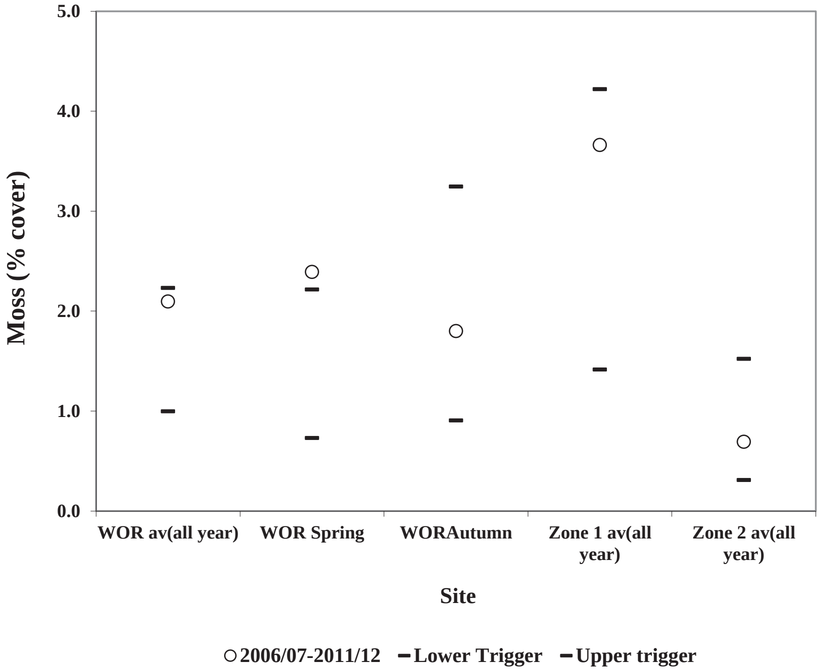


Figure 8.22: Mean percentage cover of benthic filamentous algae and moss for 2006-07-2011-12 compared with upper and lower 6-year LOAC Trigger values in the Gordon River for the following cases: Whole of River (year = seasons combined, spring and autumn), zones 1 and 2 (year). Trigger values based on the 95 percentile of pre-Basslink data.

8.7 Evaluation of the monitoring program

The Basslink Monitoring Program has provided insights into how discharge patterns at the Gordon Power Station have caused responses in macroinvertebrate community composition and abundance and in benthic algal biomass and cover, within the particular context of this type of river and presence of the Gordon Dam. The program has also clearly demonstrated that distinct elements of the flow regime are tied to, and by inference drive, specific macroinvertebrate and algal indicators, and hence the overall condition of the benthic biota. The combination of quantitative and semi-quantitative (AUSRIVAS) sampling has provided a robust set of macroinvertebrate indicators which show responses to both flow and seasonal cues that are consistent with previous conceptual understanding and have added some new insights.

Benthic algal biomass and cover are also responsive to flow changes, but are believed to do so indirectly, namely through the influence of flow on bed light levels. The euphotic depth of western tannic (‘red-light climate’) waters is limited to between 1 and 3 m depth and hence higher flows which result in water depths within the channel of between 3 and 7 m can cause much of the benthic substrate to be unsuitable for diatoms and green filamentous algae. Sustained periods of high flows, depending on local substrate conditions, may promote the relative dominance of mosses and charophytes. Neither mosses or charophytes are believed to provide suitable food resources for grazing benthic macroinvertebrates (whose diet in the Gordon River is mainly focused on diatoms – Davies & Cook, unpub. data).

The algal monitoring has been biased toward measures which relate to habitat resources for macroinvertebrates rather than fully exploring changes in benthic algal composition. Sampling across the fixed transects has been intensive and provides good local scale estimates of cover. Fixed transect monitoring has however, in hindsight, not been fully representative of reach scale dynamics, as between-site variation is marked. This could have been improved by addition of more transects per site, possibly with fewer sites per reach.

The monitoring program has enhanced the understanding of temporal changes in macroinvertebrate community composition at both individual site and at zone scales. Longitudinally, the monitoring results show the effects of inflows from unregulated tributaries on macroinvertebrate abundance and community composition, through increased flow and supply of carbon-based food resources and of colonists via downstream drift (of macroinvertebrate juveniles). At zone scale, the monitoring results have been used to reveal and quantity relationships between the incidence of two of the primary flow drivers and their biological responses – the duration of low flow periods (at or above the minimum flow) and the incidence of hydro-peaking (from 0 to 3 turbines).

Similar to the other program disciplines, the macroinvertebrate monitoring results have not been definitive in identifying ‘Basslink’ changes because of the complex inter-dependency of the Gordon Power Station operations and other environmental factors. The results have provided a sound understanding of how flow regulation influences the Gordon River at both reach and whole-of-river scales, and how this interacts with the influence of flow and biological condition in the larger un-impacted catchment.

The program has also shown the strong influence of the presence of the minimum flow on abundance and composition – both upstream and downstream of the Denison junction. Longer periods of minimum flow are strongly related to increases in abundance of a number of flow-obligate and flow-sensitive taxa, especially aquatic insects of the EPT group and filter-feeders. The extent of relative increase in these groups has shifted upstream from the Denison River junction (pre-Basslink) to include almost the entire zone upstream of the Denison River (to the

Piguenit River junction - site G4a). It appears therefore that the minimum flow is successfully mitigating any impacts from the post-Basslink flow changes experienced between 2006 and 2012. The full potential effect of hydro-peaking operations has not yet been experienced with the periods of intense hydro-peaking frequency having been quite limited.

8.8 Conceptual model

Changes in hydrology during the post-Basslink period have included a number of recognisable flow patterns (see Section 2.5.2).

Macroinvertebrates can be immediately impacted by a flow event but take from several months to one to two years to recover. Short term flow patterns (e.g. hydro-peaking to 3 turbines with rapid rises and falls in flow between peaks, or sustained baseload generation with 3 turbines) can impact macroinvertebrate abundance and composition through such effects as:

- *Near-bed shear stress*: high shear-stress forces at the river bed prevent colonisation by many flow-sensitive and flow-avoiding macroinvertebrate taxa. Pulses of high shear stress may also lead to mobilisation of deposited sand which causes local bed scour, and will force established fauna into the drift, resulting in downstream emigration from the reach. Sustained high shear stress under 3 turbine conditions greatly reduces habitat suitability on the bed.

- *Upper bed dewatering*: Prolonged periods of higher flows (especially with 2 to 3 turbine releases) cause inundation of upper bed slopes (e.g. on bars and upper cobble channel margins). This can lead to colonisation by macroinvertebrates both from the channel centre and from tributaries – especially mobile flow-obligate taxa. Longer periods (ca. 2-3 months) of inundation can lead to establishment of ‘net-fields’ (areas with silken nets produced by Hydropsychid caddis) with the substantial increase in Hydropsychid caddis numbers, if flows are relatively constant.

  Sudden declines in flow lead to dewatering of this formerly wetted habitat area. Some mobile species can evade stranding. Many do not, and after a brief period seeking shelter in bed crevices, there can be considerable stranding mortality.

Since 2008 flow patterns have been dominated by daily hydro-peaking of 0-3 turbines, daily hydro-peaking 0-1 or 0-2 turbines and the low flow dominant patterns (10-40 m^3s^{-1}) (See Figure 2.16 and Figure 2.17). Between 2006 and 2008 baseload and hydro-peaking in the 2-3 turbine level also dominated. General macroinvertebrate responses to prolonged periods of these various flow patterns are summarised in Table 8.4.

Table 8.4: Response of macroinvertebrates to prolonged flow patterns occurring on the Gordon River.

Flow pattern	Macroinvertebrate response
Low flow dominant-minimum flow with occasional peaks to 1-2 turbine level	• Macroinvertebrate communities persist within area inundated by minimum flow. • Macroinvertebrate communities are maintained throughout area inundated by minimum flow. • Sustained low flows create low shear stress on the bed, predictable hydraulic conditions for filter-feeders and permanent wetted refuge habitat between flow peaks. Occasional flow peaks are short-lived and have moderate impact due to occasional higher bed shear stress. Flow peaks are too short to allow macroinvertebrate colonisation of bars. • Macroinvertebrate communities show increased diversity and abundance, especially of flow-obligate and flow-sensitive taxa (e.g. mayflies), and filter-feeders (e.g. Hydropsychid caddis). Benthic algal production during daylight hours in areas < 3 m depth (shallow runs, riffles and bars). • Community contains more expected taxa downstream of the Denison River due to colonisation from drift in larger tributary inflows.
Daily hydro hydro-peaking to 1 or 2 turbines	• Macroinvertebrate communities persist within area inundated by minimum flow. • Periods of high flow leads to raised shear stress on the bed, combined with reduced benthic algal production due to reduction in bed illumination. Some benthic algal production occur between peaks during daylight hours. Sudden drops in flow between peaks leads to bed dewatering and stranding mortality. • Macroinvertebrate density and diversity declines. Abundance of grazers and flow obligate taxa declines, and communities are dominated by worms (depending on local substrate composition), chironomids and stoneflies. Growth rates decline and populations are dominated by small instars with delayed development. Mobile flow obligate taxa are dislodged from inter-peak low flow areas as flows rise rapidly and emigrate as drift in the water column. • Community contains more expected taxa downstream of the Denison River due to colonisation from drift.
Daily hydro hydro-peaking to 3 turbine level – rapid, regular alternation between minimum flow and 3 turbine discharge – with and without mitigation	• Periods of high flow leads to sustained high shear stress on the bed, combined with reduced algal production due to reduction in bed illumination. This does not constitute a food resource as macroinvertebrate colonisation of these habitats is minimal and is lost when flows drop. • Sudden drops in flow between peaks leads to bed dewatering and stranding mortality. • Macroinvertebrate density and diversity declines. Abundance of grazers and flow obligate taxa declines, and communities are dominated by worms (depending on local substrate composition), chironomids and stoneflies. Growth rates decline and populations are dominated by small instars with delayed development. • **With mitigation –** macroinvertebrate communities persist within area inundated by minimum flow. • **Without mitigation –** macroinvertebrate abundance declines substantially upstream of the Denison River, and is dependent on natural flows from much smaller tributaries.

Table 8.4 continued on next page

Flow pattern	Macroinvertebrate response
Daily hydro hydro-peaking in 2-3 turbine level - rapid, regular alternation between flow at 2 and 3 turbine flow levels	• Periods of high flow leads to sustained high shear stress on the bed, combined with elimination of algal production due to reduction in bed illumination. • Macroinvertebrate density and diversity declines. Abundance of grazers and flow obligate taxa declines, and communities are dominated by worms (depending on local substrate composition), chironomids and stoneflies. Growth rates decline and populations are dominated by small instars with delayed development. • Mitigation – Minimum flow mitigation makes no difference until flows decline. Sudden drops in flow after this flow regime leads to bed dewatering for mobile species and stranding mortality for those areas not inundated by residual or minimum flows.
Base load utilising 3 turbines.	• Constant high flows leads to sustained high shear stress on the bed, combined with prolonged periods of low algal production due to reduction in bed illumination. Some algal production established on banks and marginal snags during prolonged baseflow periods. • Macroinvertebrate density and diversity declines. Abundance of grazers and flow obligate taxa declines, and communities are dominated by worms (depending on local substrate composition), chironomids and stoneflies. Growth rates decline and populations are dominated by small instars with delayed development • Minimum flow mitigation makes no difference until flows decline. Sudden drops in flow after cessation of baseload peaks leads to bed dewatering for mobile species and stranding mortality for those areas not inundated by residual or minimum flows.

Table 8.4 continued

8.9 Conclusions

8.9.1 Benthic macroinvertebrates

Most benthic macroinvertebrate indicators did not show a major change between pre- and post-Basslink period. There were significant pre- vs. post-Basslink differences in some macroinvertebrate indicators. These changes are consistent with the conceptual model of how they may be affected by the implementation of a minimum environmental flow. There is a seasonal component to the temporal variation in macroinvertebrate indicators, controlled largely by natural seasonal biological cues, in addition to seasonal differences in biological response to the flow regime in the Gordon River.

Lagged responses to post-Basslink conditions were detected in several macroinvertebrate indicators, mainly due to lagged increases in the abundance of several EPT taxa. These upward trends have led to exceedances for some triggers. These exceedances do not represent a negative Basslink effect, but rather a positive response to the minimum environmental flow. However, if high flows vary more in future, in line with previous predictions of the post-Basslink flow regime, these indicators are likely to decline again toward and/or within trigger bounds, as several highly flow-sensitive taxa respond to increased variability in flow velocities and near-bed shear stress.

The Basslink Monitoring Program has shown strong influences of minimum flows but it has been difficult to identify other Basslink changes due to the complex interactions between Gordon Power Station operation and other environmental factors.

8.9.2 Instream flora

Filamentous algal and benthic moss cover values varied during the monitoring program and showed substantive differences between zones in the Gordon River. However, cover generally fell within or close to pre-Basslink triggers and ranges. There was therefore no detectable change in algal or moss cover that can be ascribed to post-Basslink operations. Algal monitoring was mostly effective but the survey design could have been improved by having more transects per site and fewer sites per reach.

8.10 Recommendations

It is recommended that macroinvertebrate monitoring be continued until the end of the 2012-14 interim monitoring period, at which point the program should be reviewed.

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9. Fish

9.1 Summary

The consolidated trends of the fish monitoring data collected during six years of post-Basslink operation show that:

- Brown trout were the most common fish species in the Gordon River over the duration of the post-Basslink Monitoring Program;
- Spotted galaxias and short finned eels were the most commonly occurring native species. MDS ordination showed a significant pre/post-Basslink differentiation in the river's fish community primarily driven by increased spotted galaxias abundance;
- Spotted galaxias also exhibited a small upstream increase in range over the post-Basslink period.
- The majority of native species generally exhibited a consistent decrease in relative abundance with distance upstream over the duration of the monitoring program, which is consistent with other published information on decreasing freshwater fish community species diversity with distance upstream (Davies 1989). Climbing galaxias were a notable exception due to the presence of isolated (tributary) populations in zone 1, in addition to zones 3-5. The zone 1 population appeared to recruit infrequently; and
- There has been little evidence of fish stranding during the monitoring period.

The fish monitoring program has performed within expectations over the six year post-Basslink period, although the ability to statistically check trends are limited due to the limited number, restricted patchy distribution and seasonal migratory characteristics of the Gordon River fish community. The monitoring program has provided sufficient information to assess whether the fish community of the Gordon River has changed markedly after the commencement of Basslink operations.

The fish monitoring program has limited capacity to differentiate between a direct Basslink effect and confounding factors such as changed hydrology due to natural temporal variation in climate and hydrological changes due to altered Tasmanian generating system operating strategies. However, the increased abundance and upstream range of spotted galaxias may be linked to the environmental flow.

The triggers utilised in the Basslink Monitoring Program have been adequate to detect large changes in the fish population and community structure, particularly in relation to changes in the native species.

9.2 Introduction

This chapter examines and discusses the response of the freshwater fish communities in the middle Gordon River during the first six years following the commencement of electricity trading into the National Electricity Market (NEM). A full discussion of the predicted impacts is contained in the Basslink Integrated Impact Assessment Statement (Summary Report Locher 2001) and Basslink Baseline Report (Hydro Tasmania 2005a).

The Basslink Monitoring Program was designed to collect data both prior to the commissioning of Basslink to provide a comparative basis to monitor the response of the river to operation after the implementation of Basslink (the post-Basslink period).

This chapter examines the trends in consolidated data and evaluates the fish monitoring program and its triggers.

9.3 Method

Thirty-one monitoring sites in the Gordon catchment were scheduled for sampling twice a year. These sites are located in the main channel of the Gordon River, or in tributaries of the Gordon River, with fish populations at these sites either directly or indirectly affected by power station operation. The monitoring sites are distributed through a series of Gordon catchment monitoring zones and are indicated in Figure 9.1 to Figure 9.4.

The fish monitoring zones are defined as follows:

- zone 1: Gordon River and tributaries from Gordon Dam downstream to, and inclusive of, Abel Gorge;
- zone 2: Gordon River and tributaries from Albert River downstream to, and inclusive of, the First Split;
- zone 3: Gordon River and tributaries from Orange River downstream to Sunshine Falls;
- zone 4: Gordon River and tributaries from Sunshine Falls to the Sprent River;
- zone 5: Gordon River from Angel Cliffs downstream to Big Eddy;
- zone 7: Franklin River between Pyramid Island and Big Fall;
- zone 8: Franklin River and tributaries upstream of Big Fall;
- zone 9: Birches Inlet catchment;
- zone 13: Henty River at and downstream of the Yolande River; and
- zone 14: Henty River upstream of the Yolande River.

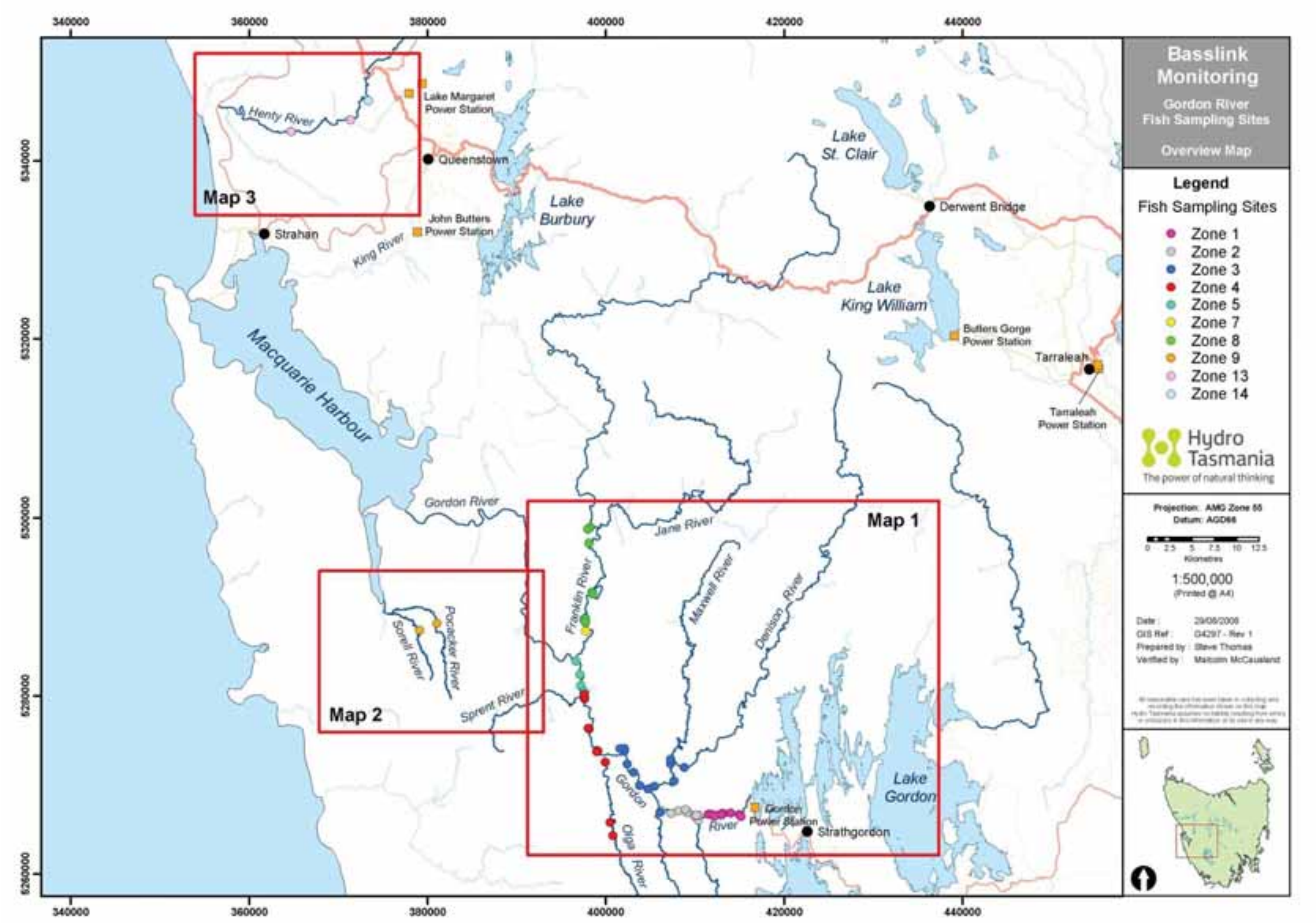

Figure 9.1: Fish monitoring sites and zones in the Gordon River (zones 1–5), Franklin River (zones 7–8), Birches Inlet (zone 9) and Henty River (zones 13–14).

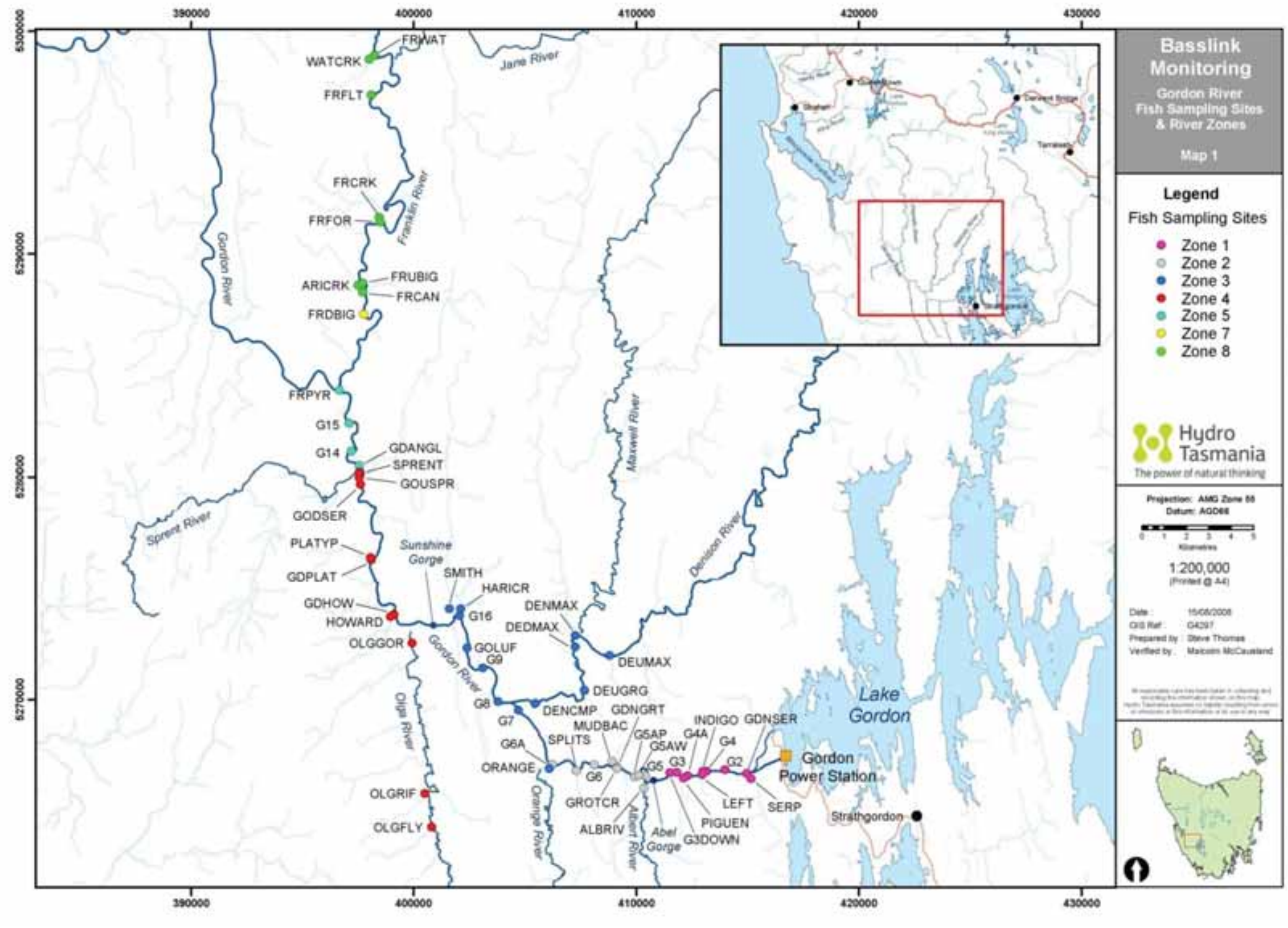

Figure 9.2: Gordon River fish sampling sites and river zones, zones 1–8.

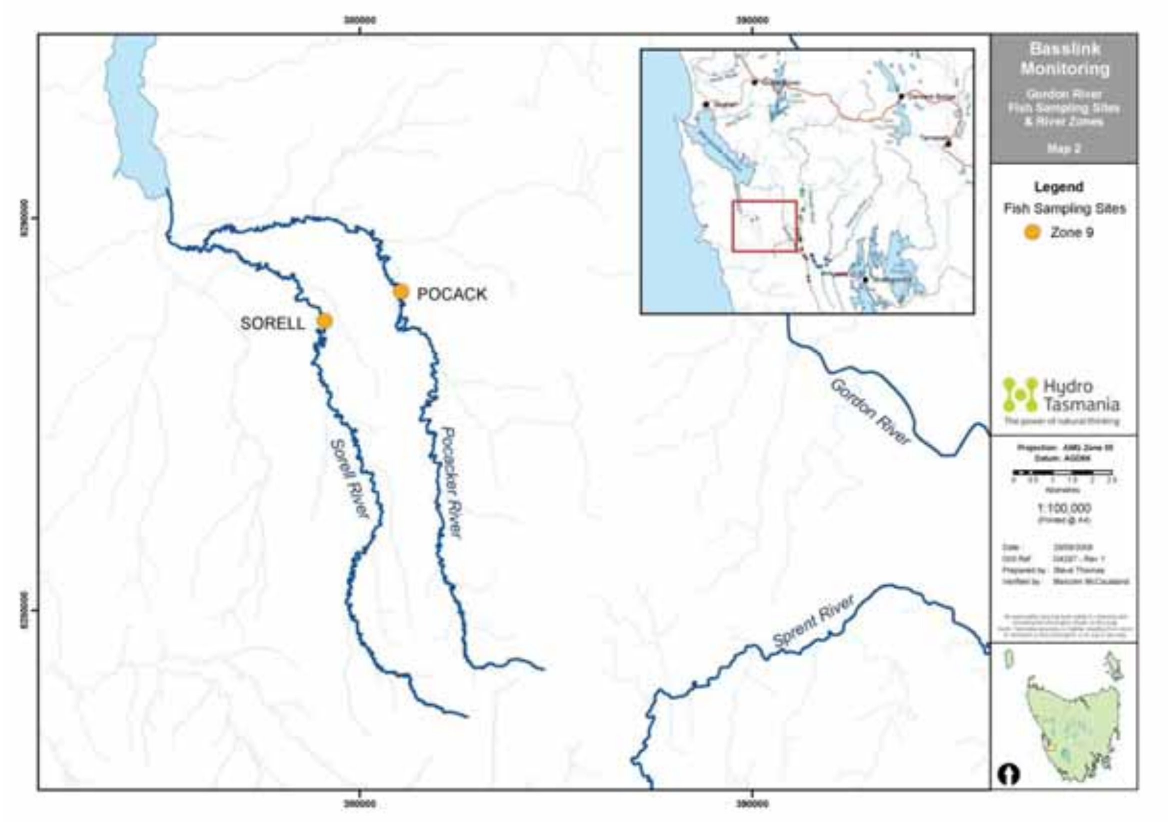

Figure 9.3: Sorell and Pockacker River fish reference sampling sites, zone 9.

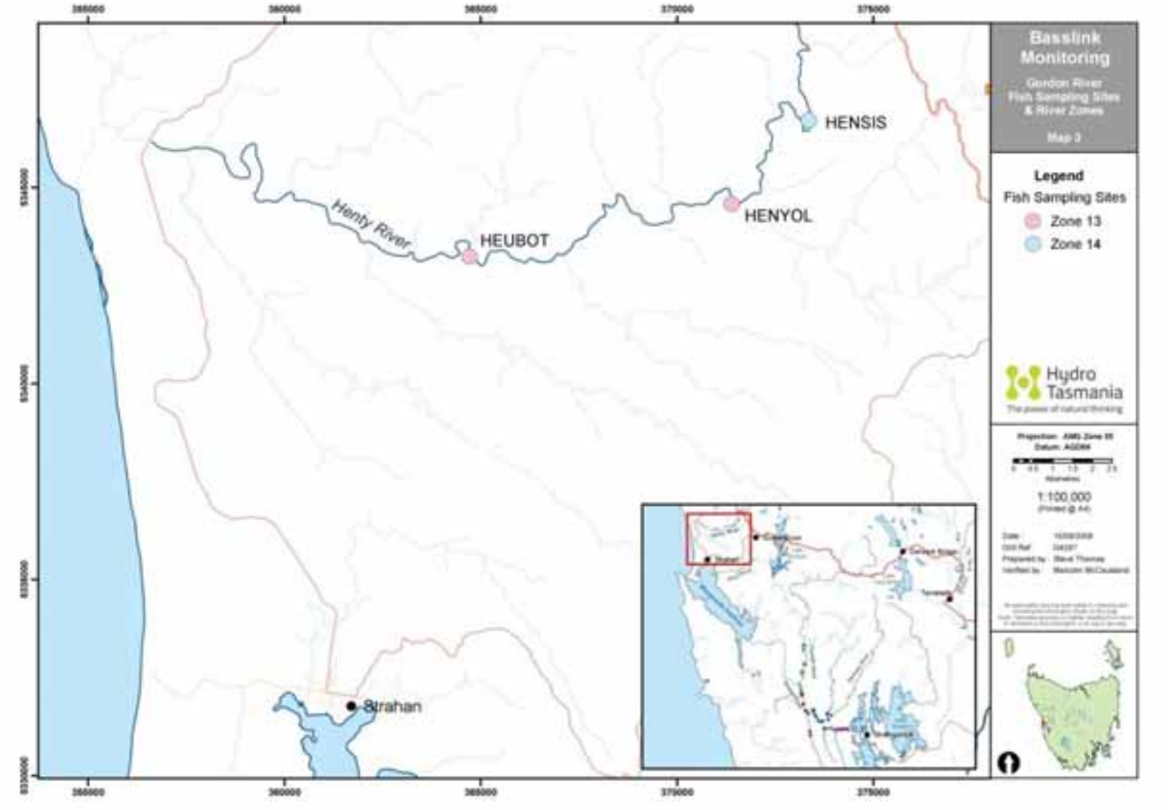

Figure 9.4: Henty River fish reference sampling sites, zones 13 and 14.

9.4 Trends in consolidated data

Thirteen species of fish were captured from the Gordon River, its tributaries and the reference sites, consisting of four introduced and nine native species. Table 9.1 shows the pre- and post-Basslink species composition of fish captured from the Gordon River and reference sites. The catch percentages in the table are based on electrofishing derived catch per unit effort (CPUE) data.The longitudinal distribution of fish species within the Gordon River and tributaries is shown in Figure 9.5 and Figure 9.6.

Appendix 5 shows the population structure for a range of key fish species collected during the monitoring program.

Table 9.1: Pre- and post-Basslink fish species composition in Gordon River and reference sites. Catch percentages are based on electrofishing derived catch per unit effort data.

Species	Pre-Basslink Gordon sites	Post-Basslink Gordon sites	Pre/post Gordon variance	Pre-Basslink reference sites	Post-Basslink reference sites	Pre/post reference variance
Anguilla australis	12.6 %	14.9 %	2.3 %	11.1 %	7.0 %	-4.1 %
Geotria australis	6.4 %	4.5 %	-1.9 %	7.3 %	5.4 %	-1.9 %
Galaxias brevipinnis	7.2 %	1.7 %	-5.5 %	8.3 %	5.3 %	-3.0 %
Galaxias cleaveri	0 %	0 %	0 %	0.4 %	1.6 %	1.2 %
Galaxias maculatus	5.8 %	1.2 %	-4.6 %	4.3 %	4.1 %	-0.2 %
Galaxias truttaceus	13.0 %	26.7 %	13.6 %	26.5 %	38.3 %	11.9 %
Mordacia mordax	0.6 %	0.9 %	0.3 %	0.9 %	0.3 %	-0.6 %
Perca fluviatilis	2.3 %	0.9 %	-1.5 %	0 %	0 %	0 %
Prototroctes maraena	0 %	0 %	0 %	0.1 %	0.0 %	-0.1 %
Pseudaphritis urvillii	3.9 %	5.3 %	1.4 %	16.2 %	18.5 %	2.3 %
Salmo salar	<0.1 %	0 %	0 %	0 %	0 %	0 %
Salmo trutta	48.0 %	43.7 %	-4.3 %	24.9 %	19.4 %	-5.6 %
Oncorhynchus mykiss	0 %	<0.1 %	0 %	0 %	0 %	0 %

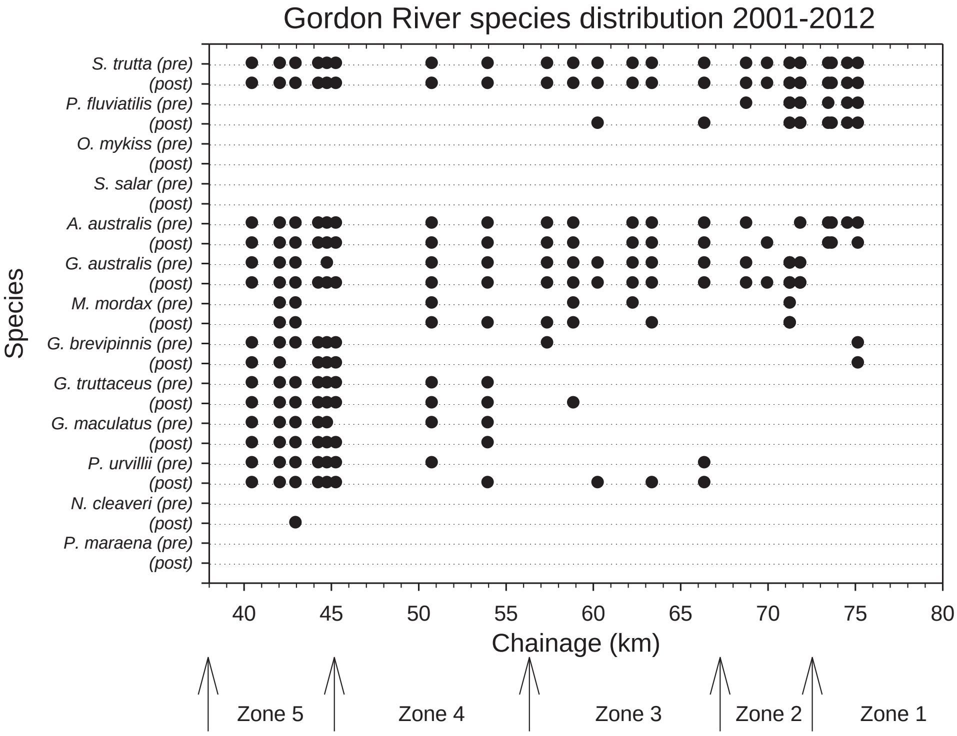

Figure 9.5: Fish species distribution in the Gordon River zones. Chainage indicates distance from Macquarie Harbour. (pre) represents data collected between 2001 and 2005 and (post) indicates data collected between 2006 and 2012.

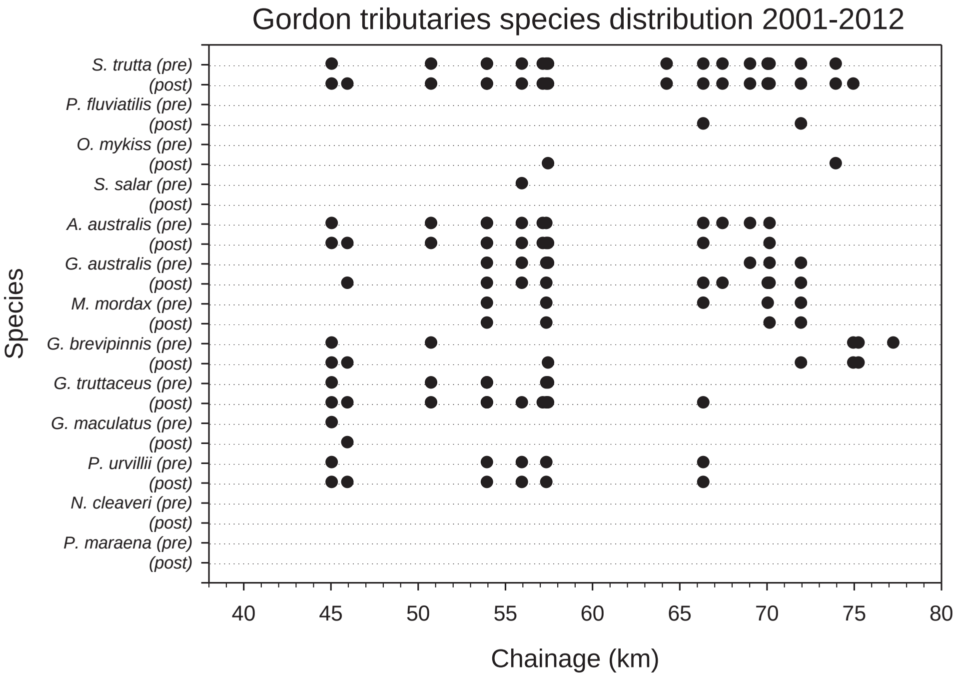

Figure 9.6: Fish species distribution in the Gordon River tributaries. (pre) represents data collected between 2001 and 2005, and (post) indicates data collected between 2006 and 2012. Note that zones have not been displayed, as the total distance from Macquarie Harbour does not necessarily reflect zone position in all cases. Zone 5 does not contain any tributary sites.

9.4.1 Exotic species

Four exotic fish species were captured in the Gordon River during the monitoring program; brown trout (*Salmo trutta*), redfin perch (*Perca fluviatilis*), rainbow trout (*Oncorhynchus mykiss*) and Atlantic salmon (*Salmo salar*).

Brown trout (*Salmo trutta*) were by far the most abundant and have the widest distribution. Two rainbow trout (*Oncorhynchus mykiss*) and one Atlantic salmon (*Salmo salar*) have been captured in the Gordon River tributary monitoring zones. Atlantic salmon are diadromous, brown and rainbow trout are selectively diadromous, that is, a proportion of their riverine populations may exhibit sea run behavior, whilst redfin perch are non-migratory.

Figure 9.5 and Figure 9.6 show the longitudinal distribution of all fish species captured in the Gordon River and tributaries for the duration of the monitoring program, and Table 9.1 shows proportion of each species in pre- and post-Basslink catches.

9.4.1.1 Brown Trout (Salmo trutta)

Brown trout comprised 48 % of the pre-Basslink and 44 % of the post-Basslink catches from the Gordon River monitoring zones, which was considerably higher than the 25 % pre-Basslink and 19 % post-Basslink catch composition from the reference sites. Brown trout were distributed widely throughout the Gordon River and were present in all of the test and reference monitoring zones. Catches from zone 9 (Sorell and Pocacker Rivers at Birches Inlet in Macquarie Harbour) were consistently low throughout the monitoring program, with only sporadic catches of individual fish from these rivers. It is thought that this may be related to the large amount of sand in these river systems that reduce the availability and accessibility of gravel spawning habitat (redds) required by brown trout.

Figure 9.7, Figure 9.8 and Figure 9.9 show temporal plots of brown trout relative abundance (electrofishing catch per unit effort or CPUE) in the Gordon River, Gordon tributary and reference river monitoring zones over the duration of the monitoring program. Brown trout relative abundance has consistently been highest in the middle zones, particularly tributary catches from zones 2 and 3, which may be related to the increased availability of suitable spawning habitat in these areas. Abundances in the main river monitoring sites have generally been highest in zones 2 and 3, and this trend appears to be clearer in the post-Basslink data. Brown trout relative abundance in zone 1 has shown a general increase post Basslink, particularly from autumn 2008 onwards. Increased trout relative abundance in the upstream zones may be indicative of a minimum environmental flow response, as the fauna in zones 1 and 2 (upstream of the Denison) would be the primary beneficiaries of the flow.

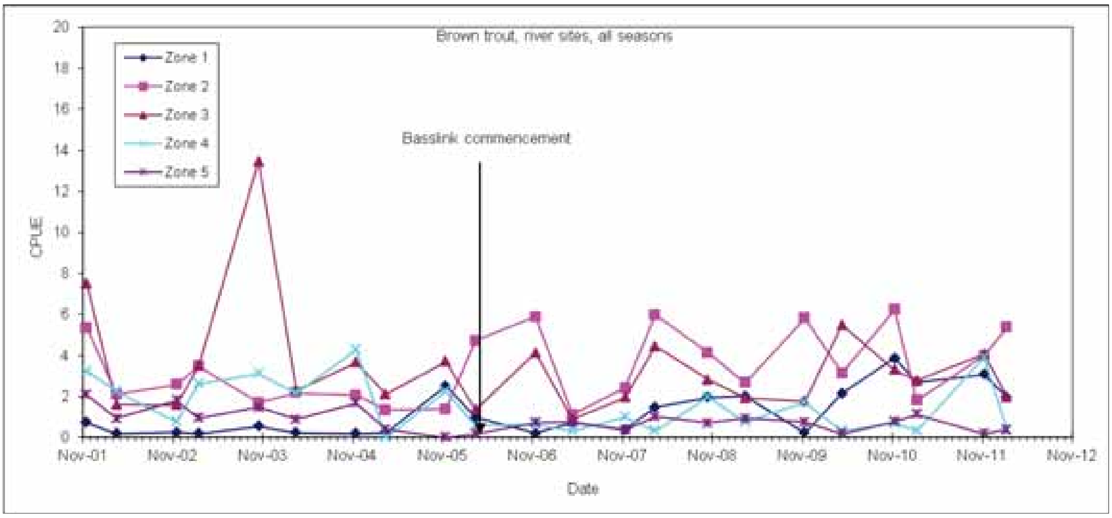

Figure 9.7: CPUE for brown trout caught in the Gordon River monitoring zones between December 2001 and March/April 2012.

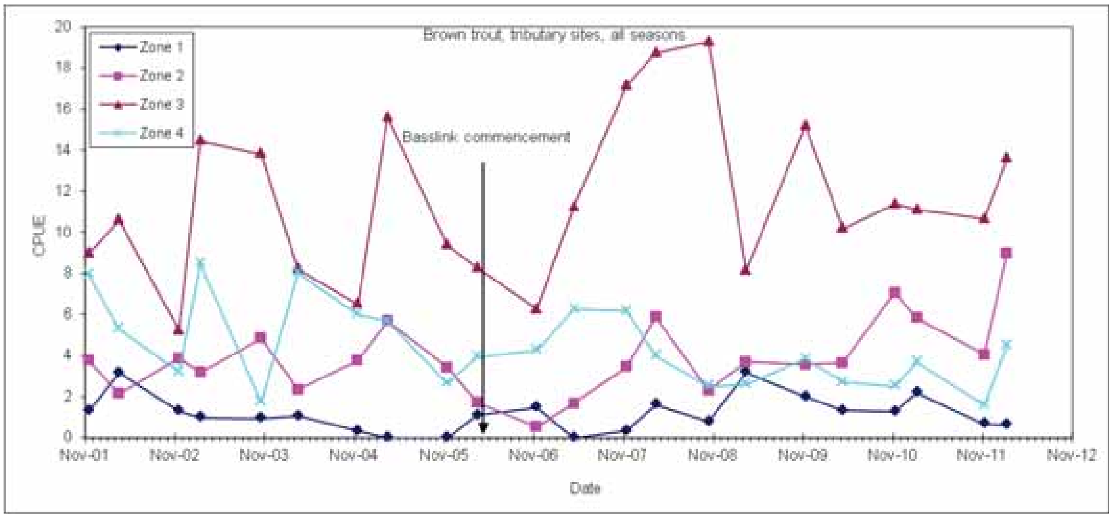

Figure 9.8: CPUE for brown trout caught in the Gordon tributary monitoring zones between December 2001 and March/April 2012.

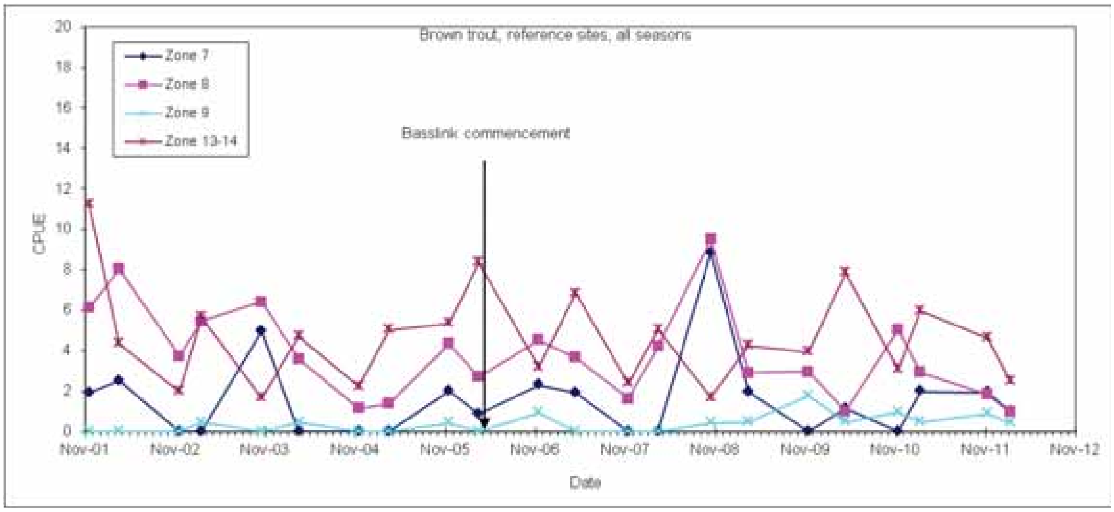

Figure 9.9: CPUE for brown trout caught in the reference monitoring zones between December 2001 and March/April 2012.

Appendix 5 shows length frequency histograms for a range of key fish species captured from the Gordon River during the monitoring program. Two sets of length frequency histograms are shown for brown trout, the first set shows pooled data for zones 1-5 and the second set shows pooled data for zones 1-2. The zone 1-2 histograms were produced to see if there was a noticeable change in recruitment in the upper zones due to the minimum environmental flow. Brown trout population structure was relatively consistent in pooled zones 1-5 over the monitoring program, with evidence of recruitment apparent in most years, and a range of year classes apparent in the data. The pooled zone 1-2 data showed some evidence of improved post-Basslink recruitment, but this was generally inconsistent between years.

9.4.1.2 Atlantic salmon (Salmo salar) and rainbow trout (Oncorhynchus mykiss)

Atlantic salmon and rainbow trout were a minor component of the catch from the Gordon River sites, comprising less than 0.1 % of the catch in each instance (Table 9.1). Only two rainbow trout and one Atlantic salmon were captured over the duration of the monitoring program. These species were considered vagrants as they had most likely entered the river as fish farm escapes from Macquarie Harbour. These species were not captured from the reference sites.

9.4.1.3 Redfin perch (Perca fluviatilis)

Redfin perch comprised 2.3 % of the pre-Basslink catch and 0.9 % of the post-Basslink catch from the Gordon River zones (Table 9.1). They maintained a restricted range within the Gordon River zone 1 - 3 over the monitoring program and were not captured from the reference zones.

Figure 9.5 and Figure 9.6 show the pre- and 6 year post-Basslink longitudinal species distribution in the Gordon River and tributaries. The majority of fish have been captured from river sites, with occasional captures from the lower reaches of zone 2 and 3 tributaries. Figure 9.10 shows redfin relative abundance for the duration of the monitoring program. There appears to be a decreasing relative abundance over time in zones 1-2, however the limited sample size makes valid statistical testing difficult.

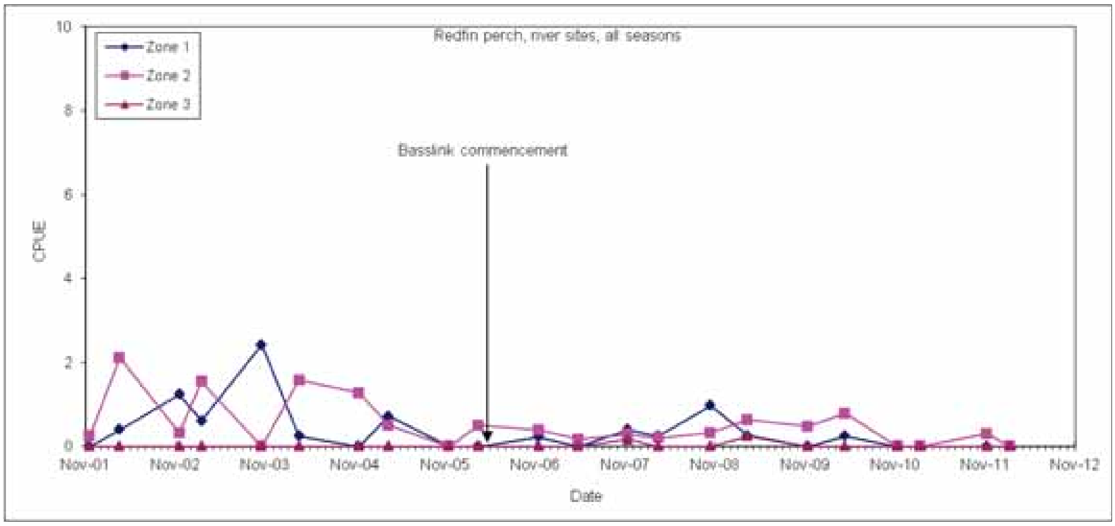

Figure 9.10: CPUE for redfin perch caught in the Gordon River monitoring zones 1, 2 and 3 between December 2001 and March/April 2012.

9.4.2 Native species

Nine native species were captured from the reference sites over the monitoring program, and eight of these species were captured from the Gordon River. The Australian grayling was only recorded from the reference sites. The species present in the Gordon River fall into four taxonomic categories; galaxiids (four species), eels (one species), lampreys (two species) and sandys (one species). The longitudinal distribution of each species in the Gordon River monitoring zones and tributaries is shown in Figure 9.5 and Figure 9.6 respectively. All of these species require access to marine waters at some stage of their life cycle. While there had previously been some doubt about the life cycle requirements of sandys, Crook et al. (2008) have recorded diadromous behaviour in female sandys.

9.4.2.1 Short headed lamprey (Mordacia mordax) and pouched lamprey (Geotria australis)

Short headed lampreys comprised a small proportion of the catch in both the Gordon River and tributary test sites and reference monitoring sites. Table 9.1 shows that pre- and post-Basslink catch proportion percentages at the Gordon River sites were 0.6 % and 0.9 %, while pre- and post-Basslink catches from the reference sites were similarly low at 0.9 % and 0.3 % respectively.

Figure 9.11 and Figure 9.12 shows the relative abundance of pouched lampreys in the Gordon River monitoring sites and reference sites over the duration of the monitoring program. Pouched lampreys had a similar range or distribution in the river, but were far more common or abundant in comparison to short headed lampreys. They comprised 6.4 % of the pre-Basslink catch declining to 4.5 % of the catch following the commencement of Basslink operation (Table 9.1). Pouched lampreys made up a similar proportion of the catch from the references sites (7.3 % and 5.4 % of the pre- and post-Basslink catches respectively) and showed a similar decline in the post-Basslink samples (-1.9 %) when compared to the Gordon River sites. While Table 9.1 indicates that post-Basslink declines of pouched lamprey catches appear to have occurred in both the Gordon River and references sites, Figure 9.11 and Figure 9.12 tend to show that the Gordon River sites have exhibited higher variability in the post-Basslink period, and consistently low abundances in the last three years of the monitoring program (2009-12).

The majority of short headed and pouched lamprey specimens captured were juveniles (ammocoetes), usually associated with sandy substrates, with small numbers of macrothalmia (sub adults) and adults present in catches.

Pre- and post-Basslink distribution ranges in the Gordon River and tributary sites were similar, with short headed lampreys caught in zones 2-5.

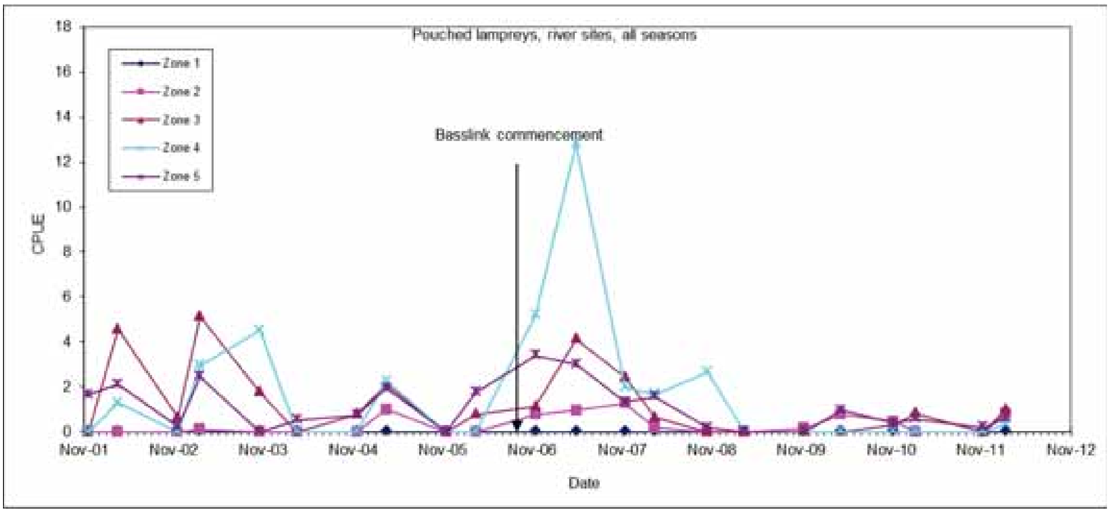

Figure 9.11: CPUE for pouched lampreys caught in the Gordon River monitoring zones between December 2001 and March/April 2012.

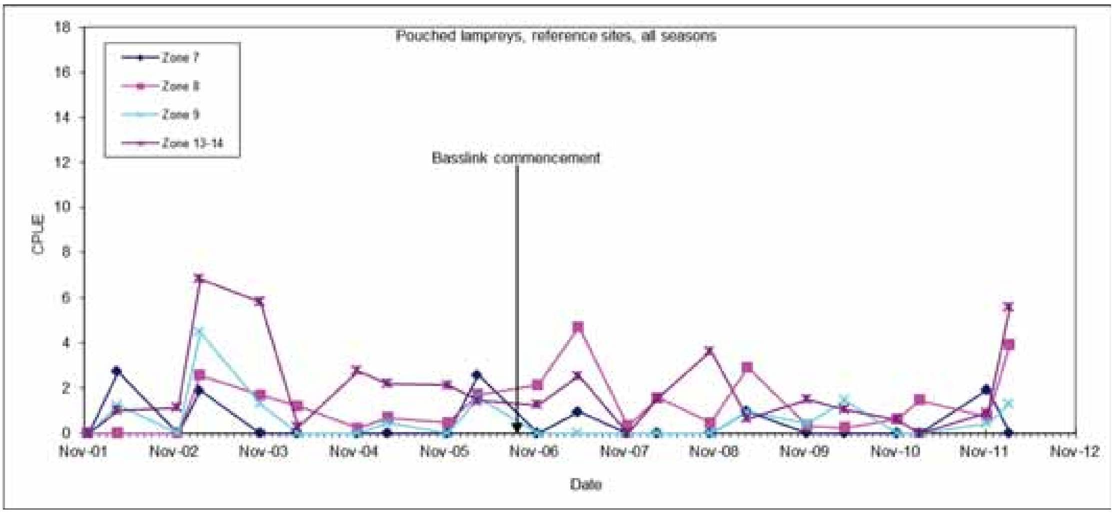

Figure 9.12: CPUE for pouched lampreys caught in the reference monitoring zones between December 2001 and March/April 2012.

9.4.2.2 Short-finned eels (Anguilla australis)

Short-finned eels were the second most abundant native fish in the Gordon River monitoring sites, comprising 12.6 % of the pre-Basslink and 14.9 % of the post-Basslink catch (Table 9.1). They were the third most abundant native fish in the reference sites comprising 11.1 % and 7.0 % of the pre- and post-Basslink catch respectively.

Lengths ranged from approximately 60 mm to 100 mm, with consistent modes in 140-160 mm size classes reflecting juvenile recruitment. Population structure varied between years reflecting annual changes in eel recruitment to the river, but there was no consistent trend or change in population structure between pre- and post-Basslink catches (Appendix 5).

As well as being one of the most abundant native fish in the Gordon River, they were also the most widespread species, occurring in all five monitoring zones (Figure 9.5). Juvenile eels (elvers) are capable of passing significant instream barriers, and this is reflected in their distribution throughout all of the monitoring and reference zones.

Figure 9.13 and Figure 9.14 show the relative abundance of short finned eel in each Gordon River and reference monitoring zone over the duration of the study period. Abundances varied over the duration of the monitoring program, and were consistently higher downstream of the Splits (zones 3-5) when compared to the upstream zones. There was no obvious difference in the pre/post-Basslink abundance or distribution of short finned eels.

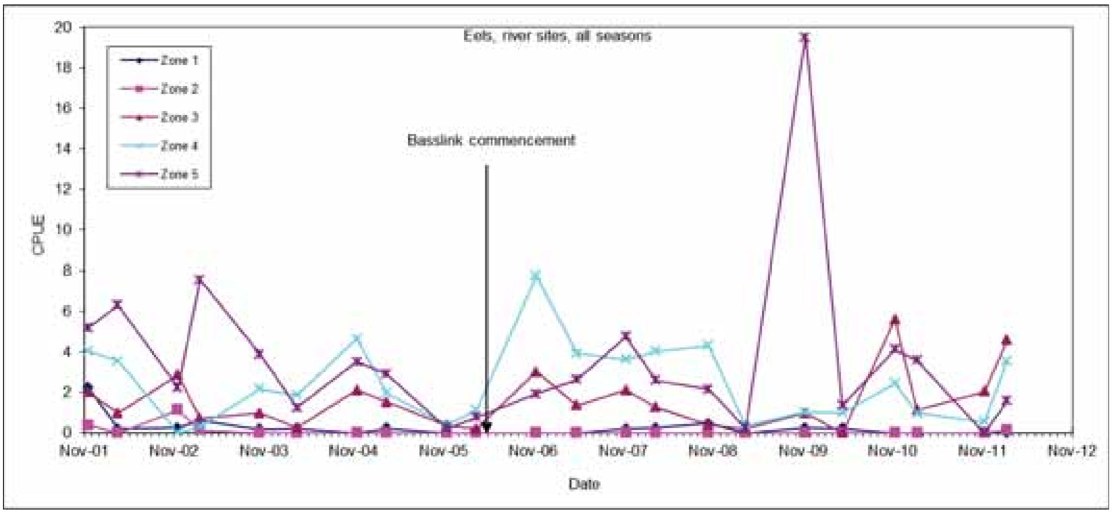

Figure 9.13: CPUE for shortfinned eels caught in the Gordon River monitoring zones between December 2001 and March/April 2012.

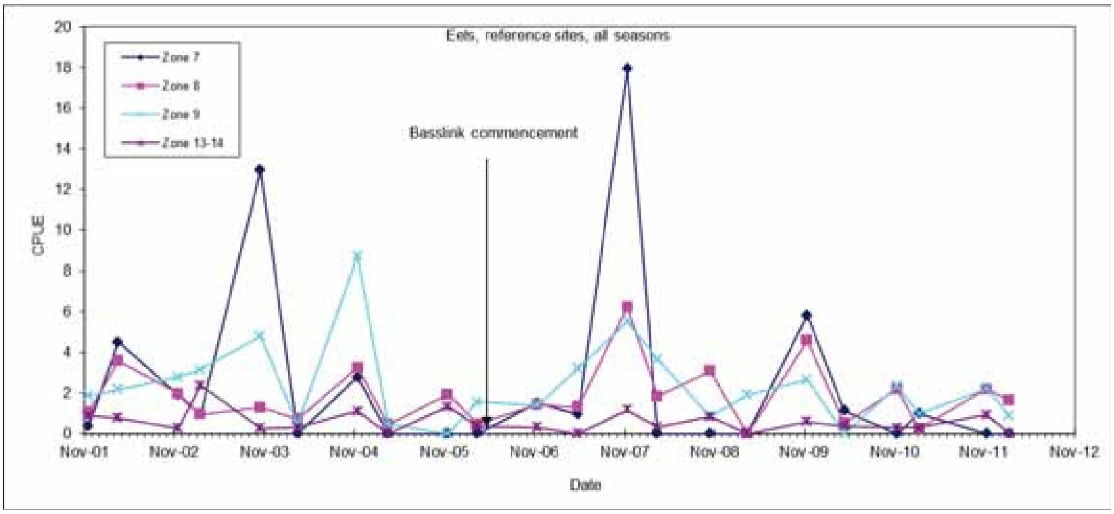

Figure 9.14: CPUE for short finned eels caught in the reference monitoring zones between December 2001 and March/April 2012.

9.4.2.3 Galaxiids

Spotted galaxias (*Galaxias truttaceus*) were the most abundant native fish in the Gordon River, and were the most abundant fish (native or exotic) in the reference sites (Table 9.1). They comprised 13.0 % of the pre-Basslink and 26.7 % of the post-Basslink catch in the Gordon River sites, and 26.5 % and 38.8 % of the catch from the reference sites. The proportion of spotted galaxias in post-Basslink catches increased by 13.6 % in the Gordon River sites and 11.9 % in the reference sites compared to pre-Basslink catches.

Figure 9.5 and Figure 9.6 show the relatively small range exhibited by spotted galaxias in the Gordon River. Catches were restricted to zones 4 and 5 during the pre-Basslink period, with fish subsequently captured into the lower reaches of zone 3 (mainly Smith River and Harrison Creek upstream of Sunshine Gorge) in the post-Basslink period.

Climbing galaxias (*Galaxias brevipinnis*) and jollytails (*Galaxias maculatus*) were captured in similar proportions (7.2 % and 5.8 % respectively) from the Gordon River during the pre-Basslink period (Table 9.1). Post-Basslink catch proportion fell to 1.7 % and 1.2 % respectively for these species. Figure 9.5 and Figure 9.6 show that the distribution of jollytails in the Gordon River was limited to zones 4 and 5, and tributary catches were restricted to a small number of fish from the Sprent River in the downstream reaches of zone 4. Climbing galaxias were relatively widespread in the river as they were present in all five monitoring zones, however the majority of fish from the Gordon River were captured from the zone 1 tributaries and zone 5 river sites. The longitudinal distribution of these species did not show a marked difference between the pre- and post-Basslink period.

Catches of Tasmanian mudfish (*Neochanna cleaveri* from the Family Galaxiidae) in the Gordon River were rare, and only two fish were captured from zone 5 in the post-Basslink period. They were marginally more common in the reference sites, comprising 0.4 % and 1.6 % of the pre- and post-Basslink reference site catches. All of these fish were captured in zone 13 (Henty River).

Figure 9.15 and Figure 9.16 show the pooled catch per unit effort results for galaxiids (*G. brevipinnis*, *G. truttaceus*, *G. maculatus* and *N. cleaveri*) sampled from the Gordon River and tributary sites, and Figure 9.17 shows catches from the reference sites over the monitoring program. Relative abundances in the Gordon River and reference sites show high variability between seasons, with the summer peaks reflecting the influx of new recruits into the Gordon River and reference catchments. Catch variability in the Gordon River sites was reduced in post-Basslink catches, but continued at the reference sites. This may be related to changes in the pre/post-Basslink community composition of galaxiids in the Gordon River. Prior to the commencement of Basslink operation the catch was comprised of 13 % spotted galaxias, 7.2 % climbing galaxias and 5.8 % jollytails. The proportion of spotted galaxiids in post-Basslink catches increased to 26.7 %, whilst climbing galaxias and jollytail catches fell to 1.7 % and 1.2 % respectively (Table 9.1). Post-Basslink relative abundances in zone 5 show reduced variability, whilst zone 4 CPUE appears to have shown a general increase post Basslink.

The length frequency histograms (Appendix 5) for spotted galaxias show significant levels of spring/summer juvenile recruitment in the post-Basslink period, indicated by summer and autumn modes in the 60 mm and 75 mm size classes respectively. Strong recruitment in the post-Basslink period was the primary driver for the 13.6 % increase of spotted galaxias in the post-Basslink species composition in the Gordon River, and may also have been related to the species increased range post Basslink.

The length frequency histograms for climbing galaxias (Appendix 5) show a population with an under representation of the “middle” size classes between 65 mm and 135 mm. Evidence of recruitment is sporadic, with occasional episodes of high juvenile abundance in summer samples, which appear to be a less common occurrence in the post-Basslink period.

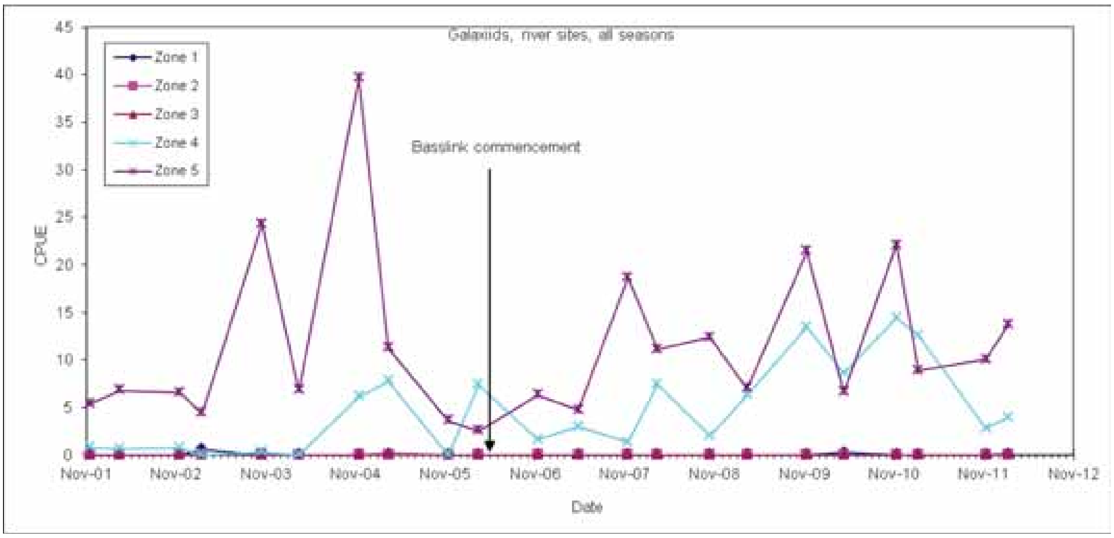

Figure 9.15: CPUE for galaxids caught in the Gordon River monitoring zones between December 2001 and March/April 2012.

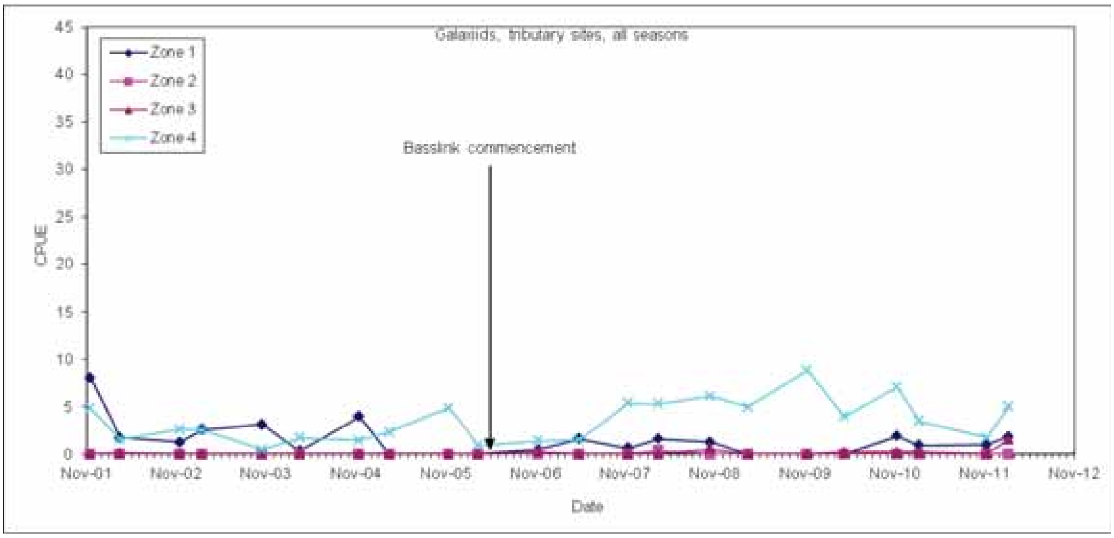

Figure 9.16: CPUE for galaxids caught in the Gordon tributary monitoring zones between December 2001 and March/ April 2012.

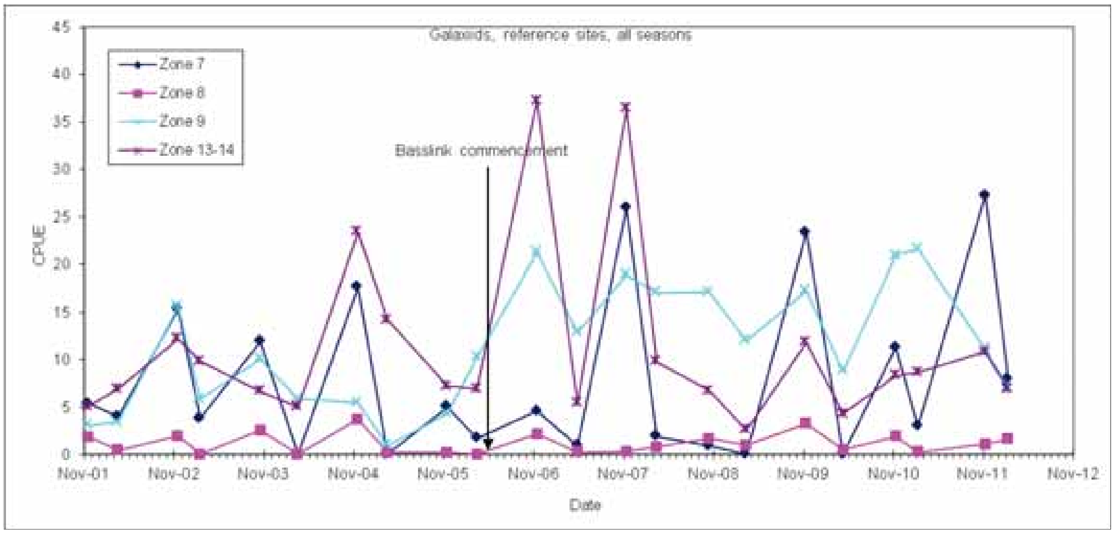

Figure 9.17: CPUE for galaxids caught in the reference monitoring zones between December 2001 and March/April 2012.

9.4.2.4 *Sandys (Pseudaphritis urvillii)*

Sandys comprised a small proportion of the pre-Basslink catches in the Gordon River (3.9 %) which increased to 5.3 % in the post-Basslink period. They were a significantly higher proportion of the catch in the reference site, comprising 16.2 % and 18.5 % of the pre- and post-Basslink catch (Table 9.1).

Figure 9.5 and Figure 9.6 shows the longitudinal distribution of sandys in the Gordon River and tributaries encompassed zones 3-5, however the majority were captured from zones 4-5.

The relative abundance of sandys in the Gordon River monitoring zones for the duration of the monitoring program is shown in Figure 9.18. Figure 9.19 shows the relative abundances from the reference sites. Relative abundances were generally highest in zone 5. No clear pre/post-Basslink trends in relative abundance were apparent in the data.

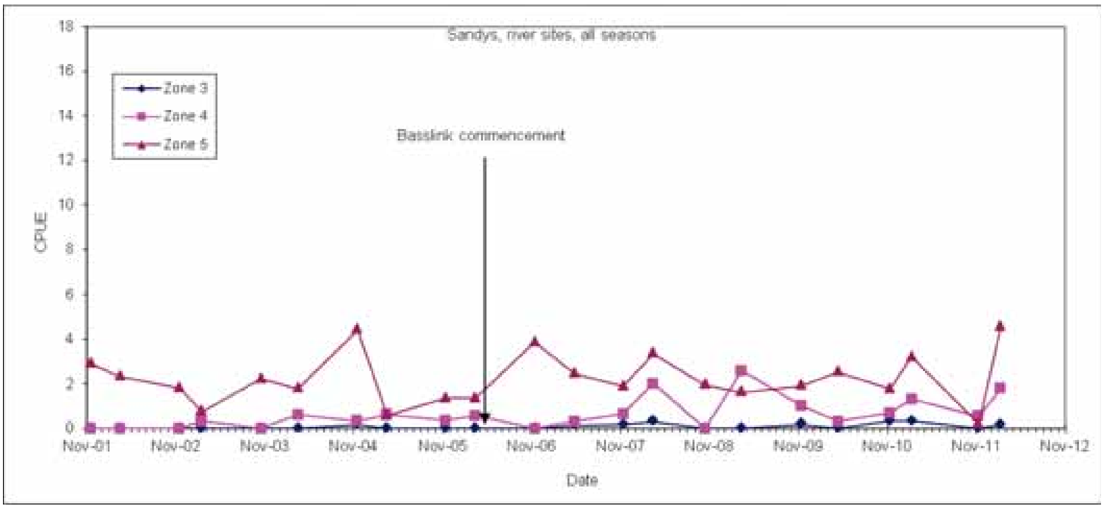

Figure 9.18: CPUE for sandys caught in the Gordon river monitoring zones between December 2001 and March/April 2012.

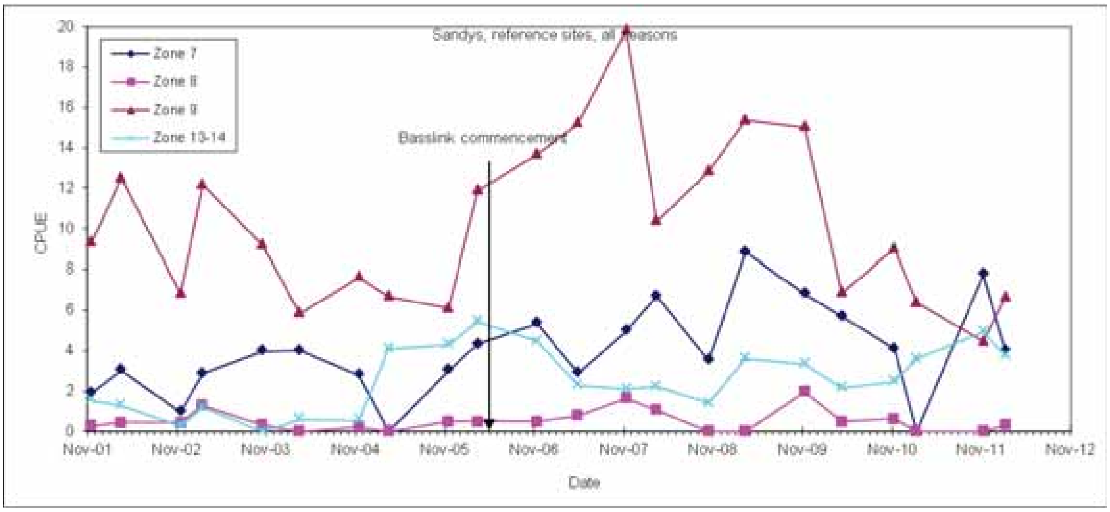

Figure 9.19: CPUE for sandys caught in the reference monitoring zones between December 2001 and March/April 2012.

9.4.2.5 *Australian grayling (Prototroctes maraena)*

Australian grayling have been caught on one occasion only during the monitoring program. One fish was caught at the Henty u/s Bottle Creek reference site in December 2004. No Australian grayling were caught in the Gordon River during the post-Basslink Monitoring Program. Australian grayling is listed as vulnerable under the *Threatened Species Protection Act 1995* and *Environment Protection and Biodiversity Conservation Act 1999*.

9.4.3 Fish stranding

There has been little evidence of fish stranding during six years of Basslink operation. A single, live stranded redfin was collected from site G5 during the May 2007 survey, which was considered to be a recent stranding associated with the monitoring shutdown (Hydro Tasmania 2007). Two dead redfin and one large short finned eel were recorded in zone 1 in December 2008; however it could not be determined whether these fish had died due to stranding or passage through the power station (Hydro Tasmania 2009). No stranded fish have been reported during the last three years of the monitoring program to 2012 (Hydro Tasmania 2010b, 2011, 2012).

While there is little evidence of stranding during either the pre or post Basslink period, the monitoring program has not been designed to maximize the chances of detecting fish strandings (Hydro Tasmania 2010a). The Gordon power station is shut down the night prior to the monitoring trip in order to give the river sufficient time to drain to low levels before monitoring commences the following morning. If fish are stranded that night or during the early hours of the morning, it is possible that they are scavenged by nocturnal carnivorous mammals or birds of prey prior to the arrival of monitoring teams and thus not be detected.

9.4.4 Multivariate analysis of fish abundance

Multivariate analysis was conducted to determine whether the fish species abundance data showed any indication of a pre/post-Basslink change. Multidimensional scaling (MDS) ordination was used to determine whether temporal partitioning of the fish community data was evident. Analysis focused on native species due to their ecological significance and data analysis was restricted to zones 4 and 5 due to the paucity of galaxiids upstream of these zones. The ordination plot is shown in Figure 9.20.

The ordination indicates that there is a degree of pre/post-Basslink difference in the Gordon River fish community (ANOSIM, P=0.002). SIMPER analysis was then used to identify the species responsible for this differentiation. The results of the SIMPER analysis are shown in Table 9.2 and they indicate that changes in galaxiid relative abundance (*G. truttaceus*, *G. maculatus* and *G. brevipinnis*) were primarily responsible for the pre/post-Basslink split in the fish community ordination.

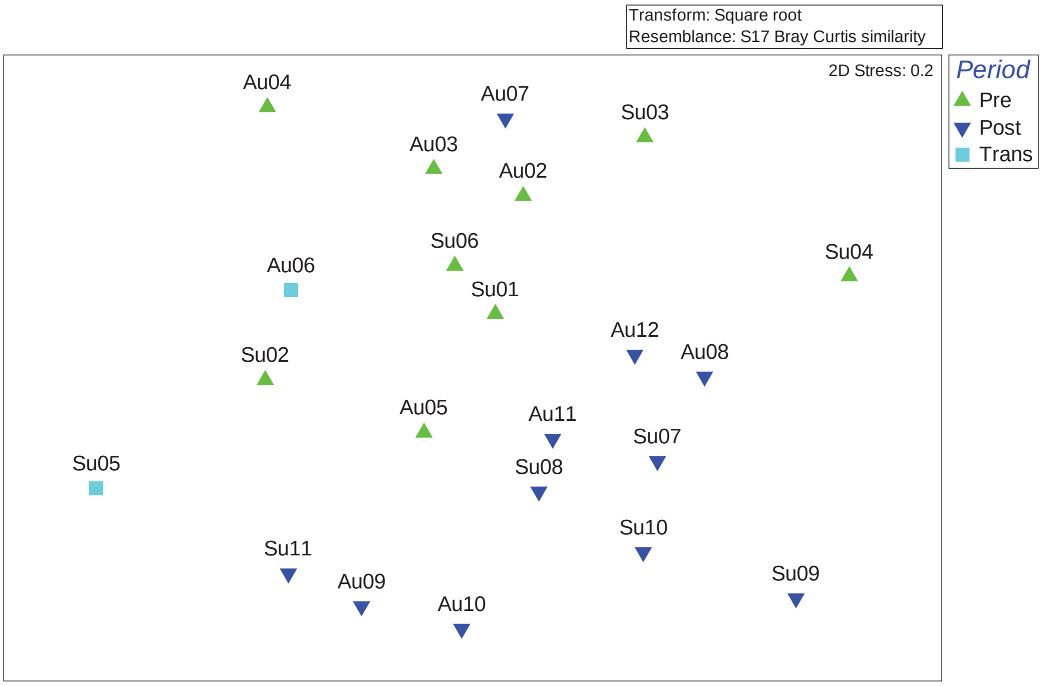

Figure 9.20: MDS ordination of pre- and post-Basslink Gordon River fish community relative abundance data collected between December 2001 and April 2012 from zones 4-5. CPUE data were square root transformed prior to ordination.

Table 9.2: Results table of SIMPER analysis on MDS ordination results.

Species	Pre BL average abundance	Post BL average abundance	Average dissimilarity	Dissimilarity / SD	Contribution %	Cumulative %
G. truttaceus	1.74	2.75	6.18	1.75	22.15	24.15
G. maculatus	0.93	0.47	3.97	1.22	15.53	39.69
G. brevipinnis	0.91	0.35	3.68	1.32	14.38	54.07
A. australis	1.56	1.46	3.25	1.20	12.70	66.77
G. australis	0.98	0.85	2.75	1.33	10.74	77.50
S. trutta	1.74	1.36	2.51	1.43	9.81	87.31
P. urvillii	0.98	1.17	1.70	1.46	6.63	93.94

9.5 Evaluation of the monitoring program

The design of the Basslink fish monitoring program was initially proposed in the Fish Appendix of the Basslink IIAS (Howland et al., 2001). The monitoring program design was based on BACI principles (before, after, control, impact), with a range of Gordon River and tributary “test” sites distributed between the Serpentine River immediately downstream of Gordon dam, to the confluence with the Franklin River. The sites were allocated to five longitudinal demarcation sections or zones along the length of the river, the boundaries of which reflect significant hydrological control features. “Control” sites were established within a major tributary of the lower Gordon River, (the Franklin River), two rivers flowing into Macquarie Harbor at Birches Inlet (Sorell and Pocacker Rivers) and the Henty River. This design was subsequently accepted by the Basslink Joint Assessment Panel (JAP) as suitable for testing for a Basslink effect on the fish communities of the Gordon River and was subsequently incorporated into Hydro Tasmania’s Special Water Licence. Monitoring was initiated in December 2001.

The Basslink Baseline Report (Hydro Tasmania 2005a) provides a detailed assessment of the suitability and performance of the fish monitoring program at the end of the baseline data collection period in 2005. Much of the discussion in the Baseline Report remains applicable to the assessment of the monitoring program at its completion. The main points of note are that the study design is not a true BACI design due to the difficulty in identifying true control sites, as there are no comparable regulated rivers in the region that will not also be subjected to Basslink related changes. For these reasons, sites that were initially selected as controls have been used as reference sites, as they have value in indicating significant non-Basslink environmental change (Hydro Tasmania 2005a).

The limited number, restricted patchy distribution and seasonal migratory characteristics of the Gordon River fish community presented difficulties when attempting to detect a post-Basslink effect. These difficulties are discussed in detail in the Basslink Baseline Report (Hydro Tasmania 2005a). The sparseness of fish data requires pooling of site CPUE to zone level for each monitoring trip, and species are also pooled into ecological groups to allow trigger level analysis with a meaningful level of statistical power.

Taking into account the limitations discussed above and in previous reports (Hydro Tasmania 2005a, 2010a), the fish monitoring program has performed within expectations over the six year post-Basslink period. Although the ability to statistically check trends in individual species’ relative abundance, zone level distribution and species population structure are limited, the monitoring program has provided sufficient information to assess whether the fish community of the Gordon River has changed markedly after the commencement of Basslink operations. The development of triggers (see Section 9.6) has facilitated assessment for a post-Basslink effect across a range of ecological categories; community composition, ecologically significant species and biomass/productivity. No negative impacts have been detected during the first six years of post-Basslink operation. However the fish monitoring program, like most of the other Basslink monitoring disciplines, has limited capacity to differentiate between a direct Basslink effect and confounding factors such as changed hydrology due to natural temporal variation in climate and hydrological changes due to altered Tasmanian generating system operating strategies. The breaking of a long drought during the latter part of the monitoring program is one example of a significant, natural, broad scale environmental factor that has potentially affected the aquatic fauna of the Gordon and reference rivers. The “rebuilding” of Lake Gordon storage levels is an example of a business driven operational factor which has resulted in different discharge volumes through the Gordon Power Station during the post-Basslink period.

The limitation imposed by the inherent variability and patchy distribution of the fish data were stated earlier in this section, and a range of factors contribute to the underlying variability in fish relative abundance data. The migratory/diadromous behaviour of the majority of native fish in the Gordon River introduces difficulties when attempting to determine whether Basslink operations have had an impact on the rivers' native fish communities. Short finned eels and both lamprey species move between marine and fresh water during their lifecycle, and eels migrate particularly large distances to spawn in the Coral Sea. Changes to oceanic current may influence numbers of leptocephali (pelagic eel larvae) encountering the west coast of Tasmania. Coastal currents and the hydrodynamic characteristics of Macquarie Harbour may also affect elver recruitment to rivers entering the harbour, including the Gordon River. Similarly, larvae of migratory galaxiids are washed downstream to Macquarie Harbour or out to sea, and so broad scale climatic and catchment factors play a role in settlement or recruitment success to the Gordon River. While the reference sites are of value in identifying catchment or regional trends in recruitment or abundance, they are not true controls in a statistical context and the information they provide has to be interpreted with this in mind.

Natural flows encountered during sampling may vary significantly due to rainfall in the catchment during or immediately prior to sampling. Evaluation of the fish monitoring program in the Basslink Review Report 2006-09 (Hydro Tasmania 2010a) reported that researchers had observed reductions in catches when sampling was conducted during or immediately following a flood event (i.e. a hydrological fresh or spate). Hydro Tasmania (2010a) compared a range of flow variables from hydrological monitoring sites in the Gordon River with components of the fish data to determine whether prior flow levels had an influence on the relative abundance of fish sampled by electrofishing. The model that best described CPUE was $Y = -4E\text{-}05X + 10.209$ ($r^2=0.655$), where Y represents pooled CPUE (all species and all Gordon River monitoring zones) and X represents the estimated natural inflow volume (megalitres, upstream of the Franklin confluence) for the 7 day period prior to sampling. The r^2 for this relationship was 0.655 which indicated that 65.5 % of the variance in pooled CPUE was explained by natural inflows to the Gordon River. When the estimated 7 day prior natural inflows were compared with native species relative abundance, the equation $Y = -6E\text{-}05X + 5.6451$ ($r^2=0.571$) best defined the relationship between flow and CPUE.

However, when the hydrological and catch data from the 2009-12 period was incorporated into these analyses the r^2 value for the natural inflows/test sites all species CPUE fell from 0.655 to 0.294, indicating that only 29 % of the variance in the relationship was explained by natural inflows. Similarly the r^2 for relationship between natural inflows and native species abundance in the Gordon River fell from 0.571 to 0.111.

High galaxiid and short-finned eel relative abundance in summer 2009 and summer 2010, and to a lesser extent March 2012 relative to pre-Basslink catches, was the primary driver that weakened the relationship between flow and relative abundance. Flow volumes for the 7 days prior to sampling over these periods ranged between 26,430 ML and 76,266 ML, however catches were relatively high, which weakened the high flow/low catch relationship.

In summary, the first three years of post-Basslink monitoring showed reasonable relationships between flows prior to sampling and fish relative abundance, particularly native fish, however this relationship was not apparent in the last three years of monitoring. The influence of pre sampling flows on fish relative abundance may vary between years, and may be less influential in years when native species show strong recruitment/migration into the catchment.

9.6 Review of triggers

Hydro Tasmania (2005a) and Hydro Tasmania (2006) provide a full discussion on the rationale behind and derivation of trigger levels for the fish monitoring program. In summary, ten trigger levels have been developed for the fish monitoring program. They have been designed to indicate whether the monitoring data provides significant evidence of a post-Basslink effect indicated by changes in fish community composition, abundance of ecologically significant species, or changes to the productivity of the Gordon River fish community.

During the development of the trigger levels it was identified that, with the exception of the exotic species variable, the trigger levels would indicate an environmental impact if relative abundance levels fell below pre-Basslink means. One tailed trigger levels were calculated to reflect this for these variables and were used to assess potential impacts during the post-Basslink period. It became apparent during analysis of the first three years of post-Basslink data (Hydro Tasmania 2010a) that two tailed triggers would be beneficial for all of the indicator variables, as they would allow detection of a post-Basslink impact in addition to identification of potential post-Basslink improvement in ecological condition. Two tailed triggers were subsequently adopted in line with recommendations of the Basslink Review Report (Hydro Tasmania 2010a), and have been used when assessing 4-6 year post-Basslink data.

The fish trigger levels were grouped into three ecological categories. Trigger values were initially estimated using a Type 1 error rate, or alpha level, of 0.05. These were calculated using the 97.5th and 2.5th percentiles of pre-Basslink variable data (Hydro Tasmania 2006, 2010a). However, for all the fish indicator variables, an alpha of 0.05 resulted in a low probability that the limits of acceptable change would have been triggered before substantial change occurs. The fish trigger values were subsequently re-evaluated to assess the level of alpha which will increase the probability of detecting a meaningful environmental effect, and the revised alpha levels were incorporated into the final triggers (Hydro Tasmania 2012). This approach was adopted with the knowledge that it would result in an increased risk of falsely declaring that significant environmental change has occurred. The trade-off between ability to detect a meaningful effect at the expense of increasing the risk of false triggering means that the fish indicator variables have an increased Type 1 error level probability.

Figure 9.21 and Figure 9.22 show the results of the fish monitoring program against the individual year trigger values for each post-Basslink sampling years, whilst Figure 9.23 and Figure 9.24 show performance of the pooled 6 year post-Basslink data against the cumulative trigger levels.

Abundances and abundance ratios across all categories were above the lower trigger level in both individual year and cumulative year triggers. The autumn trigger for exotic species closely approached but did not fall below the lower trigger in 2006-07.

CPUE has varied to differing degrees between the ecological categories, but has remained above lower trigger levels in all categories indicating that there has not been a significant decline in native fish CPUE or total biomass following the commencement of Basslink operation, nor has there been an increase in exotic species abundance. With the exception of 2008-09, minor exceedances of the upper trigger level have occurred in the native to exotic ratio and/or galaxiid relative abundance triggers (single year) in most of the post-Basslink years.

The cumulative year triggers confirm this trend, with small upper exceedances in the native to exotic ratio and galaxiid relative abundance in the cumulative autumn triggers, and exceedence up the upper native fish relative abundance trigger in the annual trigger. While it is possible that an increased alpha may be responsible for an increased incidence of upper trigger exceedances, the number and category consistency of the upper exceedances indicating increased native fish abundance are strong evidence of a real effect.

There has been noticeable variation between annual and autumn CPUE within most of the ecological categories in the post-Basslink period, but the increased sample size in the cumulative six year data has reduced the variation between the cumulative autumn and cumulative annual trigger levels. This assisted in interpreting the significance of annual trigger exceedances, as they could be assessed in a pooled, multiple year context. It therefore appears that the triggers utilised in the Basslink Monitoring Program have been adequate to detect large changes in the fish population and community structure, particularly in relation to changes in the native species.

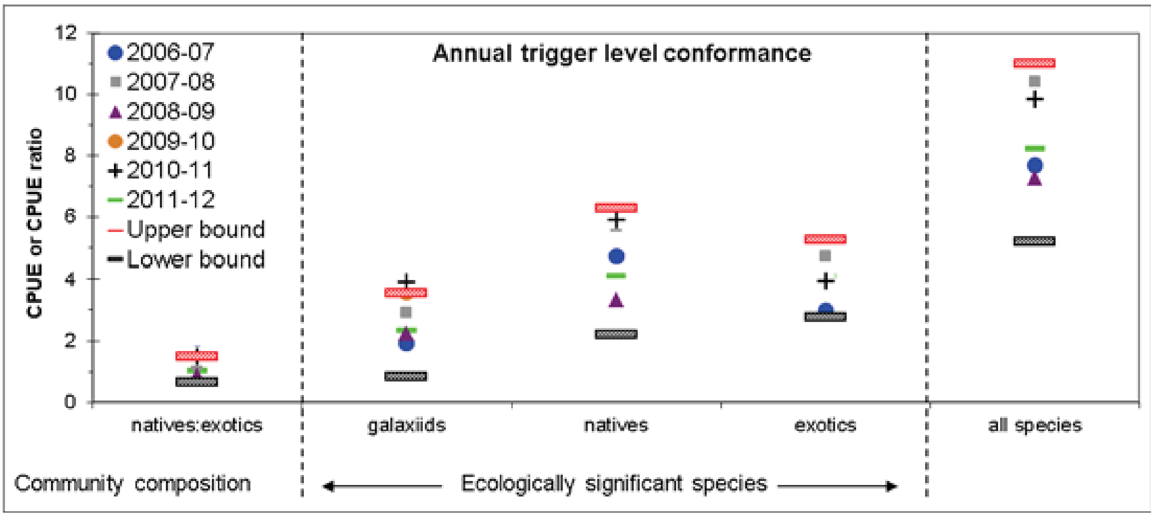

Figure 9.21: Individual year conformance with annual fish trigger levels.

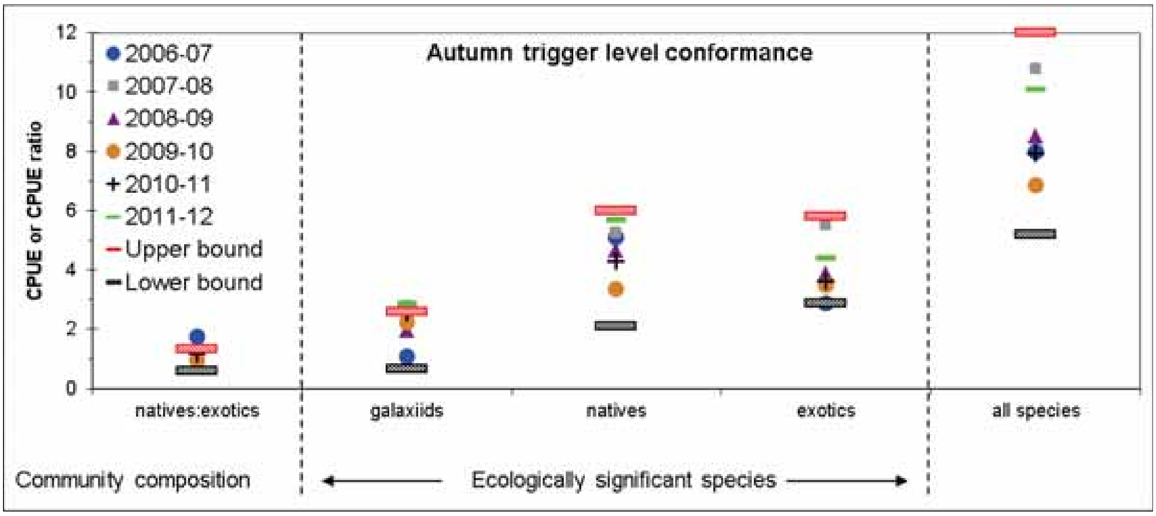

Figure 9.22. Individual year conformance with autumn fish trigger levels.

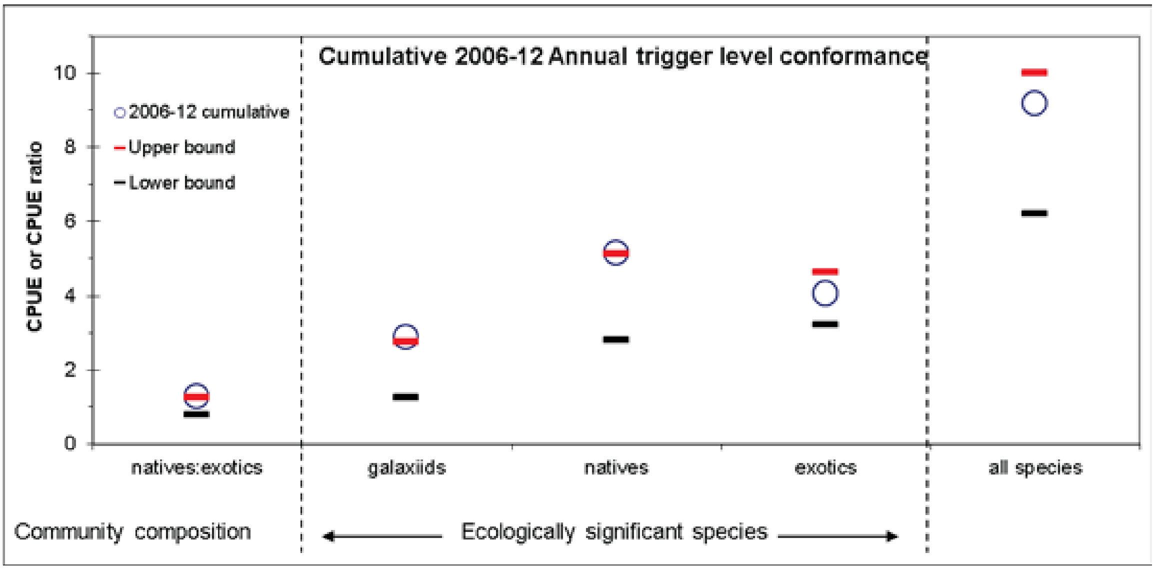

Figure 9.23. Cumulative (6 year) conformance with annual fish trigger levels.

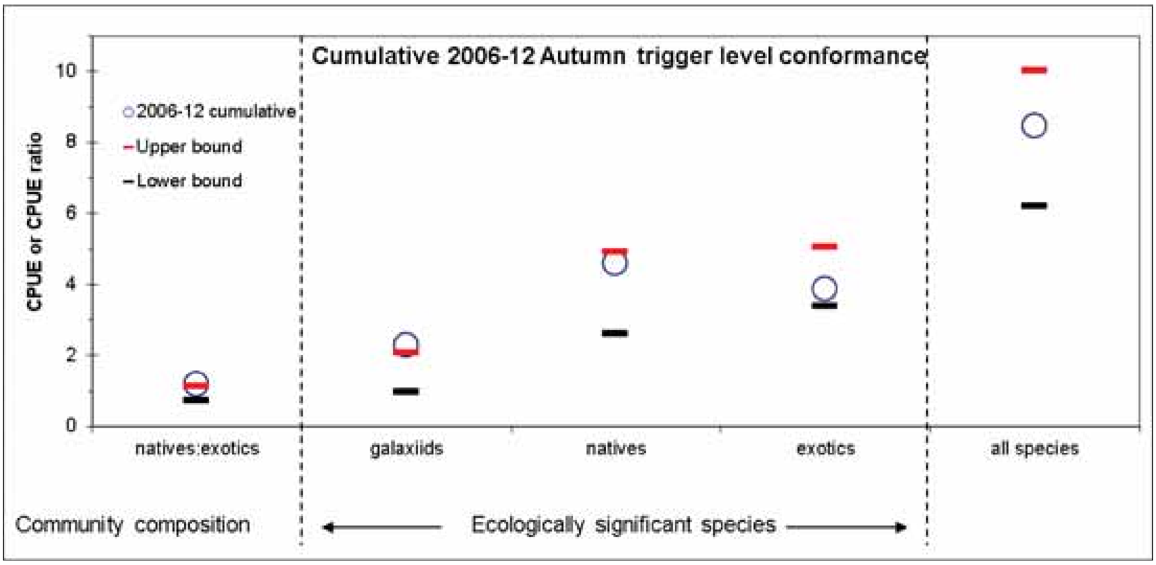

Figure 9.24. Cumulative (6 year) conformance with autumn fish trigger levels.

9.7 Conceptual model

The post-Basslink hydrological regime has altered in comparison to the pre-Basslink period. While no single hydrological pattern could be clearly identified as being dominant since Basslink commissioning, the post-Basslink hydrograph can be summarised using a range of distinctive flow categories (refer to Section 2).

Analyses of the fish data in this section and in Section 10.2.2 have served to further inform our understanding of the post-Basslink conceptual models which are described in Section 3. Most notable is the increase in galaxiid relative abundance in the post-Basslink period (refer to Section 9.4.2), which is linked to increases in the low flow dominant component of the post-Basslink hydrograph (refer to Section 10.2.3). A summary of the fish fauna components of the conceptual model are shown below (Table 9.3).

Table 9.3: Response of fish to prolonged flow patterns occurring on the Gordon River.

Flow pattern	Fish response
Low flow dominant- minimum flow with occasional peaks to 1-2 turbine level;	The minimum flow provides stable, low flow, refuge habitat area between flow peaks for aquatic fauna. Flow sensitive fish and macroinvertebrate species favour this flow regime. The increased macroinvertebrate food resource for fish can lead to lagged increases in fish condition and abundance. The benefits of the minimal flow to fish are greatest upstream of the Denison River, as tributary inflows are limited in this area..
Daily hydro-peaking to 1 or 2 turbines;	Habitat availability for lamprey ammocetes is reduced in the 1-2 turbine level and there is an increased risk of fish stranding in the zones upstream of the Denison River.
Daily hydro-peaking to 3 turbine level – rapid, regular alternation between minimum flow and 3 turbine discharge – with and without mitigation;	**Without mitigation -** The in-stream habitat area will be reduced without a minimum flow as there will be longer periods with low flow mainly above the Denison River. There will be reduced habitat for fish and macroinvertebrates and an increased risk of stranding mortality, both due to the lack of minimum flow and lack of ramping during drawdowns. Again, the strongest impact will be above the Denison River. **With mitigation -** In-stream biota benefit from the minimum flow providing refuge habitat between flow peaks. Some species sensitive to high velocities may still be disadvantaged by hydro-peaking to the three turbine level which will reduce upstream migration opportunities because of high velocity flows through hydraulic restrictions. The habitat availability for lamprey ammocetes is reduced in the 1-3 turbine level and there is an increased risk of fish stranding, particularly upstream of the Denison River.
Daily hydro-peaking in 2-3 turbine level - rapid, regular alternation between flow at 2 and 3 turbine flow levels	The 2-3 turbine hydro-peaking disadvantages flow sensitive fish species due to reduced upstream migration opportunities and limited habitat availability.
Base load utilising 3 turbines.	The constant high discharge reduces fish migration opportunities due to high velocities through hydraulic bottleneck in the river. Flow sensitive fish species are disadvantaged. Food resources will be reduced.

9.8 Conclusions

The fish monitoring program has performed within expectations over the six year post-Basslink period, although the ability to statistically check trends were limited due to the limited number, restricted patchy distribution and seasonal migratory characteristics of the Gordon River fish community. The monitoring program has provided sufficient information to assess that there were some differences between pre- and post-Basslink fish composition, mainly driven by increased post-Basslink galaxiid abundances. Sandys and spotted galaxias showed evidence of increased frequency of occurrence at their upstream range limit, and climbing galaxias exhibited an uncommon recruitment event to the upper zones of the Gordon River during the post-Basslink period. There were exceedances of the cumulative autumn and annual galaxiid trigger level indicator variables indicating a positive Basslink change, possibly due to the 10/20 environmental flow.

9.9 Recommendations

Given that there has been no evidence of a decline in the fish fauna of the Gordon River over the range of power station operating patterns encountered during the post-Basslink period, there is no justification to continue fish monitoring in the Gordon River. It is recommended that the fish monitoring program be discontinued as it has met its original aims, particularly given that abundances within components of the native fish fauna have increased post Basslink.

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10. Appropriateness of mitigation measures

10.1 Introduction

A number of potential impacts post-Basslink were identified during the IIAS process (Locher 2001) based on the anticipated changes to the power station operating regime. These included:

- Fluvial Geomorphology: change in the geomorphic processes controlling stability of the Gordon River banks relative to pre-Basslink, including probability of scour, changes to seepage erosion processes and bank saturation. Basslink changes were anticipated to be limited to adjustments of alluvial bank profiles, with no change to river planform compared to existing effects of flow regulation pre-Basslink.
- Riparian Vegetation: acceleration of pre-Basslink rates of loss of riparian vegetation communities, including migration of the existing vertical zonation in the river banks up the bank. However, it was noted that loss of the majority of the riparian vegetation (particularly upstream of the Splits to a height of 2.5 m above low water mark on the river banks) was expected to occur in the long-term under pre-Basslink conditions and that Basslink would not change this.
- Aquatic Macroinvertebrates: alteration of macroinvertebrates community composition in the middle Gordon River, resulting in reduced diversity and abundance both upstream and downstream of the Denison River confluence. Such changes have the potential to impact other fauna (e.g. fish, platypus and native water rats) which rely on macroinvertebrates for their food supplies, as well as to impact on rates of instream processes (algal grazing, carbon fractionation).
- Fish: reduced availability of fish habitat and food supplies (through impacts on macroinvertebrates) within middle Gordon River, leading to further reduced populations.

In order to minimise the potential adverse impacts of Basslink operations, two mitigation measures were proposed and incorporated into Hydro Tasmania's Special Licence Agreement. These measures aimed to minimise the anticipated impacts of Basslink through regulation of power station operation and to manage discharges into the middle Gordon River by:

- providing a minimum environmental flow to maintain habitat availability and ecological processes; and
- implementing a ramp-down rule for the Gordon Power Station to restrict rapid drawdowns of water levels along the Gordon River, reducing the risk of increased seepage erosion.

The following sections discuss the appropriateness and effectiveness of the minimum environmental flow (Section 10.2) and the ramp-down rule (Section 10.3) as mitigation measures based on analysis of monitoring data collected during the Basslink Monitoring Program.

10.2 Minimum environmental flow

A minimum environmental flow of 19 m^3s^{-1} in summer (from 1 December to 31 May) and 38 m^3s^{-1} in winter (from 1 June to 30 November) (known as the 19/38 environmental flow) at site 65 is specified in the Licence with an option to trial a reduced flow.

In February 2006 the minimum environmental flow requirement was amended to allow Hydro Tasmania to trial a smaller environmental flow for the first three years of the post-Basslink period. Permissions were subsequently granted by the Minister to extend the 10/20 environmental flow period until April 2014.

The 10/20 environmental flow regime provides:

- 10 m^3s^{-1} summer flow (from 1 December to 31 May); and
- 20 m^3s^{-1} winter flow (from 1 June to 30 November)

Assessment and evaluation of the benefits of the 10/20 environmental flow regime from a geomorphic, biological and operational point of view was provided in the Basslink Review Report 2006-09 (Hydro Tasmania 2010a) along with recommendations. That assessment included:

1. Relevant hydrological analysis;
2. Hydrological correlations with the biota;
3. Habitat risk analysis;
4. Comparisons between 10/20 and 19/38 for both habitat availability and sediment transport analysis;
5. Erosion pin analysis at low flows; and
6. Operational assessment in relation to the delivery of the environmental flow.

The following section in this report updates and expands the analyses under items 1 and 2 above. No additional understanding would be gained from reanalysing items 3-6.

10.2.1 Macroinvertebrate and algae assessment

10.2.1.1 Relevant analysis of the Gordon River flow regime

The overall pattern of annual discharge at the power station is shown in the hydrology chapter for the period prior to each sampling event during the Basslink Monitoring Program. Important features include:

- limited duration of high flows (> 200 m^3s^{-1}) during the post-Basslink period, especially from spring 2009 to autumn 2012; and
- increased incidence of flows between 10 and 40 m^3s^{-1} (winter) or 20 and 40 m^3s^{-1} (summer), reflecting compliance with the environmental flow requirements post-Basslink (from mid-2006 onward).

The latter phenomenon is illustrated clearly in for the 90 day periods prior to each macroinvertebrate spring sampling event (Figure 10.1), where the proportion of time when flows were less than 10/20 m^3s^{-1} is markedly reduced post-Basslink, though it should be noted that this phenomenon is evident only for the period preceding spring sampling. Flows during summer-autumn generally were higher than the environmental flow requirement as this is the main period of power station operation, and no pre- vs. post-Basslink change is therefore evident for the periods preceding autumn sampling.

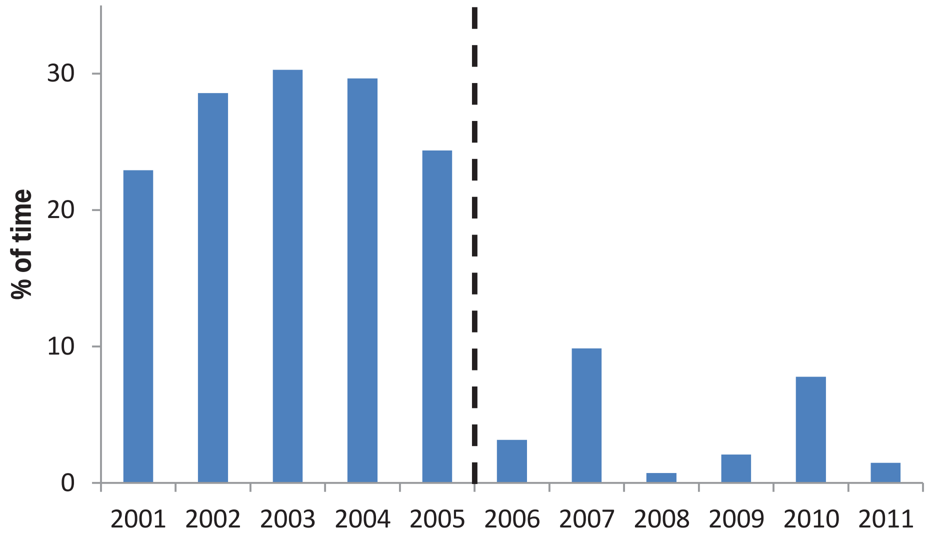

Figure 10.1: Percentage of time flow was < 20 m^3s^{-1} environmental flow at site 65 during the 90 days prior to macroinvertebrate and algal sampling in spring of each year. Dashed line indicates commencement of Basslink operations.

Gordon flow data were also analysed using multivariate methods (factor analysis, linkage tree and ordination analysis, distance based linear modelling and redundancy analyses) to reduce redundancy and evaluate pre- vs post-Basslink flow differences and patterns that may be of meaning to the benthic biota. Analyses were often conducted separately by season or zone due to the marked spatial and seasonal variation in some biotic variables.

Principal component analysis (PCA routine in Primer) on flow data was conducted on the following flow variables:

- Proportions of time between:
  - 0 and 2 m^3s^{-1}
  - 2 and 10/20 m^3s^{-1}
  - 10/20 and 40 m^3s^{-1}
  - 40 and 100 m^3s^{-1}
  - 100 and 200 m^3s^{-1};
- proportions greater than 100, 200 or 10/20 m^3s^{-1};
- Median, mean, minimum and maximum flow;
- Standard deviation of flow; and
- The number of rapid low to mid-range flow increase events during each of the 30, 60, 90 and 365 day periods prior to macroinvertebrate sampling, where an event is defined as an increase in flow from <25 m^3s^{-1} to >100 m^3s^{-1} over a 2 hour period.

This set of flow variables was generated for three overlapping time periods – 30, 90 and 365 days – immediately prior to each field sampling occasion.

PCA factor plots are shown in Figure 10.2 for spring and autumn. There is a marked difference in the occurrence of minimum flows (< 20 m^3s^{-1}) between the pre- and post-Basslink periods in spring sampling periods, as well as some variation in both periods in the incidence of large flows (> 100 m^3s^{-1}).

There is, therefore, a clear change in the low flow regime from pre- to post-Basslink in spring, dominated by the presence of the minimum 10/20 environmental flow; however, this change is not seen in autumn. No such separation occurs for autumn periods in flows of the magnitude of the environmental flow. There was however a separation of autumn pre- and post-Basslink sample periods based on the number of days with flows > 100 and 200 m^3s^{-1}, with some variation in the incidence of flows between 20 and 40 m^3s^{-1} (Figure 10.2).

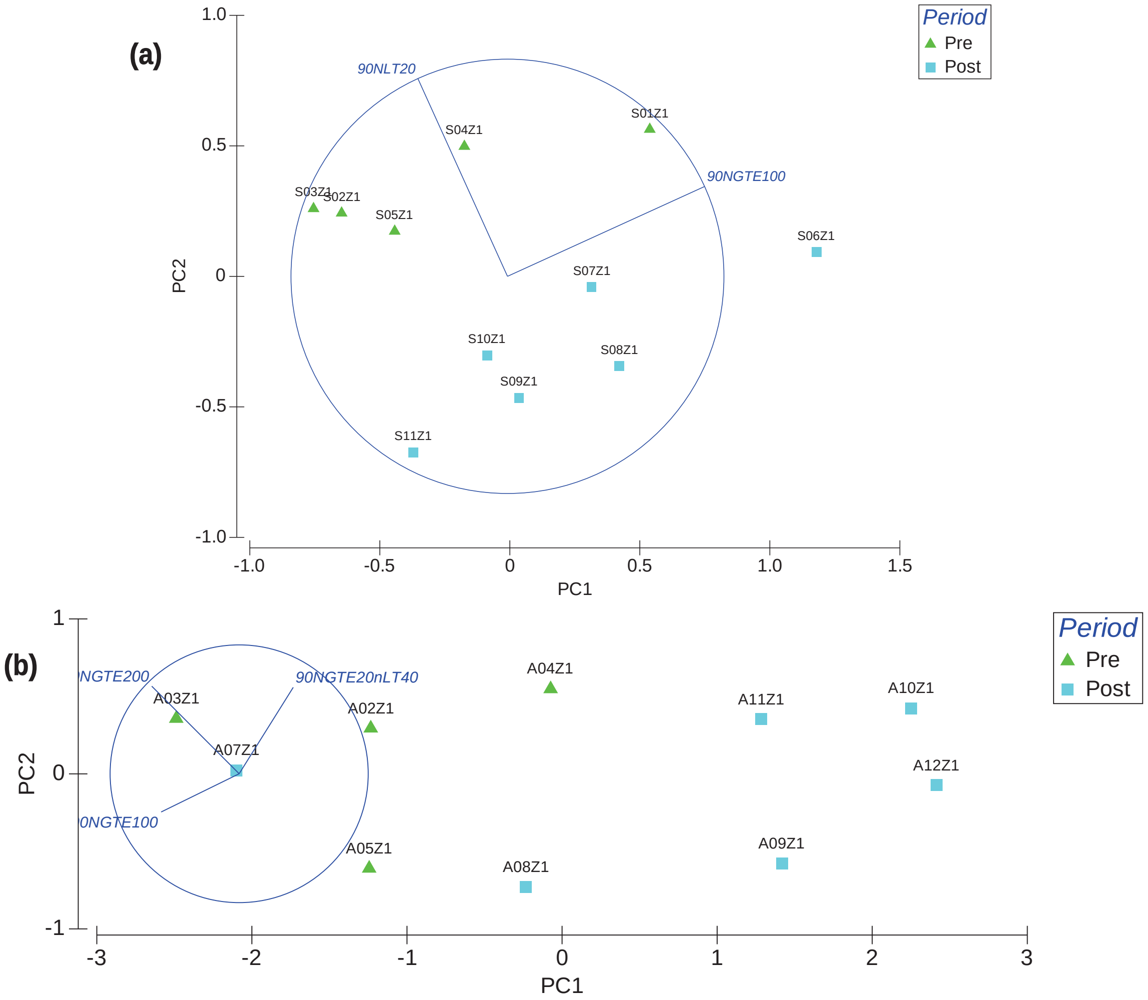

Figure 10.2: Principal Component analysis of Gordon River at site 65. Flow summary variables for the 90 day period preceding each biota sampling event in spring (a) and autumn (b) of each year of the Basslink Monitoring Program. Pre- vs post- Basslink periods are indicated by different symbols.

Natural catchment flows

In relation to understanding the responses in the reference sites, the pattern of natural catchment flows is illustrated in Figure 10.3 for the Franklin River (at Mt Fincham) site.

Calendar years 2002 to 2004 were markedly wetter, with more prolonged higher winter-spring flows than the other years in the sequence (Figure 10.3). Flows were lower overall in 2005 to 2008, with lower peak monthly flows and fewer months with flows more than 60 m^3s^{-1}, which is partly but less strongly reflected in the mean flows for the three month period prior to each sampling event (shown as points in Figure 10.3).

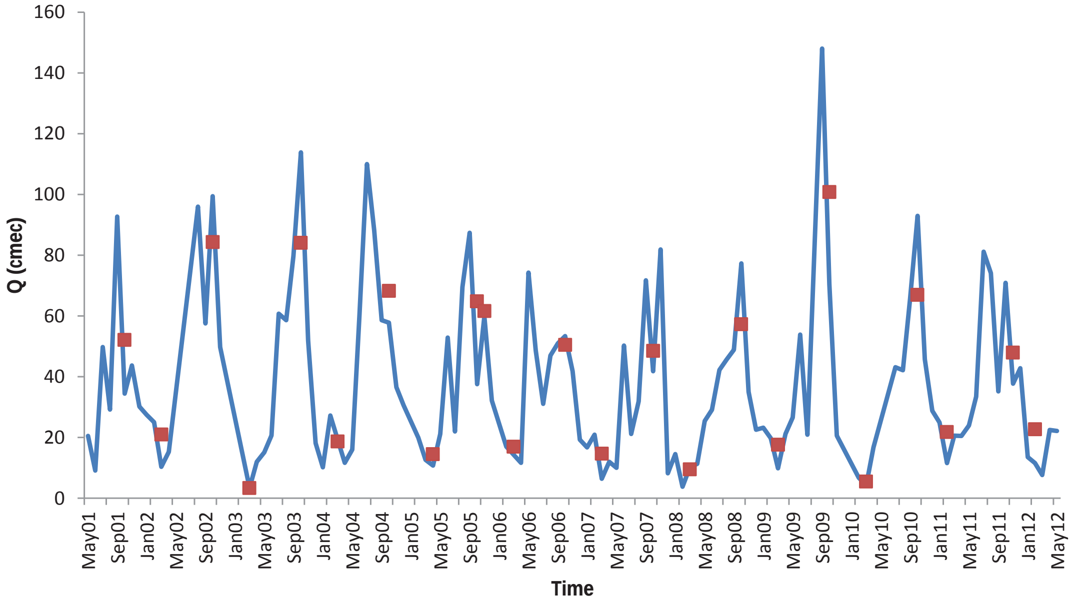

Figure 10.3: Mean monthly flows in the Franklin River (the 'natural' flow regime) over the period of the Basslink Monitoring Program. Red points indicate timing of all macroinvertebrate and algal sampling and the value of the 3-monthly mean flow preceding each sampling event. Flow data sourced from at gauging site 145 (Franklin at Mt Fincham).

10.2.1.2 Biology-flow analyses

Several approaches were used to explore the nature of the relationship between biological status and flows (both for pre- and post-Basslink data), especially to assess the influence of the minimum environmental flow. These were:

- exploring correlations between biological indicators and flow variables;
- pair-wise comparison of data from sample events whose preceding flow histories differed principally only by the presence of the environmental flow; and
- multivariate analyses designed to relate flow variables to biological variables (using the BEST, DISTLM, DRBA, LINKTREE routines in the Primer-E and Permanova+ multivariate analysis package) and evaluating the role of the environmental flow component in those relationships.

10.2.1.3 Biology – flow correlations

Univariate correlations

All biological variables were initially correlated with all derived flow variables across all sample events. Correlations and plotted relationships were examined.

The spring mean zone 1 O/Epa values were negatively correlated with the number of days when flows were less than 20 m^3s^{-1} at site 65 (Pearson r = 0.77, p < 0.0004, n = 11, Figure 10.4). In zone 2, autumn O/Epa was negatively correlated with the number of days when flows were greater than 200 m^3s^{-1} (Pearson r = 0.84, 0.62, p < 0.001, respectively, n = 11, Figure 10.5). While these relationships were statistically significant, they had small slopes i.e. large variations in incidence drove only small changes in the value of O/Epa. This is expected, as complete loss of families is unlikely to be driven by anything other than extreme floods or drying events.

Community compositional similarity of zone 1 sites to reference sites (as measured by the Bray Curtis Similarity measure) was both significantly positively correlated and varied substantially with the incidence of flows over the minimum environmental flow threshold in both spring and autumn (r = 0.71 and 0.69, p = 0.014 and 0.019, respectively, n = 11, Figure 10.6). This pattern reflects the substantial changes in relative abundance of flow-sensitive taxa experienced in this zone as flows persist at or above the minimum flow threshold. Thus, community compositional similarity increases by 30 – 50 % as the incidence of flows > 10/20 and less than 40 m^3s^{-1} approaches toward 70 – 100 %.

In zone 2, the number of taxa (families) was positively correlated with the number of days when flows were greater than 40 m^3s^{-1} and less than 100 m^3s^{-1} (Pearson r = 0.83, p = 0.003, n = 10, Figure 10.7), with up to three additional families gained as flow incidence changed from 0 to 50 % of the time. In zone 2, the Bray Curtis Similarity (abundance) was also negatively correlated with the number of days at which flows were greater than 100 m^3s^{-1} (Pearson r = 0.77, p < 0.001, n = 10), with this relationship strongest in autumn (Figure 10.8).

These results in zone 1 and 2 are all consistent with the conceptual model and the following macroinvertebrate responses to the flow regime:

- increases in the number of expected families with time in zone 1, and the community composition similarity to reference, as flows greater than the 10/20 environmental flow threshold become more frequent;
- an increase in representation of EPT taxa when minimum flows in zone 2 are consistent with the environmental flow; and
- sustained high flows (> 100 or 200 m^3s^{-1}) in zone 2 causing changes in compositional similarity away from that in reference rivers.

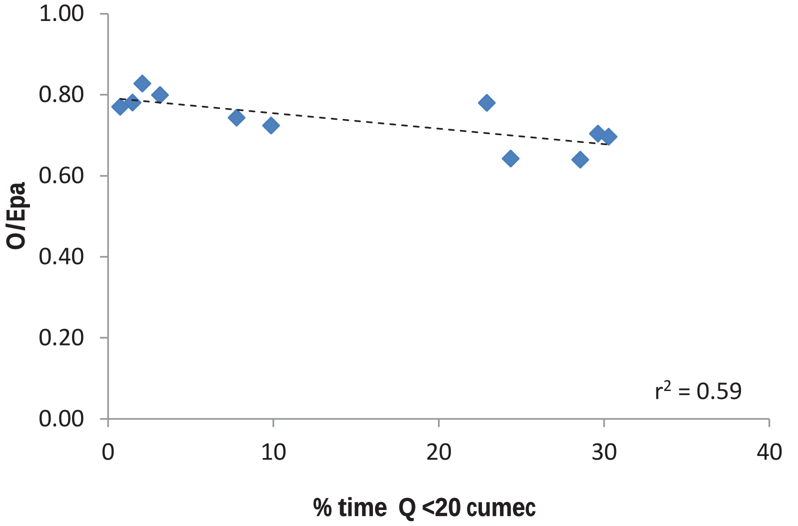

Figure 10.4: Relationship between spring mean Gordon zone 1 O/Epa and % time when flows at site 65 were < 20 m^3s^{-1} during the 90 days prior to sampling.

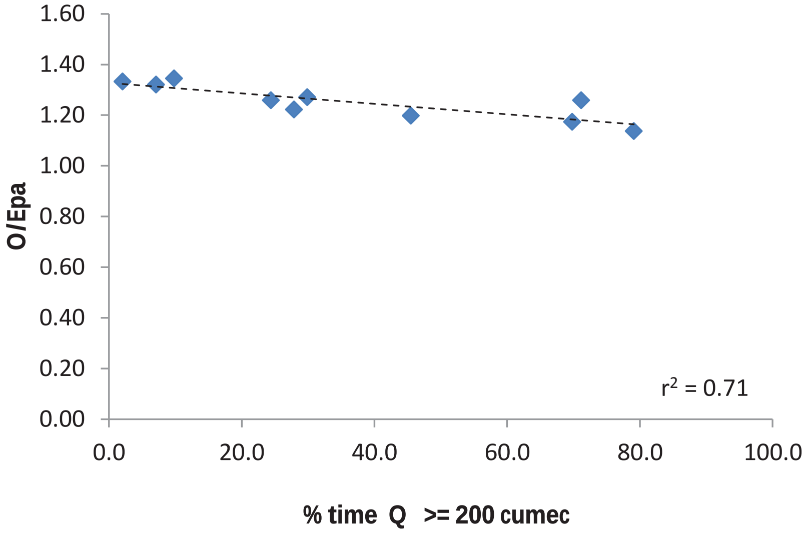

Figure 10.5: Relationship between O/Epa for zone 2 of the Gordon and % time when flows in the Gordon above Franklin were between 10/20 and 40 m^3s^{-1} during the 90 days prior to sampling in autumn.

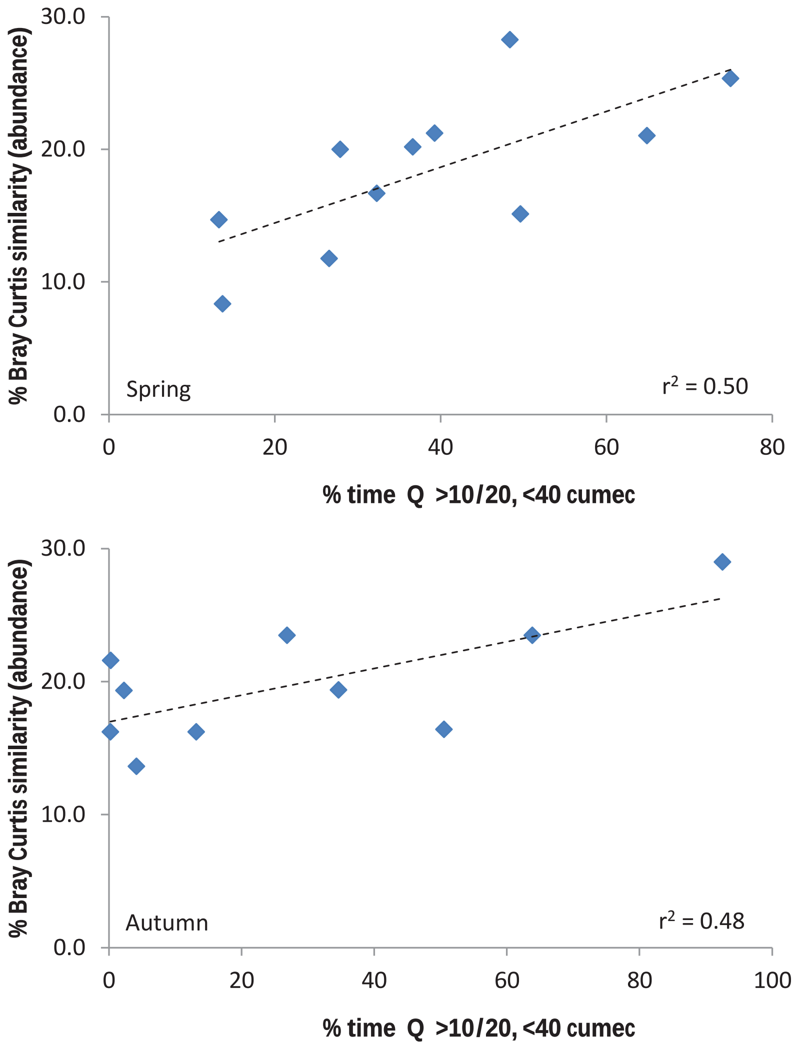

Figure 10.6: Relationship between % Bray Curtis Similarity to Reference sites for zone 1 of the Gordon and % time when flows when flows in the Gordon above Franklin were above the minimum environmental flow and less than 40 m^3s^{-1} during the 90 days prior to sampling in spring and autumn.

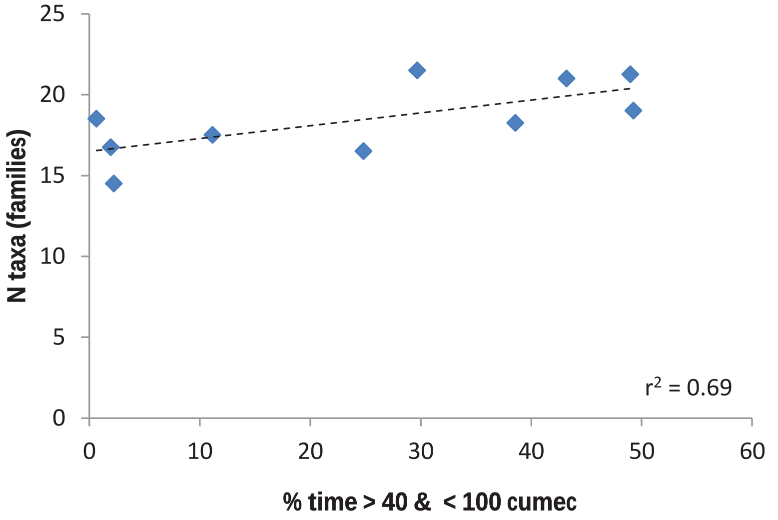

Figure 10.7: Relationship between the mean number of macroinvertebrate families per site for zone 2 of the Gordon and % time when flows when flows in the Gordon above Franklin were > 40 and < 100 m^3s^{-1} during the 90 days prior to sampling in autumn.

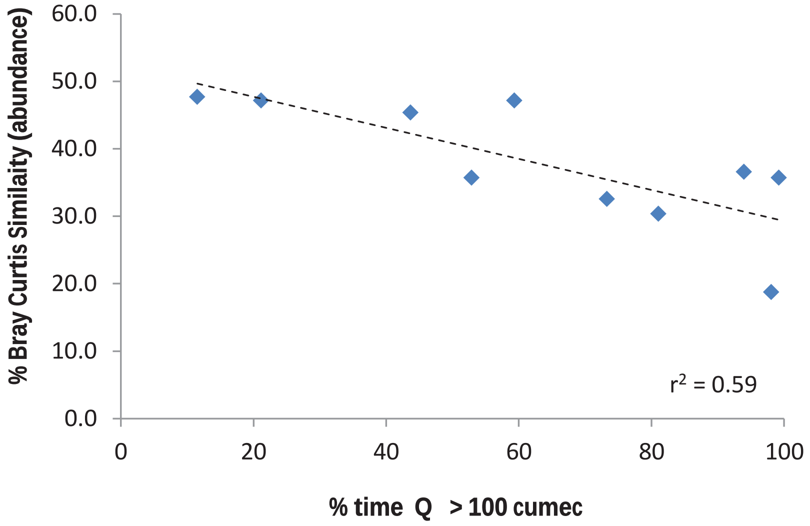

Figure 10.8: Relationship between % Bray Curtis Similarity to Reference sites for zone 2 of the Gordon and % time when flows when flows in the Gordon above Franklin were above 100 m^3s^{-1} during the 90 days prior to sampling in autumn.

The percentage filamentous algal cover for zone 1 correlated positively with the number of days when flows were less than the 10/20 m^3s^{-1} environmental flow), with the relationship strongest in spring (Pearson r = 0.65, p = 0.027, n = 11, Figure 10.9). Raised algal levels in zone 1 are expected when flows decline to the point where sufficient light reaches the stream bed to stimulate algal growth (see conceptual model). The % filamentous algal cover for zone 2 correlated positively with the number of days when flows were greater than 40 but less than 100 m^3s^{-1} (Pearson r = 0.69, p = 0.019, n = 11), which is consistent with the conceptual model (that is, a negative response to higher flows (as a result of lower light levels) and a positive response to sustained periods when flow downstream of the Denison corresponds to the 10/20 environmental flow measured at site 65 (i.e. approximately 40 – 60 m^3s^{-1}).

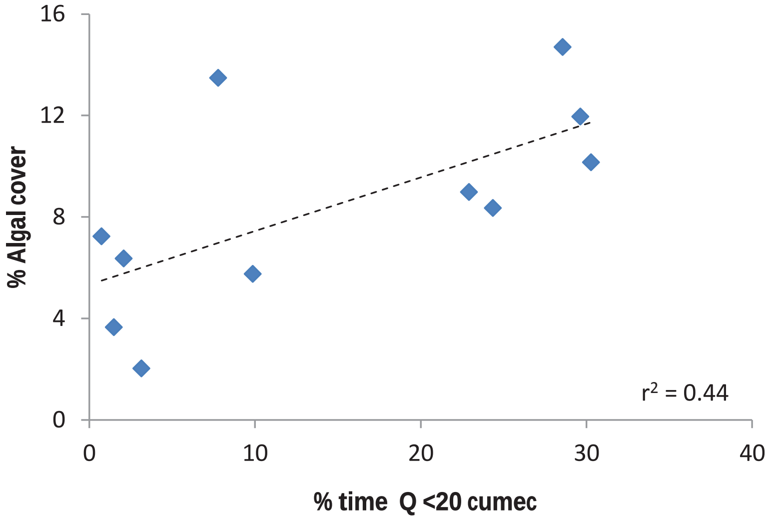

Figure 10.9: Relationship between % filamentous algal cover in zone 1 of the Gordon and % time when flows at site 65 were < 10/20 m^3s^{-1} during the 90 days prior to sampling in spring.

Multivariate correlations

Flow patterns

The flow time-series for the Gordon above Denison was classified into flow regime categories (see Section 2.5.2.5 for example of consolidated analysis for annual periods) for each two week period during the 182 days prior to every macroinvertebrate sampling event. Two weeks was the minimum reliable period for which a dominant flow regime could be identified. Thus for each sampling event, the number of antecedent 2 week periods in which each flow category was dominant was recorded.

Highly significant Pearson and Spearman correlations were observed only between macroinvertebrate indicator values and the proportion of time under the ‘low flow dominant’ regime in Zone 1 – at the $p < 0.0002$ to < 0.005 level (spring and autumn data together, $n = 21$). These correlations, for five macroinvertebrate indicators (O/Epa; mean and proportional abundance of EPT taxa; Bray Curtis similarity for presence/absence and abundance data), were strongly positive. Only two other flow regime categories (‘3 turbine baseload’ and ‘daily hydro-peaking of 0-1 or 1-2 turbines’) showed weak (and negative) correlations with the macroinvertebrate indicators ($p < 0.02$ to 0.05).

Multivariate relationships between the flow regime categories and macroinvertebrate indicators were explored using Generalised Linear Modelling (GLM), in SYSTAT (version 11), in stepwise, forward mode. Generalised linear models of the relationships in Zone 1 between the proportions of time under the flow regime categories explained between 37 and 72 % of the variance in the five macroinvertebrate indicators O/Epa, mean and proportional abundance of EPT taxa and the Bray Curtis similarity for presence/absence and for abundance data (Table 10.1). The contribution to the variance explained in all these models was dominated by the proportion of time under the ‘low flow dominant’ category. The coefficient for ‘low flow dominant’ was always positive (i.e. a positive correlation between the macroinvertebrate indicator values and the proportion of time low flow dominant’ category), while other contributing flow category variables varied in their sign and made much smaller contributions to the variance explained by the models.

The models were developed based on data from all 21 sampling occasions. The contribution of season (modelled as a dummy variable) to the models, or to any of the overall correlations, was not statistically significant with the exception of the model for O/Epa. This suggests that the relationship between the prevalence of the environmental flow and the value of most macroinvertebrate indicators (and hence possibly most macroinvertebrate responses to the flow conditions) was independent of season. For O/Epa the influence of season was statistically significant, but contributed only 17 % out the 72 % of the variance explained by the model.

Figure 10.10 shows the relationship between the proportion of abundance in EPT and the proportion of time under the low flow dominant regime during the 6 months prior to sampling – as both scatter plot and time series. The overall consistency between the pattern of prevalence of low flow dominant regime and the macroinvertebrate variable is marked, with the timing of the post-Basslink rise in the proportional abundance of the EPT group suggesting a lag of approximately one year relative to the post-Basslink rise in the proportion of time when the environmental flow dominated.

Table 10.1: Results of Generalised Linear Modelling of relationship between biological indicators and flow regime category variables derived for the six month period prior to each sampling event, for Zone 1 (n = 21).

Biological indicator	Flow category variables in each model	Direction	p	% of variance explained by model
O/Epa	Low flow dominant	positive	0.001	72 %
	3 turbine baseload	negative	0.004	
	Spring (dummy variable)	negative	0.0005	
Abundance of EPT taxa	Low flow dominant	positive	0.0001	53 %
	Daily hydro-peaking 0-1 turbines	negative	0.022	
Proportional of EPT taxa	Low flow dominant	positive	0.00001	64 %
	Daily hydro-peaking 0-3 turbines	negative	0.017	
Bray Curtis (abundance)	Low flow dominant	positive	0.002	37 %
Bray Curtis (presence/absence)	Low flow dominant	positive	0.0003	50 %
	Power station off	positive	0.017	

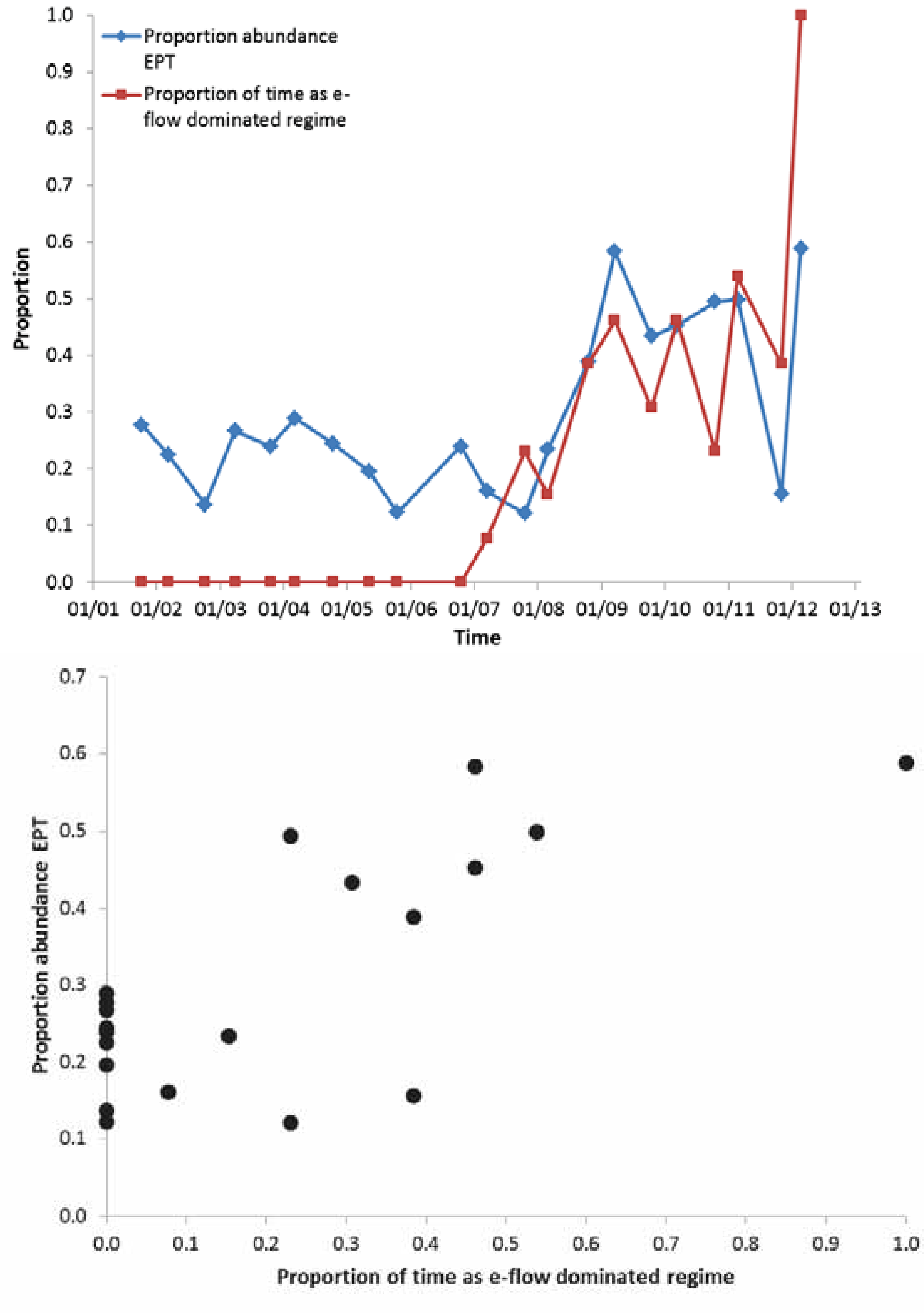

Figure 10.10: Time series and scatter plot of the relationship between the proportion of macroinvertebrate abundance as EPT taxa and the proportion of time during the 6 months prior to sampling in which the environmental or low flow dominated. The data plotted are for all sampling occasions (spring and autumn) from 2001 to 2012, for Zone 1.

Flow variables

Multivariate relationships between individual flow variables and biological indicators were also explored using Generalised Linear Modelling. Relationships between flow variables and the multivariate biological data (the taxon abundance x sample data matrix) were explored using the non-parametric equivalent, distance based linear modelling (DISTLM) and AIkake's Information Criterion (AICc) coupled with distance based redundancy analysis (dbRDA) in the Primer Permanova+ package.

GLM was carried out in stepwise, forward mode, separately for each zone, and the independent variable set always initially included the value of the biological indicator at the previous sampling occasion ('time step -1') to account for any autocorrelation. Each flow variable was derived separately for this analysis for each of the 30, 60, 90 and 365 day periods prior to sampling (see Section 10.2.1.1). The results of the GLM analyses are shown in Table 10.2.

GLM revealed nine variables with significant relationships in Zone 1 with the incidence (% of time) of flows greater or lower than the minimum flow threshold during either the 30 or 90 day period prior to each sampling event, including filamentous algal cover (Table 10.2).

By contrast, only 3 variables demonstrated such relationships with flows associated with the minimum environmental flow in Zone 2 (10/20 or 40 m^3s^{-1}), with the majority of variables being dominated by the incidence of mean or higher (>100 m^3s^{-1}) flows (Table 10.2).

The majority of macroinvertebrate variables showed a positive relationship with the proportion of time for which flows stayed higher than the minimum environmental flow, especially in Zone 1, and often showed a negative relationship with the incidence of high flows. This was less evident in Zone 2, where minimum flows are likely to be less limiting of macroinvertebrate community composition and abundance due to the influence of the Denison River inflow.

The incidence of rapid low to mid-range flow increase events during the 30 or 90 day period prior to sampling had a significant negative influence on community compositional similarity (Bray Curtis indicators) in Zone 1 (Table 10.2). By contrast, in Zone 2 the number of rapid low to mid-range flow increase events which occurred over the entire year prior to sampling was found to have a negative influence on the Bray Curtis abundance indicator and on moss cover. Overall however, the influence of hydro-peaking events was weaker than the influence of the duration of minimum flows. This is consistent with the suggestion that the minimum flow has a mitigation effect on the negative influence of hydro-peaking.

Filamentous algae cover showed a positive relationship with the incidence of lower flows in both zones, since lower flows (<10/20 m^3s^{-1} in Zone 1, and 40 – 60 m^3s^{-1} in Zone 2) are optimal for bed light conditions. Moss cover in Zone 2 was greater when maximum flows were higher pre-sampling, reflecting moss's preference for low light conditions.

Table 10.2: Results of Generalised Linear Modelling of relationship between Biological indicators and flow variables derived for up to a year immediately prior to each sampling event. * = biological variable value at time step -1 (for which n = 20). 30d, 60d, 90d, 1 yr = period of 30, 60 or 90 days or 1 year duration prior to sampling.

Biological indicator	Flow variables in each model	Direction	p	% of variance explained by model
Zone 1 (n = 21)				
O/Epa	1yr % >10/20, <40 m^3s^{-1}	positive	0.000004	65 %
	30d % >100, <200 m^3s^{-1}	positive	0.006	
	30d Standard Deviation	positive	0.012	
O/Erk	90d % <20 m^3s^{-1}	negative	0.06	31 %
	% >200 m^3s^{-1}	negative	0.0044	
Number of families	90d % >10/20, <40 m^3s^{-1}	positive	0.01	27 %
Number of EPT taxa	90d % >10/20, <40 m^3s^{-1}	positive	0.004	33 %
Abundance of EPT taxa	90d % >10/20, <40 m^3s^{-1}	positive	0.008	29 %
Total Abundance	90d % >10/20, <40 m^3s^{-1}	positive	0.011	26 %
Bray Curtis (abundance)	90d % >10/20, <40 m^3s^{-1}	positive	0.00009	57 %
	30d % < 20 m^3s^{-1}	negative	0.06	
	90d N low to mid-range events	negative	0.019	
Bray Curtis (presence/absence)	90d % >10/20, <40 m^3s^{-1}	positive	0.0014	56 %
	90d % < 10/20 m^3s^{-1}	negative	0.019	
	60d N low to mid-range events	negative	0.018	
Filamentous Algal cover	90d % <10/20 m^3s^{-1}	positive	0.017	23 %
Zone 2 (n = 21)				
O/Epa	90d % >10/20, <40 m^3s^{-1}	positive	0.02	79 %
	90d Minimum flow	positive	0.026	
	O/Epa-1*	negative	0.00001	
O/Erk	No vars significant at 0.05			
Number of families	90d % > 40, < 100 m^3s^{-1}	positive	0.0003	60 %
	90d % > 100, < 200 m^3s^{-1}	negative	0.009	
Number of EPT taxa	90d % >100 m^3s^{-1}	negative	0.0018	64 %
	90d Minimum flow	negative	0.0022	
	30d Minimum flow	positive	0.0004	
	1yr Median flow	positive	0.014	
Proportion of EPT taxa	90d % > 100 m^3s^{-1}	negative	0.048	58 %
	90d Mean flow	positive	0.001	
	90d Minimum flow	negative	0.006	
	1yr Median flow	positive	0.007	
Abundance of EPT Taxa	90d Mean flow	positive	0.011	26 %
	1yr % > 10/20, <40 m^3s^{-1}	positive	0.045	

Table 10.2 continued next page

Biological indicator	Flow variables in each model	Direction	p	% of variance explained by model
Total Abundance	90d % >100 m^3s^{-1}	negative	0.002	38 %
Bray Curtis (abundance)	90d % > 100 m^3s^{-1}	negative	0.001	53 %
	1yr N low-mid range events	negative	0.047	
	BCab – 1*	positive	0.02	
Bray Curtis (presence/absence)	90d % >100 m^3s^{-1}	negative	0.006	30 %
Filamentous Algal cover	90d % >40, <100 m^3s^{-1}	positive	0.025	20 %
Moss cover	90d Maximum flow	positive	0.0001	62 %
	1yr N low to mid range events	negative	0.035	
	Moss cover – 1*	negative	0.039	

Table 10.2 continued

Distance based linear modelling (DISTLM) conducted on the flow variables and the macroinvertebrate multivariate taxon abundance data also revealed strong flow dependencies of macroinvertebrate community composition. Initial models, including multiple season and zones, were dominated by seasonal and zonal differences, confounding the differential relationships between the biota and flow variables. Accordingly separate models were developed for each zone in each season.

The spring zone 1 DISTLM model revealed a single redundancy analysis (dbRDA) axis which accounted for 26 % of the variance in the biological similarity matrix. This axis was significantly positively correlated with only one hydrological variable – the % of time where flows were less than 10/20 m^3s^{-1}. The variable '% of time where flows were less than 10/20 m^3s^{-1} was selected as the best solution by DISTLM, with an AICc of 76.24 and p = 0.004. The pre- and post-Basslink macroinvertebrate samples were clearly separated along this axis (Figure 10.11)

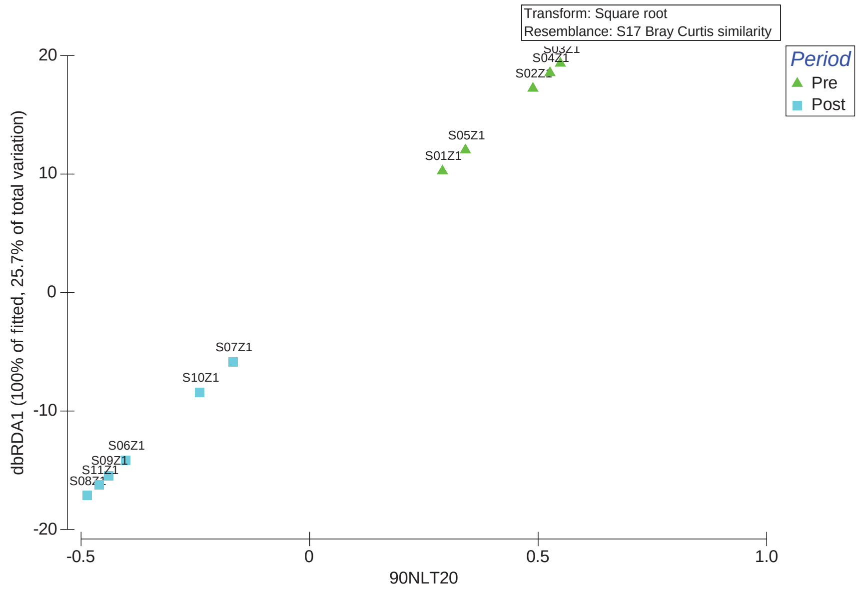

Figure 10.11: Plot of Distance Based redundancy analysis scores and axes derived from the DISTLM procedure in Primer-E Permanova+ package for spring zone 1 macroinvertebrate samples, Gordon River, 2001-11. Pre- vs Post-Basslink samples are indicated by different symbols.

The autumn zone 1 DISTLM model produced two redundancy axes which accounted for 40 % of the variance in the biological similarity matrix (Figure 10.12). This axis was significantly positively correlated with two hydrological variables – the % of time where flows were >40 and < 100 m^3s^{-1} ($p = 0.001$) and > 100 m^3s^{-1} ($p = 0.07$). These variables were selected in combination as the best solution by DISTLM, with an AICc of 65.2.

The pre- and post-Basslink macroinvertebrate samples were clearly separated across these two variables (Figure 10.12), with the exception of the autumn 2007 sample (A07Z1). The autumn 2007 sample has characteristics of a 'transitional' community composition, reflecting the lags in response of the zone 1 macroinvertebrate community to post-Basslink changes in the flow regime and therefore its grouping with the pre-Basslink samples in this analysis is not surprising.

The spring zone 2 DISTLM model produced two redundancy axes which accounted for 36 % of the variance in the biological similarity matrix. This axis was significantly positively correlated with two hydrological variables – the % of time where flows were >40 and < 100 m^3s^{-1} ($p = 0.05$) and > 100 m^3s^{-1} ($p = 0.017$). These are the same variables as for the DISTLM model for autumn in zone 1, and were selected in combination as the best solution, with an AICc of 63.8. The pre- and post-Basslink macroinvertebrate samples were clearly separated across these two variables (Figure 10.13), with the exception of the spring 2006 sample (S06Z2). The spring 2006 sample has characteristics of a 'transitional' community composition, reflecting the lag in response of the zone 2 macroinvertebrate community to post-Basslink changes in the flow regime and therefore its grouping with the pre-Basslink samples in this analysis is not surprising.

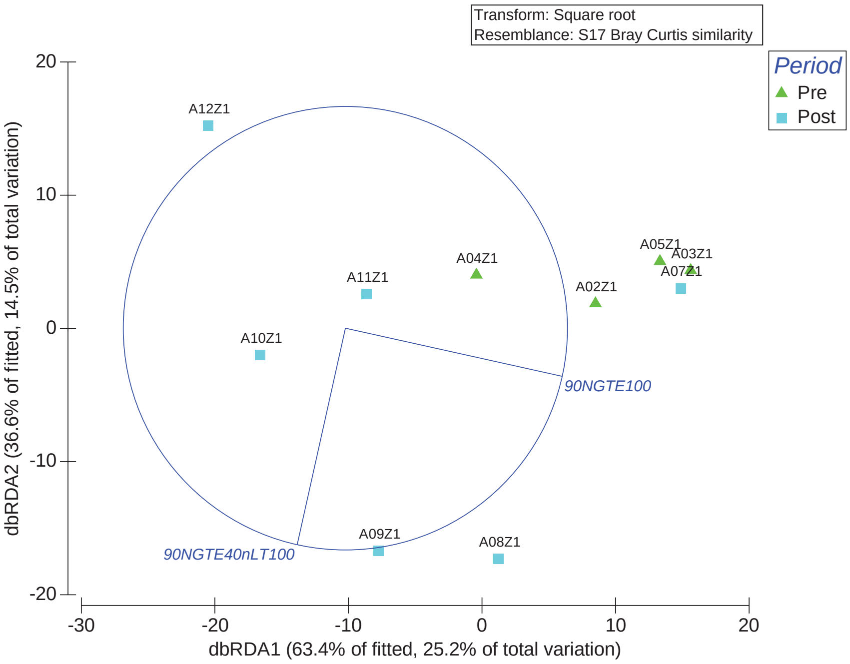

Figure 10.12: . Plot of Distance Based redundancy analysis scores and axes derived from the DISTLM procedure in Primer-E Permanova+ package for autumn zone 1 macroinvertebrate samples, Gordon River 2002-12. Pre- vs Post-Basslink samples are indicated by different symbols.

The autumn zone 2 DISTTLM model revealed a single redundancy analysis (dbRDA) axis which accounted for 33 % of the variance in the biological similarity matrix. This axis was significantly positively correlated with only one hydrological variable – the % of time where flows were > 200 m^3s^{-1}. The % of time where flows were > 200 m^3s^{-1} variable was selected as the best solution by DISTLM, with an AICc of 58.1 and $p = 0.004$. The pre- and post-Basslink macroinvertebrate samples were clearly separated along this access (Figure 10.14), with the exception of the autumn 2007 sample (A07Z2), which again is a ‘transitional sample’, reflecting the lagged response in community composition to post-Basslink flow changes.

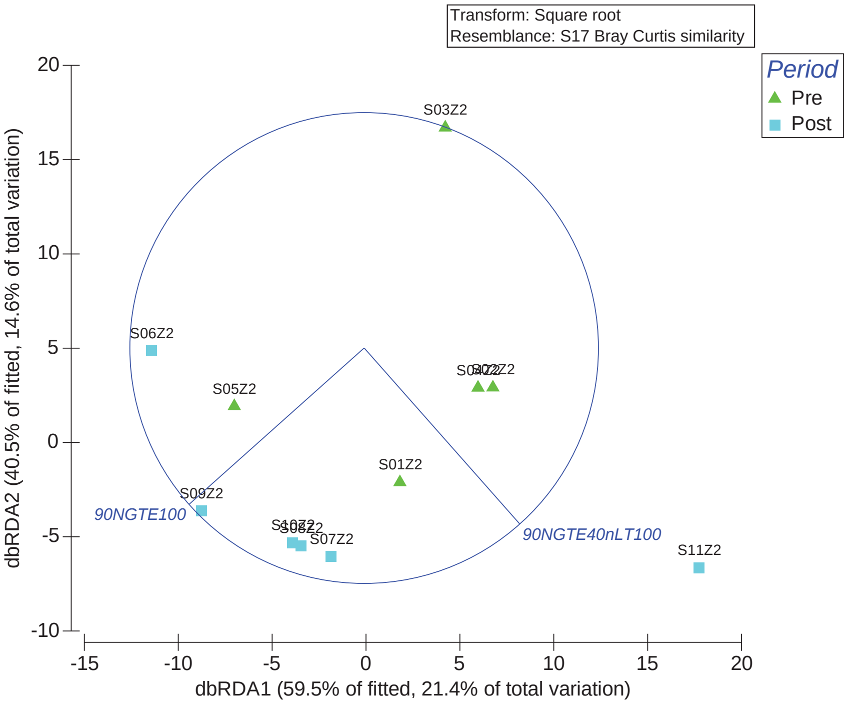

Figure 10.13: Plot of Distance Based redundancy analysis scores and axes derived from the DISTLM procedure in Primer-E Permanova+ package for spring zone 2 macroinvertebrate samples, Gordon River, 2001-11. Pre- vs Post-Basslink samples are indicated by different symbols.

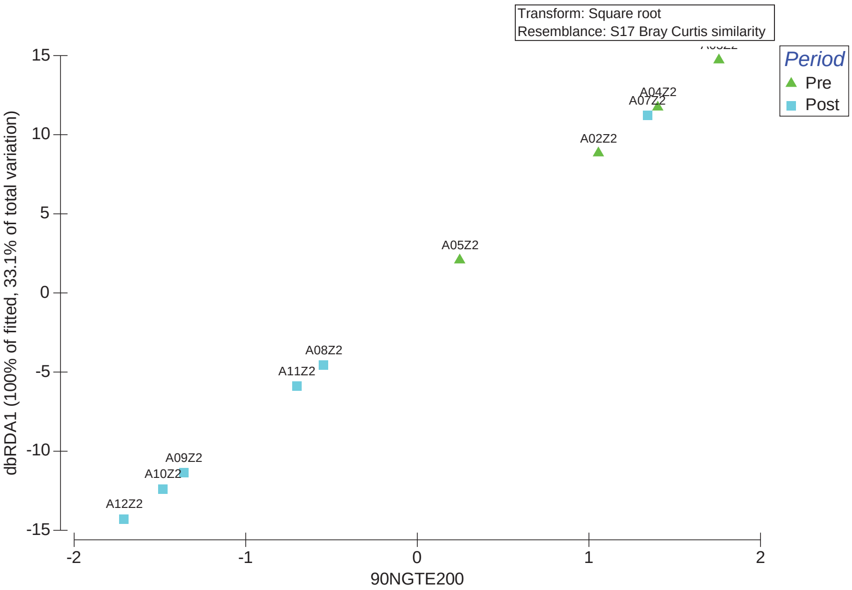

Figure 10.14: Plot of Distance Based redundancy analysis scores and axes derived from the DISTLM procedure in Primer-E Permanova+ package for autumn zone 2 macroinvertebrate samples, Gordon River, 2002-12. Pre- vs Post-Basslink samples are indicated by different symbols.

Overall, the DISTLM-dbRDA analyses have shown that:

- Variation in biological community composition can be explained by variation in key flow variables in the order of around 26 – 40 %;
- Pre- and post-Basslink samples are clearly separated both biologically and in terms of the flow regime;
- Sample community composition appears to be strongly dependent on the incidence of on both low (environmental flows) and high flows (> 100 or 200 m^3s^{-1});
- Samples collected immediately post commencement of Basslink operations (spring 2006 to 2007) were intermediate in composition and did not reflect the flow regime experienced by the post-Basslink samples collected subsequently.

Gradient response analysis

Since sufficient numbers of sample events with similar high but differing low flow histories could not be identified for comparison, a ‘gradient’ correlative approach was pursued.

Ordination had successfully discriminated post- from pre-Basslink macroinvertebrate communities in zone 1 upstream of the Denison confluence when based on family level abundance data and Bray Curtis Similarities. An analysis was performed using the Primer-E (version 6) package’s ‘BEST’ routine. This analysis associates environmental variables with the biological ordination space and attempts to find the best match between multivariate among-sample biotic pattern (e.g. for the macroinvertebrate community in the Gordon) and the pattern from environmental (e.g. flow) variables associated with those samples. The extent to which these patterns match reflects the degree to which the environmental variables ‘explain’ the biological pattern. The BEST routine searches for the ‘best’ combination of flow variables which describe the biotic pattern. The analysis was conducted using zone 1 spring data only, as only site 65 spring flow records were significantly discriminated between pre- and post-Basslink periods based on the presence of the environmental flow.

The Bray Curtis similarity matrix for all pre- and post-Basslink spring samples was used in the analysis, along with the normalised data set for all flow summary variables, Euclidean distances for the environmental data and Spearman rank correlation. A correlation of 0.49 (Spearman rho coefficient) was achieved between the biological ordination of spring samples and the flow data matrix with two flow variables: the proportion of time when flows were less than 10/20 m^3s^{-1}, and the proportion of time when flows were greater than 100 m^3s^{-1}. This rank correlation was statistically significant at the $p = 0.045$ level (by Monte Carlo permutation).

The Primer-E LINKTREE routine was then used to determine the relationship between the flow variables and groupings in the spring season zone 1 macroinvertebrate community sample events. The resulting tree (analogous to a regression tree) is shown in Figure 10.15. The post-Basslink samples (spring 2008 to 2011) and the ‘transitional’ spring 2006 sample (Samples 6, 8-11 in Figure 10.15) were grouped and collectively discriminated from all other samples by having a high proportion of time with flows > 10/20 m^3s^{-1} (>57 % of the time). These two tree groups are statistically significantly different ($r = 0.47$, $p = 0.02$).

These results indicate that the significant macroinvertebrate community compositional differences between pre- and post-Basslink periods in zone 1 are significantly associated with differences in the low flow regime, but not the high flow regime. These differences were correlated with the incidence of the 10/20 environmental flow (and no other aspect of low flows). The post-Basslink spring zone 1 macroinvertebrate community was characterised by flows of greater than or equal to 10/20 m^3s^{-1} being present for at least 57 % of the time during the 90 days prior to sampling.

This is strong correlative evidence for the post- vs pre-Basslink macroinvertebrate community changes being related to the sustained presence of the 10/20 m^3s^{-1} environmental flow, and no other aspect of the flow regime.

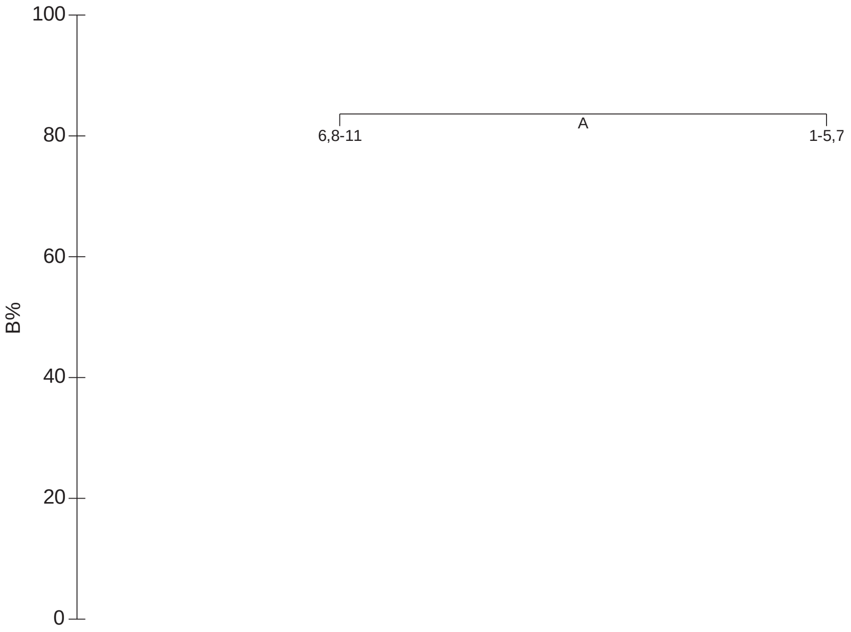

Figure 10.15: LINKTREE diagram showing separation of spring zone 1 macroinvertebrate samples based on flow variables. Numbers indicate year of sampling. Samples 1 – 5 are pre-Basslink (spring 2001 – spring 2005). B % = average between group ranks as % of largest rank in matrix = 84 %. r = 0.47. The tree splitting rule is :90NLT20<-0.43 (>-0.35).

10.2.2 Fish assessment

10.2.2.1 Multivariate analysis of flow and fish biological variables

The multivariate analysis was conducted to determine whether the fish species abundance data showed any indication of a pre/post-Basslink change that could be related to specific aspects of the flow regime, particularly the provision of an environmental flow. The results of the multidimensional scaling ordination are discussed previously (Section 9.4.4 – Fish) and shown in Figure 9.20 and Figure 10.16

The ordination indicates that there is a degree of pre/post-Basslink difference in the Gordon River fish community (ANOSIM, P=0.002) but no significant seasonal difference. SIMPER analysis indicated that changes in galaxiid relative abundance (*G. truttaceus*, *G. maculatus and G. brevipinnis*) were primarily responsible for the split in the fish community ordination.

Principal Component Analysis (PCA) was employed to determine which hydrological time step/s (7, 30, 90, and 365 days prior to the first day of each Gordon River fish sampling event) were the primary driver for the observed relationship between flow and fish abundance in the pre/post-Basslink period. Flow data from the Gordon River (Gordon above Franklin hydrological site) was used in this analysis. The results of this analysis are shown in Figure 10.16.

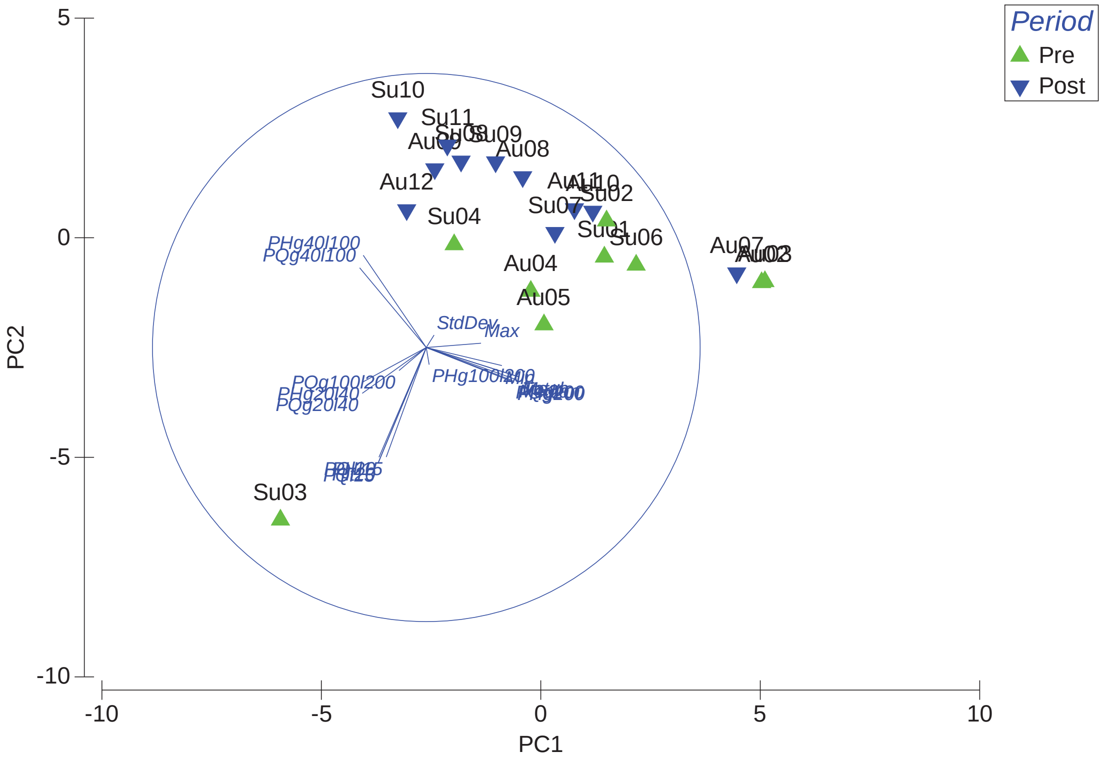

Figure 10.16: Principal Component Analysis of flow variables derived from the Gordon above Franklin hydrological site.

BEST analysis was then employed to determine which subset of flow variables best relates to fish community between sample relationships. The flow variables utilised were:

- Proportions of time between:
  - 0 and 2 m^3s^{-1}
  - 2 and 10/20 m^3s^{-1}
  - 10/20 and 40 m^3s^{-1}
  - 40 and 100 m^3s^{-1}
  - 100 and 200 m^3s^{-1};
- proportions greater than 100, 200 or 10/20 m^3s^{-1};
- proportions less than 15 m^3s^{-1};
- Median, mean, minimum and maximum flow; and
- Standard deviation of flow.

This analysis showed that the relative fish abundance was related to the 30 days (prior to sampling) temporal category in combination with the proportion of the total number of days less than 15 m^3s^{-1} and proportion of the total number of days ≥40 and <100 m^3s^{-1} (p=0.03).

DISTLM analysis (distance based linear model) showed that the proportion of flow duration ≥40 and <100 m^3s^{-1} accounted for 20.9 % of variation in the ordination (p=0.001) and the proportion of flow duration <15 m^3s^{-1} explained 9.8 % of total variation in fish relative abundance (p=0.026). The distance based redundancy analysis (dbRDA) plot showing the contribution of these variables is shown in Figure 10.17.

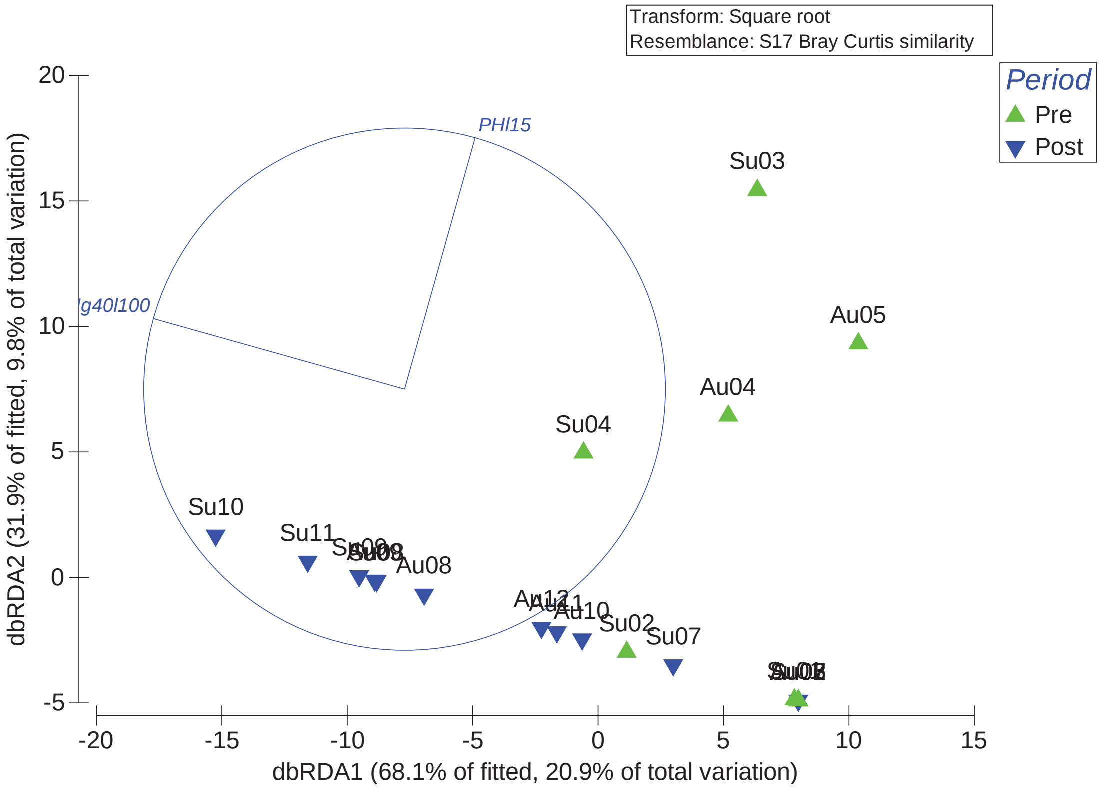

Figure 10.17: Distance based redundancy analysis plot showing contribution of significant flow variables to total variation in fish relative abundance.

Both of these significant flow variables are particularly relevant to the assessment of an environmental flow effect on fish abundance as they relate directly to the ecological responses of the fish community to low flows in the lower Gordon River zones. These flow variables were derived for the lower zones from Gordon above Franklin flow data. The lower river reaches were targeted for analysis as they contain a range of native species, and the relevance of conducting the analysis further upstream is particularly limited as native species abundance and diversity rapidly declines upstream of Sunshine Gorge. The proportion of flow duration ≥40 and <100 m^3s^{-1} and the proportion of flow duration <15 m^3s^{-1} reflect environmental flow releases from the power station (10 or 20 m^3s^{-1}) combined with natural catchment inflows from tributaries such as the Albert, Orange, Denison and Sprent Rivers located upstream of the Gordon above Franklin hydrographic site.The relative abundance of *G. truttaceus*, *G. maculatus and G. brevipinnis* in zones 4 and 5 was correlated with each of the two significant flow variables to determine the nature of the relationship between the flow variables and the galaxiid community. Figure 10.18 shows a trend of increasing relative abundance of *G. truttaceus* with increasing duration of flows in the ≥40 and <100 m^3s^{-1} range, which is described by the equation $y=0.0129x+2.66$ ($r^2=0.4259$). The remaining abundance/flow relationships showed increased *G. maculatus* and *G. brevipinnis* abundance with increasing duration of flows <15 m^3s^{-1}, described by the equations $y=0.1032x+0.3672$ ($r^2=0.4991$) and $y=0.0626x+0.3982$ ($r^2=0.2595$) for each species/flow relationship.

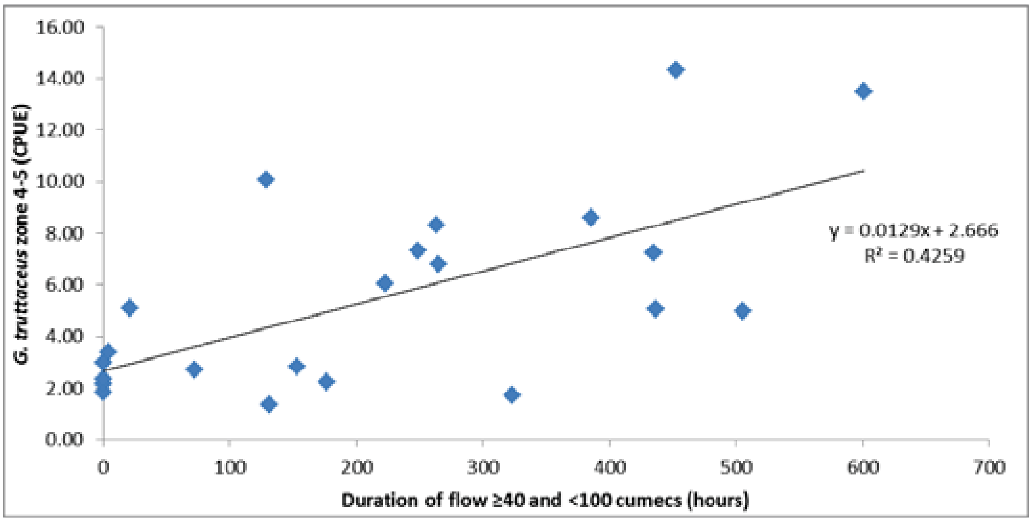

Figure 10.18: Relationship between the *G. truttaceus* in zones 4-5 and flow variables accounting for the greatest proportion of variation in the analysis.

The flow variables identified above were tested for evidence pre/post-Basslink temporal effect. The analysis indicated that the percent time >40 and < 100 m^3s^{-1} was significantly higher post-Basslink at the Gordon above Franklin flow monitoring site (p=0.01, two tailed t-test, equal variance). Duration of flows <15 m^3s^{-1} was significantly different between the pre- and post-Basslink periods (p=0.05, two tailed t-test, unequal variance), as low flow durations within this range were higher in the pre-Basslink period.

In summary, multivariate analysis of the relative abundance data showed change over the pre/post-Basslink period, and this was associated with two low flow variables which showed a significant change over the pre/post-Basslink period. Flows in the >40 and < 100 m^3s^{-1} range increased in the post-Basslink period and were associated with increased spotted galaxias abundance. Flows in the <15 m^3s^{-1} range decreased post-Basslink and were associated with decreased jollytail and climbing galaxias abundance.

While it is difficult to assess the efficacy of the 10/20 minimum environmental flow on the fish community of the Gordon River, there has been an increase in the galaxiid catch post Basslink. This is associated with increased flows in the 40 to 100 m^3s^{-1} range in the downstream reaches of the river, which are a product of minimum environmental flow releases and low catchment inflows. Post-Basslink galaxiid community composition has altered, with an increased proportion of spotted galaxias in catches.

10.2.2.2 Assessment of potential flow variability on fish

Chapter 2 discusses the hydrological characteristics of the Gordon Power Station discharge and evaluates changes that have occurred since the introduction of Basslink, and identifies the frequency of occurrence of rapid changes from low to mid-range flows during the post-Basslink period. An assessment of the potential response of the river's fish fauna to the occurrence of such flow changes was conducted by deriving a set of hydrological parameters to quantify flow variability at the low to mid-range flows, and comparing these with the fish indicator variables used in the trigger analyses. The parameter was chosen that reflected 'peaked' operation in flows of hydrological significance for fish, namely from flows <25 to >100 m^3s^{-1}. Refer to Section 2-Hydrology and water management for further discussion on derivation of these hydro-peaking parameters.

Appendix 6 shows the results of these analyses. The series of graphs show relative abundance of each of the trigger taxa groups (native:exotics, galaxiids, natives, exotics, and all species) relative to frequency of 'peaked' operation (increases in flow to >100 m^3s^{-1} within 2 hours of being <25 m^3s^{-1}). The graphs in Appendix 6 show that this operation has been infrequent, and has only occurred as a significant component of the post-Basslink hydrology during parts of the period autumn 2010 to autumn 2012. A clear relationship between trigger species groups and the occurrence of rapid increases from low to mid-range flows was not apparent in the data, and so no further analysis was conducted.

10.2.2.3 Species distribution and population structure

One of the justifications for the 10/20 minimum environmental flow trial instead of the 19/38 was the hypothesis that a lower environmental flow may be beneficial to diadromous native fish species. It was argued that increased shutdown frequency under Basslink operation would increase the incidence of low flows through hydraulic 'bottlenecks' in the river, particularly Sunshine Gorge and the First and Second Split. It was argued that the potential for increased upstream migration of native fish during power station shutdowns would be facilitated by a reduced environmental flow such as the 10/20 environmental flow (Howland et al 2001).

Analysis of fish distribution data over the pre-Basslink period (Hydro Tasmania 2005a, 2010a) indicated that the upper reaches of zone 4 (Sunshine Gorge) was a distinct demarcation point for native fish, particularly galaxiids and sandys. The number of incursions of these species into the lower reaches of zone 3 was infrequent over the pre-Basslink period, and so any increase in migration success through Sunshine Gorge should result in increased observations of galaxiids (especially juveniles) and sandys upstream of zone 4 (Hydro Tasmania 2010a). Figure 9.5 and Figure 9.6 show the fish species distribution in the Gordon River and Gordon River tributaries. The post-Basslink longitudinal distribution of the majority of species is similar to the pre-Basslink, however there are several exceptions that are relevant to the assessment of whether migration conditions have changed post Basslink.

Tasmanian mudfish (*Neochanna cleaveri*)

Tasmanian mudfish were not collected during the pre-Basslink period (Fig 9.5). Two fish (39 mm and 44 mm) were collected from zone 5 during December 2007, but no further specimens have been collected since this time. The one-off occurrence of this species provides little evidence to support the hypothesis that migration conditions have changed under Basslink.

Sandy (*Pseudaphritis urvillii*)

Sandys have only been collected in small numbers upstream of Sunshine Gorge over the course of the monitoring program. Two fish (108 mm and 126 mm) were collected from site G6a and Orange River (zone 3) during the December 2004 trip, and these were the only examples of this species that were captured upstream of zone 4 during the five year pre-Basslink period, which equates to a 0.4 fish per year observation rate. Three sandys (106, 181 and 135 mm) were collected upstream of zone 4 during the first three years of post-Basslink operation. These fish were collected from G6a and G7 in zone 3 during May and December 2007, and April 2008 (i.e. 1 fish per year observation rate). A further 5 fish (134, 153, 163, 185 and 210 mm) were caught during the 2009-12 period, from sites G7, G9, Gordon @ Orange River and Orange River (1.66 fish per year). In summary, an increase in frequency of occurrence in zone 3 has occurred in the post-Basslink period, but no extension in upstream range has been detected.

Spotted galaxias (*Galaxias truttaceus*)

The longitudinal distribution of spotted galaxias has increased by approximately 5km following the commencement of Basslink operation and release of the 10/20 minimum environmental flow (Figure 9.5 and Figure 9.6). They are common in the downstream monitoring reaches but are only present in small numbers upstream of zone 4. A 177 mm fish caught in Harrison Creek during April 2002 (refer to Appendix 5) was the only spotted galaxias captured upstream of zone 4 during the pre-Basslink baseline data collection period, (0.2 fish per year observation rate). Four spotted galaxias were captured in zone three during the first three years of post-Basslink operation. A 136 mm fish was caught from Harrison Creek in December 2006, a 108 mm fish was captured in the Smith River and two fish (103 mm and 126 mm) were captured from Harrison Creek in November 2008 (1.33 fish per year observation rate). Eleven spotted galaxias were captured in the last three years of the monitoring program (3.66 fish per year). These fish ranged in size from 111-180 mm and were captured from Harrison Creek, Smith River, Orange River and Gordon @ Fluffies.

Appendix 5 includes seasonal length frequency histograms for spotted galaxias collected over the duration of the monitoring program. Migration amplitude is indicated by modes in the 55-60 mm size class (summer) and progression to 70-75 mm size class (autumn). Pre-Basslink recruitment was generally inconsistent, and only two of the five pre-Basslink monitoring years (40 %) showed evidence of significant recruitment. While juvenile recruitment in the post-Basslink datasets was also variable, four of the six monitoring years (66 %) showed clear evidence of strong recruitment. These results suggest that recruitment/migration of juvenile spotted galaxias to the Gordon River increased during the post-Basslink period.

In summary, observations of spotted galaxias upstream of zone 4 have increased in frequency under Basslink, and an upstream range extension of approximately 5km has been observed. Improved migration conditions in the Gordon River may have contributed to strong post-Basslink recruitment.

Climbing galaxias (*Galaxias brevipinnis*)

Figure 9.5 and Figure 9.6 indicate that the post-Basslink distribution of climbing galaxias in the Gordon River monitoring zones is similar to the pre-Basslink period. Only four climbing galaxias were collected upstream of zone 4 during the pre-Basslink period, and one fish was collected from these monitoring reaches during the post-Basslink period. The majority of these fish (n=4, size range 105-180 mm) were captured in the Gordon River in the immediate vicinity of the Indigo Creek outflow at site G4. Indigo Creek contains a small but persistent population of climbing galaxias. The remaining fish was a 55 mm juvenile collected from Harrison Creek. Climbing galaxias do not appear to have experienced a significant post-Basslink change to their riverine distribution.

The distribution of climbing galaxias in tributaries of the Gordon River monitoring zones was similar in the pre-Basslink and post-Basslink periods, with no evidence of significant range expansion or contraction. A small number of juveniles were captured from zone 1 and the upper reaches of zone 2 in 2007-08 indicating that climbing galaxias had recruited to these sections of the river. Previous catches from zone 1 had not shown evidence of recent juvenile recruitment, and Howland et al. (2001) hypothesised that climbing galaxias in zone 1 constituted a remnant population that received little if any recruitment. A single juvenile climbing galaxias was caught a tributary in the upper reach of zone 2 in April 2008, which was the first recorded occurrence of this species in this zone. Length frequency histograms derived from summer 2007 and autumn 2008 data (Appendix 5) show that relatively few juvenile fish were caught in either sample, and a large climbing galaxias migratory run was not detected in the 2007-08 monitoring data. Hydro

Tasmania (2008, 2010a) reported that analysis of the otolith microchemisty from the zone 1 juveniles was indeterminate, and as such their origin (marine/diadromous or freshwater/landlocked) could not be determined.

10.2.3 Conclusions

Based on the analyses of biological and flow data it can be concluded that the 10/20 environmental flow has led to positive changes in the Gordon River. This assessment concludes that:

- some macroinvertebrate indicators showed strong positive relationships with low flows at, or just above, the environmental flow. The 10/20 minimum environmental flow was linked to increased presence of macroinvertebrate families and EPT species, the abundance of EPT taxa and overall community compositional similarity to reference sites in the greater Gordon-Franklin catchment;
- macroinvertebrate data also showed a sensitivity to the occurrence of higher flows (>100 m^3s^{-1}), with the potential for any increases in incidence of these flow to result in declines in macroinvertebrate condition;
- the overall condition of the macroinvertebrate community of the Gordon River remained similar to that observed pre-Basslink. No substantive or statistically significant negative Basslink effect has been observed. Some indicators showed some improvement as a result of the presence of the minimum environmental flow;
- relationships of algae and moss with minimum flows were consistent with the established conceptual relationships between light and flow, especially with increasing algae as flows decrease in zone 1;
- algal and moss cover largely remained within pre-Basslink levels, and no substantive or statistically significant Basslink effect was observed;
- the galaxiid abundances have increased post Basslink. This is primarily linked to increased low flows ≥40 and <100 m^3s^{-1} in the downstream reaches of the river, which was the result of minimum environmental flow releases in combination with low catchment inflows. Post-Basslink galaxiid community composition has altered, with an increased proportion of spotted galaxias in catches; and
- components of the native fish fauna showed small upstream increases in distribution; however there was insufficient evidence to support the hypothesis that the 10/20 environmental flow may improve upstream migration past hydraulic bottlenecks such as Sunshine Gorge.

10.2.4 Recommendations

Based on the results of the analysis undertaken into the effects of the environmental flow, it is recommended that the 10/20 flow is maintained.

10.3 Ramp-down rule

10.3.1 Geomorphic assessment

The original ramp-down rule which was initially implemented in 2006 contained inconsistencies which at times promoted increased bank saturation prior to reductions in power station discharge levels, resulting in increased seepage erosion (Hydro Tasmania 2008). In response to this impact, Hydro Tasmania undertook adaptive management actions to assist in revising the ramp-down rule. The overall objective of revising the rule was to enhance environmental outcomes whilst minimising operational constraints at the Gordon Power Station.

The following adaptive management actions were undertaken to assist in revising the ramp-down rule:

- A comprehensive review of the ramp-down rule (Koehnken 2008) which found that the original rule did not achieve its original aim of reducing seepage erosion;
- An independent geomorphic and ramp rule assessment (Rutherfurd 2009) confirmed the findings of the above ramp-down rule review and provided additional suggestions on undertaking of a multiple lines of evidence approach to define the changes that have occurred on the banks, rather than just trigger ranges;
- Following from these reports it was recommended that a more appropriate ramp-down rule be investigated. In response, the following work was undertaken:
    - the development of a newly calibrated SEEP-W model, which was used to investigate the possible impacts of varying operations and ramping scenarios on bank stability (Entura 2010);
    - the undertaking of field monitoring trials to test selected results of the modelling under a range of operational scenarios including hydro-peaking operation, and ramping at different rates. This work also identified the critical bank saturation level at which seepage erosion would occur and ramping rates at which only minimal seepage erosion was apparent (Koehnken 2011); and
    - the development of a robust regression model that accurately predicts the saturation level of the banks by utilising available real-time discharge data from Gordon Power Station (Hydro Tasmania 2012).

The revised rule was approved and implemented in April 2012. It is as follows:

> *Whenever the bank saturation level at site 71 as calculated by the Bank Saturation Model is greater than 2.75 m above the local datum and the discharge from the Gordon Power Station is greater than 150 m^3s^{-1}, the plant control system must be set to control any reductions in generation load at a rate of 1 MW per minute until the power station discharge is less than 150 m^3s^{-1}.*

The rule utilises the newly developed Bank Saturation Regression Model (Hydro Tasmania 2012) to determine when it is appropriate to apply the rule. The Bank Saturation Regression Model utilises real-time discharge data from the Gordon Power Station to predict the level of saturation of the banks at Site 71 (Gordon River below Albert). The reduction in generation by 1 MW per minute is equivalent to an average flow reduction of 45 m^3s^{-1} per hour or less.

The components of the revised ramp-down rule are:

- use of the bank saturation model with antecedent power station operating patterns to predict present levels of bank saturation;
- unrestricted power station operation if modelled bank saturation is below a target level (2.75 m -equivalent to 2-turbine bank level in zone 2); and
- implementation of a 1 MW per minute ramp-down rate if modelled bank saturation exceeds the target level in zone 2, with ramp-downs required for *all* reductions in power

station discharge above 150 m^3s^{-1} until bank saturation is reduced to below the target level. The 1 MW per minute ramp-down rate is the slowest rate acceptable by the National Electricity Market (NEM).

The advantages of the revised ramp-down rule include:

- Ramping is only implemented when bank saturation is high. This prevents additional bank saturation occurring during 'ramp-downs' under conditions of low bank saturation;
- Ramping is implemented for *all* drawdowns under conditions of high bank saturation, rather than only when the 'intention' of the operator is to reduce discharges to <150 m^3s^{-1} as was contained in the original ramp-down rule. This prevents repeated rapid drawdowns to the 150 m^3s^{-1} level when the station is discharging >150 m^3s^{-1}; and
- The rule aligns environmental goals with operational flexibility. Under the revised rule, maximum operational flexibility is maintained under conditions of low bank saturation, so it is beneficial for the operator to avoid conditions which promote bank saturation. Once the banks are saturated, operational flexibility is limited until bank saturation levels have decreased.

10.3.2 Fish assessment

Howland et al. (2001) suggested that there may be an increased potential for stranding following the commencement of Basslink operation. They hypothesised that while there was little evidence of fish stranding during the IIAS investigative period, improved post-Basslink fish migration and access to upper river zones may result in more stranding due to potentially increased fish abundances. It was suggested that a temporary stabilisation of flows at approximately 150 m^3s^{-1} for one hour during large drawdown events could have benefits in reducing fish stranding, particularly to fish in high risk stranding areas such as the wide, flat bars in zone 2.

There has been little evidence of fish stranding during six years of post-Basslink operation. Due to amendments to the ramp-down rule, the potential for fish stranding under the revised rule is unknown. However, the occurrence of un-ramped drawdowns (similar to the situation likely to occur under the revised ramp-down rule) during monitoring shutdowns in the pre-Basslink period indicated no evidence of significant stranding (Hydro Tasmania 2005a).

Specific observations to determine if the revised rule will cause an increase in fish strandings would be costly, and given the lack of evidence to date of significant strandings under analogous ramp-down conditions during the pre-Basslink period, it would appear to be unwarranted.

10.3.3 Conclusions

Because the revised ramp rule was only implemented in April 2012 near the end of the 6 year post-Bassslink monitoring period, it has not been possible to objectively evaluate the efficacy of the new rule in regard to seepage erosion.

10.3.4 Recommendations

Further monitoring is required to determine the effectiveness of the revised ramp-down rule at reducing the occurrence of rapid decreases in flow at high bank saturation, and subsequently reducing the occurrence of seepage erosion. It is recommended that two years of geomorphic monitoring be undertaken from 2012-14 as recommended in Section 5 –Fluvial geomorphology.

Specific monitoring for evidence of fish stranding is considered impractical, however it is recommended that observation of any fish strandings be reported as part of the 2012-14 geomorphic and macroinvertebrate monitoring.

11. Conclusions

11.1 Trends in consolidated data

11.1.1 Hydrology

The post-Basslink period was characterised as one of low rainfall and low system-wide inflows and storage levels in the first three years, followed by three years of above average inflows and rising storages. It can be concluded that the Gordon Power Station discharge in its six years of post-Basslink operation was characterised by a higher level of variability between and within years, and a lower level of seasonal predictability in comparison to the pre-Basslink and historical periods.

Basslink's influence appears to be one that provides a greater degree of flexibility in the operation of Gordon Power Station, rather than relying on it as a producer of significant base load power over summer. Notable discharge patterns recorded post-Basslink include:

- prolonged periods of lower flows (i.e. <50 m^3s^{-1}) between 2008 and 2012;
- higher variability (peakiness) of flows in much of the second, fifth and sixth years post-Basslink; and
- a substantial reduction in time where there was zero discharge as a result of the implementation of the minimum environmental flow.

These changes are partly due to Basslink operations but are not similar to predicted changes.

11.1.2 Significant monitoring trends

The major findings of the monitoring relate to the fluvial geomorphology, riparian vegetation and macroinvertebrate disciplines. These all showed Basslink-related impacts associated with changed aspects of the power station discharge which can be partially linked to Basslink operation.

Erosion rates have declined in the post-Basslink period. The reduction in net change is attributable to the large reduction in total flow in the river combined with the increased deposition associated with local seepage processes resulting from increased hydro-peaking.

There has been a measurable increase in total vegetation cover on the banks of the Gordon River in the post-Basslink period. There was also an increase in species richness post-Basslink. The increase in vegetation cover and associated increase in species richness in the past 4 years have been promoted by the low flows observed over this period.

Macroinvertebrate studies revealed changes in some macroinvertebrate indicators; most of which may be considered positive Basslink-related impacts. Lagged responses to post-Basslink minimum flow conditions were detected including increases in abundance of several EPT taxa, which may take several generations (i.e. 2-3 years) to occur and represent improvements in overall condition of macroinvertebrate communities.

11.1.3 Other monitoring trends

It can be concluded that post-Basslink power station operation has had minimal impact on water quality in the middle Gordon River. Changes in water quality in the middle Gordon River post-Basslink are largely related to the water level in Lake Gordon. High lake levels lead to reduced seasonal variations in water temperatures compared to low lake levels.

Karst geomorphology has not been significantly impacted in the post-Basslink period. Evidence suggests that the sediments in the caves are more protected and buffered from the effects of the power station operations than the sediments in the river channel, and that the caves are relatively robust.

Filamentous algal and benthic moss continues to be largely controlled by natural seasonal biological cues and no substantive changes were observed after Basslink operations commenced.

There was evidence of an increase in frequency of occurrence of native fish at their upstream range limit in the Gordon River. In addition the climbing galaxias exhibited an uncommon recruitment event to the upper zones of the Gordon River during the post-Basslink period. Galaxiid abundances have increased post Basslink which has been linked to increased flows between 40 and 100 m^3s^{-1} range in the downstream reaches of the river, which are a product of minimum environmental flow releases and low tributary inflows.

11.2 Adequacy of the monitoring program

Evaluation of the adequacy of the existing monitoring program was conducted for each discipline. The karst geomorphology, algae and moss, macroinvertebrate and water quality disciplines considered the monitoring program adequate to identify any Basslink-related changes.

The monitoring programs for the fish and riparian vegetation disciplines continued to have low statistical power, however were able to provide adequate information to assess major trends and determine if post-Basslink impacts were occurring.

The fish studies had limited ability to statistically test for trends in the relative abundance of individual species, zone level distribution and species population structure. However, the monitoring program has provided sufficient information to determine that the fish community has not changed markedly.

The riparian vegetation monitoring had limited replication, a small sample size and high degree of variability which presented difficulties when attempting to detect a post-Basslink change. While it was possible to identify trends in species composition and diversity as well as vegetation cover, the ability to statistically validate trends was limited.

Fluvial geomorphology results have provided a good understanding of how flow regulation has affected the Gordon River at a large scale. The monitoring program has provided a consistent picture of how the flow regime determines the relative contributions of erosional processes in the river, and how these processes are shaping the banks over time frames of months to years.

11.3 Review of triggers

Triggers (or limits of acceptable changes) were established for five disciplines to assist in assessing whether a Basslink-related change had occurred. The triggers were considered to be a useful tool for assisting in determining the impacts of Basslink changes for macroinvertebrates, fish, algae and moss.The triggers for geomorphology and riparian vegetation were considered to be inadequate in isolation as they did not take into account all of the processes that may induce a change.

The vegetation monitoring triggers were considered inadequate as they were based on data that did not capture the degree of variation present. They also were not ecologically meaningful as some were highly sensitive to minor changes in measures because of the small scale of the sampling. Whilst the triggers may not have been of particular ecological significance, they were useful in setting benchmarks against which to explain ecological change and the processes likely to be responsible for it.

The Basslink Review Report 2006-09 (Hydro Tasmania 2010a) identified that the fluvial geomorphology trigger values were not useful as indicators of Basslink change in isolation, and should not be the main focus of reporting. Instead, the triggers were one of the multiple lines of evidence, along with field observations, hydrologic parameters, photo monitoring results, piezometer results, and vegetation results that were used to determine the effect of Basslink.

11.4 Appropriateness and effectiveness of the mitigation measures

A number of potential impacts post-Basslink were identified during the IIAS process based on the anticipated changes to the power station operating regime. In order to minimise the potential adverse impacts of Basslink operations, two mitigation measures were proposed and incorporated as part of Hydro Tasmania’s Special Licence. These measures aimed to minimise the anticipated impacts of Basslink through regulation of power station operation and to manage discharges into the middle Gordon River by:

- providing a minimum environmental flow to maintain habitat availability and ecological processes; and
- implementing a ramp-down rule for the Gordon Power Station to restrict rapid drawdowns of water levels, reducing the risk of seepage erosion.

As part of the review, the appropriateness and effectiveness of the minimum environmental flow and the ramp-down rule as mitigation measures was assessed.

11.4.1 Minimum environmental flow

The Basslink Monitoring Program has shown that the implementation of the minimum environmental flow regime has had a positive environmental effect. The macroinvertebrate data showed that the 10/20 minimum environmental flow in the post-Basslink period has increased the presence of macroinvertebrate families and EPT species, the abundance of EPT taxa and overall community compositional similarity to reference sites in the greater Gordon-Franklin catchment.

The galaxiid abundances have increased post-Basslink and appears to be linked to increased low flows (≥40 and <100 m^3s^{-1}) in the downstream reaches of the river, which are the result of minimum environmental flow releases and low catchment inflows.

11.4.2 Ramp-down rule

The original ramp-down rule which was implemented at the beginning of Basslink operations contained inconsistencies which at times promoted increased bank saturation prior to reductions in power station discharge levels. These deficiencies were highlighted through a number of reports and review. As a result new modelling and field investigations were conducted in 2010-11, with the aim of developing and implementing a revised rule. The overall objective of the revised rule was to enhance environmental outcomes whilst minimising operational constraints at the Gordon Power Station.

The revised ramp-down rule was implemented in April 2012. The advantages of the revised rule include:

- Ramping is only implemented when bank saturation is high.
- Ramping is implemented for *all* drawdowns under conditions of high bank saturation, rather than only when the 'intention' of the operator is to reduce discharges to <150 m^3s^{-1} as was contained in the original ramp-rule. This prevents repeated rapid drawdowns to the 150 m^3s^{-1} level when the station is discharging >150 m^3s^{-1}.
- Under the revised rule, maximum operational flexibility is maintained under conditions of low bank saturation. Once the banks are saturated, operational flexibility is limited until bank saturation levels have decreased.

Because the revised ramp rule was only implemented in April 2012, and discharge from the power station and bank saturation has been low since that time, there have been insufficient results from the monitoring program to evaluate the efficacy of the new rule. Two years of additional monitoring is being undertaken which it is anticipated will provide sufficient information for an assessment of the effectiveness of the new rule. At the end of the two years of monitoring a review of the revised rule will be carried out.

12. Recommendations

At the completion of the Basslink Monitoring Program, Hydro Tasmania has fulfilled the Basslink monitoring requirements of the Special Water Licence Agreement. The Basslink Monitoring Program has directed the collection and analysis of a significant body of data and has provided insight into, and an understanding of the physical and biotic processes in the Gordon River. With this information the monitoring program has enabled an assessment of the impacts of Basslink on the Gordon River.

The following recommendations are made in regard to the completion of the Basslink Monitoring Program and the transition to a phase where the focus of monitoring will be to fulfil obligations in relation to the mitigation measures.

The recommendations are:

1. Maintain the ramp-down rule and 10/20 environmental flow

To continue operating Gordon Power Station with both mitigation measures implemented. The environmental flow has been seen to have some positive impacts in the Gordon River and should be maintained. The revised ramp-down rule has been in operation for just a short period. The revised ramp-down rule should be maintained and its effectiveness tested.

2. Monitoring

Complete the agreed interim monitoring program in 2014. This will involve the continuation of macroinvertebrate and geomorphology monitoring and continued maintenance and monitoring of piezometers. This will enable an ongoing assessment of the effectiveness of the mitigation measures.

Further Gordon River monitoring will be considered as part of a broader aquatic environment monitoring program undertaken by Hydro Tasmania. This program will prioritise monitoring requirements across Tasmania. The monitoring obligations in relation to the Gordon River will be determined in consultation with DPIPWE.

3. Adaptive management

Hydro Tasmania is committed to an adaptive management approach with regard to the effectiveness of the mitigation measures that are being implemented in the Gordon River.

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