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the renewable energy business

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# Basslink Baseline Report

## Information from all consolidated data collected by the Gordon River Basslink Monitoring Program 2001-05

## Volume 1: The Report

Prepared by

Hydro Tasmania

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# Executive summary

The aim of the Basslink Baseline Report (BBR) is to present the consolidated results of the past four years of monitoring within the middle Gordon River by the Gordon River Basslink Monitoring Program (BMP). The middle Gordon River is the length of river most significantly affected by changes in operation to the Gordon Power Station brought about by Basslink.

The results of the monitoring work have been combined with available information from previous studies to indicate trends, variability and data ranges for a number of scientific disciplines. These represent the pre-Basslink environmental conditions and provide the pre-Basslink baseline against which post-Basslink conditions will be compared. The primary purpose of the BBR is to provide an accurate and appropriate statement of the pre-Basslink environmental conditions in the Gordon River.

### Conceptual model

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

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

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

## Design and inference

The design and inference chapter examines the broad sampling design pertinent to the Basslink Monitoring Program and the factors which influenced it. It also discusses the limitations and assumptions of the statistical analyses performed on the pre-Basslink dataset, and describes the methods for assessing the capability of detecting post-Basslink changes.

The major topics covered are sampling design, modelling, identifying differences and trends in pre-Basslink data, and evaluating the effectiveness of monitoring to detect post-Basslink changes.

## Pre-Basslink hydrology (2001-05)

Pre-Basslink hydrologic information shows that during 2001-05, the pre-Basslink monitoring period, Gordon Power Station operation exhibited higher discharge for longer durations than is seen in the pre-2000 record. This was due to changes in the transmission system allowing more electricity to be transmitted from the site compared to the pre-2000 period, and to drought conditions in much of Tasmania, requiring Hydro Tasmania to draw extensively on the water stored in Lake Gordon. During the pre-Basslink monitoring period autumns tended to be dry and winters wet, and the extended power station usage in summer resulted in a large shift in 'seasonality' compared with historical operations.

## Water quality

Both Lakes Pedder and Gordon demonstrated good water quality during the pre-Basslink monitoring period, with parameter values similar to natural lakes in south-western Tasmania. There were no parameters measured in the lakes which would have a detrimental effect on downstream biota.

Lake Gordon is almost permanently stratified at the power station intake site. During the pre-Basslink period relatively low water levels in Lake Gordon contributed to a decrease in the incidence of low dissolved oxygen water being released from the power station, and a degree of seasonal variability in the thermal regulation effects of the power station discharge.

Water discharged from the power station over the monitoring period has contained both low and high concentrations of dissolved oxygen. These extremes have shown a marked decrease since 2002 as power station operating procedures were adjusted to reduce their incidence. Extreme values are unlikely to be persistent, as the downstream channel provides ample opportunity for re-oxygenation or de-gassing.

Thermal regulation produced by the power station discharge tends to keep temperatures cooler than ambient during September-March and warmer than ambient during April-August. The regulated thermal regime is dominant in the reach between the power station and the Denison confluence. Downstream of the Denison, natural inflows may have an ameliorating effect if power station discharge is low and natural inflows relatively high.

Three approaches to determining indicator variables for detection of Basslink change were developed for dissolved oxygen:

- The recording of extreme values at site 65;
- Increased frequency of extreme values at the tailrace; and
- The exceedence of 20th and 80th percentile values at the tailrace.

For water temperature, two related parameters, daily means and standard deviations of the hourly difference between the tailrace and downstream water temperatures, were used to determine monthly 80th and 20th percentile exceedence values, which may be used to indicate post-Basslink changes to the thermal regulation pattern.

### Fluvial geomorphology

Flow changes associated with damming, diversion of additional water into the catchment, and flow regulation have lead to river bed armouring and channel widening in the alluvial sections of the middle Gordon River. The planform of the river remains unaffected due to the large amount of bedrock and boulder control in the river channel.

Bank disturbance is generally limited to the area (height) inundated by power station operation, where vegetation has been removed through inundation leading to the exposure of the underlying sandy alluvial banks. Upslope of power station-controlled water levels, vegetation has increased, and bank disturbance is limited to flood disturbance downstream of the Denison confluence. Land slips upslope of power station operating levels have been found to be stable, and to revegetate relatively rapidly.

The erosion pin results indicate erosion of the banks is progressing in a downstream direction, with zone 1 immediately downstream of the power station largely stable, zones 2 and 3 (upstream of the Denison) having stable bank toes with erosion concentrated in the 1-2 and 2-3 turbine bank level, and zones 4 and 5 undergoing erosion of bank toes, with dynamic but stable upper banks (1-2 and 2-3 turbine bank level). It is unknown how much of the erosion is associated with the initial damming of the river, and how much is associated with increased-duration 3-turbine power station operation over the pre-Basslink period.

Indicator variables have been identified based on the present erosion trends in the river. They were derived by grouping erosion pins by zones and/or turbine levels, recognizing that, over time, rates are likely to change in the presence or absence of Basslink due to the non-equilibrium condition of the river. Photo-monitoring, bank profiling, observations of seepage erosion and piezometer results will be used to assist in the interpretation of post-Basslink changes.

### Karst

The karst monitoring was undertaken to identify how the pre-Basslink Gordon River regime affects sediment behaviour in the caves. In the Gordon-Albert karst area, the sites of interest include a backwater channel, two dolines and a newly discovered cave: GA-X1. In the Nicholl's Range karst area, two caves - Kayak Kavern and Bill Neilson Cave - were monitored.

In general, the sediment processes in the caves showed summer erosion occurring when the power station flow was high and the contribution from natural flow in tributaries was low, and winter deposition when the power station contribution was small and the sediment rich tributary flow was high. There were three cases where this trend was contradicted:

- In Bill Neilson Cave, the cave stream affects the sediment at lower levels where the trend is for winter erosion which occurs when the stream is high;
- In Kayak Kavern, localised transfer processes have been identified on the active slope of the sediment mound due to the nature of the hydraulic connection with main river channel; and
- At all sites the impacts of uncharacteristic power station events prior to the monitoring trip have been found to affect the seasonal results.

The measured changes in sediment that occurred as a result of this complex hydrological regime are, on average, very small (average change at all pins in sediment banks 5.5 mm). Changes due to Basslink will need to be reasonably distinctive and significant in the context of all the other potential sources of change before they will be identifiable as specific Basslink changes.

In the karst sediment banks, the indicator variables for Basslink change are current range and average changes at erosion pins, and current long-term trends. An additional indicator variable in the Bill Neilson Cave is the current percentage of the time that the pins in the dry sediment bank are inundated, both on a long-term basis and on an average seasonal basis, together with the current maximum height of inundation in the cave. In the dolines, the trigger is a change in distances between the pins of more than 20 mm.

### Riparian vegetation

The riparian vegetation monitoring has found that the riparian vegetation within the middle Gordon River over the past three years has generally been stable in terms of abundance and diversity. The main factor that controls the extent of the vegetation is flow regulation and the subsequent level of disturbance and inundation. This has led to the mature vegetation being highly stratified up the bank of the river resulting in a distinct Plimsoll line, below which there are a reduced number of trees, shrubs and ground cover species, with only those species that are highly tolerant of inundation of leaves and waterlogging of roots persisting.

The germination and recruitment of seedlings shows a similar pattern. Seedlings germinated at most bank levels over the spring and summer but did not persist or develop into larger plants. The impacts of regulated flows decreased with distance downstream of the power station, with a greater diversity and abundance of species evident at downstream sites. This is the result of the influence of tributary inflows.

The regulated flow regime also influenced the vegetation through erosion and deposition along the river banks. Erosion can lead to physical removal of vegetation whilst deposition can lead to smothering of small plants, in particular seedlings. These factors further increased the level of disturbance to the vegetation, and further limited development.

Soil analyses showed that dieback (*Phytophthora cinnamomi*) is present in the Gordon River. This soil-borne pathogen may cause mortality in susceptible plant species, some of which form a substantial component of the riparian flora of the middle Gordon River, including many of the larger trees that occur below the current regulated flow level. Since the inception of Basslink investigative studies and the monitoring program, Hydro Tasmania has addressed the risk of *Phytophthora* introduction by implementing hygiene procedures as recommended by DPIWE.

For riparian vegetation, the indicator variables for identifying post-Basslink change are based on the abundance and density of flora species, seedlings or groundcover condition: total number of seedlings, number of seedlings less than 5 cm, total number of seedlings, and percentage cover for bare ground, bryophytes, ferns, shrubs and total vegetation.

**Benthic macroinvertebrates and algae**

The major findings of macroinvertebrate monitoring were that the middle Gordon River is less diverse than reference sites in the tributaries and the greatest differences occur upstream of the Denison confluence. Density and abundance upstream of the Denison confluence were also less than at reference sites. Further downstream diversity was approximately 25 % lower than at the reference sites, and taxonomic composition differed (more simuliids, fewer beetles, mayflies and worms). Densities within the Gordon River upstream of the Olga confluence and downstream of the Denison confluence were between 20-50 % of the reference stream densities.

Simuliids (blackfly larvae), Grypoptyerygid stoneflies and worms numerically dominated the middle Gordon River sites. Aphroteniid chironomids, Ceratoponid chironomids and freshwater worms tended to be widespread at reference sites and were observed rarely or at lower abundances in the middle Gordon River. Orthoclad chironomids, Janiirid isopods, Hydropsychid caddisfly, Diamesinid chironomids and amphipods were found at higher abundances in the upper middle Gordon than in reference sites.

The gradient of increasing diversity and abundance downstream of the power station is likely to be a product of:

- Reduced severity of velocity changes;
- Reduced area of channel dewatering and probability of stranding mortality;
- Increased availability of food resources;
- Increased input of colonisers from tributary rivers;
- Adult insect reproduction; and
- Increased availability of substrate interstices.

There was a general trend of O/E values increasing with distance downstream of the power station. O/E values for reference sites were consistently high falling within A or X bands on all occasions. Values for the middle Gordon River generally fell in the B or C bands upstream of the Denison confluence and in the A band downstream of the Denison confluence.

Benthic algal and moss cover was relatively high (15-30 % of the total bed stream) downstream of the power station. These levels equated to 100 % cover of the wetted stream bed during periods of low flow and power station shut-downs. Cover decreased to very low levels (typically < 2 %) for sites downstream of the Denison confluence. Assessment of algal cover for the reference sites only commenced in spring 2004, revealing an average of 1.3 % cover across all sites. The lower cover in reference sites may be due to low nutrient levels, or low light availability (high colour) coupled with bed instability during large floods. Temporal variation in cover is between seasons and years and with the timing and duration of power station shut-downs. Spatial variation in cover is evident across the river channel and with distance along the Gordon River.

A range of indicator variables have been selected for benthic macroinvertebrates, which provide data on the status of abundance, diversity and community composition. Changes are possible in all three areas following commencement of Basslink operations. In addition, exploration of community compositional changes will be conducted by multivariate comparison using multi-dimensional scaling ordination and multivariate analysis of variance (ANOSIM) derived from a matrix of Bray Curtis similarities.

Any changes in benthic algae and moss post-Basslink are expected to manifest primarily in overall cover and position within the channel. Accordingly, total in-channel percentage cover of algae and moss are the two core indicators to be reported and analysed during Basslink monitoring and assessment.

In addition, changes in position of peak cover within the channel will be assessed. Composition of algal assemblages has not been monitored, though samples of dominant species are being collected. These samples will be inspected for qualitative assessment of any shifts in the identity of dominant taxa.

All benthic macroinvertebrate, algal and moss data will be analysed at site level initially, due to the recognition of a number of site-specific effects on temporal variation in key indicators. Spatial trends in the status of benthic macroinvertebrate, algae and moss, and the nature of temporal variation in key indicators, do not conform to the 'zone' structure described for other disciplines (e.g. geomorphology, fish). This is partially due to marked trends in several indicators with distance from the lake, but also due to local site-scale factors (hydraulic, proximity to tributary junctions, etc.).

The potential and need for data aggregation (to reach or zone levels) has been explored, and will be evaluated in detail during the major post-Basslink data analysis stages (years 3 and 6). Exploration of patterns in the pre-Basslink data, as well as initial evaluation of variance in the data indicates that two major zones may form a reasonable basis for data aggregation during analysis - upstream and downstream of the Denison junction.

In addition to analysis of indicator changes based on site-scale and zone-scale aggregation, formal analysis may also include assessment of changes in the whole of river downstream spatial trends in selected indicators with distance from the dam. The form of such analyses has yet to be evaluated.

### Fish

A total of 12 fish species were collected from the reference sites and 10 from the Gordon sites. One introduced species, brown trout, was recorded from the reference sites while three introduced species consisting of brown trout, Atlantic salmon and redfin perch were collected from the Gordon River sites.

Reproductive strategies of the introduced and native fish recorded during the study are significantly different, with all but one of the natives exhibiting diadromy. As a consequence, migration success has direct implications for the distribution of native fish throughout the middle Gordon River. Significant juvenile galaxiids migrations were detected in the downstream middle Gordon River reaches during the monitoring.

Native fish were well represented in catches from the downstream zones, but their diversity generally declined with distance upstream in the Gordon River, while the diversity of introduced fish species was greatest in the upstream river sites. Brown trout, short-finned eels and lampreys were the most widely distributed species, and were present in all of the Gordon River and reference zones.

Trout generally dominated the catches in the Gordon River, particularly the tributaries situated in the middle zones of the monitoring area. Redfin perch were the most abundant species in the most upstream monitoring reaches of the Gordon River. They did not occur in tributary or reference streams.

Galaxiid distribution was characterised by a distinct reduction in catch rates upstream of Sunshine Gorge in the middle reaches of the study area. An isolated population of climbing galaxias persists in a small tributary immediately downstream of the power station.

High data variability limited the number of suitable indicators to measure post-Basslink changes to fish in the middle Gordon River, to:

- Catch per unit effort (CPUE) values for all species;
- CPUE for native fish only; and
- The ratio of CPUE of trout to native fish.

**Appropriateness of mitigation measures**

A suite of mitigation measures were identified during the Basslink assessment process for maintaining and/or improving the biological and geomorphic condition of the river. Two were considered in detail and have been incorporated in the Hydro Tasmania Water Licence:

- A minimum environmental flow is intended to provide a mitigating measure for the biota by increasing the permanently wetted area of the river. The minimum environmental flow would also have minor geomorphic advantages, in that it would increase baseflow, thereby reducing in-bank water surface slopes in the 1- and 2-turbine zones (because baseflow is higher); and
- A ramp-down rule is intended to maintain or reduce seepage erosion in the 2- and 3-turbine banks zone by reducing in-bank water surface slopes.

The required minimum environmental flow post-Basslink commencement is defined as 19 $m^3 s^{-1}$ in the summer and 38 $m^3 s^{-1}$ in the winter. The minimum environmental flow is to be maintained at site 65, the Gordon above Denison, identified as the compliance point for the flow. The licence also allows Hydro Tasmania to seek approval for a lower environmental flow on a trial basis provided it does not cause unacceptable environmental risk. Hydro Tasmania is presently seeking approval for a 10 $m^3 s^{-1}$ (summer) 20 $m^3 s^{-1}$ (winter) flow to be trialled under Basslink for three years.

The Hydro Tasmania Water Licence also requires a ramp-down rule to be implemented post-Basslink commencement. This rule states that if the Gordon Power Station has been discharging water at greater than 180 $m^3 s^{-1}$ for more than 60 minutes, and water discharges are to be reduced to less than 150 $m^3 s^{-1}$ for any period, then Hydro Tasmania must ensure that water discharges from the Gordon Power Station are reduced from discharges above 180 $m^3 s^{-1}$ down to 150 $m^3 s^{-1}$ by not more than 30 $m^3 s^{-1}$ in any 60 minute period.

Since the investigations for the Integrated Impact Assessment Statement (IIAS) for Basslink, flow modelling of post-Basslink operation of the Gordon Power Station has become more refined, the delivery option for the environmental flow has been clarified, and several more years of pre-Basslink flow results (2000-04) are available. The coarseness of the earlier modelling in the IIAS which exaggerated the extent of shut-down and full-gate operation has been refined, as was indicated would occur. The proposed environmental flow regime differs from the earlier modelled Basslink flows examined as part of the IIAS most notably with a sizeable reduction in very high flows compared to the initial modelling, and a more dominant 55 $m^3 s^{-1}$ flow.

Each researcher associated with Basslink baseline monitoring evaluated the adequacy of the proposed mitigation measures with respect to their discipline, given the greater understanding of riverine processes obtained during the four-year pre-Basslink monitoring period. Information arising from the monitoring and further evaluation suggests that the mitigation measures required in the Water Licence are appropriate and adequate.

**Indicator variables**

A primary task of the post-Basslink Monitoring Program will be to determine if there is evidence of change in the biological or physical characteristics of the middle Gordon River following the introduction of Basslink.

Evaluation of post-Basslink environmental change in the middle Gordon River will utilise a three-stage process based on indicator variables derived from the various monitoring disciplines. The three-stage process is analogous to the use of trigger values as used in the ANZECC/ARMCANZ (2000) water quality guidelines, in that values are set for a suite of indicator variables which, if exceeded, invoke management actions.

The three-stage process sets out the following questions:

- Were the trigger values exceeded?
- Can the exceedence be attributed to a Basslink effect?

- Does the exceedence require management intervention?

The detection of change in the post-Basslink period will be through indicator variables exhibiting values or patterns that are judged unusual by reference to pre-Basslink values and patterns. In general, the trigger value of a scaled indicator variable would be exceeded if the value lies outside the estimated 2.5th or 97.5th percentiles for that variable, where the estimated values are determined from a suitable statistical model applied to the pre-Basslink data for that variable.

Chapter 13 Indicator variables, establishes 26 indicator variables, and presents the trigger values for each variable that will signal the need for closer assessment to determine a Basslink effect. These trigger values are considered interim until a final set is develop in April 2006, allowing incorporation of the final pre-Basslink data sets, and full statistical exploration of the data.

# Acknowledgements

The Basslink Baseline Report is the culmination of four years of field investigations in the Gordon River, its tributaries, and nearby reference rivers in south-western Tasmania. The production of this report represents a significant effort by numerous people who participated in, or otherwise supported, the monitoring program and made the study possible, practical, safe and enjoyable.

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# Acronyms

| | |
|---|---|
| ANOSIM | analysis of similarity |
| ANOVA | analysis of variation |
| ASL | above sea level |
| BBR | Basslink Baseline Report |
| BMP | Gordon River Basslink Monitoring Program |
| CPUE | catch per unit effort |
| DOC | dissolved organic carbon |
| DPIWE | Department of Primary Industries, Water and Environment |
| DRP | dissolved reactive phosphorus |
| EPTCC | Macroinvertebrate individuals in the following groups: Ephemeroptera, Plecoptera, Trichoptera, Coleoptera and Crustaceae |
| FSL | full supply level of water body |
| IIAS | Basslink Integrated Impact Assessment Statement: Potential Effects of Changes to Hydro Power Generation |
| LWD | large woody debris |
| mASL | metres above sea level |
| NMOL | normal minimum operating level of water body |
| 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). |

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| 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 |
| PAR | photosynthetically active radiation |
| RBA | rapid biological assessment - macroinvertebrate sampling protocol |
| SRC | Scientific Reference Committee |
| TKN | total Kjeldahl nitrogen |
| TP | total phosphorus |
| TWWHA | Tasmanian Wilderness World Heritage Area |
| WHA | World Heritage Area |
| WHACC | World Heritage Area Consultative Committee |

# Glossary

| | |
|---|---|
| $\mu g\ L^{-1}$ | micrograms per litre, units for the concentration of a substance dissolved in a solution |
| $\mu S\ cm^{-1}$ | microSiemens per centimetre, units for conductivity |
| Ambient | background or baseline conditions |
| Ammocoete(s) | juvenile lamprey(s) |
| Anadromous | fish species which live in marine waters and migrate up rivers to breed in fresh water |
| Anoxic | absence of oxygen (concentrations below about 2 $mg\ L^{-1}$) |
| Benthic | the bottom of a lake |
| Bray Curtis index | a measure of assemblage similarity between sites/samples |
| Bryophytes | division of photosynthetic, nonvascular plants, including the mosses, liverworts, and hornworts |
| Catadromous | fish species living in fresh water but migrate to breed in marine waters |
| 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. |
| Coleoptera | the largest order of insects comprising the beetles and weevils |
| Confluence | the location when two rivers or tributaries flow together |
| Copepoda | a subclass of Crustaceae comprising minute aquatic forms which are important as fish food |
| Depauperate | a community of organisms is diminished or impoverished of certain species |
| Diadromous | migration of fish between marine and freshwaters as part of its life history cycle |
| Diurnal | relating to or occurring in a 24 hour period |

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| Dolines | are karst features which 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. |
| Efficient load | is the discharge which provides the maximum energy production per unit volume of water passing through the turbine |
| Elver(s) | juvenile eel(s) |
| Entrainment | when the movement or distribution of an organism or particle is determined by the condition of moving water |
| Environmental flow | water which has been provided or released for the benefit of the downstream aquatic ecosystem and broader environment |
| Ephemeroptera | is an order of fragile winged insects commonly known as mayflies which develop from aquatic nymphs and live in the adult stage no longer than a few days |
| Euphotic depth | is the depth at which 1 % of the magnitude of surface irradiance penetrates to in a water body |
| Exotic | introduced organisms or species |
| Filter feeders | type of zooplankton feeding adaptation |
| Full-gate | is the discharge which produces the maximum amount of energy by the turbine |
| Geomorphic | the study of the earths shape or configuration |
| Histograms | a bar graph of a frequency distribution in which the widths of the bars are proportional to the classes into which the variable has been divided and the heights of the bars are proportional to the class frequencies |
| Humic waters | water which contains significant concentrations of humic acid |
| 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 |
| Inundation | an area of vegetation or bank which becomes cover by water associated with flows from either an upstream dam or tributary input |

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| Karst | an area of irregular limestone in which erosion has produced fissures, sinkholes, underground streams and caverns |
| $m^3 s^{-1}$ | 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 |
| Morphology | the consideration of the form and structure of organisms |
| MW | megawatts ($10^6$ watts) |
| Oligochaetes | various annelid worms of the class Oligochaeta, including the earthworms and a few small freshwater forms |
| Otoliths | one of many minute calcareous particles found in the inner ear of vertebrates and in the statocysts of many invertebrates |
| 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) |
| Photosynthetically active radiation (PAR) | the wavelength of light which is absorbed and used for plants to photosynthesise |
| Piezometer | an instrument for measuring pressure |
| Piscivorous | a predatory fish species which eats other fish including its own juveniles |
| Plecoptera | order containing weak-flying insects known as stoneflies, whose nymphs live under stones along the banks of streams. Adult and larval stoneflies are used as fishing bait. Also called plecopteran. |
| Plimsoll line | lines which show the level the water should reach when a ship is properly loaded. In this case used to describe the distinct line created on the river bank by the riparian vegetation in response to flow regulation by the power station. |
| Riffle habitat | habitat comprising rocky shoal or sandbar lying just below the surface of a waterway |
| Rill | a small brook or natural stream of water smaller than a river |

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| Synchronous | occurring or existing at the same time |
| Tailrace | the outflow structure of the power station, from which water is discharged into the river |
| Tardigrada | microscopic arachnid-like invertebrates living in water or damp moss having four pairs of legs and instead of a mouth they have a pair needle-like piercing organs connected with the pharynx |
| Taxon | a taxonomic category or group, such as a phylum, order, family, genus, or species |
| Temporal trend | change or pattern over time |
| Thalweg zone | the line defining the lowest points along the length of a river bed or valley |
| Thermal stratification | change in temperature profiles over the depth of a water column |
| Trichoptera | an order of insects consisting of caddis flies |
| Troglobitic species | are cave adapted or cave dwelling species |
| Turbellaria | an extensive group of worms which have the body covered externally with vibrating ilia |
| Zooplankton | animal constituent of plankton which are mainly small crustaceans and fish larvae |

# 1 Introduction

## 1.1 Purpose

The Basslink Baseline Report (BBR) documents the present environmental condition of the middle Gordon River between the Gordon Power Station and the Franklin confluence. This is the length of river most significantly affected by the operation of the Gordon Power Station.

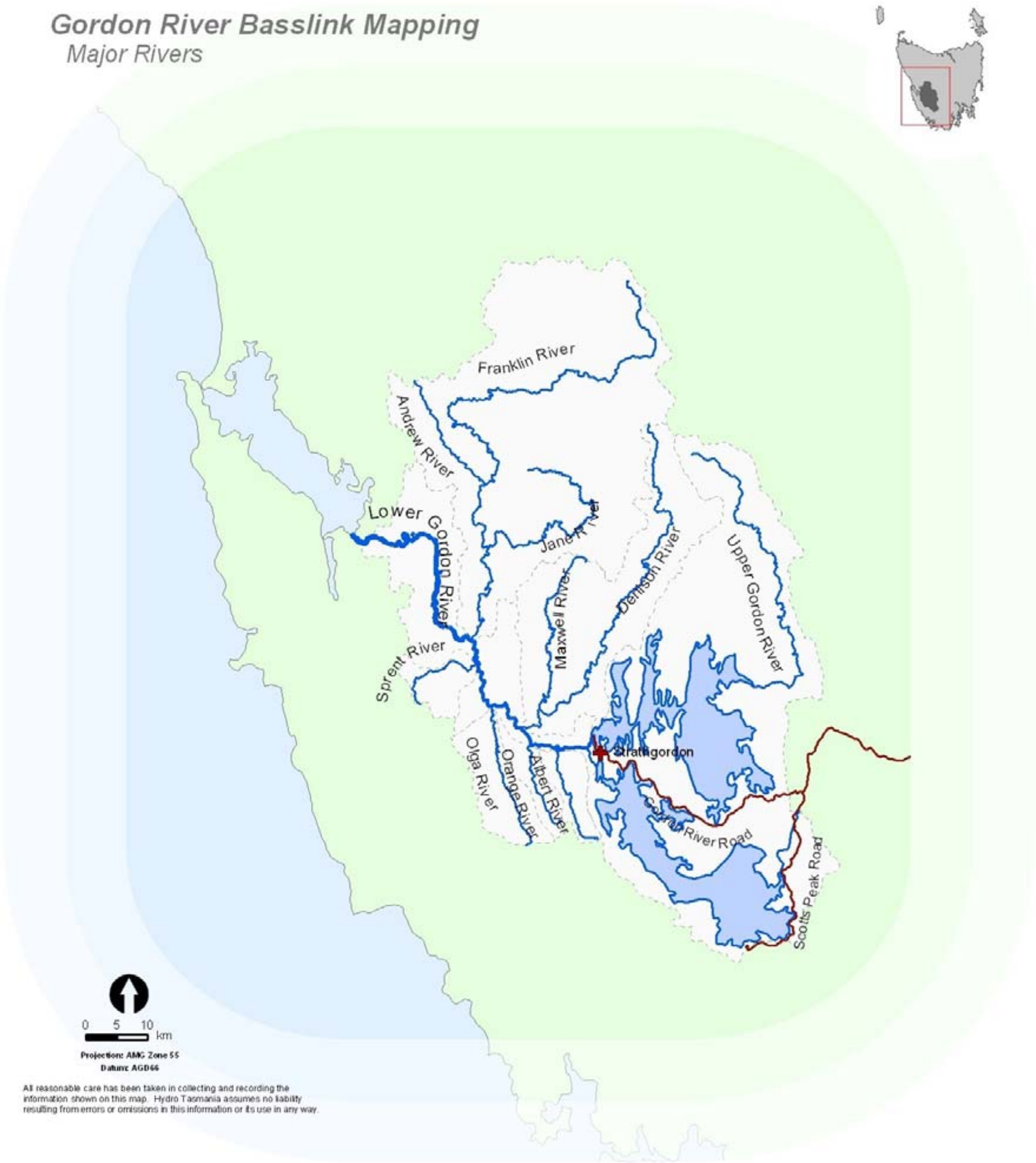
The aim of the BBR is to present the consolidated results of the past four years (2001-05) of monitoring within the middle Gordon River by the Gordon River Basslink Monitoring Program (BMP). These results have been combined with information from previous studies to indicate trends, variability and data ranges for a number of scientific disciplines.

The primary purpose of the BBR is to provide an accurate, useful and appropriate statement of pre-Basslink environmental conditions against which the post-Basslink conditions can be compared. It is submitted to the Tasmanian Minister administering the Hydro Tasmania Water Licence under the *Water Management Act* and to the Commonwealth Minister for the Environment and Heritage, and will be a reference document for assessment of post-Basslink monitoring data from the Gordon River. Section 1.4.1 lists the requirements of the BBR.

## 1.2 Basslink and the Gordon River

Basslink is the undersea power cable across Bass Strait that will connect the Tasmanian electricity network to Australia's national electricity grid. It is scheduled to commence operation in early 2006. The Basslink project will cause changes to the way some of Tasmania's power stations are operated. Hydro Tasmania's power system modelling has indicated that the Gordon Power Station will be among those with a changed operating pattern.

The Gordon Power Scheme is located on the Gordon River in south-west Tasmania. Map 1.1 shows the location of the power scheme within the Gordon catchment as well as the impoundments and other associated infrastructure. The Gordon Power Scheme is described in detail in chapter 2 (Background).



Map 1.1. The Gordon catchment showing the position of the catchment in south-west Tasmania, Lakes Gordon and Pedder, and (inset) details of the Gordon Power Scheme.

### 1.2.1 Basslink assessment process and information sources

The Basslink project was subject to a comprehensive and stringent approvals processes that extended over a two-year period from 2001 to 2002 and spanned three jurisdictions (State of Tasmania, State of Victoria, Commonwealth of Australia). The process involved the establishment of the Joint Advisory Panel (JAP) and the development of a purpose-built process for assessing the impacts on the Gordon River.

The assessment process involved the production of an Integrated Impact Assessment Statement (IIAS). This was followed by public submissions and hearings, production of a Draft Panel Report (JAP 2002), followed by further submissions and hearings before the final report was submitted to the relevant jurisdictions for approval. Figure 1.1 provides a diagram of the IIAS preparation process, while Figure 1.2 illustrates the timeline and steps of the Basslink approvals process.

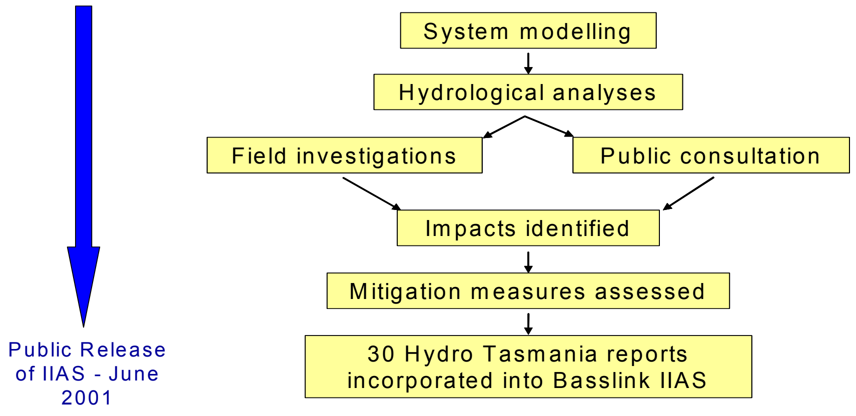


Figure 1.1. The preparation process for the Basslink Integrated Impact Assessment Statement.

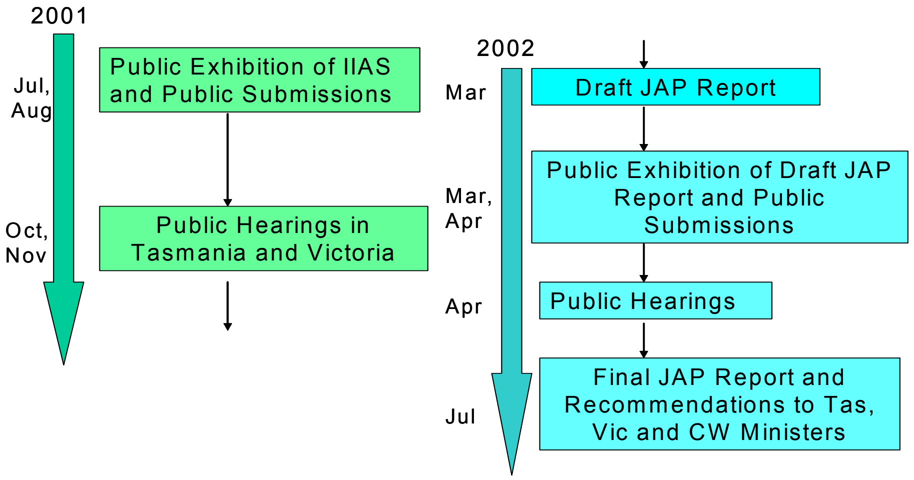


Figure 1.2. The timeline and functional steps of the Basslink approvals process.

The comprehensive "Basslink Integrated Impact Assessment Statement: Potential Effects of changes to Hydro Power Generation" included 13 separate reports on aspects of the Gordon River. These reports were the outcomes of independent investigative studies into a range of environmental and social issues. All of the IIAS documents are available on the Hydro Tasmania web site at http://www.hydro.com.au.

Of the IIAS studies, a number are direct precursors to the BMP. These include:

- Appendix 2 Gordon River Hydrology Assessment
- Appendix 3 Gordon River Water Quality Assessment
- Appendix 4 Gordon River Fluvial Geomorphology Assessment
- Appendix 5 Gordon River Karst Assessment
- Appendix 6 Gordon River Riparian Vegetation Assessment
- Appendix 7 Gordon River Macroinvertebrate and Aquatic Mammal Assessment
- Appendix 8 Gordon River Fish Assessment

The combination of these sources and four years of BMP monitoring provide the fundamental information sources on which this report is based.

### 1.2.2 Hydrological changes and environmental issues

System modelling predicted that Basslink would increase the on-off operation of the Gordon Power Station throughout the full range of discharges, result in more winter discharge than at present, increase the occurrence of high power station discharges and increase occurrences of short-term and weekend shut-downs. Inter-annual variability in power station operating patterns was also predicted to be reduced.

Environmental investigations of the middle Gordon River as part of the IIAS encompassed hydrology, water quality, fluvial geomorphology, karst geomorphology, riparian vegetation, macroinvertebrates, aquatic mammals, fish, terrestrial fauna, cave biota, meromictic lakes, cultural heritage, public use and World Heritage Area values. Outcomes from these studies, presented in the IIAS Summary document (Locher 2001), were that the predicted environmental impacts of the Basslink development, without mitigation measures in place, related to four key areas:

- **Fluvial Geomorphology**: Basslink is predicted to change the geomorphic processes controlling stability of the Gordon River banks relative to the present processes, principally scour and seepage erosion;

- **Riparian Vegetation**: Basslink is predicted to accelerate present rates of loss of riparian vegetation communities;

- **Aquatic Macroinvertebrates:** Basslink is predicted to alter the community composition of macroinvertebrates in the middle Gordon River, and further reduce diversity and abundance both upstream and downstream of the Denison confluence; and

- **Fish:** Basslink is predicted to result in reduced availability of fish habitat within middle Gordon River, and reduced food supplies through impacts on macroinvertebrates may lead to further reduced populations.

These were the predicted effects in the absence of mitigation measures. Hydro Tasmania is committed to a package of mitigation measures which are detailed below (section 1.3.2).

## 1.3 Gordon River Basslink commitments

### 1.3.1 Hydro Tasmania's Water Licence

Hydro Tasmania is committed to a number of activities designed to monitor and mitigate predicted Basslink effects. These are set out in the Water Licence held by Hydro Tasmania under the *Water Management Act* 1999.

Part 2, Section 3 of Hydro Tasmania's licence details the requirements of the Gordon River Basslink Monitoring Program, provided in appendix 1 to this report. Part 2, Section 4 of the licence lists the composition and functions of the Scientific Reference Committee (SRC), and Schedule 4 lists Hydro Tasmania's pre-Basslink monitoring and reporting commitments. Schedule 5 of the licence lists Hydro Tasmania's post-Basslink obligations, including the provision of a minimum environmental flow and implementation of a ramp-down rule.

### 1.3.2 Mitigation measures

The aim of the Gordon River mitigation measures accompanying Basslink is "no net Basslink environmental impact". "No net Basslink impact" is defined as "impact that remains within the present boundaries, recognising inherent variability in the environmental indicators as well as long-term presently occurring trends". On Basslink commencement, two mitigation measures will be introduced. These are:

- a minimum environmental flow; and
- a ramp-down rule for the power station.

The minimum environmental flow is intended to ensure watering of the 'mid-tidal' zone, inundation of marginal snag habitats, an increase in habitat for fish, and improved food supply (macroinvertebrates) for fish and platypus. Hydro Tasmania is required to maintain a minimum environmental flow in the Gordon River of at least 38 $m^3 s^{-1}$ from 1 June to 30 November each year and 19 $m^3 s^{-1}$ from 1 December to 31 May each year.

The ramp-down rule is intended to decrease the incidence of seepage erosion by reducing the in-bank water slope during turbine shut-down and, consequently, the potential for bank sediment entrainment and erosion. If the Gordon Power Station has been discharging water at greater than 180 $m^3 s^{-1}$ for more than 60 minutes, and water discharges are to be reduced to less than 150 $m^3 s^{-1}$ for any period, then Hydro Tasmania must ensure that water discharges from the Gordon Power

Station are reduced from discharges above 180 $m^3 s^{-1}$ down to 150 $m^3 s^{-1}$ by no more than 30 $m^3 s^{-1}$ in any 60 minute period.

Chapter 12 of this report reviews the appropriateness of these mitigation measures for those aspects of the river ecosystem most at risk from post-Basslink impacts.

### 1.3.3 Basslink Monitoring Program

The BBR is the culmination of more than six years of investigative studies (IIAS) and comprehensive monitoring activities (BMP) in the Gordon River. As a result of the investigative studies, the Gordon River Basslink Monitoring Program (BMP) was developed to monitor those aspects deemed to be at most risk of impact from post-Basslink changes in power station operations. These included:

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

The Gordon River Basslink Monitoring Program has conducted more than four years of monitoring prior to Basslink commencement. It will continue for at least six years post-Basslink, with major review and reporting activities scheduled each three years.

Monitoring work commenced in October 2001. Since then, the BMP has produced four Gordon River Basslink Monitoring Annual Reports, presenting the monitoring results for 2001-02, 2002-03, 2003-04 and 2004-05. These reports are available on the Hydro Tasmania web site. The fifth annual report (2005-06) will be delivered in September 2006. It will cover the last of the pre-Basslink period and the initial post-Basslink period.

The BMP has benefited from the continuing involvement of a range of researchers, most of whom were also directly associated with the IIAS investigative studies. As well, the BMP is advised by a Scientific Reference Committee (SRC).

### 1.3.4 Scientific Reference Committee

The Gordon River Scientific Reference Committee, which provides advice for, and review of, the BMP and its reports, is chaired by Dr Colin Buxton and comprises:

- three Hydro Tasmania representatives;
- three researcher representatives;
- four DPIWE representatives; and
- two representatives from the Department of Environment and Heritage (formerly Environment Australia).

The primary functions of the committee are to consider scientific and technical issues relating to the implementation of the Gordon River Basslink Monitoring Program and other Gordon River Basslink scientific reports. The committee meets annually to consider the Annual Monitoring reports, and has held additional meetings as required.

### 1.3.5 Adaptive management

Ecosystems are dynamic systems subject to change, environmental influences and human impacts. In recognition of the scientific uncertainties associated with ecosystem management, operational practices which are flexible and respond to new knowledge and information are increasingly being implemented by resource managers. This has become known as adaptive management. Adaptive management allows for adjustments to be made in response to changing events, decisions and circumstances as new knowledge is gained.

Adaptive management techniques rely on long-term experience, the assessment of experimental interventions and the collection of large amounts of data which are examined in the context of an agreed set of environmental indicators. Time effects, and the interactions of various ecosystem components, are assessed in determining outcomes and management interventions. Adaptive management relies on a commitment to regular monitoring, review and feedback to deliver sustainable resource management outcomes.

In the context of managing the impacts of Basslink on the Gordon River, the aims of adaptive management are:

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

The principal information base for adaptive management, post-Basslink, will be the Annual and Review Reports from the BMP and the trigger values of indicator variables determined from the pre-Basslink monitoring (chapter 13). The Gordon River Basslink Monitoring Annual Reports will be delivered by 30 September each year, and the Basslink Review Reports will be delivered in the third and sixth years following Basslink commencement. All of these will be public documents.

## 1.4 The Basslink Baseline Report

The BBR is an output of the Gordon River Basslink Monitoring Program, and the requirements are specified in Hydro Tasmania's Water Licence.

### 1.4.1 BBR requirements

The BBR has five essential requirements. It must:

- present trends from all consolidated data collected subsequent to the IIAS investigations;
- evaluate the adequacy of the Gordon River Basslink Monitoring Program and, if necessary, propose refinements;
- evaluate the appropriateness of the proposed Mitigation Measures based on this further data;
- consider and, if appropriate and practicable, propose 'limits of acceptable change' for each of the key scientific disciplines which: are consistent with the aims of adaptive management; recognise the regulated nature of the Gordon River; and recognise the potential for conflicts between the management objectives of different disciplines; and
- respond to any written comments on the Draft Basslink Baseline Report received from the World Heritage Area Consultative Committee (WHACC), following Hydro Tasmania's written invitation to comment.

The first four requirements form the core of the Basslink Baseline Report, the structure of which is detailed in section 1.4.2.

The fifth requirement, to respond to WHACC comment on the Draft BBR, has been met as outlined in appendix 2. This appendix provides the comments of the WHACC on the previous draft to this report, along with Hydro Tasmania's response.

The BBR examines the presently existing conditions of the middle Gordon River in terms of hydrology, geomorphology and a number of biotic disciplines, as well as the interactions between them. It draws on all of the data gathered over the four years of the BMP and includes information from the IIAS investigative studies and any other relevant available material. The BBR does not reproduce in detail these studies, but draws from them and the IIAS studies should be read in conjunction with this report to obtain more detailed background information. This information forms the baseline for evaluating the effectiveness of the proposed mitigation measures and identifying any effects of post-Basslink power station operations.

### 1.4.2 Document structure

The Basslink Baseline Report is presented in two volumes: the Report and the Appendices. The main report comprises 14 chapters, subdivided into three groups:

- foundation chapters;
- individual discipline chapters; and
- integration chapters.

The **foundation chapters** establish the rationale for the BBR and provide essential background information in five chapters:

- **Introduction**: discusses the purpose of the BBR, the Basslink project and its potential effects on the Gordon River, the development of the Basslink Monitoring Program and post-Basslink management and mitigation measures;
- **Background:** provides a description of the physical setting of the Gordon catchment, the history of the power scheme and historical hydrology (pre- and post-impoundment), and references to historical research. It also discusses the expected fish distribution and historical macroinvertebrate community composition;
- **Conceptual model**: provides information fundamental to each of the individual discipline chapters in terms of an overarching conceptual model of the interactions between the various monitored disciplines under the existing regulated conditions;
- **Design and inference**: provides a discussion of the statistical designs and analyses undertaken for this report. It identifies methods that may be employed post-Basslink and addresses issues raised about the role of reference rivers; and
- **Pre-Basslink hydrology (2001-05)**: based on the hydrological information provided in the Background chapter and the processes detailed in the Conceptual model chapter, it provides the hydrological information relevant to the individual discipline chapters.

The **individual discipline** chapters cover each of the monitoring disciplines and provide a detailed analysis of the data collected to date and any relevant data from earlier investigations. Each chapter presents the findings of the monitoring and their analysis and interpretation, as well as providing an evaluation of the adequacy of the BMP. Additionally, each chapter will provide discussion on the identification of key indicator variables which may be used to identify post-Basslink changes in conditions.

The individual discipline chapters are:

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

The individual discipline chapters are supported by appendices (volume 2), as needed.

The **integration chapters** link the information presented in the individual discipline chapters through assessments of the appropriateness of the mitigation measures and how post-Basslink changes will be identified and managed. The integration chapters are:

- **Appropriateness of mitigation measure**: evaluates the likely effectiveness of the mitigation measures which were set out in the July 2002 JAP Report based on the further four years of monitoring data which has been collected in the Gordon River;
- **Indicator variables**: takes the suggested indicator variables from the individual scientific disciplines and presents trigger values for these variables that will initiate closer examination of whether a change in the variable could be attributed to Basslink. This chapter provides the framework for post-Basslink assessment and management; and
- **Conclusion**.

The **appendices** are contained in volume II and comprise:

- the specifications of the BMP (extracted from Hydro Tasmania's Water Licence);
- the response to the comments of the World Heritage Area Consultative Committee; and
- appendices for each of the monitoring disciplines (water quality, fluvial geomorphology, karst geomorphology, riparian vegetation, macroinvertebrates and algae, and fish).

### 1.4.3 BBR compilation

The process of compiling the BBR has involved considerable effort from a range of participants. The researchers have been directly involved through their own research and reporting and through working groups which helped define the structure of the document and its contents. Where needed, independent advice was sought to address issues of general concern. This was particularly the case for the complex statistical issues which became evident during the preparatory data analyses.

The Gordon River SRC has been involved throughout the process including holding several meetings dedicated to the development of the BBR, which has resulted in a broader perspective and revised structure for the document. The BBR has benefited from the input, both formal and informal, of the World Heritage Area Consultative Committee.

## 1.5 Status of this document and further documents

The Final Basslink Baseline Report is required in the Hydro Tasmania Water Licence to be submitted to the Minister prior to the commencement of Basslink. However, it does not contain the full set of pre-Basslink monitoring data, and the indicator variables in chapter 13 will undergo further statistical exploration.

Monitoring data will be collected during the spring and summer period leading up to Basslink commencement in early 2006, and it has not been possible to have this data analysed and incorporated into this report. For some disciplines, data for a particular site may only be collected twice a year, and so these final data sets are quite important for development of the trigger values. As a consequence, the BBR trigger values set out in chapter 13 of this document are considered 'interim' trigger values until a final set is produced by April 2006.

During January to March 2006, the lead researchers will work with the consulting statistician to the Gordon Basslink Monitoring Program (BMP) to incorporate the final data into the statistical models, and to fully explore a range of statistical approaches to developing trigger values. The outcome will be reviewed by the SRC in April 2006. The final set of trigger values will be provided to the relevant Tasmanian and Commonwealth Ministers once agreement is reached by the SRC.

Having only interim values at this point should not pose any problems. Depending on the exact commencement date of Basslink, the earliest post-Basslink data collection could be in March 2006, by which time the final set of trigger values would be well developed. Trigger values are only the first part of a three-stage process explained in section 13.7.

The 2005-06 Annual Report for the BMP will include the final pre-Basslink data sets, and the final set of trigger values. Annual reports will report on any data exceedences, and the follow-up and responses to these exceedences.

Within six months of the third and sixth anniversaries of the Basslink commencement date, Hydro Tasmania must prepare a Basslink Review Report which includes analysis and discussion of previous three (or six) years of data, and evaluates the effectiveness of the monitoring and mitigation commitments and any "limits of acceptable change". It will also update the presentation of the Gordon River conceptual model (chapter 3 of this report) based on the further understanding of post-Basslink ecosystem function.

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# 2 Background

This chapter presents a broad overview of the Gordon River catchment with the aim of providing a spatial and temporal context for the Basslink investigations, including a brief description of the pre-impoundment catchment, the history of the power scheme, and the hydrologic changes resulting from damming. This information provides the background against which the conceptual model has been developed. Additional information on the Gordon River catchment and the Basslink IIAS investigations is available in Locher (2001) and its appendices.

## 2.1 The natural Gordon River catchment

### 2.1.1 Regional setting

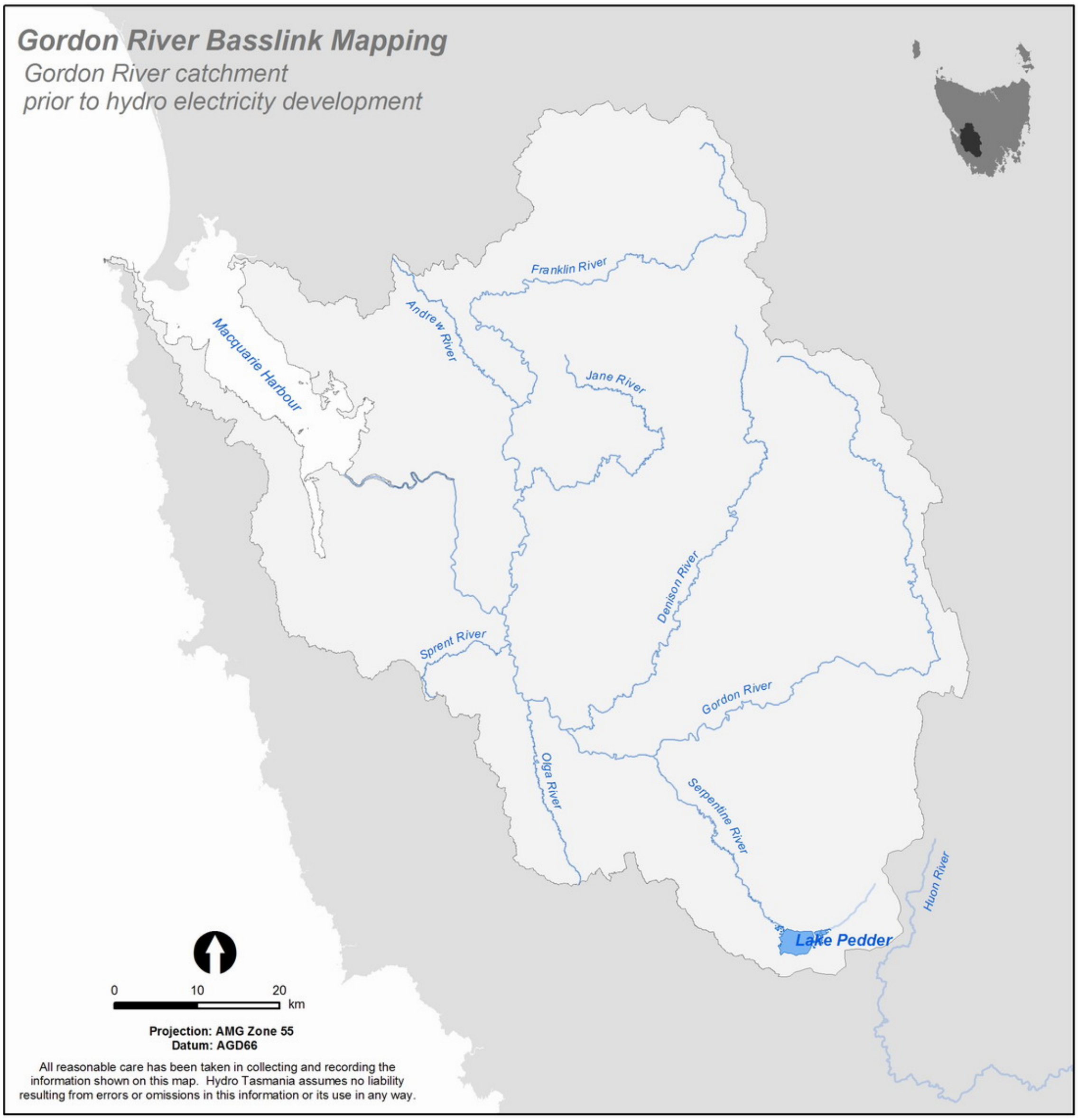
Before damming, the Gordon River catchment encompassed *ca* 5,000 km$^2$. The river rises in the King William Range in central Tasmania at an elevation of approximately 1360 m and flows 180 km in a southerly, westerly and then north-westerly direction to Macquarie Harbour, on Tasmania's west coast. The river loses altitude quickly in the headwaters, before flowing through broad flat valleys alternating with short, steep gorges cut at right angles through parallel ranges. Pre-dam flow ranged from <5 m$^3$ s$^{-1}$ to 3,190 m$^3$ s$^{-1}$, with a mean discharge of ~264 m$^3$ s$^{-1}$. Major tributaries include the Denison-Maxwell, Olga, and Franklin Rivers, all of which drain pristine wilderness and collectively have a mean annual run-off of ~135 m$^3$ s$^{-1}$. The river loses most of its elevation by the Franklin confluence, with the final 38 km affected by tides. Map 2.1 illustrates the Gordon catchment prior to the power development.

The geology of the Gordon catchment is predominantly Precambrian basement rocks, more than 1,000 million years old, as well as Palaeozoic rocks including Ordovician limestones and sandstones, and Devonian-Silurian limestone-siltstone-shale sequences. Glaciation during the Quaternary consisted of mountain glaciers, resulting in rugged ranges and extensive sand and gravel deposits in valleys (Roberts and Naqvi, 1978). Periglacial activities on mountain slopes gave rise to talus deposits. The east-west trending reach of the river, postulated to be derived from a pre-Tertiary land surface, has cut narrow gorges through the Precambrian ranges which have exerted a strong control on the evolution of the river. Tributaries have formed broad valleys in less resistant strata, and in the north-south trending Olga-Gordon-Franklin valley, the carbonate substrate has been modified by dissolution processes to produce cave and karst systems (Roberts and Naqvi, 1978). The underlying geology provides strong bedrock control for the Gordon River.

### 2.1.2 Land uses

The principal land uses of the Gordon catchment are hydro-electric power generation (described in detail in section 2.2), wilderness activities, tourism, recreation and nature conservation.

Strathgordon village is the only settlement in the catchment and it was established for the construction and maintenance of the power scheme. The village is now also utilised by tourists, bushwalkers, boaters and anglers. Most of the Gordon catchment is within either the Franklin-Gordon Wild Rivers National Park or the South-West National Park. These national parks form part of the Tasmanian Wilderness World Heritage Area (TWWHA).



Map 2.1. Map of Gordon River catchment prior to damming.

The Gordon River catchment, comprising the area associated with hydro-electric development but excluding Lake Gordon and the Gordon River from the dam site to the Olga River, was included in the listing of the Tasmanian Wilderness World Heritage Area in 1982. The area is recognized for its natural and cultural values, meeting all four criteria for natural values and three of the six criteria for cultural values (see Kriwoken 2001). The WHA listing recognized the area as being one of the last expanses of intact temperate rainforests in the world, an outstanding example of a major stage of the earth's evolutionary history, representing significant ongoing geological processes and biological evolution and containing superlative natural phenomena, formation and features. Culturally, the WHA is recognized as significant due to the presence of Aboriginal communities from at least 30,000 years ago through to the Pleistocene.

The 1982 and 1989 World Heritage Area nominations expressly acknowledged existing hydro-electric schemes and the direct impact those schemes have on natural waterways in the TWWHA. Implicit in this acknowledgement is that downstream ecosystems are modified by flow regulation. In a discussion of the World Heritage Area values, Kriwoken (2001) documented that the Gordon River was a regulated, highly modified river environment and not representative of a pristine ecosystem when listed under the World Heritage Convention.

### 2.1.3 Pre-dam hydrology

Rainfall over the Gordon catchment is largely the result of the passage of westerly fronts across Tasmania, and ranges from an average of 1,500 mm annually in the Gordon headwaters to over 3,200 mm at some points along the mountain ranges. Rainfall at Strathgordon has a long-term annual average of approximately 2,500 mm. Rainfall occurs throughout the year (Figure 2.1), with highest falls occurring between May and October.

The rainfall pattern was reflected in the natural flow of the Gordon River, as shown in Figure 2.2 which compares pre-dam flow at the Gordon below Serpentine (present site of power station, site 77) and Gordon above Franklin (site 44), with storm fronts resulting in discrete high flow events superimposed on seasonal baseflow (Figure 2.3). The hydrologic monitoring stations used in this and subsequent sections are shown in Map 2.2.

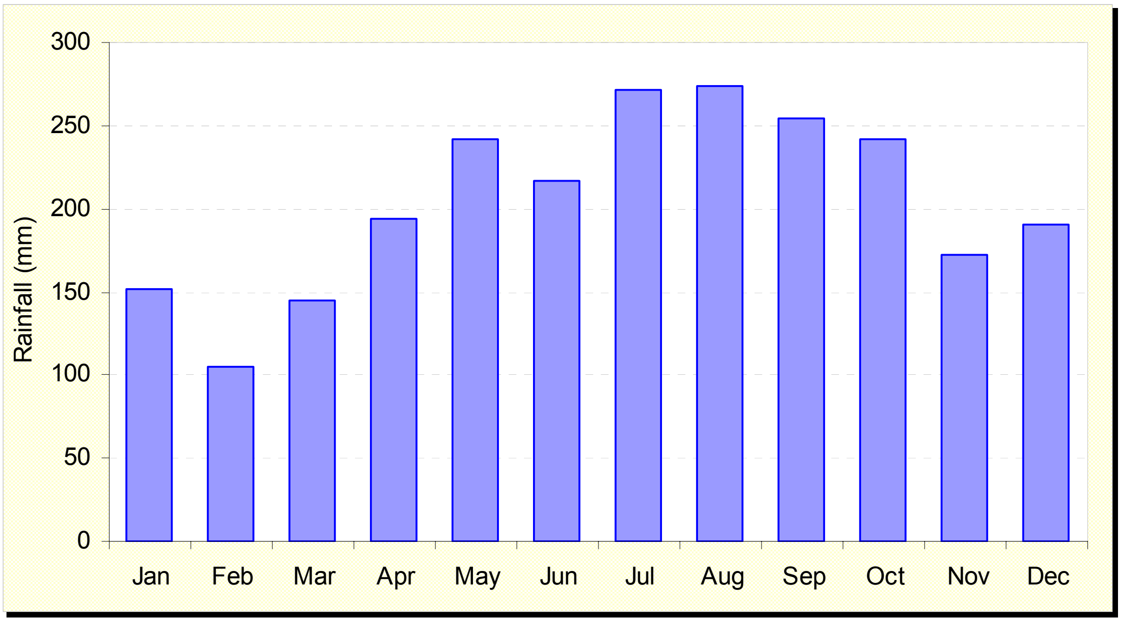
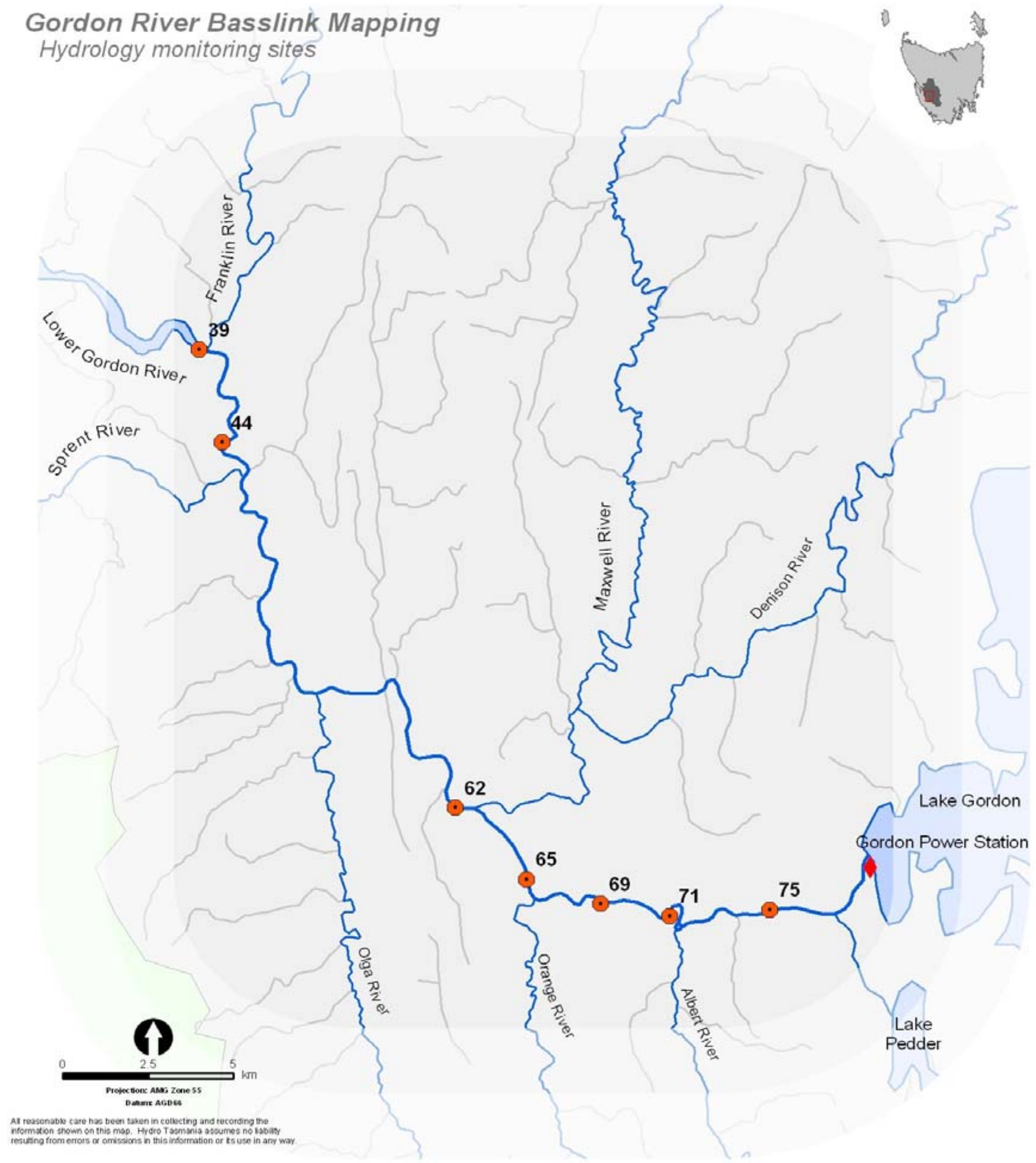


Figure 2.1. Average monthly rainfall at Strathgordon (data from February 1970 to August 2005)

Figure 2.2 shows high variability in monthly flows at both the Gordon at Serpentine and Gordon above Franklin sites. Comparing the graphs in Figure 2.2 shows the sizeable contribution of tributaries in the middle Gordon River with winter and summer median flows increasing by ~30 $m^3 s^{-1}$ and 160 $m^3 s^{-1}$, respectively. On an annual basis, flow at the upstream site averaged 89 $m^3 s^{-1}$, while flow above the Franklin averaged 160 $m^3 s^{-1}$. Of the 89 $m^3 s^{-1}$ at the upstream site, about 25 $m^3 s^{-1}$ was attributable to the entrance of the Serpentine River, with the remainder from the Gordon upstream of the dam site.



Map 2.2. Map of the middle Gordon River showing the location of hydrology monitoring sites downstream of the Gordon. Note: Throughout this report, monitoring locations are identified by site number. These represent the approximate distance upstream from the Gordon River mouth at the south-eastern end of Macquarie Harbour. The monitoring work is conducted between sites 39 (immediately downstream of the Franklin confluence, at the upstream tidal limit) and site 77 (the power station tailrace).

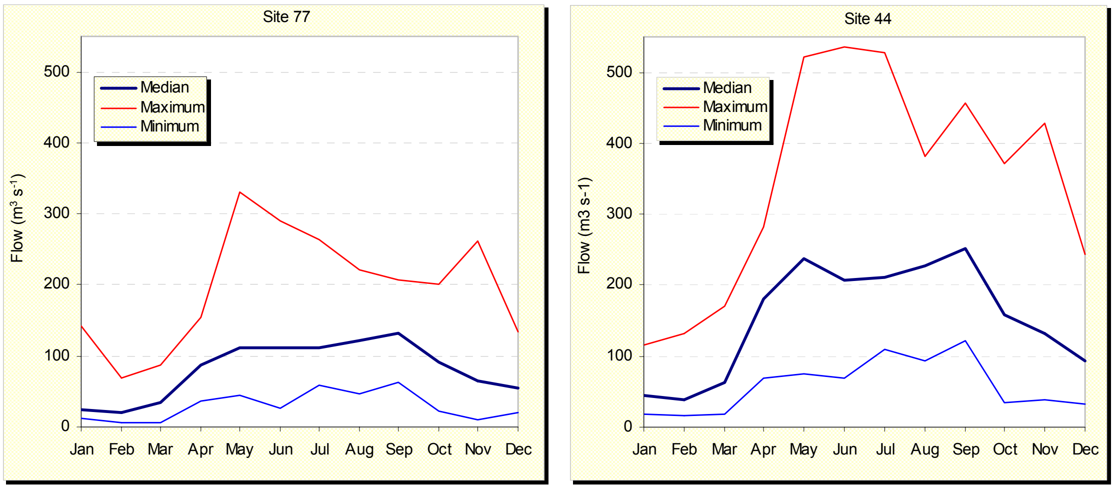


Figure 2.2. Median, maximum and minimum monthly flows in the Gordon River at the Serpentine River (site 77, power station tailrace, left) and upstream of the Franklin River (site 44, right), 1958-73.

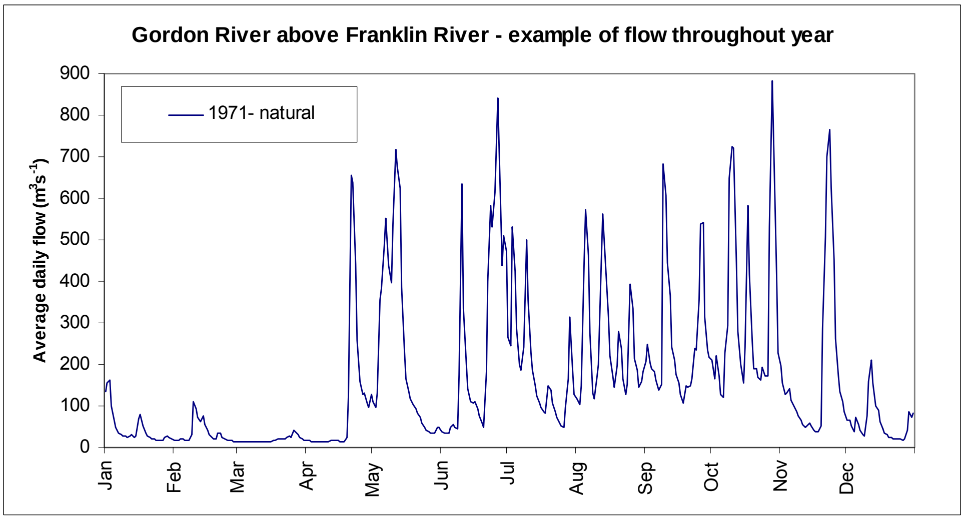


Figure 2.3. Example of pre-dam flow regime at the Gordon above Franklin (site 44) in 1971.

### 2.1.4 Ecology

The dominant vegetation types in the Gordon region is *Eucalyptus nitida* and *Eucalyptus obliqua* wet forest, rainforest, buttongrass moor, and wet scrub. Rainforest and wet scrub occur mainly in the western part of the catchment, while buttongrass moors are located throughout the region. Vegetation has resulted in stable river channels in western Tasmania since the Pleistocene due to the re-establishment of dense riparian rainforest, and the longevity of fallen timber in the channel (Nanson *et al.* 1995).

The river ecosystems are typified by a highly diverse and productive macroinvertebrate fauna, with high relative abundances of filter feeders and predators. Mayflies, caddisflies and stoneflies dominate the aquatic insect fauna; riffle beetles, blackfly and midge larvae are abundant. Native fish are predominantly species of galaxiids; *Galaxias maculatus*, *G. truttaceus* and *G. brevipinnis*. Diversity and abundance of native fish are highest in downstream reaches, declining upstream with a shift in dominance to *G. brevinnis* and shortfinned eel (*Anguilla australis*). Three exotic fish species are known in the Gordon catchment, with brown trout being widespread. Freshwater crayfish (*Astacopsis tricornis)*, platypus (*Ornithorhynchus anatinus)* and native water rat (*Hydromys chrysogaster*) are resident throughout the middle Gordon catchment.

## 2.2 The Gordon River Power Development

### 2.2.1 Gordon Power Scheme description

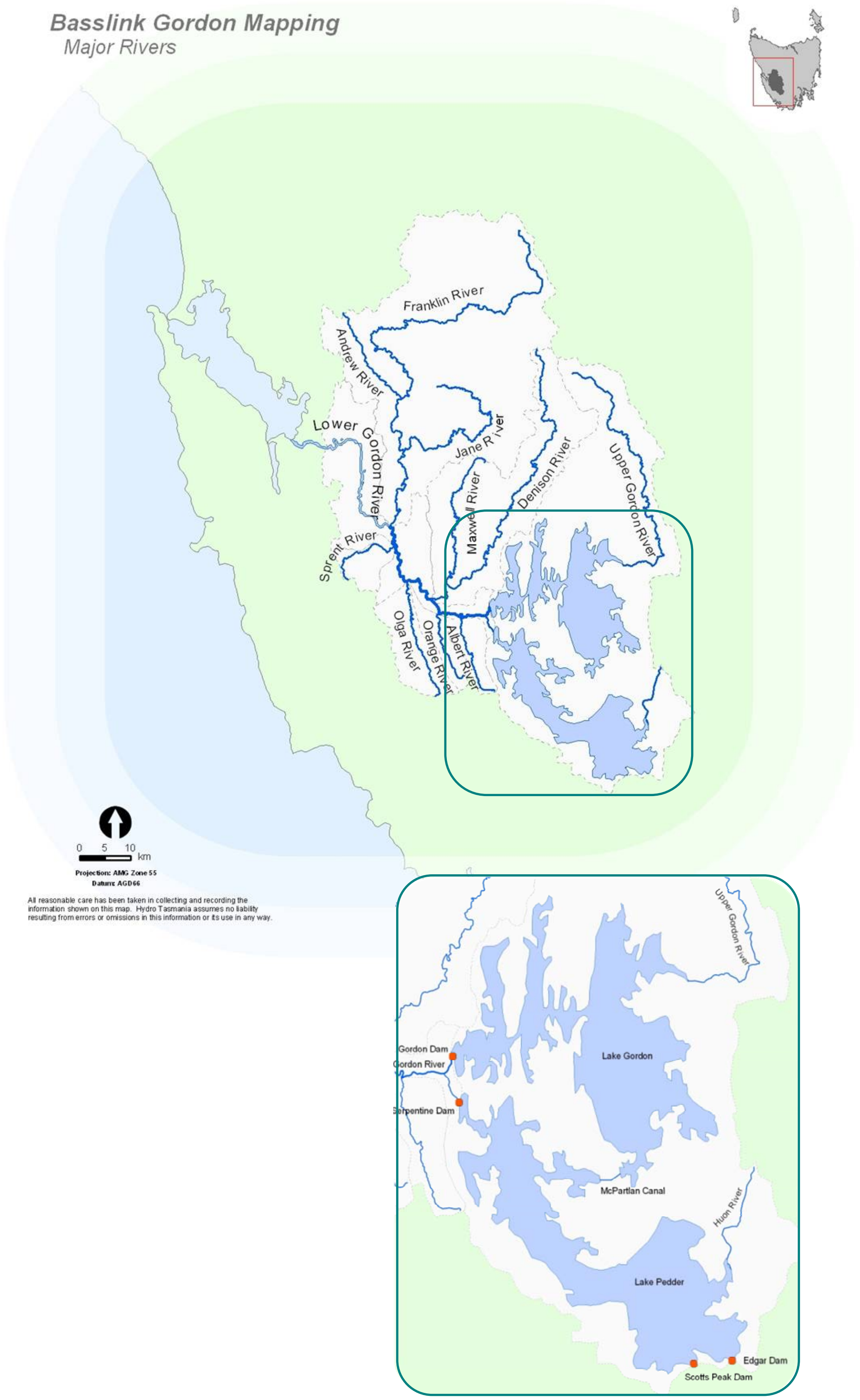
The Gordon Hydro-Electric Power Development was approved by the Tasmanian State Parliament in 1967 and dam construction was completed in 1974. As shown in Map 2.3, the scheme consists of two impoundments, Lake Pedder and Lake Gordon, and the Gordon Power Station. The creation of Lake Pedder involved the construction of three dams, captured the headwaters of the Serpentine River (which enters the Gordon downstream of the power station) and diverted the headwaters of the Huon River, augmenting flow down the Gordon River by about 15%. Lake Gordon was created through the construction of the Gordon Dam, which is adjacent to the underground Gordon Power Station. The volume of the lake is approximately four times the volume of present mean annual discharge, and five times the volume of the pre-dam annual discharge.

Lakes Gordon and Pedder effectively operate as a single storage for the Gordon Power Scheme, with water transfers via McPartlan Canal (Map 2.3). Lake Gordon has a surface area at full supply level of 278 km$^2$, a reservoir volume of 12,450 Mm$^3$, and an operating range of almost 52 m. Lake Pedder has a surface area of 241 km$^2$, a reservoir volume of 2,960 Mm$^3$, and an operating range of 1.53 m. The full supply level (FSL) and normal minimum operating level (NMOL) for Lake Pedder are set by legislation to protect aesthetic values.

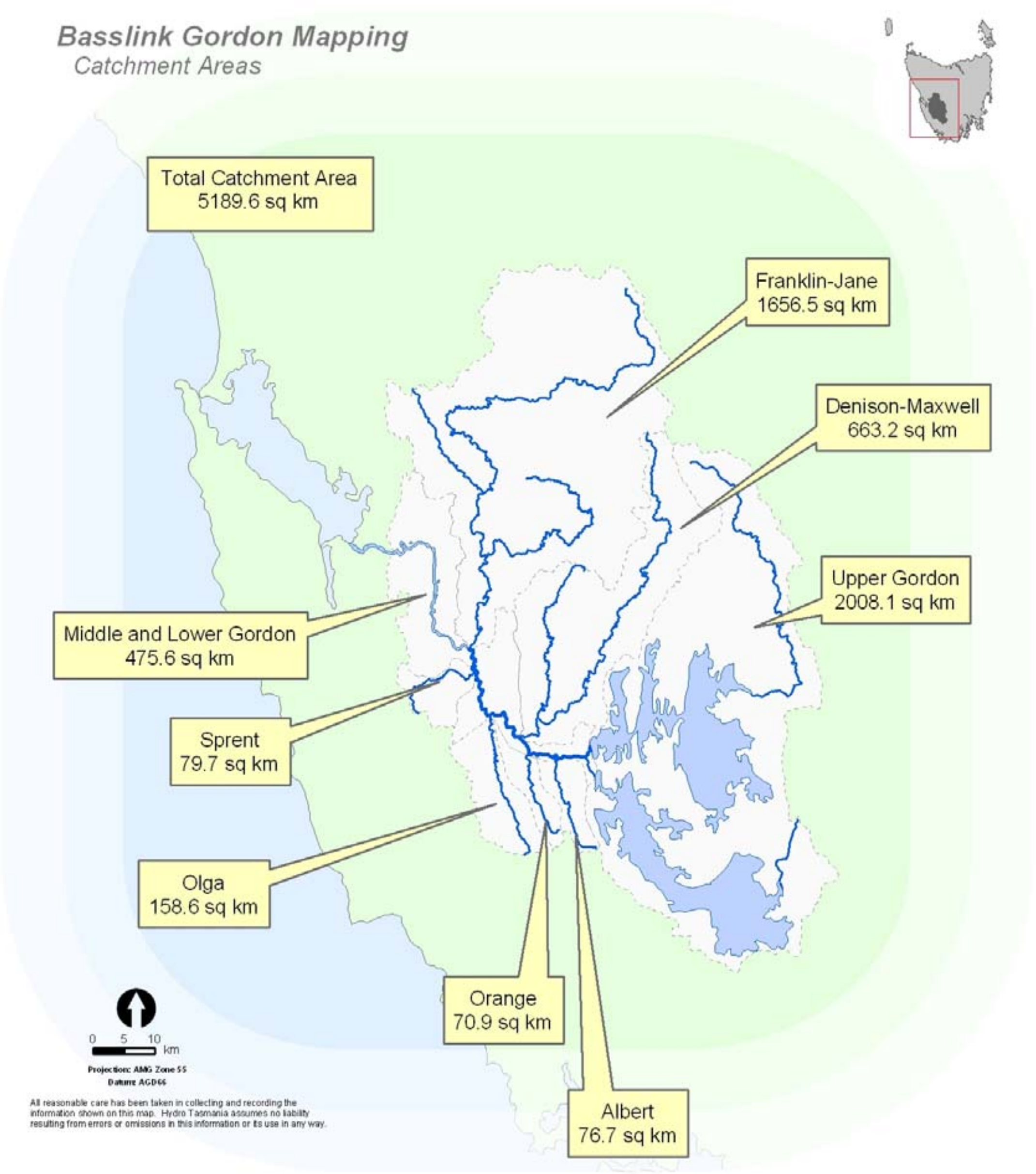
The underground Gordon Power Station receives water from Lake Gordon through an 80 m intake tower. Water leaving the power station discharges along a 1.6 km tailrace to the Gordon River, immediately upstream of the Serpentine confluence.

The creation of the power scheme divided the catchment at the Gordon Dam. The upper Gordon River comprises Lake Gordon, Lake Pedder and their catchment areas.

The remaining Gordon catchment downstream of the dam has an area of around 3,000 km$^2$. It includes a number of unregulated tributaries including the Denison-Maxwell, Olga, Sprent and Franklin. Downstream of the dam the catchment is sub-divided into the middle Gordon River (upstream of the Franklin confluence) and the lower Gordon River (downstream of the Franklin confluence). The middle Gordon River covers about 39 stream kilometres with flows substantially controlled by the operation of the Gordon Power Station. The lower Gordon River is an estuarine reach extending 38 km to the mouth at Macquarie Harbour. The lower Gordon is subject to tidal variation and natural inflows from the Franklin River, which diminish the influence of the regulated flows. These regions, including the major tributaries entering the middle Gordon River are shown in Map 2.4.



Map 2.3. The Gordon catchment showing major rivers, with an inset showing the dams and impoundments of the Gordon Power Scheme.



Map 2.4. Map of the present Gordon River catchment showing major tributaries and catchment areas.

### 2.2.2 Operation of the Gordon Power Station

The Gordon Power Station commenced operation in November 1977 with one turbine, resulting in discharges of up to ~90 $m^3 s^{-1}$. In 1979 a second turbine was commissioned, which increased discharge from the power station to a maximum of ~180 $m^3 s^{-1}$. In 1988 a third turbine was installed, increasing generating capacity to ~430 MW, with associated maximum water releases of up to 260 $m^3 s^{-1}$.

Lake Gordon has an operational range of over 50 m and, to date, the lake has never reached its full supply level.

Discharge from the power station is determined by the number of turbines operated, how the turbines are operated, the water level in Lake Gordon, and the capacity of transmission lines to conduct electricity from the station. The turbines are typically operated at either 'efficient load' or 'full-gate' capacity. 'Efficient load' is the discharge which provides the maximum energy production per unit volume of water passing through the turbine. 'Full-gate' is the discharge which produces the maximum amount of energy from the turbine, and results in a comparatively greater water discharge than 'Efficient load'. Table 2.1 summarises the range of flow releases from the power station for 1-, 2- and 3-turbine operation. The table shows a 6 $m^3 s^{-1}$ release associated with 'No load'. The power station operates in this mode to assist with frequency control for the state's power generation system. A full shut-down of the power station, for maintenance or monitoring, results in no water being released.

Table 2.1. Summary of power station discharge range under 1-, 2- and 3-turbine operation. Discharge ranges were deteremined by minimum flow at minimum lake level and maximum flow at full supply level in Lake Gordon.

| **Power Station Operation** | **Power Station Discharge Range ($m^3 s^{-1}$)** | | |
|---|---|---|---|
| | **Total achievable range** | **Efficient Load** | **Full-gate** |
| 1 turbine | 18-90 | 59-70 | 78-90 |
| 2 turbines | 76-184 | 122-142 | 158-184 |
| 3 turbines | 148-262 | 188-214 | 234-262 |
| No load | 6 | | |
| Shut-down | 0 | | |

### 2.2.3 Relationship between power station operation and rainfall

Operation of the Gordon Power Scheme is directly dependant on the availability of water in other catchments in the Hydro Tasmania generation network. Because the Gordon has a large storage with a low risk of spill, wind power and other hydro stations with smaller storage capacities are used in preference to the Gordon whenever possible. This generally occurs during the winter months when the smaller 'run of river' schemes are receiving winter rains. During these periods the Gordon Power Station is used less frequently and typically at only 1- or 2-turbine capacity.

During dry (usually summer) periods, when the run of river storages are low, the Gordon Power Station is used extensively to provide base-load electricity for the State. Electricity demands during these periods frequently require continuous 3-turbine operation for days to weeks at a time.

This role of the Gordon Power Station within the Tasmanian power grid leads to a strong seasonality in operations, with discharge from the station typically having a pattern inverse to rainfall, i.e. high discharge during low rainfall periods and low discharge during high rainfall periods. On a catchment scale, this translates to reduced power station discharge during periods of high tributary inputs, and high discharge during dry summer periods, when tributary inputs are reduced. Examples of summer and winter flow patterns are presented and discussed in section 2.3.1.

### 2.2.4 Power station operation through time

Since 1979, the proportion of time the power station has been off, or operated under 1-, 2- or 3-turbines has varied. Table 2.2 summarizes power station usage based on daily power generation records between 1978 and 1999, and hourly flow data where available (1996-99). The use of daily records is likely to under-estimate power station usage, as indicated from comparing the 1989-99 and August 1996 -99 records (although the difference in time periods must be recognised). Similar information for the pre-Basslink period is presented in chapter 5 (Pre-Basslink hydrology 2001-05).

Table 2.2. Summary of 1-, 2 and 3-turbine at the Gordon Power Station since 1978.

| Years | Period (see section 2.3) | Percentage of time turbines operating | | | | Basis for analysis |
|---|---|---|---|---|---|---|
| | | Off | 1-turbine | 2-turbine | 3-turbine | |
| 1978-88 | Historical (2-turbine) | 8% | 35% | 57% | | Daily power records |
| 1989 -99 | Historical (3-turbine) | 23% | 34% | 35% | 7% | Daily power records |
| Aug 1996-99 | Historical (3-turbine) | 13% | 16% | 41% | 30% | Hourly flow data |

## 2.3 Description of post-dam flow regime

The hydrology of the middle Gordon River was initially altered in 1974 when the river was dammed to create Lake Gordon. Between closing of the dam in 1974 and initiation of power generation in 1977, flow was greatly reduced in the middle Gordon as no water was released during the filling of the lake.

The damming of the Gordon River resulted in alterations to the magnitude, duration, frequency, timing of flows and rates of water level rise and fall, all of which contribute to important ecological processes. The impact of the dam on these flow parameters has changed through time, due to changes at the power station.

In this chapter, the regulated ‘Historical’ time period of 1979-99 is considered, while the period relating specifically to pre-Basslink monitoring, 2001-05, is considered in chapter 5. The ‘Historical’ period is further divided into 1- and 2-turbine power station capacity (1979-88) and 3-turbine capacity (1989-99). The following sections compare the pre-dam flow regime with ‘Historical’ flow data for a range of flow parameters (flow magnitude and seasonality, duration, frequency, timing of flows, and rates of water level rise and fall). In some of the analyses, 'Historical' has been divided into 2- and 3-turbine operating periods, but for most parameters there were insufficient data to make this distinction (see for example figures 2.5 to 2.7). The results in this section have been derived from a range of hydrologic monitoring sites downstream of the power station, as shown in Map 2.2.

### 2.3.1 Flow magnitude and seasonality

Annual average flows for the three power station operating periods (1-, 2- and 3-turbine) and for natural flow are shown in Figure 2.4 for the Gordon at the power station, and the Gordon above Franklin site. The plots show that since operation of the power scheme, the average annual flow of water in the middle Gordon River has increased due to the diversion of ~15 m$^3$ s$^{-1}$ of water from the Huon catchment into the Gordon River via Lake Pedder. Differences in the average annual flow since 1978 are attributable to the amount of time the power station operated, and reflect changes in the net storage of water in Lake Gordon (lake storage increases during periods of low power station usage and decreases during periods of high power station usage).

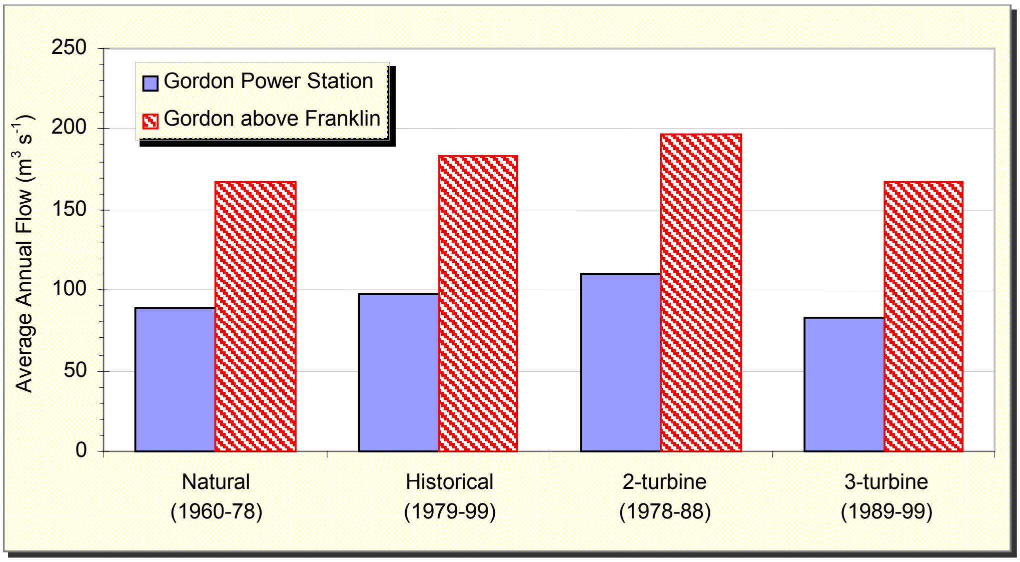


Figure 2.4. Average annual flow at the Gordon Power Station (site 77) and at the Gordon River upstream of the Franklin River(site 44). Natural = 1960-78; 2-turbine = 1978-88; 3-turbine = 1989-99; Historical = 1979-99. Note: the natural flow includes the inflow of the Serpentine River which occurs immediately downstream of the power station tailrace.

Median monthly flows for the pre-dam 'Natural' period and the regulated 'Historical' period for the same two sites are shown in Figure 2.5. The data show a change to the seasonality of flow in the river since damming, with much higher summer flows and reduced late winter discharges. At the power station tailrace (site 77), historical summer median flows exceed pre-dam winter medians by up to 20 m$^3$ s$^{-1}$. At the downstream site (site 44), the seasonality has changed, but the range of median flows has remained approximately the same.

Minimum and maximum monthly flows for the same sites and time periods are shown in Figure 2.6. These again show the reversed seasonality of flow and increase in summer releases from the power station. These seasonal trends are quantified in Table 2.3.

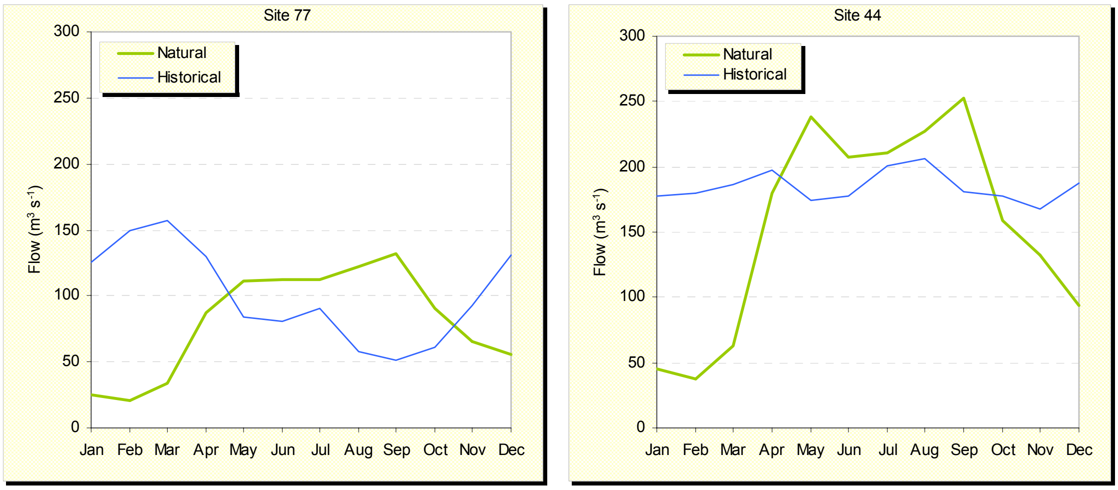


Figure 2.5. Median monthly flows at the Gordon at Serpentine (power station tailrace, site 77) (left) and Gordon above Franklin River (site 44) (right). Natural = 1960-78; Historical = 1979-99. Natural results are simulated, and calculated from available data at different sites.

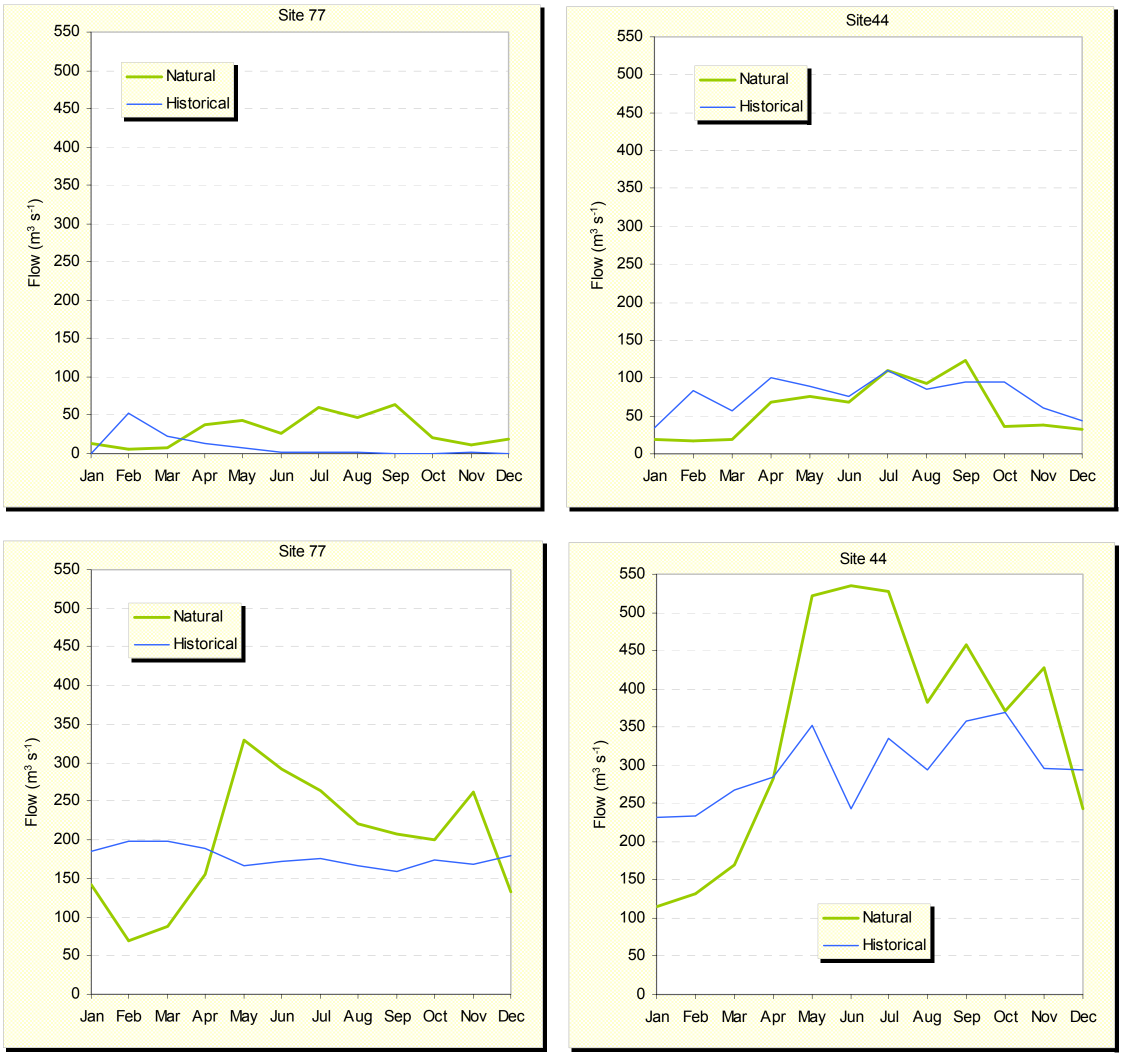


Figure 2.6. Minimum monthly flows for the Gordon at Serpentine (power station tailrace) (top left), and Gordon above Franklin (top right). Maximum monthly flows for the Gordon at Serpentine (bottom left) and Gordon above Franklin (bottom right). Natural = 1960-78; Historical = 1979-99.

Table 2.3. Flow at the Gordon Power Station (site 77) and Gordon above Franklin (site 44) by season, for Natural (1960-78) and Historical (1979-99) time periods.

| | **% of annual flow** | | | |
|---|---|---|---|---|
| | **Spring** | **Summer** | **Autumn** | **Winter** |
| **Gordon Power Station** | | | | |
| Natural (simulated) | 28% | 12% | 24% | 36% |
| Historical | 16% | 34% | 32% | 17% |
| **Gordon above Franklin** | | | | |
| Natural (simulated) | 28% | 10% | 26% | 36% |
| Historical | 24% | 24% | 26% | 26% |

Flow regulation in the Gordon has led to a change in the relative contribution of tributaries on a seasonal basis. With distance from the power station, the tributaries of the middle Gordon River (Map 2.4) increasingly augment the river's flow. Under pre-dam conditions, the contribution of flow from tributaries relative to the total Gordon flow was uniform throughout the year, with the Albert and Orange contributing ~5 % each of the total flow, and the Denison contributing ~40 %. Since damming, the relative contribution from tributaries varies throughout the year due to the decoupling of flow regimes in the Gordon River and its tributaries.

The tributaries contribute relatively little flow during the dry summers when the power station discharges are high, and the majority of the flow downstream of the Denison during the winter months when power station discharges are reduced. In summary, power station discharges dominate upstream of the Denison River year round but, downstream of the Denison, natural inflows dominate winter flows, with the power station discharge dominating summer flows.

### 2.3.2 Flow duration

Flow duration curves based on average daily flow for the middle Gordon River are presented in Figure 2.7 for the Gordon River at the power station (site 77) and upstream of the Franklin River (site 44) for the Natural and Historical time periods. The curves show the regulation of the Gordon has resulted in a reduction in very high flows (>300 $m^3 s^{-1}$) and an increase in the duration of flows between ~20 and ~200 $m^3 s^{-1}$.

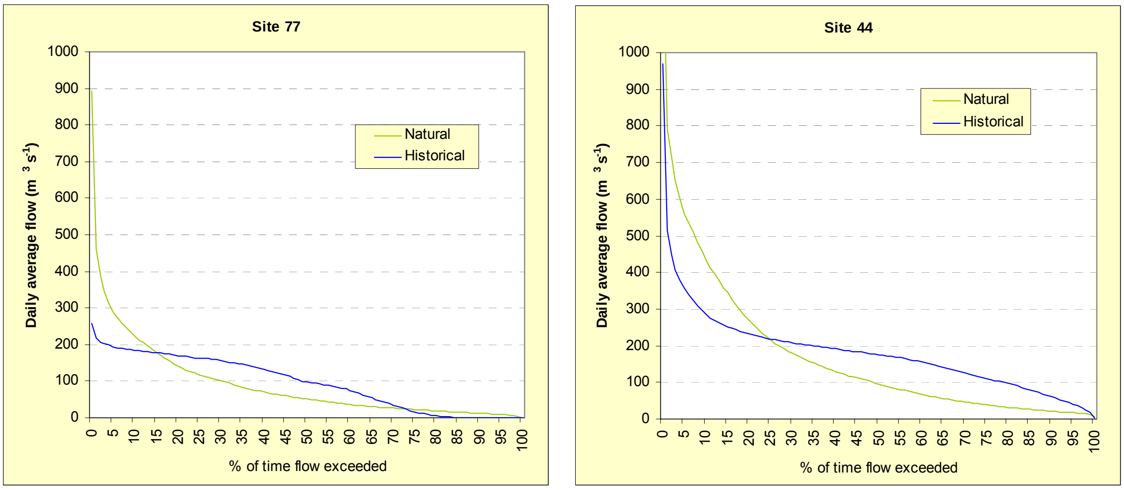


Figure 2.7. Daily average flow duration curves for the Gordon Power Station (site 77) (left) and Gordon above Franklin (site 44) (right). Natural = 1960-78; Historical = 1979-99.

### 2.3.3 Event frequency

Discharge from the Gordon Power Station occurs as discrete events bracketed by power station shut-downs. The frequency of events determines the number of times within a year that water levels rise and fall in the river due to power station operation. To accurately quantify events, hourly flow data were used, which are only available from 1996. Table 2.4 summarises the number of power station shut-down events, and the number of events when maximum flow from the station was <100 $m^3 s^{-1}$ (approx. 1-turbine), between 100 and 200 $m^3 s^{-1}$ (approx. 2-turbine operation), and >200 $m^3 s^{-1}$ (approx. 3-turbine operation).

Table 2.4. Summary of flow frequency at the Gordon Power Station for various events. Note shorter time period for 'Historical' due to lack of hourly flow data prior to 1996.

| **Flow events** | **Average annual number of events Historical (1996-99)** |
|---|---|
| Power station shut-downs (no flow) | 99 |
| Max discharge <100 $m^3 s^{-1}$ | 50 |
| Max discharge >100 $m^3 s^{-1}$ and <200 $m^3 s^{-1}$ | 152 |
| Max discharge >200 $m^3 s^{-1}$ | 112 |

### 2.3.4 River water level change and rates of rise and fall

The magnitude and rate of river water level change associated with flow in the middle Gordon River varies as the slope and width of the river changes, and the antecedent flow conditions. The magnitude and rate of events is similar for all post-damming time periods as the rate of starting or shutting down the power station has not altered through time. Figure 2.8 shows the response of river water level at five sites in the middle Gordon in response to intermittent 2-turbine and 3-turbine power station operation during the summer of 2004.

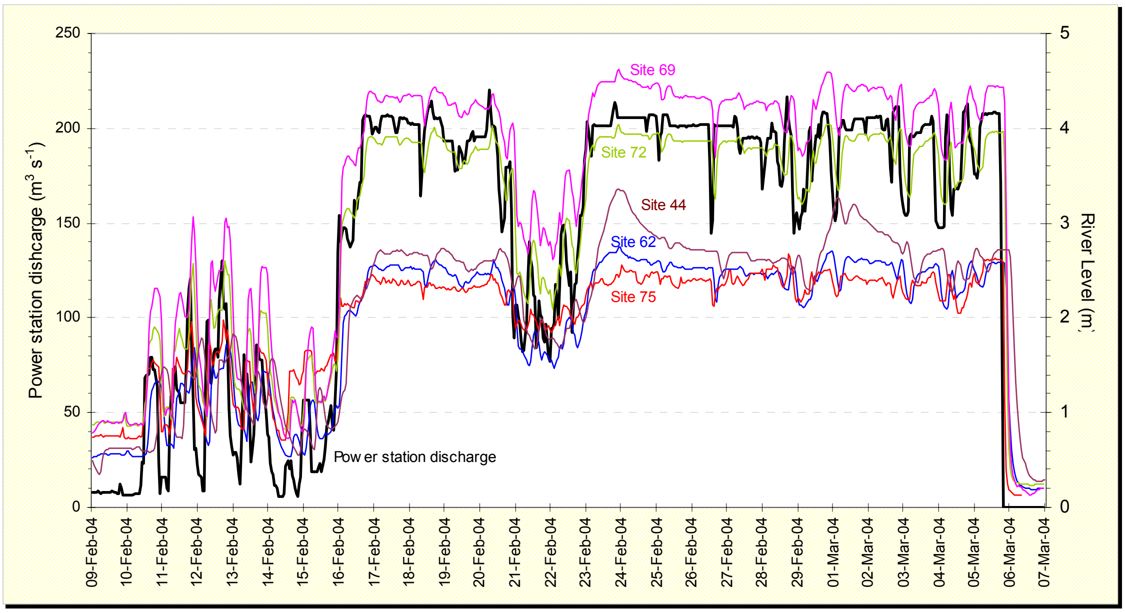


Figure 2.8. River level change at various points in the middle Gordon River compared to power station discharge. Power station discharge scale shown on left axis ($m^3 s^{-1}$), with river level changes (m) on right axis. River level changes are all relative to 'power station-off' low water levels, and are not linked to a common datum.

Between the power station and Abel Gorge (just upstream of the Albert confluence at site 72), the river is narrow with a steep bed profile through the reach, resulting in high velocities and water level changes of ~2.5 m in response to 3-turbine power station operation, as shown by water level at site 75 (see Figure 2.8). Downstream of Abel Gorge the slope of the river decreases causing slower velocities, and river level changes of ~4 m are associated with 3-turbine power station discharge. Further downstream at site 69, which is subject to backwater effects from the Splits, water level variations increase to 4.5 m.

Downstream of the Denison confluence, the river widens and water level variation associated with 3-turbine releases reduces to about 2.5 m (site 62). At the Gordon above Franklin site (site 44) the range in river level variations are similar (<3 m), with the effect of tributary inflows evident on 24 February and 1-2 March 2004 (Figure 2.8). During the summer months these tributary inputs increase the variability of flows downstream of the Denison confluence, although the majority of flow is derived from the power station.

Figure 2.9 shows an enlarged section of 1- and 2-turbine power station operation from Figure 2.8. The first event in the plot clearly shows the lag time between power station operation and water level rise at each of the sites, with the sites upstream of the Splits all responding similarly, and the sites downstream (Gordon above Denison, site 62, and Gordon above Franklin, site 44) showing longer lags and smaller water level changes.

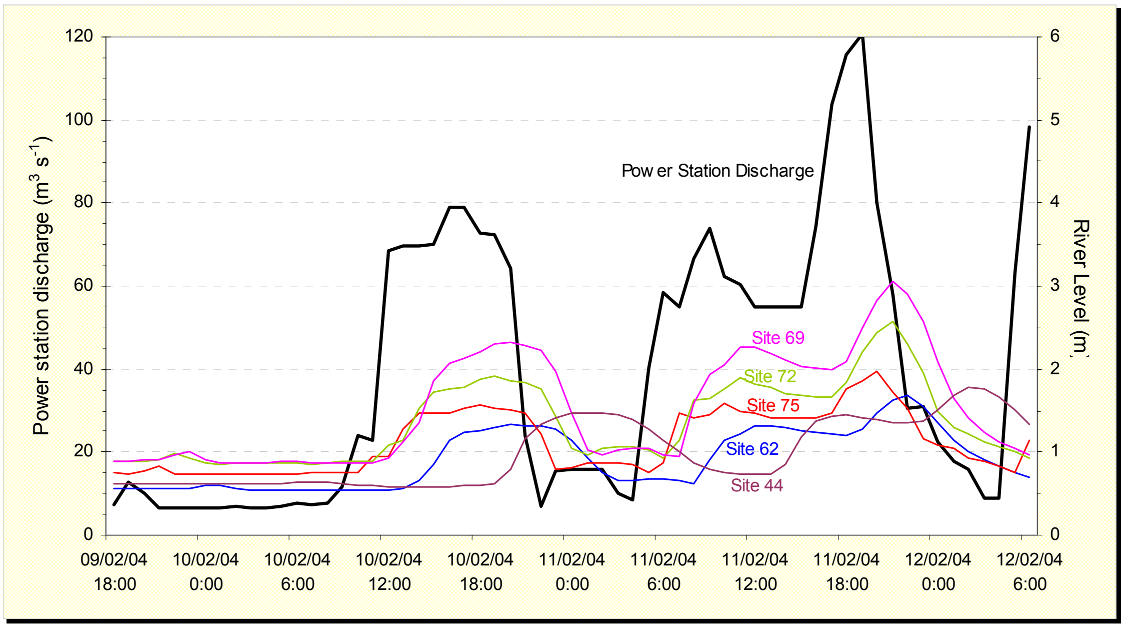


Figure 2.9. Enlarged section of Figure 2.8 showing the lag time between power station operation and river level change in the middle Gordon.

A summary of typical lag times, time to rise and fall, and water level changes for sites in the middle Gordon River is given in Table 2.5. The table indicates that the lag time, and time taken to rise or fall, increases with distance from the Gordon Power Station. These times were obtained during power station shut-down and start-up between 3-7 March 2000 and are representative of periods when the power station discharge provides the majority of flow in the middle Gordon River.

Table 2.5. Summary of lag times along the Gordon River.

| **Sites**<br>**(see Map 2.2)** | **Gordon Power Station shut-down** | | **Gordon Power Station start-up** | | **Water level change (m)** |
|---|---|---|---|---|---|
| | Lag time in start of drop (hours) | Time taken to drop (hours) | Lag time in start of rise (hours) | Time to rise (hours) | |
| 75 | 0.25 | 3.00 | 0.25 | 0.75 | 2.23 |
| 72 | 1.00 | 5.00 | 1.25 | 1.50 | 3.54 |
| 69 | 1.25 | 7.00 | 1.50 | 2.00 | 4.12 |
| Gordon above Denison (site 65) | 1.75 | 9.00 | 2.25 | 2.75 | 2.74 |
| Gordon below Denison (site 62) | 2.00 | 10.50 | 3.00 | 3.50 | 2.83 |
| Gordon above Franklin (site 44) | 3.50 | 15.00 | 7.00 | 7.00 | 2.63 |
| Gordon below Franklin (site 39) | 4.00 | 24.75 | 8.00 | 7.50 | 1.67 |

Water level rise and fall in the middle Gordon River have been estimated based on 15-minute level records at several sites in the middle Gordon River during power station operations in the summer of 2000. Rates have been found to vary by a factor of two, based on previous power station operations and tributary inputs. Table 2.6 contains a summary of maximum rates measured in the middle Gordon, including pre-dam rates established by Palmer *et al.* (2001) for the Gordon below Denison (site 62).

Table 2.6. Summary of maximum rates of water level change in the middle Gordon River. Pre-dam rates from Palmer *et al.* (2001) and determined using Gordon above Olga historical flow records. Rates are based on maximum change over a 15-minute period, normalised to metres per hour.

| **Condition** | **Period** | **site 75 (m h$^{-1}$)** | **site 72 (m h$^{-1}$)** | **site 65 Gordon above Denison (m h$^{-1}$)** | **site 62 Gordon below Denison (m h$^{-1}$)** | **site 44 Gordon above Franklin (m h$^{-1}$)** |
|---|---|---|---|---|---|---|
| Drawdown from efficient load | Current | 2.64 | 1.44 | 0.80 | 0.80 | 0.40 |
| Drawdown from efficient load | Pre-dam | | | | 0.013 | |
| Flow rise to efficient load | Current | 4.56 | 5.48 | 5.48 | 3.12 | 2.88 |
| Flow rise to efficient load | Pre-dam | | | | 0.15 | |

### 2.3.5 Summary post-dam flow regime

- Construction of the power scheme has resulted in an increase in the average annual flow in the Gordon River by ~15 $m^3 s^{-1}$ due to the diversion of water from the Huon River into the Gordon River via Lake Pedder;
- The seasonality of flow in the middle Gordon River has been altered due the power station being used predominantly during dry periods of low rainfall (summer), when tributary inputs are low;
- Compared to pre-dam conditions, the duration of high flows (>300 $m^3 s^{-1}$) in the middle Gordon River has decreased, while the duration of 20-200 $m^3 s^{-1}$ flows has increased;
- The magnitude of flow in the middle Gordon River upstream of the Denison River is dictated by releases from the power station, with water levels typically occurring in discrete steps associated with 1-, 2- or 3-turbine power station usage;
- The operation of the power station results in rapid changes in water level compared to pre-dam conditions, with lag times increasing with distance from the power station, and the rate of water level change and magnitude of water level change decreasing with distance from the power station; and
- In spite of the large flows controlled by the Gordon Power Station, downstream of the Denison confluence tributary inflows provide a large proportion of total flow during the winter months, when such inflows are high and power station discharges are limited.

## 2.4 Impact of damming on the middle Gordon River

### 2.4.1 Historical monitoring in the middle Gordon River

The development of the Gordon Power Scheme did not include environmental investigations documenting the pre-dam condition of the catchment, nor impacts associated with damming. However, scientific investigations in the regions (Lower Gordon River Scientific Survey) were completed in 1974-78 associated with the proposed Gordon below Franklin Power Scheme, which was never constructed (note: at the time, the entire area downstream of the Gordon Power Station was referred to as the Lower Gordon River). These investigations focused on potential environmental impacts associated with the placement of a second dam in the Gordon River, downstream of the Franklin confluence. The investigative field seasons (1975-76, 1976-77, and 1977-78) coincided with the closure of the Gordon Dam and filling of Lake Gordon, so little flow was present in the river upstream of the Denison confluence during the studies.

Although the objectives of these investigations did not include an assessment of the impact of damming on the middle Gordon River, some investigations and observations made by the researchers provide insights into the initial impacts of the dam and flow regulation. The relevant findings include:

- Dam construction and lake filling led to increased sedimentation in the middle Gordon (distribution not described);
- During dam construction there was an increase in algal growth and loss of mosses from banks upstream of the Denison confluence compared to unregulated rivers;
- Flow regulation led to water quality changes as the relative proportions of ground water derived flow and catchment runoff was altered by power station operation; and
- The salt wedge from Macquarie Harbour, which had extended up to 38 km upstream in the Gordon River under natural flow conditions, was pushed down the river during power station operation.

The only scientific discipline which completed specific investigations into the impact of damming the river was in-stream macroinvertebrates. The benthic macroinvertebrate fauna of the middle Gordon River was first sampled by Coleman (1978) in 1977, during the period after dam construction but prior to discharge of water from the power station i.e. under very low flows. Quantitative sampling (with surber samplers) was conducted by Coleman (1978) at 15 sites in the middle Gordon and eight in the greater Gordon-Franklin catchment, with several surber sample units taken per site. This sampling was repeated in the summer of 1978, three months after the commencement of flow releases with 1-turbine operating at the power station. The results showed that the initial damming led to a large decrease in the abundance of mayflies, caddis flies, isopod crustaceans, beetles, snails and flies for the first 5 km downstream of the dam (upstream of the Albert confluence), with a similar but smaller reduction continuing downstream to the Denison confluence. The second set of monitoring results differed from the post-dam, pre-power station operation sample, but there was no general trend which could be attributed to the effects of the regulated flow. The investigator suggested there had been insufficient time under the regulated flow regime to allow the establishment of a new macroinvertebrate population, and the impacts of damming continued to mask any flow effect (Coleman, 1978). In spring 1995 and autumn 1996 the sites sampled by Coleman were re-visited by Davies *et al.* (1999), with 'rapid bio-assessment' (RBA) kick net sampling of benthic macroinvertebrates. These sites were subsequently incorporated into the initial IIAS Basslink investigations and the Basslink Monitoring Program. A comparison of the (1999) present results with historical (1997) results was presented in the IIAS (Davies and Cook 2001).

### 2.4.2 IIAS Basslink investigations

Because of the lack of environmental monitoring in the Gordon River between damming in the 1970's and the Basslink proposal in 2000, the IIAS needed to establish the impact of damming on the river, as well as assess potential changes to the river due to the implementation of Basslink. The findings of these investigations are available in the IIAS report series and, combined with the results of the pre-Basslink monitoring program, have been used to formulate the pre-Basslink baseline, as described in the 'Present' section of the Conceptual model (chapter 3), and the individual research discipline chapters (chapters 6-11).

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# 3 Conceptual model

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

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

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

In the 'Present' section (section 3.2), the present characteristics of the catchment are described, and linkages are made between components of the flow regime and these characteristics. This section contains considerable detail, as it forms the pre-Basslink understanding of the river, and serves as the model against which post-Basslink monitoring results will be interpreted. Although flow changes related to damming, combined with the influence of the dam itself, are linked to, and largely responsible for, the present condition of the river, it should be noted that the 'baseline' for post-Basslink monitoring is the present condition of the river. That is, although changes from the natural flow regime are useful for interpreting and understanding the present characteristics of the middle Gordon, it is the present condition of the river which constitutes the baseline against which Basslink changes will be measured.

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

- the impact of regulated water temperatures or a reduction in the availability of organic matter on aquatic organisms;
- changes in flow or temperature on migration cues; and
- the effect of bank desiccation on bank stability and vegetation viability.

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

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

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

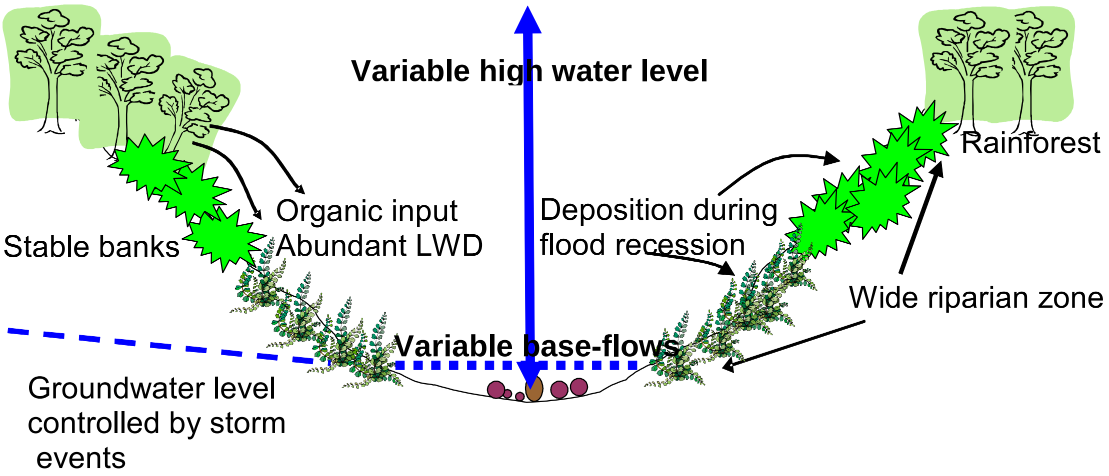
The emphasis of this report is on the documentation of a pre-Basslink baseline and so a conceptual model for post-Basslink conditions is not presented. Post-Basslink predictions were made for each discipline and presented in the IIAS (Locher 2001) and its appendices.

## 3.1 Pre-dam conceptual model

As discussed in 'Regional setting' (section 2.1.1), the Gordon River catchment is underlain by Precambrian basement rocks, and Palaeozoic rocks including Ordovician limestones and sandstones, and Devonian-Silurian limestone-siltstone-shale sequences. The east-west trending reach of the river, postulated to be derived from a pre-Tertiary land surface, has cut narrow gorges through the Precambrian ranges, which have exerted a strong control on the evolution of the river. The catchment was shaped by glaciation during the Quaternary resulting in rugged ranges and extensive sand and gravel deposits in valleys (Robers and Naqvi, 1978, J. Bradbury, pers.com.).

Periglacial processes on mountain slopes gave rise to talus deposits. Tributaries have formed broad valleys in less resistant strata, and in the north-south trending Olga-Gordon-Franklin valley, the carbonate substrate has been modified by dissolution processes to produce cave and karst systems (Roberts and Naqvi, 1978).

Prior to damming, the Gordon catchment was largely undisturbed except for some small scale forestry activity in the catchment and along the banks (Huon pining), and minor mining operations. The characteristics of the Gordon River were similar to the present large dynamic unregulated tributaries in the region, with stable channels primarily due to the presences of abundant riparian vegetation, low physical weathering rates in the catchment, and organic-acid rich, low ionic strength waters. Pre-dam flow in the Gordon and its tributaries was controlled by rainfall patterns in the catchment and groundwater inputs. Large rainfall events occurred throughout the year, but were more common in winter months. As depicted in Figure 3.1, water levels in the river were highly variable, with low (<0.2 m h$^{-1}$) rates of water level change. Water temperature varied seasonally from ~5 to ~20 °C, with a ~1-3°C diurnal variation.



**Characteristics**

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

Figure 3.1 Generalised conceptual model of pre-dam Gordon River showing cross-section of river.

River banks had low rates of change due to the high proportion of bedrock control and presence of a wide, dense riparian vegetation zone which extended from low summer baseflow level to high flood level (Photo 3.1). Episodic disturbance resulted in localized erosion of banks and bars, with replenishment occurring through the deposition of sediment and organic matter during the recession stage of storm events. Rainforest occupied the valley above the flood disturbance zone. Within the riparian zone there was a high level of diversity, with vegetation distributions determined by flood disturbance patterns.

Photo 3.1. Photo of river bank in the Franklin River during low river flow.

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

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

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

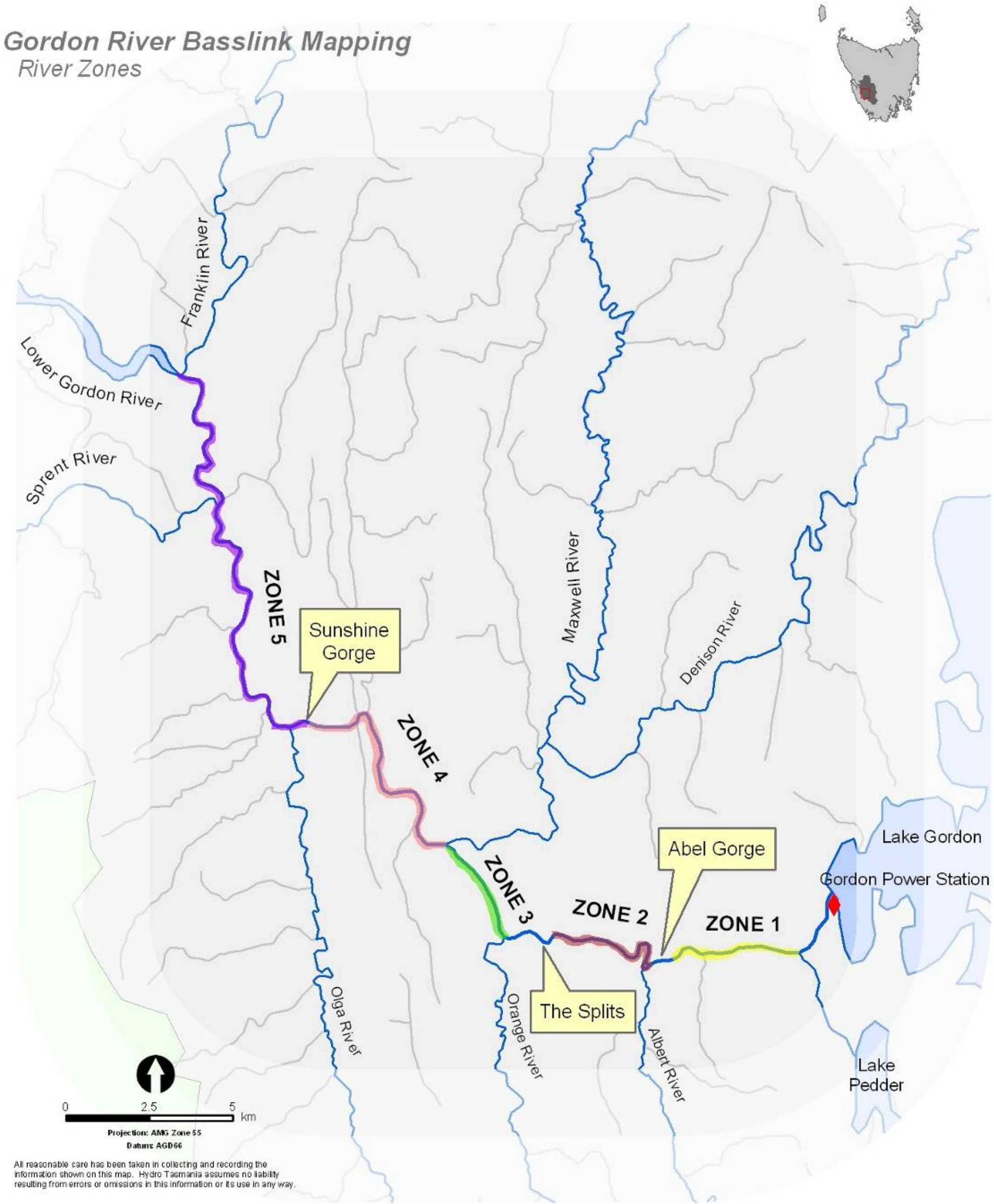
Native fish were naturally highly diverse and abundant in the reaches upstream of the tidal limit, with recruitment from whitebait migrations varying annually, depending on coastal and oceanic conditions. Native fish decreased in abundance and diversity with distance upstream due to life-history factors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

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

## 3.2 Present characteristics of the middle Gordon River

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

The middle Gordon River has been divided into five geomorphic zones, separated by major hydraulic features (Map 3.1). The key characteristics of the five zones are discussed in this section, with subsequent sections discussing the important processes operating in each zone, and identifying linkages between ecosystem components.



Map 3.1. The middle Gordon River, showing the location of the five geomorphic zones.

The banks in the middle Gordon River can be broadly classified as bedrock, cobbles and sandy alluvium, or a combination of bedrock overlain by cobbles or sandy alluvium, or cobbles overlain by sandy alluvium. Representative photos of these bank types are shown in Photo 3.2 - Photo 3.4, with the distribution of the banks presented in Figure 3.2. Additional background information about the composition and distribution of bank types as determined during the IIAS is contained in Koehnken *et al.* (2001).

Photo 3.2. Example of alluvial bank from zone 2.

Photo 3.3. Example of cobble bank in zone 1.

Photo 3.4. Example of bedrock bank in zone 1.

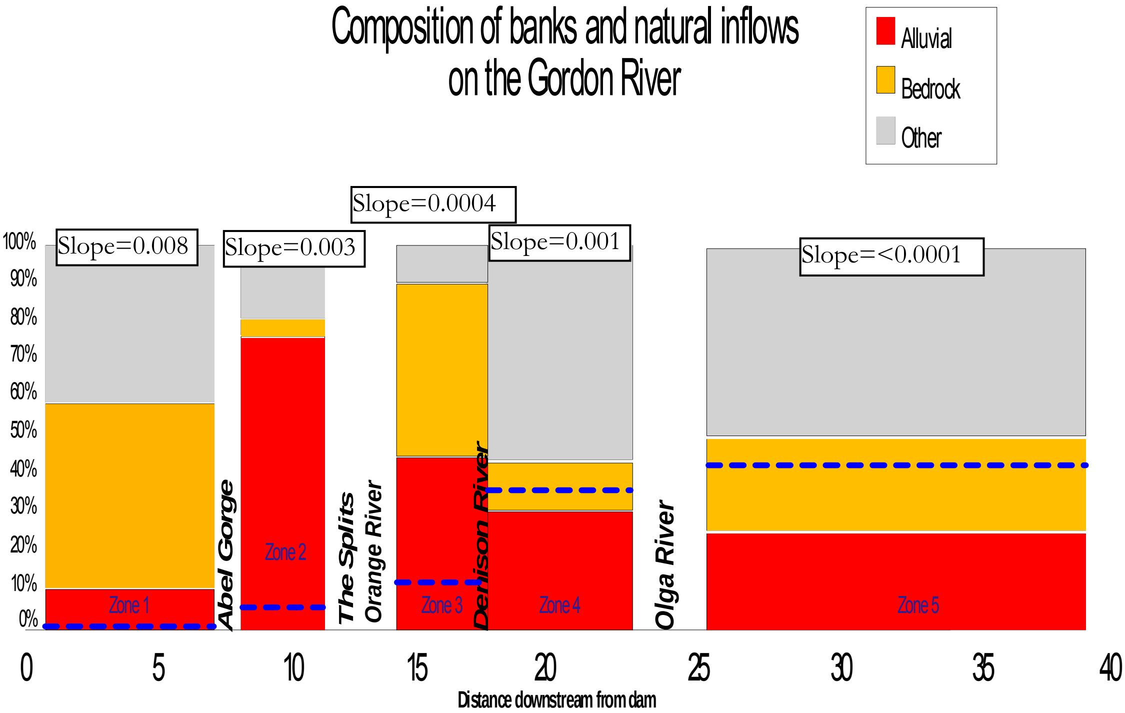


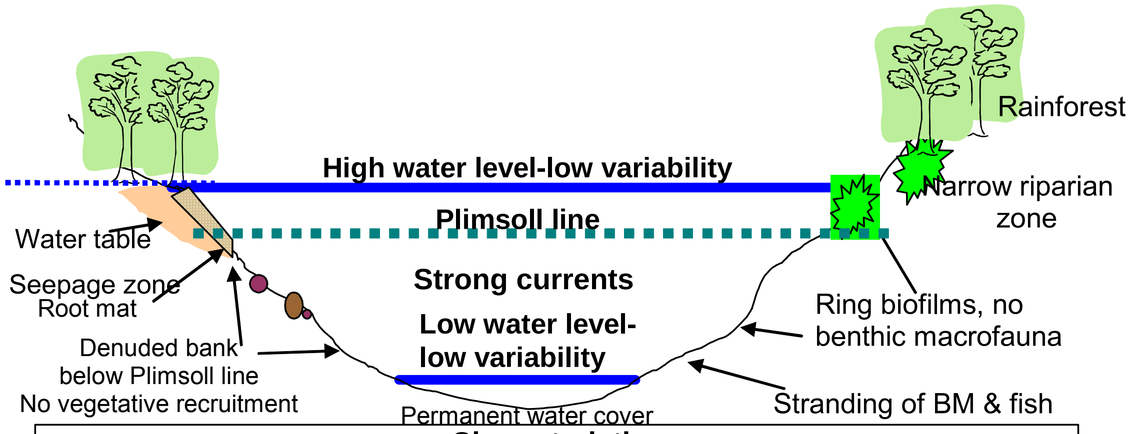
Figure 3.2. Summary of the composition of banks in the middle Gordon River and the level of natural inflows in each geomorphic zone. 'Other' banks include consolidated vertical cobble banks and combinations of bedrock overlain by cobbles or alluvium, or cobbles overlain by alluvium. The percentage of natural inflow entering the zone on an annual basis is shown by the blue dashed line. The average channel slope of the zone is displayed in the boxes at the top of the diagram.

### 3.2.1 Zones 1 and 2: Gordon Power Station to the Splits

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

The river is narrow (~40-70 m wide) in these zones, with a steep channel slope dropping 40 m in zone 1 (slope = 0.008), and 10 m in zone 2 (slope = 0.003). The only significant tributary stream is the Albert River (Map 3.1) which provides about 5 % of the total flow in zone 2. Characteristics of these zones are shown schematically in Figure 3.3.

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



**Characteristics**

- * Fixed high & low flows
- * Reversed seasonality & Temp of flows
- * Organic input removed by currents
- * Armoured bed / Poor habitat
- * Restricted fish migration
- * Poor and patchy benthic macro communities
- * Elevated water table
- * Inundation of tree roots
- * LWD stabilizes banks
- * Few fish
- * No recruitment below Plimsoll
- * >3m $hr^{-1}$ of water level change
- * Low deposition of sed/org matter
- * Decoupling of flows between Gordon & tribs
- * Scour of bank toes
- * No seasonal flow / Temp cues
- * Seepage erosion in 2-3 turbine level
- * Spring algae dense on bed, summer algal bathtub ring

Figure 3.3. Characteristics of zones 1-3 of the middle Gordon River (downstream of the power station and upstream of the Denison confluence). LWD=large woody debris, BM = benthic macroinvertebrates.

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

The 3-turbine operating level (1-1.5 m below high water level) is characterised by a decrease in vegetation cover. There is low species richness in the riparian zone compared to those of tributaries in the catchment, with tea tree the most widespread riparian species. The extent of vegetation on the banks is sharply defined by a 'Plimsoll line', which generally falls between the level of 2-turbine and 3-turbine power station operation. Between the Plimsoll line and the power station-controlled high water level, de-vegetated alluvial banks are prone to collapse following rapid bank de-watering. Photo 3.5 shows examples of the vertical zonation produced by the regulated flows.

Photo 3.5. (Left) bedrock controlled reach downstream of power station showing the ‘Plimsoll line’ and encroachment of vegetation down to the Plimsoll line. (Right) Alluvial reach upstream of the Splits showing the distinct ‘Plimsoll line’. (L. Koehnken photos)

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

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

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

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

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

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

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

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

### 3.2.2 Zone 3: the Splits to the Denison River:

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

The characteristics of zone 3 are similar to those of the upstream zones (Figure 3.3), however the range of power station-induced water level fluctuations in zone 3 is lower (~2.5 m) compared to zone 2. The 'Plimsoll line' on the banks is lower, seepage erosion is less common and less active, and there is a slightly greater diversity and abundance of benthic macroinvertebrates in the permanently wetted portion of the channel compared to zones 1 and 2.

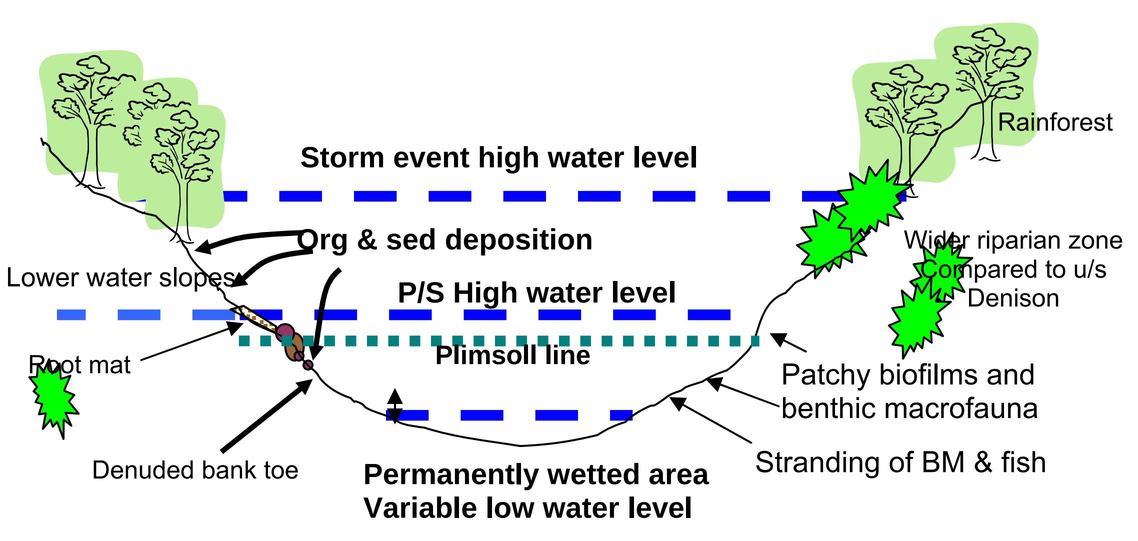
The diversity of fish species increases downstream of the Splits, although abundance remains low. Eels (*Anguilla australis)*, brown trout (*Salmo trutta)*, and lamprey (*Geotria australis)* are present in zone 3. In the tributaries, these species have been found along with spotted galaxias (*Galaxias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

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

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

### 3.2.3 Zones 4 and 5: the Denison River to the Franklin River

Zones 4 and 5 extend 23 km from the Denison confluence to the Franklin confluence. Bedrock control of the channel is extensive in these zones, as the river cuts through the Ordovician limestone of the Olga and Franklin valleys. The Denison is a large tributary, contributing ~30 % of the flow to the downstream river on an annual basis. Because much of the flow enters during the winter months when power station operation is generally reduced, the Denison provides a large unregulated flow and sediment input to the lower river. There is a notable step-change in the appearance and riverine processes occurring in the Gordon River downstream of this confluence. Characteristics of these zones are shown in Figure 3.4.



**Characteristics-Compared to Upstream Denison**

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

Figure 3.4. Characteristics of the middle Gordon River downstream of the Denison River.

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

Riparian vegetation in these zones extends further up the bank, and has greater species richness compared to zones 1 and 2. The Plimsoll line is lower and less distinct compared to upstream of the Denison confluence (see Photo 3.6), and there is a greater occurrence of muds and organic material deposited on the banks, especially above power station-controlled water levels. The biological zonation of the banks is similar to upstream, although it is condensed into a smaller vertical distance due to the lower water level fluctuations associated with power station operation.

Photo 3.6. Zone 5 alluvial bank showing less defined Plimsoll line and greater occurrence of vegetation compared to zones upstream of the Denison confluence.

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

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

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

## 3.3 Model drivers and linkages

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

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

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

### 3.3.1 Alteration of sediment and water flow at a catchment scale

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

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

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

### 3.3.2 Restricted range of the regulated discharge regime

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

The elimination of very high flow events has led to an increase in vegetation cover in many areas of the river no longer periodically disturbed by high energy floods. This includes the crests of cobble bars and banks situated above levels affected by power station discharges. The narrow gorge immediately downstream of the power station (zone 1) is a good example of where vegetation in general, and the occurrence of rainforest species in particular, has expanded since damming (Photo 3.5 (left), Photo 3.7).

Photo 3.7. Increase in vegetation above power station-controlled operating level in zone 1. Vegetation above the Plimsoll line has grown since the power station began operating.

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

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

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

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

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

### 3.3.3 Prolonged high flow events

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

Where banks consist of bedrock-cobbles-boulders, this process has led to the exposure of the underlying rock substrate and the establishment of a distinct Plimsoll line below which there is no vegetation (Photo 3.1). The impact of vegetation removal on sandy alluvial banks has resulted in an increased susceptibility of the underlying bank to both scour and seepage erosion processes. The impact of vegetation removal on bank stability in the Gordon River cannot be overstated, as vegetation is a primary bank stabilising mechanism.

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

#### *3.3.3.1 Impact of vegetation removal on banks*

In the absence of riparian vegetation, buttressing of the bank toe or bank face by large woody debris (LWD), cobbles or boulders has become the main bank stabilising process in the middle

Gordon. LWD is common throughout both the regulated Gordon River and unregulated tributaries and its role in bank accretion is discussed in the next section.

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

The impact of vegetation removal on the banks is greatest upstream of the Denison confluence, where power station-controlled water levels are highest (up to 4.5 m), catchment inflows are low, and there is a high prevalence of sandy alluvial banks. The rapid reduction in river levels accompanying power station shut-down results in high in-bank water surface slopes. Because the banks are not stabilised by vegetation, water draining from the sandy banks may have sufficient energy to entrain and transport sand. This results in seepage erosion, leading to the creation of cavities at the site of sediment entrainment, and deposition of sediment flows downslope of the cavity. Photo 3.8 illustrates this process. The progressive enlargement of bank cavities further increases bank instability, and eventually the overlying vegetation and bank collapse. Through this process, riparian vegetation not directly lost to inundation or waterlogging continues to be lost, which further destabilises the upper bank.

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

Photo 3.8. Active seepage erosion (water and sediment exiting bank) following power station shut-down (left) leads to sediment flows (right) on alluvial banks in zone 2.

#### *3.3.3.2 Impact of vegetation removal on aquatic habitats*

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

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

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

### 3.3.4 Decoupling of flow and sediment delivery

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

In addition to a decrease in sediment delivery to the middle Gordon River, the decoupling of flow and sediment delivery from the tributaries has also decreased the deposition of organic matter and sediment on the banks and bed of the river. Because a power station shut-down rarely coincides with the falling limb of natural storm events in the catchment, the middle Gordon has largely become a sediment throughput zone for tributary derived fine-grained material (Photo 3.9).

Photo 3.9. Comparison of alluvial banks immediately following power station shut-down (left) with no mud or organic matter on bank toe, and following an extended shut-down (right) when muds have accumulated due to unregulated flow events originating in tributary streams.

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

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

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

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

The decoupling of flow and sediment supply in the Gordon River compared to the tributaries also affects the lower reaches of tributaries, especially upstream of the Denison confluence. During periods of low natural flow and high power station discharge, water from the Gordon River inundates the mouths of tributaries up to the power station-controlled high water level. This has led to seepage erosion occurring in the lower reaches of creeks and tributaries, causing channel widening. Additionally, tributary floods combined with power station shut-downs create large water surface slopes with great erosive energy. The mouth of the Albert River is a prime example of this, widening by up to 30 m near the confluence with the Gordon since the establishment of the power scheme. Widening in alluvial reaches near the mouth of the Orange River and small creeks in zone 2 has been estimated at 10-20 m based on aerial photo analysis. Photo 3.10 shows the conditions at the mouth of the Albert River.

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

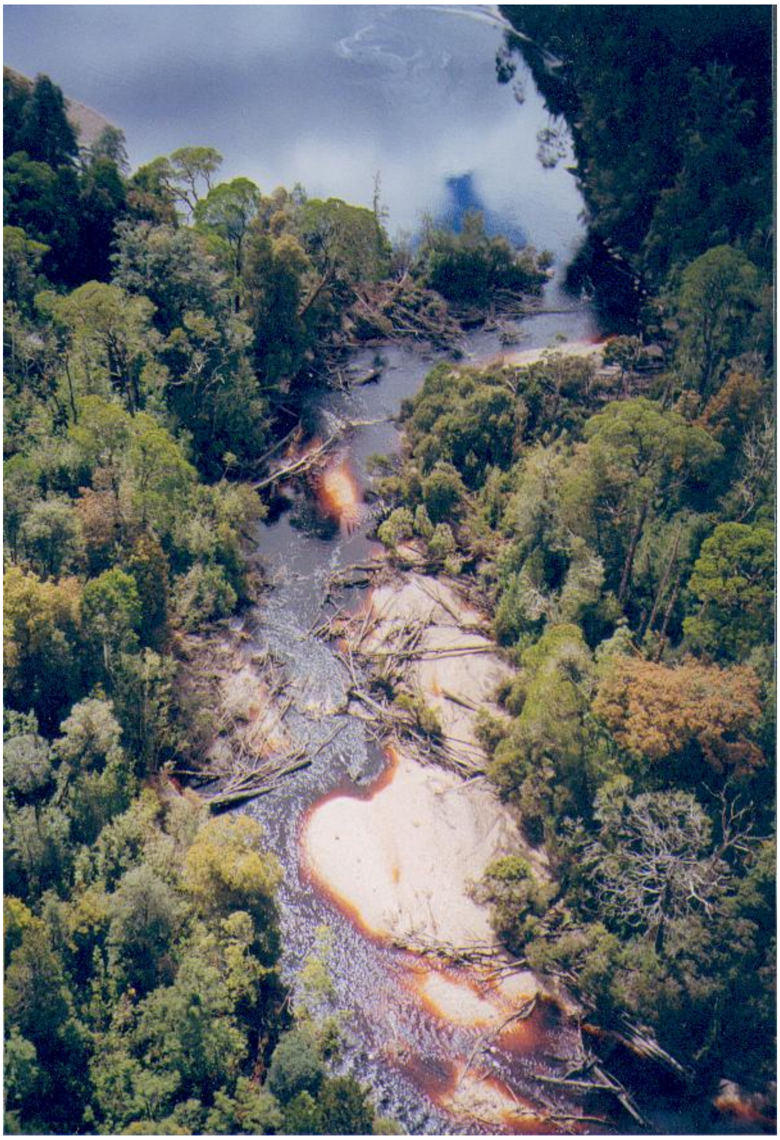


Photo 3.10. Aerial view of mouth of Albert River showing channel widening. The confluence of the Albert and Gordon Rivers is towards top of the photo. Tree fall is associated with seepage erosion and scour.

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

### 3.3.5 High rates of water level and velocity change

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

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

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

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

### 3.3.6 Reversed seasonality of flows, regulated water temperatures, variable oxygen levels

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

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

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

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

### 3.3.7 Limitations of the model

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

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

## 3.4 Longitudinal trends

As discussed in section 3.2.3, the input of the Denison River results in a large step change with respect to the degree of regulation of the flow and sediment inputs, and the magnitude of FPOM and CPOM loads. Downstream of this confluence, during periods of high catchment input, there is a large increase in flow variability and sediment input to the river, and a relative decrease in the role the regulated flow plays in ecological processes in the middle Gordon River. How flow, sediment input and important biological indicators vary with distance downstream of the power station is shown schematically in Figure 3.5. In each diagram, relative changes with distance from the power station are shown, along with an indication of the relative range of each parameter in unregulated reference streams. For all parameters, there is a shift towards the reference condition with increased distance downstream.

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

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

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

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

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

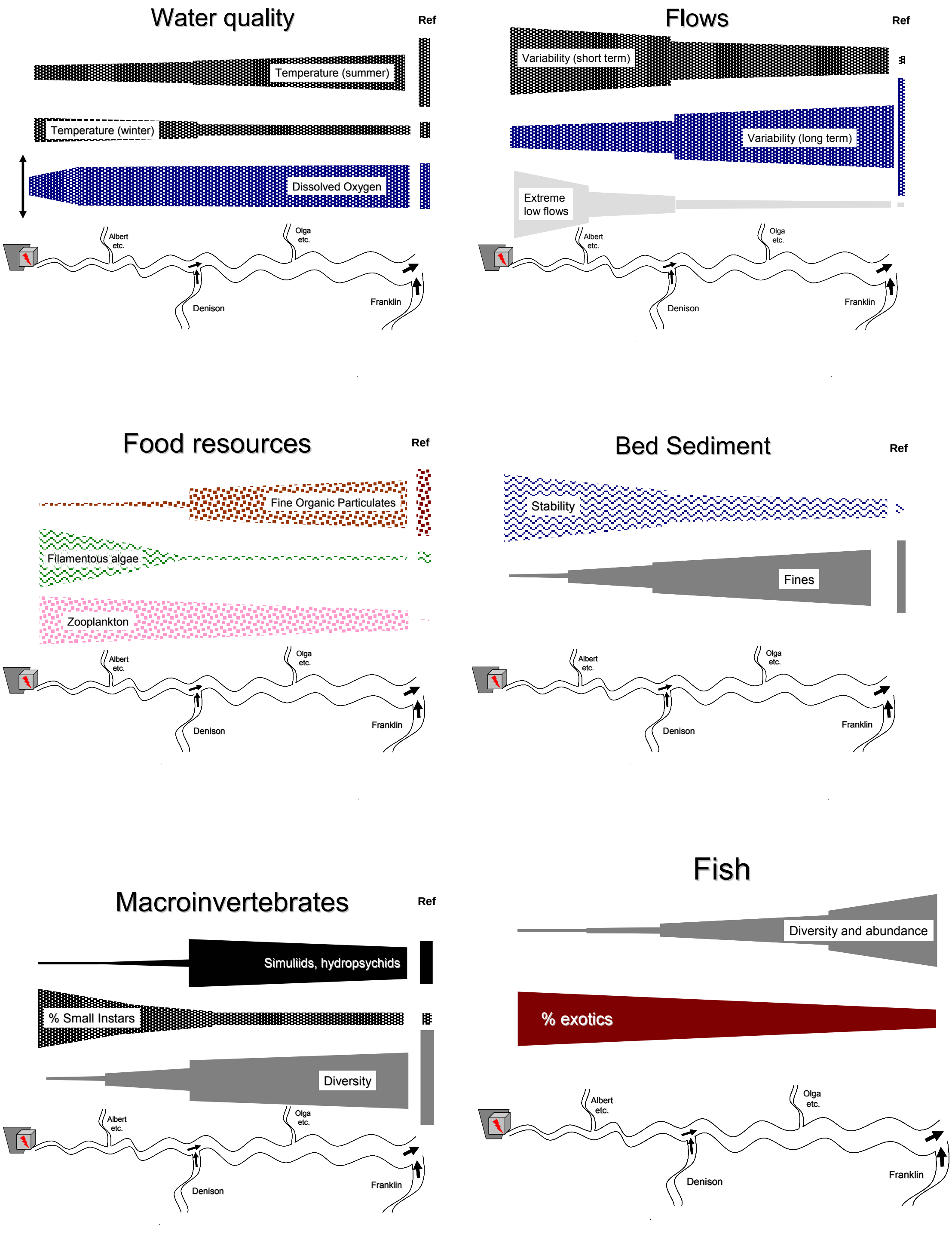


Figure 3.5. Schematic diagrams showing changes in important environmental characteristics and ecological components in relation to distance from the dam and power station. Note arrow indicates variable dissolved oxygen conditions in power station discharge. Variation in fish diversity is naturally dicated by distance from the sea and is also affected by the presence of barriers, especially at Sunshine Gorge and the Splits.

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

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

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

## 3.5 Stability of present characteristics of the middle Gordon River

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

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

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

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

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

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

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# 4 Design and inference

Previous chapters have described the conditions presently operating in the middle Gordon River and the conceptual model underlying the monitoring work undertaken by the BMP. This chapter examines, in detail, the sampling design pertinent to the BMP and the factors which influenced it. It also discusses the limitations and assumptions of the statistical analyses performed on the pre-Basslink dataset, and describes the methods for assessing the capability of detecting post-Basslink changes.

## 4.1 Topics covered in this chapter

- **Sampling design:** The general features of the sampling design employed in the monitoring process by the various disciplines are described, and this description is accompanied by discussion of the particular problems and issues that have arisen;
- **Modelling:** There is consideration of the potential for, and the manner in which, statistical modelling may be employed as a basis for an objective assessment of change in physical and biological processes over time in the Gordon River, and for studying interrelations between the broad collection of variables on which data are collected from sites in the Gordon River and tributaries in the monitoring process plus hydrological variables and other supplementary variables. Practical issues and limitations are explained;
- **Identifying differences and trends in pre-Basslink data:** There is a discussion of the choice of statistical methods that might be employed to analyse pre-Basslink variation with the aim of distinguishing real spatial differences and temporal trends from the high level of sampling variability in the data. The methods selected for use are described; and
- **Evaluating effectiveness of monitoring to detect post-Basslink changes:** Basic statistical tools are introduced and discussed for objectively evaluating the effectiveness of the monitoring process as a precursor to the definition of the “limits of acceptable change” and the determination of the capability of the monitoring process to establish that change has occurred.

Additional discipline-specific material and discussion on some of the above topics is provided in individual discipline chapters (chapters 6-11).

## 4.2 Sampling design

The development of the design for the Gordon River Basslink Monitoring Program (BMP) is based on the investigations carried out for the IIAS (Basslink Integrated Impact Assessment Statement)

(Locher 2001). The requirements of the BMP are specified in Hydro Tasmania's Water Licence, held under the *Water Management Act* 1999 and are listed in appendix 1.

To appreciate the choice of design and the capability of the chosen design to detect and measure any Basslink effect it is necessary to understand the limitations that apply to monitoring the Gordon River.

### 4.2.1 'Test', 'control' and 'reference' rivers

Interest lies in the changes, if any, in characteristics of the middle Gordon River post-Basslink. For this reason it is termed the '**test**' river.

The ideal design for assessing the effect of an intervention in a test river utilises sampling points in that river which are monitored before and after intervention plus corresponding monitoring at sampling points in a neighbouring river that is subject to similar conditions but without application of the intervention. The neighbouring river is termed a '**control**' because it provides information on temporal changes that are not associated with the intervention. This has two advantages. The danger of confusing an intervention effect with another source of temporal change is prevented, and, by matching data from the 'intervention' and 'control' river sites, the effects of natural changes over time are eliminated thereby increasing the capability of the statistical analysis to detect change that is associated with the intervention.

The use of 'control' rivers is not possible with respect to monitoring the middle Gordon River because there are no comparable regulated rivers in the region that will not also be subject to Basslink-related changes. Of particular relevance are: (i) the complete flow regulation achieved by the Gordon Dam; and (ii) the reversed seasonality of power station discharge.

There are also practical limitations:

- Pairing of sites or collections of sites between those on the Gordon and those on tributaries is generally not possible. The Gordon is divided into zones that show different characteristics and the zonal conditions which are not replicated in the tributaries; and
- The time limitations on gaining access to the Gordon River and its tributaries for monitoring purposes have required a careful consideration of the allocation of resources among sites. The need to adequately sample five zones in the Gordon River, which may also be subject to substantial intra-zonal variation, has meant that the number of tributary sites that could be sampled is limited.

In respect of specific disciplines:

- *Geomorphology*: Erosional effects in the Gordon River are dominated by the discharges from the Gordon dam, whereas the erosional effects in tributaries are dominated by rainfall and flooding events. Localised inter-site variation makes comparisons among comparable sites in the Gordon River and tributaries difficult to establish, zonal differences in the Gordon are not replicated in the tributaries, and vertical bank profiles are formed into sections based on the number of turbines discharging water into the river in a manner which is not found in the tributaries. For all of these reasons the use of erosion pin data in tributaries is not seen as useful;
- *Vegetation*: The vegetation on the tributaries is in a natural state, with a wide riparian ecotone present from areas of high flood events to the low water level. This section includes many disturbance-tolerating or disturbance-requiring species adapted to the flow regimes and seasonal variation. Conversely, the vegetation of the middle Gordon River is highly stratified in terms of species abundance and generally lacks a true riparian ecotone. Further, the natural flow regimes in the tributaries mean the vegetation persistence and recruitment patterns are driven by natural flow processes such as seasonal flood events, longitudinal transport of propagules along the rivers, natural bank disturbances and sediment inflows. Whereas on the middle Gordon River, seedling recruitment and species persistence is largely influenced by individual species tolerance to prolonged inundation and geomorphic processes which differ markedly themselves and reversed seasonality of flows. There is also no direct correspondence of tributary sites with the Gordon River sites largely because of logistical constraints. Due to difficulties accessing all areas by boat (without substantial portages, accessible under most flow conditions, etc.), all sites had to be accessible by helicopter. Therefore all sites on both the Denison and Franklin Rivers are located adjacent to cobble bars;
- *Macroinvertebrates*: In addition to the general points made above, there are significant local, site-scale influences on all sites (Gordon and tributaries) which preclude defensible specific pairings of sites between the Gordon River and tributaries; and
- *Fish*: The fact that seasonality of flows is essentially inversed in the Gordon relative to tributaries means that fish behaviours such as migration, spawning and recruitment are potentially affected. Hydraulic control features in the Gordon River, such as the First and Second Splits, affect the upstream migration of diadromous fish species, which is reflected in longitudinal trends in native fish abundance and species diversity. The reference rivers do not have equivalent hydraulic control features, and longitudinal changes in abundance and diversity are not as clearly defined, and so migration success in the reference rivers is not necessarily reflected in the Gordon River. The Sorell and Pocacker reference sites have

a near absence of trout, and quantitative trigger levels derived from their data would be of little value in indicating a potential post-Basslink effect.

While unregulated tributaries to the Gordon River cannot act as controls, they have value as indicators of significant non-Basslink environmental change or change in species abundance or diversity that could prevent erroneous conclusions of a Basslink-related effect. Rivers used in this context are termed '**reference**' rivers in this report.

Examples of non-Basslink changes in macroinvertebrate abundance or composition are wildfires, very low and very high flow events, major catchment/sub catchment-wide insect recruitment due to favourable climatic conditions, and new/enhanced exotic species invasions. In respect of vegetation, regional-scale processes such as drought or unusual seasonal or climatic conditions may influence seedling recruitment and species persistence.

When there is evidence of events or factors that cause broad regional change that would be expected to affect the Gordon River, it is anticipated that models can be developed which incorporate pre- to post-Basslink changes in some tributary variables and to alter the indicators of change ("trigger values") that are presented in chapter 13 (Indicator variables) to take account of such effects. This is generally seen as a task for post-Basslink analysis because:

- there is no prior indication of what the future events or factors might be;
- the limited number of monitoring times in the pre-Basslink period and the high level of variability in data have limited the opportunity to construct multivariate models; and
- the practical time constraints between final data collection and time for the pre-Basslink report submission have restricted the opportunity for the discipline experts and statistician to explore beyond the models and variables that are presented (and those that have been explored and rejected) in this report.

Two special situations where indicator variables use data from reference rivers have been established in respect of taxonomic composition of macroinvertebrates. Similarity measures are derived that compare taxonomic composition at individual Gordon sites with that at reference sites, with a single measure derived by averaging values across all six reference sites. A broader regional comparison in composition is also made by the use of data collected from selected least-disturbed Tasmanian rivers, employed in deriving AUSRIVAS O/E scores. An assumption underlying the use of these variables that incorporate data from reference rivers is that non-Basslink related taxonomic compositional changes in the Gordon River, where the flow characteristics are strongly determined by human controls, will at least partially mirror the changes in unregulated rivers. During the pre-Basslink period this assumption appears to have been satisfied. Whether the assumption will hold in the presence of a major event will be regularly evaluated during the post-Basslink period.

### 4.2.2 The basic sampling structure

For the purpose of monitoring, the middle Gordon River is divided longitudinally into 'zones' where there is an expectation that the impact of the regulated flow could be relatively much larger between zones than within zones. The divisional points between the zones are broadly consistent for geomorphology and vegetation but differ for macroinvertebrate and for fish monitoring. Additionally, there is a likelihood of a continuous gradation down the river at least in respect of macroinvertebrates. Individual discipline chapters present maps displaying the zonal boundaries used and discuss the differences in zonal characteristics. Zones are differentiated by significant geomorphic characteristics, such as major gorges or tributary confluences.

Within each zone sampling 'sites' are selected with the aim of choosing locations that reflect the characteristics of the zone and the variation found in a zone. The selection of sites is subject to logistic and safety considerations that are detailed below. Ideally, the aim is to employ sufficient sites to reflect the different conditions that apply within each region. In practice, the ideal cannot be met: logistic and safety limitations prevent access and monitoring of the number and location of sites required, particularly with respect to geomorphology.

An important constraint in determining the number of sites that can be accessed in one monitoring period is the requirement that there must be a power station shut-down to allow access of monitoring staff to the river. Coupled with the other constraints this has generally limited the number of sites being monitored to a maximum of three in each zone.

What is important is that researchers have selected sites that are most likely to be affected by Basslink operations. If this is the case then the effect of limited access is unlikely to be significant since an assessment of spatial variability is not required to obtain a valid comparison of pre-Basslink levels with post-Basslink levels. In effect, each site acts as its own control since the primary aim of the monitoring is to examine *temporal changes* associated with Basslink. The designs employed ensure that statistical analysis for this purpose makes no use of spatial variation *per se*.

Site selection is also important if there are to be comparisons in changes between different zones in the river. In general terms it is important that the sites selected in the different zones should have similar characteristics if a fair comparison is to be made. Additionally there is scope for classifying sites on the basis of specific characteristics and only comparing sites with common characteristics. However this option is limited by the small number of sampling sites in each zone.

### 4.2.3 Limited timeframe

Data collection for the Basslink Monitoring Program began in mid-2001. This timeframe has provided four years of pre-Basslink monitoring to establish a baseline against which post-Basslink values can be assessed. This is a short timeframe given the absence of a 'control' river. There is a danger that one or more years of the pre-Basslink monitoring period could be non-representative of the behaviour or characteristics of the river under the current operating conditions. If that behaviour is also present in reference rivers and there is sound biological argument that the impact would be similar in regulated and unregulated rivers it may be possible to make allowance for an 'odd' year. Failing that, statistical methods take account of the short sampling period by increasing the measure of uncertainty in findings.

### 4.2.4 Existing and spurious trends and other non-Basslink effects

Extensive 3-turbine operation of the power station has produced hydrological changes, particularly in relation to maximum regulated river height. If the river is still adjusting to these changes then some of the parameters defining pre-Basslink characteristics may not be constant over the period in which baseline data were collected. This is especially likely with respect to erosion where a number of years may be required to achieve a stable bank structure after hydrologic change and with riparian vegetation where there may be a lag between river flow changes and related changes in the vegetation.

There is little likelihood that spurious trends or dislocations could be separated from normal variation based on responses from only four years of pre-Basslink monitoring - a sequence of four independent observations has, *in the absence of a trend*, a one in eight chance of being either an increasing or a decreasing sequence. The pre-Basslink data are employed to obtain a measure of natural variation, yet if the difference between one pair of observations is much greater than the difference between the other two pairs of observations in a sequence of four observations, there is little capability of determining whether the largest difference is a solely natural temporal variation or whether it includes a one-off dislocation.

As increasing years of data are added to the post-Basslink dataset, the potential for detecting such trends increases. Consequently it is important to appreciate that some judgments about the sources of change may have to wait for up to six years of Basslink operation. There may also be the possibility of using information from supplementary variables, e.g. hydrological variables, to provide evidence of the existence of trends or dislocations and for use in adjusting responses to take account of these non-Basslink effects. Where it is appropriate and possible, supplementary variables are introduced into statistical models that describe pre-Basslink and post-Basslink responses.

The situation is made more complex by the fact that observations made in successive years may be related, e.g., an above-average reading on one year may tend to be followed by an above-average reading (or a below-average reading) in the following year. Statisticians refer to this situation as serial correlation. It can produce short-term trends in data that are not separable from systematic upward or downward movement. Statistical methodology is available to accommodate serial correlation. However, in short-term studies, evidence of the presence of serial correlation might just as reasonably be explained by assuming the existence of a trend, implying that projection of pre-Basslink behaviour into future years in the presumed absence of a Basslink effect may lead to different, equally plausible, options.

### 4.2.5 Logistical considerations

#### *4.2.5.1 Safety and access*

For safety and logistical reasons access to monitoring sites is restricted both in a temporal and spatial sense.

In the middle Gordon River, field staff must generally be transported to the monitoring sites by helicopter. The places where the helicopters can land are limited, and are mostly confined to suitable river bars. For some teams, small inflatable boats offer the only feasible means of accessing sites up and down the river from the helicopter landing sites. Other teams rely on short-distance overland movement from the landing sites to reach their monitoring locations.

Helicopter access and field monitoring is only possible when the power station is shut-down. Scheduling a power station outage is, in itself, a major factor given that Gordon is the largest power station in the state and is essential for meeting power demand during dry periods. Power station outages are generally available only on weekends, when power demand is somewhat lower than usual.

There are safety and logistical constraints related to high tributary flows. These limit times that tributary monitoring sites can be accessed.

The combination of timing, duration of outage, helicopter space and availability, coupled with the need for acceptable weather conditions, places severe constraints on the number of sites that can be monitored and the number of persons who can be deployed in a monitoring session. Consequently it is not possible to have the range and number of sites required to ensure every potential type of river condition is monitored.

#### *4.2.5.2 Timing considerations*

Each discipline undertakes two monitoring trips per year, once in autumn and once in either spring or summer depending on the specific discipline. Geomorphology, karst, macroinvertebrate and algal monitoring is conducted in spring whereas riparian vegetation and fish monitoring is carried out in summer.

If there is seasonal variation, statistical modelling and statistical analysis must take account of any differences that may result.

Another dimension to time of sampling is the water flow characteristics in the river prior to monitoring. This is dictated by power station usage patterns prior to the monitoring and, in some zones, natural water inflows from tributaries and runoff. Identical antecedent power station operating patterns cannot be ensured prior to each monitoring event because power station operations are dependent on state-wide rainfall and power demand.

For some variables an environment that is sampled within 48 hours of maximum power station discharge may have different characteristics to an environment that has received no flow from the power station for several weeks. Additionally, the pattern and amount of flow from the tributaries in the period preceding monitoring may have a substantial effect. Statistical models must seek to account for the effects of the difference in pre-monitoring discharge patterns.

### 4.2.6 Discipline-specific issues

#### *4.2.6.1 Matched site selection among disciplines*

Relationships are expected between data collected on variables in different disciplines, e.g. between measures of vegetative change and bank erosion. Taking account of these relationships in the process of analysing the data may assist in explaining the nature of change, if any, under Basslink operating conditions. For disciplines where this is relevant the ideal is to select sites that are subject to similar conditions.

There are practical limitations to achieving this aim. The limited monitoring time period, different monitoring times, and limited number of monitoring sites combine to make the value of attempting to study interrelations among disciplines uncertain.

#### *4.2.6.2 Matched site selection pre-Basslink to post-Basslink*

The pre-Basslink monitoring sites will continue to be monitored post-Basslink to maximize the capability of detecting Basslink-related change by eliminating spatial variability.

The licence requirement for a minimum ‘environmental’ flow to be provided post-Basslink may affect the comparability of pre- vs. post-Basslink monitoring results. For example, in the geomorphic monitoring the bank ‘toe’ (presently monitored by erosion pins) may change because of the effect of the minimum flow. Monitoring can only be safely done under power station shut-down conditions. This means that sampling will be conducted under conditions in which (post-

Basslink) the minimum environmental flow is not being released, making sampling less representative of 'usual' conditions than at present.

## 4.3 Variables and data structure

There is a commonality in the structure of data across most disciplines that is employed for statistical comparison of pre- and post-Basslink values. The structure is illustrated schematically in Figure 4.1.

**Spatial structure:** The river is divided into zones, each containing selected sites. At each site one or more monitoring positions are selected. For vegetation studies and geomorphology studies the monitoring positions may represent bank positions typically on a vertical transect. For macroinvertebrate and fish studies they may represent locations in the river channel. In the vegetation monitoring a further structure is added by the use of two quadrats at each monitoring point in order to improve the reliability of the values obtained.

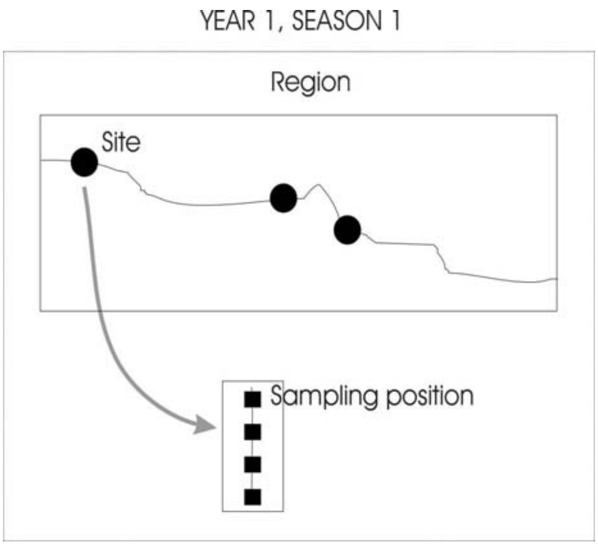

Figure 4.1. The basic sampling layout employed in the monitoring program.

In riparian vegetation and geomorphology studies the monitoring points are distinguished by bank position or other feature. For purposes of analysis, each position provides data for a different variable, e.g., the length of an erosion pin at the top of a bank is providing information for a different quantity than is the length of an erosion pin at the bottom of the bank. In macroinvertebrate and fish studies multiple sampling positions are generally chosen to provide values that can be averaged to give a more reliable estimate of the response at that site.

**Temporal structure:** Repeated responses are intended to be obtained at each sampling point at selected times prior to, and following, the introduction of Basslink. In most cases monitoring takes place in two seasons.

### 4.3.1 Primary variables

**Indicator variables:** The discipline experts have selected a set of variables which they consider reflect important physical and biological characteristics of the middle Gordon River that should be monitored for changes in the post-Basslink period. These response variables are termed 'indicator variables' to reflect the fact that they are indicators of potential change following the introduction of Basslink.

**Explanatory variables:** A second set of variables are monitored because variation in their values is considered to possibly provide explanation for non-Basslink sources of variation in the indicator variables. Such variables are called 'explanatory variables'. Principal among these are hydrological variables.

### 4.3.2 Derived variables

In general terms, averaging or smoothing values reduces the contribution from sampling variation which in turn increases the capability to detect a Basslink-related effect.

**Averaging spatial variation:** Basslink-related effects will be temporal. The primary purpose of collecting observations on a variable from different sites within a zone is generally not to explore spatial variation, rather it is to provide a more reliable estimate of the average level of that variable within the region. Thus, to test for the existence of a Basslink-related effect, responses at different sites might be averaged and tests for evidence of a Basslink-related effect applied to the average values from the zones.

The extent to which averaging within sites, across sites, or across zones is sensible must be considered on a variable-by-variable basis. In the case of many geomorphic variables, averaging is required to prevent the large unexplained site-to-site variation from obscuring systematic trends and changes that are of interest.

**Building variables from profile data:** Erosion and deposition at a point on a river bank can be highly variable over time. Hence the data from individual erosion pins may be too variable to be of value in detection of a Basslink-related effect. There is the possibility of using data from a sequence of erosion pins down a bank to define a characteristic of the bank profile that smooths variation at individual pins and thereby provides a more reliable indicator of change over time.

## 4.4 Modelling

In chapter 3 a conceptual 'model' is introduced that describes, in words, the processes that operate on the middle Gordon River and how this has affected the physical and biological characteristics of the river over time.

In this chapter attention is focused on a different modelling process, namely the manner in which broadly-based statistical tools can be employed to use the differences, trends and other variation evident in data collected during monitoring, coupled with input from discipline-based experts and other studies, to provide a quantitative description of the physical and biological characteristics of the middle Gordon River over the pre-Basslink period and beyond.

The modelling process is approached at two levels:

- For individual disciplines statistical models for indicator variables are developed for the purpose of characterising pre-Basslink behaviour to serve as a baseline for comparison with post-Basslink behaviour and to determine the capability of the variables to detect post-Basslink change that is of a magnitude to require consideration; and
- To provide a broader picture of changes in the physical and biological characteristics of the middle Gordon River over time modelling is required that incorporates information from interrelations among indicator variables and draws on information from many different sources and of varying quality.

The application of the modelling process to individual indicator variables is an essential requirement in the pre-Basslink evaluation. It is this modelling process that provides the basis for constructing objective indicators of change and an objective measure of the capability of the variables to detect change in the post-Basslink period. Necessarily such modelling relies on the formal methods of inferential Statistics. Development of appropriate models is considered below.

The broader modelling process is primarily viewed as a tool that will have application if change is observed in the post-Basslink period, when it will be employed to assist in finding possible explanations for the change and ramifications of the change. In this context it is likely that formal hypothesis testing and estimation procedures will have a limited role. Rather there will be an emphasis on data analytic tools for model fitting and possibly on incorporating results from different sources using techniques like meta-analysis and multiple lines of evidence.

### 4.4.1 Modelling variation in indicator variables in the pre-Basslink period

As described above the basic structure of the pre-Basslink sampling operation leads to data being collected from several sites in each of five river zones for two seasons over four years. Thus variation in the data for a variable can be attributed to the following sources:

| **Spatial effects** | |
|---|---|
| Zone | Differences among zones |
| Sites within zones | Residual spatial variation |
| **Temporal effects** | |
| Season | Difference between two seasons |
| Trend | Systematic change in mean response across time |
| Times within seasons | Residual temporal variation |
| **Space × time interactions** | |
| Zone × season | Differences in seasonal effects among zones |
| Zone × trend | Different trends over time among zones |
| Residual | Remaining unexplained variation |

Additionally, there was limited consideration of longitudinal variation. For macroinvertebrates this arose from the suggestion that 'distance from dam' might extract meaningful information. However within the two zones defined (above and below the Denison River) there was no evidence to support this conjecture. The other possible source of variation that could be explored is in the form of contrasts among the zones. There are many possibilities ranging from the difference between specific pairs of zones to trend contrasts, e.g. linear or quadratic trends. This is part of an ongoing area of investigation that may produce additional indicator variables that reflect the different ways in which Basslink changes impact on different zones of the river.

All indicator variables are scaled variables and, for each variable, it is possible to find a scale on which the responses can be expressed as the sum of components representing the above effects, i.e., a linear additive model can be employed.

The trend effect is accommodated by assuming there are two components - a linear trend component to reflect the possibility that there is a constant rate of change in the average level, and a quadratic trend component to accommodate departure from linearity.

The variation among sites within zones, the residual temporal variation and the residual variation are presumed to be random variation. This is a reasonable assumption in respect of the residual temporal and residual components as it reflects the chance effects of weather and environmental fluctuations from time to time. Ideally the application of the random assumption to site-to-site variation within zones is a consequence of random selection of sites within zones. As noted above there were practical limitations to site selection. However this assumption is not crucial to the primary analysis which relates to the study of temporal variation.

Through a combination of statistical theory, past empirical evidence and the application of model checking to the current data it is established that the assumption of Normality is appropriate for the random components in the model. In some cases a transformation is required to a scale on which both additivity and Normality are acceptable.

**Serial correlation:** The fact that repeated measurements are made at a common site raises the possibility that successive responses may be correlated. The initial model that is proposed allows for this possibility i.e., where possible, repeated-measures models are fitted.

A Bayesian approach was considered, particularly given the sparseness of the fish data. The decision to use a classical approach is based on:

- the familiarity of readers with the standard forms of presentation of limits and power curves;
- the fact that a single basic model can be employed across all disciplines; and
- the ease with which the multi-strata spatial/temporal variation can be accommodated.

### 4.4.2 Model-fitting objectives

The primary objectives of the statistical analysis centre on the temporal variation in the pre-Basslink period, and are to use the observed temporal variability to:

- determine what it is an acceptable range of values for the indicator variable in the post-Basslink period assuming there is no change in the processes that are generating the data obtained for the indicator variables; and
- establish the capability of the monitoring to detect change in the post-Basslink period that is considered to be large enough to be of practical importance.

There is a need for the statistical analysis to determine whether it is reasonable to assume that the temporal changes are consistent across zones. If there is consistency then data can be averaged across zones thereby providing more reliability in statistical conclusions. The reason is tied to the variance of the mean responses at the set of monitoring times since this is the yardstick against which temporal differences are judged. For each mean the variance of the mean is $V/r$ where $V$ is a measure of temporal variability and $r$ is the number of observations on which the mean is based. If there are five zones and three sites per zone, then $r=15$ if data can be averaged across zones, whereas it is only three if each zone must be considered separately. Consequently, if analysis is based on averages across all zones the chance of detecting a change of specified size is greater and the interval between the trigger values is smaller. However it is stressed that averaging across zones is sensible only if there is no evidence that the temporal pattern changes across zones.

### 4.4.3 Model-fitting strategies

#### *4.4.3.1 Checking the assumption of serial correlation*

For indicator variables from riparian vegetation and macroinvertebrates it is possible to base a model on responses from individual sites. In this case the initial model fitted is a repeated-measures model and the primary objective is to determine if there is evidence of serial correlation.

The reason for seeking to simplify the model by removing the serial-correlation assumption is that forward predictions are more complicated because the predicted mean response is a function of at least one of the preceding means. If the requirement to assume serial correlation can be dropped - and this is the case for all indicator variables analysed - then an independence model can be fitted.

#### *4.4.3.2 Checking space-time interactions*

The next step is to check if the pattern displayed by means across the pre-Basslink monitoring times is consistent across zones. Most importantly is a test for evidence of the zone × trend effect. If this effect is significant there is evidence (a) that for at least one zone there is evidence of a systematic trend across time, and (b) the zones are not consistent in the patterns over time and consequently it is not appropriate to average results across all zones.

A significant zone × trend effect would end the attempt to simplify the model that fits the pre-Basslink data.

#### *4.4.3.3 Checking for evidence of a trend*

In the absence of evidence of a zone × trend effect, that effect is dropped from the model. When the simpler model is fitted, tests are applied for evidence of quadratic and linear trends. If there is evidence of a non-linear trend the view is taken that the indicator variable is unlikely to be reliable as an indicator of change in the post-Basslink period because of the uncertainty in defining the precise form of the systematic trend. If there is evidence the trend is linear, i.e., the mean is changing at a constant rate, then predicting into the post-Basslink period is feasible provided there is support from discipline experts that the trend is likely to continue into the post-Basslink period.

If there is no evidence of a trend the model is refitted with the trend terms removed and the variation in mean responses across the pre-Basslink monitoring period is assumed to be due to seasonal variation, if any, and unexplained temporal variation.

### 4.4.4 Essential information from the modelling process

Commonly the simplest model that fits the data requires no trend term and a consistent temporal pattern across zones. Table 4.1 provides an illustration where this simple model is applicable.

In this case the essential information that is extracted from the analysis is the sample mean from the pre-Basslink data (averaged across all pre-Basslink monitoring times) which provides an estimate of the long-term average response for the indicator variable under pre-Basslink conditions; and the estimated variance of a sample mean.

Table 4.1. Mean responses for logarithms of number of families of macroinvertebrates sampled at eight sites in the middle Gordon River for each of the eight pre-Basslink monitoring times.

| **Year** | **2001-02** | **2001-02** | **2002-03** | **2002-03** | **2003-04** | **2003-04** | **2004-05** | **2004-05** |
|---|---|---|---|---|---|---|---|---|
| **Season** | **Spring** | **Autumn** | **Spring** | **Autumn** | **Spring** | **Autumn** | **Spring** | **Autumn** |
| **Mean** | 2.560 | 2.612 | 2.810 | 2.642 | 2.902 | 2.598 | 2.663 | 2.671 |
| **No. of sites** | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |

The sample mean is the average value of the means across all monitoring times - based on the data in Table 4.1 this would be 2.682. If a seasonal effect was not included in the model the residual temporal variance would be the variance of the means. Based on the data in Table 4.1 this would be 0.01339. In the models employed in this report a seasonal effect component is included and the estimated variance of the mean is obtained as the estimated temporal variance divided by the number of sites per mean. By way of illustration, the estimated temporal variance for the logarithm of the number of families data is provided in Table 4.2 by the error means square for the temporal component as 0.0968. Since there are eight sites per mean, the estimated variance of a mean is 0.0968/8 = 0.01210. Note that this value is smaller than the variance of the means (0.01339) because allowance has been made for a possible seasonal component.

Table 4.2. Portion of the analysis of variance table from the the fit of the simplest model that fits the data for logarithm of number of families of macroinvertebrates.

| **Source** | **df** | | **S.S.** | **M.S.** | **F** | **p** |
|---|---|---|---|---|---|---|
| **SEASON** | 1 | Hypothesis | 0.1690 | 0.1690 | 1.745841 | 0.235 |
| | 6 | Error | 0.5808 | **0.0968** | | |

Note the reliance of the variance on the number of sites. If the indicator variable trigger values or power were sought for individual seasons or individual zones then the number of sites contributing to the mean would be reduced and this would, in turn, reduce the reliability of estimates and power of tests.

The mean and the variance of the mean provide the basic information required to set trigger values for indicator variables and to construct power curves that assist in establishing the capability of the analysis to detect change in the long-term average response post-Basslink.

If there is a linear trend then the mean changes over time and must be estimated from an equation of the form:

$$\textit{mean} = \text{intercept} + \text{slope} \times \textit{time}.$$

This is the case, for example, with the erosion indicator variables that measure the average amount of erosion per pin for pins that show erosion in each zone. Table 4.3presents the predicted means through the pre-Basslink period and into the first two seasons of the post-Basslink monitoring period. The predicted means are computed from the equation $\textit{mean} = 19.286 + 8.7143 \times \textit{time}$, where '*time*' is the monitoring time recorded in Table 4.3.

The intercept and slope and estimated from the observed set of means and are therefore subject to sampling error. Error in the estimate of the slope leads to increasing uncertainty in predicted values as projections as made further ahead in time. Thus the variance of a predicted mean increases as the time of prediction is further into the future.

Table 4.3. Observed and predicted means assuming a linear trend in mean erosion per pin for pins that show erosion in zone 2. (The 'Basslink' classification is based on the assumption that Basslink will commence prior to aumtumn 2006.)

| **Year** | **2002** | **2002** | **2003** | **2003** | **2004** | **2004** | **2005** | **2005** | **2006** | **2006** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Season** | Autumn | Spring | Autumn | Spring | Autumn | Spring | Autumn | Spring | Autumn | Spring |
| **Basslink** | Pre | Pre | Pre | Pre | Pre | Pre | Pre | Pre | Post | Post |
| **Data currently available** | yes | yes | yes | yes | yes | yes | yes | no | no | no |
| **Monitoring time** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Predicted mean** | 28 | 37 | 45 | 54 | 63 | 72 | 80 | 89 | 98 | 106 |
| **Observed mean** | 16 | 39 | 59 | 59 | 58 | 73 | 75 | | | |

### 4.4.5 Modelling when there is a need to pool across sites

To provide meaningful analysis for erosion pin data from the geomorphic study and for abundance data in the fish study it was necessary to pool data across sites. The modelling strategy defined above is, consequently, not appropriate for application with data from these disciplines because it relies on replication provided by the data from individual sites. The manner in which modelling is approached in these two disciplines is necessarily different, so they are considered separately.

#### *4.4.5.1 Modelling erosion pin data*

The high level of spatial variability in pin erosion data produced a need for extensive pooling of data.

In the initial data analysis of the erosion pin data it was found that two major explanatory factors of changes in pin height over time were 'zone' and 'turbine level'. The five zones reflect different conditions from the power station to the downstream reaches of the river, and the turbine levels represent the maximum water height produced by 1-, 2- or 3-turbines. Since the turbine effect is expected to differ across the zones, ideally the modelling should employ the 15 zone by turbine level combinations. However not all combinations are represented at every site and even after pooling, the level of unexplained variation was so large as to hide temporal changes. Consequently it was decided to proceed down two parallel paths with the statistical analysis. For each of the geomorphic indicator variables that were analysed, one set of data was formed by combining all values for each zone at each of the monitoring time, and a second set of data was formed by combining all values at each turbine level each monitoring time.

While it is understood that this approach leads to confounding of zone and turbine-level effects, it is anticipated that the discipline expert can take account of this limitation when providing an overall interpretation of change.

With respect to model fitting, the approach described in the previous section is not applicable because of the absence of replication, i.e., the pooling has removed the site-to-site variation.

The situation is complicated by the fact that basic examination of the data revealed the erosional process was not in equilibrium and for many indicator variables there was evidence of a systematic trend over time but with the rate of change varying across zones and among turbine levels. This situation could potentially be described using regression modelling with monitoring time as the explanatory variable. However this requires an assumed form for the trend line and an assumption about possible serial correlation in addition to the critical assumption that the process generating the data will be unchanging through the post-Basslink monitoring period.

The increasing erosion of the banks is changing the bank profiles and this, in time, will lead to a change in the process generating the data which in turn is expected to lead to a variation in the trend line. However it is not possible to predict when that change may occur.

The high level of uncertainty in the modelling the trend in erosion over a further pre-Basslink period and six years of post-Basslink monitoring has led to the need for a special form of assessment of changes in erosion variables which is described in chapter 13.

#### *4.4.5.2 Modelling fish data*

Fish pose a particular challenge as a vehicle for detection of Basslink changes because of their generally limited numbers, the restricted distribution of many species, the patchiness with which many species occur, and the uncertainty in timing and conditions associated with fish migration.

The practical reality is that the sparseness of fish catches requires the pooling of data across sites within zones at each monitoring time to provide a single 'catch per unit effort' value for the zone. A consequence is that formal statistical testing for the detection of zonal differences is not possible. However it is possible to construct tests to determine if there is evidence of an increasing or decreasing trend in fish numbers during the pre-Basslink period, to test for evidence of differences in trends among zones and to provide the summary statistics that are required for the estimation of limits of acceptable change and to construct power curves.

A serious limitation in respect of the spatial pooling required of the fish data is the loss of the possibility to test for serial correlation. There is an expectation that fish numbers at successive times of monitoring could be related. While this could lead to spurious trends and substantial bias in p-values based on an independence model there is no practical way in which serial correlation can be included in the model employed given that the number of pre-Basslink monitoring times is so small. This limitation in interpretation of results from the analysis of the fish data should be considered if evidence does arise of post-Basslink numbers being outside predicted limits that are formed from the pre-Basslink data. Where such a finding occurs consideration should be given to revisiting the possibility of introducing serial correlation into the model.

The need for pooling 'catch per unit effort' data was not restricted to spatial pooling. For individual species, even when data were pooled across sites within zones, there were many zero readings and often high variability. It proved necessary to pool across species to obtain sufficient stability in the numbers.

## 4.5 Statistical methodology

For the disciplines where spatial replication was present in the data, namely the macroinvertebrate and vegetation monitoring, the models and modelling strategy described above can be analysed using standard statistical methodology based on the technique of analysis of variance, using F-tests for the testing of selected effects. The initial model fitted included allowance for serial correlation and F-tests adjusted for the possibility of serial correlation. For all variables fitted, a scale of measurement was determined on which Normality and constant variance assumptions are found to be reasonable.

Where the assumption of serial correlation could be dropped, and this applied to all indicator variables employed in macroinvertebrate and vegetation monitoring, independence models were fitted. Sequentially, terms are removed in the order described in the previous section, using p = 0.01 as cut-off point.

### 4.5.1 Distribution of means and differences between means

The end point of the modelling process is one or more sets of means with each set containing one mean for each time of monitoring. Interest lies in the likely or projected means in the post-Basslink period.

| **Period** | **pre-Basslink** | | | | **post-Basslink** | | | |
|---|---|---|---|---|---|---|---|---|
| **Monitoring time** | 1 | 2 | $\cdots$ | $n_1$ | 1 | 2 | $\cdots$ | $n_2$ |
| **Mean** | $\overline{x}_{11}$ | $\overline{x}_{12}$ | | $\overline{x}_{1n_1}$ | $\overline{x}_{21}$ | $\overline{x}_{22}$ | | $\overline{x}_{2n_2}$ |
| **Period mean** | $\overline{x}_{1.}$ | | | | $\overline{x}_{2.}$ | | | |

Consider the situation where there is assumed to be no trend across the monitoring time within a period with the long-term pre-Basslink average being $M_1$ and the long-term post-Basslink average being $M_2$. Suppose the residual temporal variance is $V$ and the mean at each monitoring time is the average of responses at $r$ sites.

If $\overline{x}_{ij}$ is the variable representing the mean response at monitoring time $j$ in period $i$ ($I = 1$ for pre-Basslink and $I = 2$ for post-Basslink) then:

- $\overline{x}_{ij}$ has a Normal distribution with mean $M_i$ and variance $V/r$;
- $\overline{x}_{1.}$ has a Normal distribution with mean $M_1$ and variance $V/(rn_1)$ and $\overline{x}_{2.}$ has a Normal distribution with mean $M_2$ and variance $V/(rn_2)^{\perp}$; and
- $\overline{x}_{2.} - \overline{x}_{1.}$ has a Normal distribution with mean $M_2 - M_1$ and variance $\frac{V}{r}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)$.

The value of the variance $V$ is unknown. However an estimate is available from the residual mean square for the temporal component in the analysis of variance table obtained from the fit of the model that assumes no trend but possibly a seasonal effect. If allowance is made for a season effect, the degrees of freedom of the variance estimator is $n_1$ -2. If the monitoring is over eight pre-Basslink monitoring events, the degrees of freedom is therefore six.

If there is a trend in the long-term average then M must be expressed as a function of monitoring time. The only form of trend for which further analysis is undertaken is a linear trend in which case $M_j = A + Bt_j$, where $M_j$ is the expected mean at monitoring time *j* and the $t_j$-terms are a sequence of integers representing the successive monitoring times.

### 4.5.2 Distribution when there is a linear trend

Standard statistical regression analysis can be applied to obtain estimates of the intercept *A* and the slope *B* of the trend line using the pre-Basslink data. If these estimates are respectively *a* and *b*, then the predicted value for the trend at monitoring time *j* is $m_j = a + bt_j$. The observed mean response at monitoring time *j* is $\bar{x}_j = m_j + e_j$, where $e_j$ is the chance component that represents the effect of all unexplained sources of variation at time *j*.

The variance of $\bar{x}_j$ is the sum of the variances of $m_j$ and $e_j$,. The variance of $m_j$ reflects the uncertainty in the estimated intercept and slope which is

$$V_{m_j} = V\left[\frac{1}{n_1} + (t_j - \bar{t})^2 / \sum_{i=1}^{n_1}(t_i - \bar{t})^2\right],$$

where *V* is the averaged squared deviation of observed means from the trend line, $n_1$ is the number of pre-Basslink monitoring times for which data are available and $\bar{t}$ is the mean monitoring time computed form the monitoring times for which data are available.

The variance of $e_j$ is *V*. Hence the variance of $\bar{x}_j$ is

$$V_{\bar{x}_j} = V\left[1 + \frac{1}{n_1} + (t_j - \bar{t})^2 / \sum_{i=1}^{n_1}(t_i - \bar{t})^2\right].$$

The distribution of $\bar{x}_j$ is assumed Normal.

## 4.6 A basis for setting post-Basslink limits

If the long-term average response is constant over the pre-Basslink period and there is no change in the process generating the data after the introduction of Basslink then the same pattern of response would be expected in the post-Basslink period.

### 4.6.1 Limits when the mean is constant

If the long-term average were known to be *M*, then using the results from the previous section, the sample mean response for the first $n_2$ monitoring periods post-Basslink would have a Normal distribution with mean *M* and variance $V/(rn_2)$, where *r* is the number of sites contributing to a sample mean. However the value of *M* is not known. All that is available is the estimate provided by the sample mean from the pre-Basslink period. This additional uncertainty is reflected in the variance of the sample mean from the $n_1$ monitoring times in the pre-Basslink period, namely $V/(rn_1)$. The combined effect of these two sources of uncertainty is displayed in Figure 4.2 for the situation where there are eight pre-Basslink monitoring times and two post-Basslink monitoring times.

Further uncertainty is introduced by the fact that the value of *V* is not known but can be estimated from the pre-Basslink data as indicated in the previous section. If the estimator is denoted by $s^2$ and has *d* degrees of freedom, then lower and upper limits can be based on the fact that the studentised difference in means between pre-Basslink and post-Basslink means has a t-distribution with *d* degrees of freedom. Those limits are

$$\bar{x}_{1.} - t(0.05,d)\sqrt{\frac{s^2}{r}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)} \quad \text{to} \quad \bar{x}_{1.} + t(0.05,d)\sqrt{\frac{s^2}{r}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)} \qquad 95\%\ \text{limits}$$

$$\bar{x}_{1.} - t(\alpha,d)\sqrt{\frac{s^2}{r}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)} \quad \text{to} \quad \bar{x}_{1.} + t(\alpha,d)\sqrt{\frac{s^2}{r}\left(\frac{1}{n_1}+\frac{1}{n_2}\right)} \qquad 100(1-\alpha)\%\ \text{limits}$$

The presumption is that a value outside these limits provides possible evidence of change in the post-Basslink period, of the process that generates the data.

There is a chance that, in the absence of change, a value will fall outside the limits. The risk of this occurring is set by the value of $\alpha$. Thus if $\alpha$ is set at 0.05 there is a 5 % chance that a value will fall outside the limits when the process generating the data is unchanged.

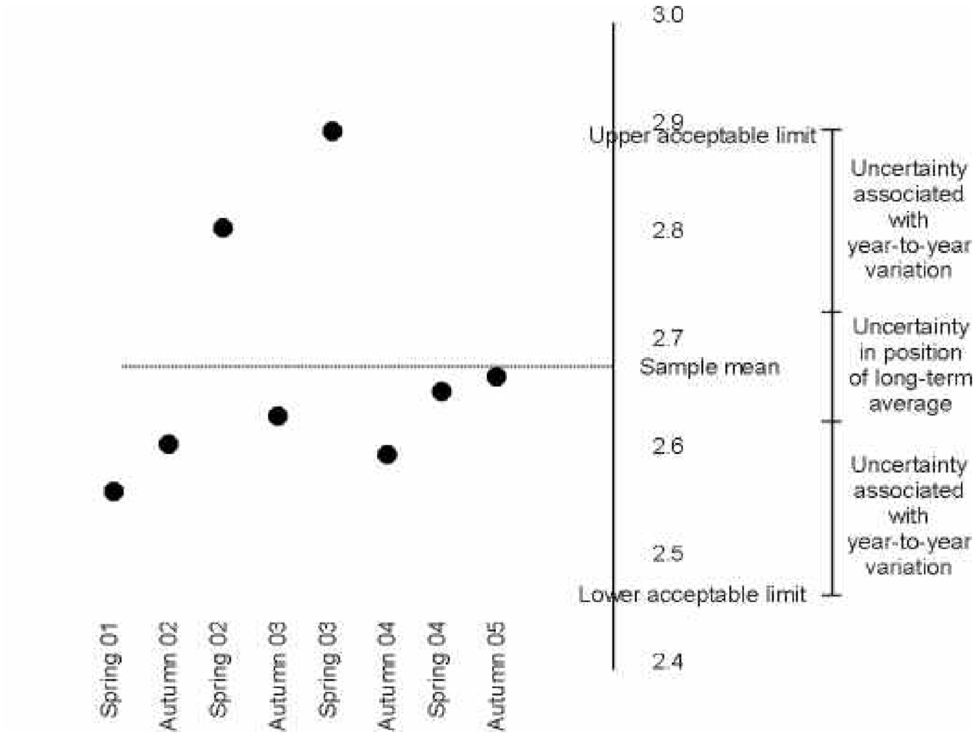

Figure 4.2. A plot of the eight means presented in Table 4.1 and the lower and upper limts constructed from these data for the mean of the first year of post-Basslink sampling for logarithm of number of macroinvertebrate families.

### 4.6.2 Limits when there is a linear trend

The basis for setting limits is identical to that introduced above. However the mean changes with time with a corresponding change in lower and upper limits. Thus at monitoring time *j* the limits are

$$\begin{array}{cccl} \bar{x}_j - t(0.05,d)\sqrt{s^2_{\bar{x}_j}} & \text{to} & \bar{x}_j - t(0.05,d)\sqrt{s^2_{\bar{x}_j}} & \text{95\% limits} \\ \bar{x}_j - t(\alpha,d)\sqrt{s^2_{\bar{x}_j}} & \text{to} & \bar{x}_j + t(\alpha,d)\sqrt{s^2_{\bar{x}_j}} & 100(1\text{-}\alpha)\text{\% limits} \end{array},$$

where $\bar{x}_j = a + bt_j$ and $s^2_{\bar{x}_j} = s^2\left[1 + \frac{1}{n_1} + (t_j - \bar{t})^2 / \sum_{i=1}^{n_1}(t_i - \bar{t})^2\right]$, with $s^2$ being the residual mean square from the analysis of variance table obtained in the regression analysis of observed means on monitoring times in the pre-Basslink period.

### 4.6.3 Determining the cause of change

Finding evidence that an indicator variable shows change in the post-Basslink period and measuring the size of that change may only be the first step. Having been alerted to the presence of change, a logical next stage is to seek an understanding of why change has occurred. Statistics has a role in this task through methodology that identifies relationships between variables and methodology that assesses the extent to which changes in one variable can be predicted by changes in other variables.

For example there might be an analysis of the extent to which changes in the rate of erosion are predicted by changes in vegetative characteristics.

While statistical models and methods are likely to be employed at stage 2, the nature of the requirement cannot be identified until the nature of any change has been determined.

It is important to note that Statistics has no capability to identify cause and effect in relationships.

## 4.7 Determining the capability of monitoring to detect a Basslink effect

The approach presented in the previous section provides a measure of the probability that a false claim has been made that a post-Basslink change has occurred when there has been no change. It does not provide a means of determining the probability that there has been a change when a change has in fact occurred.

Statistics can provide this information through the application of power analysis. In essence the statistical methodology is a simple variation on that described in the preceding sections.

Suppose that the long-term average in the pre-Basslink period is $M_1$ and, post-Basslink, this changes to level $M_2$. Then under the assumptions and using the notation presented in the previous sections, the difference in sample means $\bar{x}_{2.} - \bar{x}_{1.}$ is Normally distributed with mean $M_2 - M_1$ and variance $\frac{s^2}{r}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)$. By using the limits constructed in the previous section to define the range of values under which the decision is reached that there is no change, the probability of correctly declaring there is a change is the probability of obtaining a difference in sample means that lies outside those limits assuming the true difference in means is $M_2 - M_1$. This is known as the power of the test. An illustration is provided in Figure 4.3 using the data introduced for the number of macroinvertebrate families.

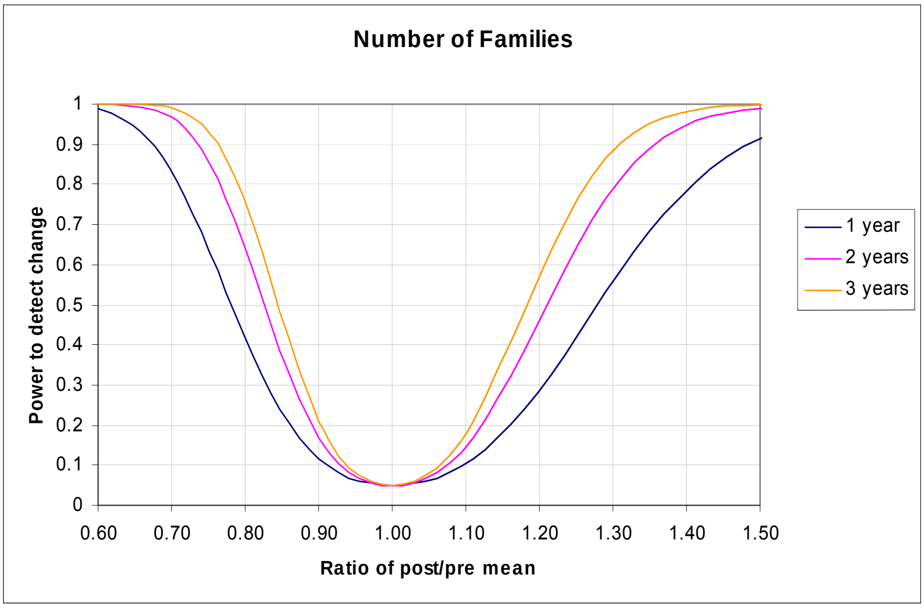

Figure 4.3. An illustration of a power curve. This curve provides the probability of detecting change in the ratio of mean number of families after one, two or three post-Basslink years to mean number of families in the pre-Basslink years. Note that the curve allows for the possibility that the post-Basslink change might be associated with either an increase or a decrease in the mean. The minimum value on the curves, namely 0.05, is the probability that the hypothesis of no change is incorrectly rejected. See chapter 13 for the application of power curves.

Rather than setting an arbitrary value for $M_2 - M_1$, it is usually more convenient to provide the power for a range of differences and to present the results in a graphical form known as a power curve. This approach is employed in chapter 13 for indicator variables employed in the vegetation, fish and macroinvertebrate monitoring.

For the geomorphic variables there was generally a trend present in the pre-Basslink period. In that case the trend is presumed to remain unchanged through the post-Basslink period and the expected difference is measured from the value predicted by the trend line at the point in time at which the power is to be determined.

## 4.8 Outcomes

The statistical approach and resultant models discussed in this chapter and employed by various scientific disciplines have allowed the derivation of sets of indicator variables for each discipline and the determination of trigger values for each indicator variable. The description and derivation of the indicator variables are discussed in the individual discipline chapters (chapters 6-11) and the determination of trigger values is discussed in chapter 13 (Indicator variables).

# 5 Pre-Basslink hydrology (2001-05)

Changes to the hydrology of the Gordon River due to damming and flow regulation have been described in chapter 2. This chapter provides hydrologic information relevant to the pre-Basslink monitoring period, 2001-05. This is the time period for which data from each scientific discipline of the BMP is presented in the following six chapters. The hydrologic information in this chapter shows that, between 2001-05, the operation of the Gordon Power Station varied from previous operations. This was due to changes in the transmission system which allowed more electricity to be transmitted from the site compared to the pre-2000 period, and to drought conditions in much of Tasmania, which required Hydro Tasmania to operate the Gordon Power Station for longer periods than would usually be the case. These factors resulted in higher discharge from the power station for longer durations compared to previous operations.

## 5.1 Rainfall, power station operation and river flow

Monthly rainfall totals for Strathgordon for the pre-Basslink monitoring period are shown in Figure 5.1, with a summary of 'wet' and 'dry' seasons presented in Table 5.1. A wet year or season is defined as one in which rainfall exceeded the 80th percentile of the long-term record for the year or season, with a 'dry' year or season defined as being less than the 20th percentile of the long-term record.

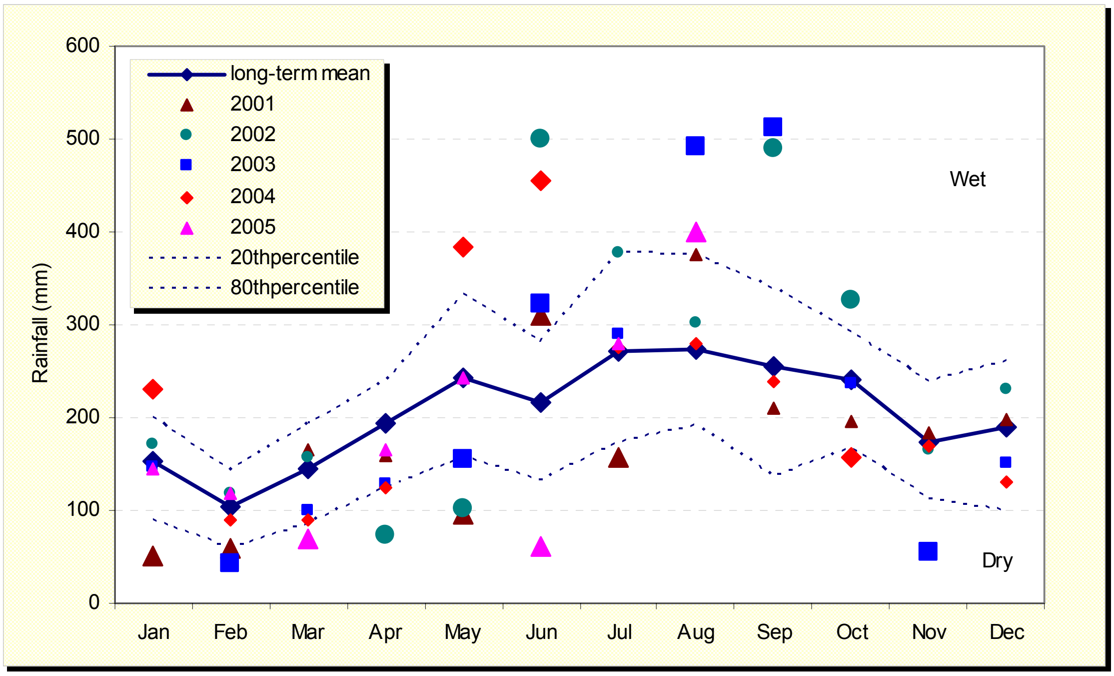

Figure 5.1. Monthly rainfall totals at Strathgordon for the pre-Basslink monitoring period. The long-term average values (1970-August 2005), plus 20th and 80th percentile values are also shown. Months which exceeded the percentile values are shown bold.

Table 5.1. Summary of wet and dry years and seasons during the pre-Basslink monitoring period. Periods not indicated as Wet or Dry fell within the 20th-80th percentile rainfall limits. (Rainfall data from January 2000 to August 2005).

| Year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 (August) |
|---|---|---|---|---|---|---|
| Annual condition | Wet | Dry | Wet | | | Not available |
| Summer (D,J,F) | | | | | | |
| Autumn (M,A,M) | Wet | Dry | Dry | Dry | | |
| Winter (J,J,A) | | | Wet | Wet | Wet | |
| Spring (S,O,N) | | | Wet | Wet | | Not available |

During the pre-Basslink monitoring, there tended to be dry autumns and wet winters. This necessitated extended power station operation during autumn periods, with lower frequency of operation during the winters when water was available in other hydro-electric catchments. These rainfall conditions led to extended usage of the Gordon Power Station compared to pre-2000 (Table 5.2.), with 3-turbine discharge occurring almost 40 % of the time. The extended usage in summer resulted in a larger shift in seasonality compared to 'historical' operations, with 78 % of the total flow released from the power station during the summer and autumn months (Table 5.3).

Table 5.2. Summary of Gordon Power Station operation through time, including the pre-Basslink period.

| Years | Period | Percentage of time turbines operating | | | | Basis for analysis |
|---|---|---|---|---|---|---|
| | | Off | 1 -turbine | 2-turbines | 3-turbines | |
| 1978-88 | Historical (2-turbines) | 8 % | 35 % | 57 % | | Daily power records |
| 1989 -99 | Historical (3-turbines) | 23 % | 34 % | 35 % | 7 % | Daily power records |
| 2000-May 05 | pre-Basslink | 13 % | 30 % | 30 % | 27 % | Daily power records |
| Aug 1996-99 | Historical (3-turbines) | 13 % | 16 % | 41 % | 30 % | Hourly flow data |
| 2000-May 05 | pre-Basslink | 20 % | 18 % | 23 % | 39 % | Hourly flow data |

Table 5.3. Seasonal percentage of flow at the Gordon Power Station and Gordon Above Franklin by season, for Natural (1960-78), Historical (1979-99) and pre-Basslink (2000-04) periods.

| % Flow | Spring | Summer | Autumn | Winter |
|---|---|---|---|---|
| **Gordon Power Station** | | | | |
| Natural (simulated) | 28 % | 12 % | 24 % | 36 % |
| Historical | 16 % | 34 % | 32 % | 17 % |
| pre-Basslink | 9 % | 38 % | 40 % | 12 % |
| **Gordon above Franklin** | | | | |
| Natural (simulated) | 28 % | 10 % | 26 % | 36 % |
| Historical | 24 % | 24 % | 26 % | 26 % |
| pre-Basslink | 18 % | 26 % | 31 % | 25 % |

Hydrographs of the middle Gordon River at the power station (site 77) and above the Franklin River (site 44) are shown in Figure 5.2., with flow at above the Franklin River superimposed on the power station discharge for comparison. The hydrographs show a number of common features:

- At the Gordon Power Station, 3-turbine operation dominates summer discharge patterns, with flows of 180-250 $m^3 s^{-1}$ occurring from January until/through May. These hourly results show that shut-downs are uncommon, with the exception of a March shut-down which is required for the Basslink baseline monitoring;
- During June through September or early October, the power station is used less frequently, and at lower discharge levels. During this period there are a relatively high number of shut-downs compared to the previous months;
- October and/or November have been characterized by extended power station shut-downs, during which time no flow is released from the power station;
- Towards the end of the calendar year (beginning of summer), increased 3-turbine power station usage is again common;
- At the Gordon above Franklin site, summer discharge is dominated by the ~200 $m^3 s^{-1}$ power station releases;
- Large storm events can occur at any time of year, but are more common during autumn and winter when Gordon Power Station usage is reduced; and
- Rainfall events in the middle Gordon catchment have increased flows to between 500 and 1000 $m^3 s^{-1}$ each year since 2000. 70 % of this in-flow can be accounted for by the Denison River, and Gordon catchment between the dam and the Denison confluence.

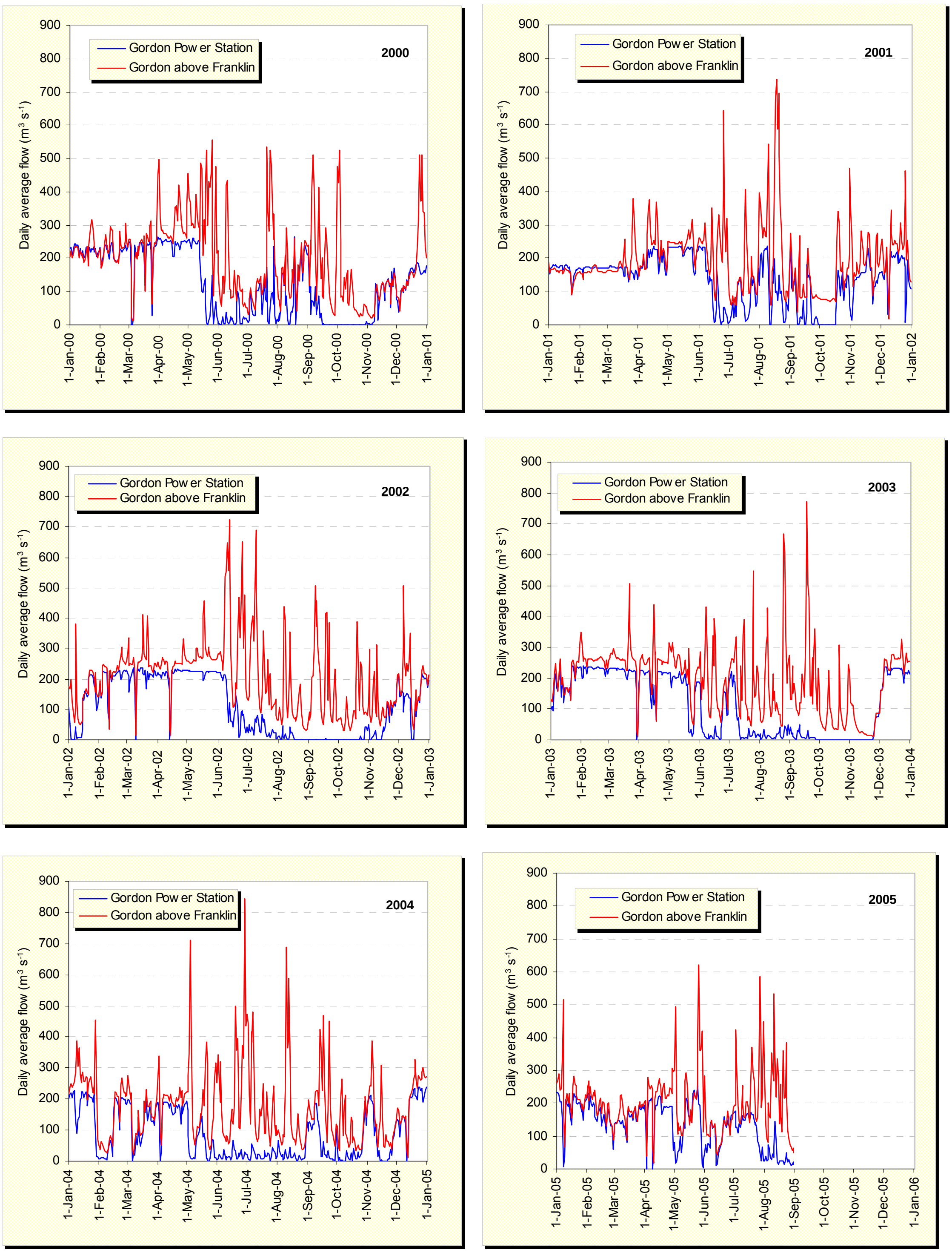

Figure 5.2. Hourly hydrographs for the Gordon Power Station (site 77) and Gordon above Franklin (site 44).

The median monthly flow results for the period 2001-05 for the Gordon Power Station and Gordon above Franklin sites are shown in Figure 5.3. The extended operation of the Gordon Power Station has led to an increase of ~50 $m^3 s^{-1}$ in the median summer flow in the Gordon compared to 'historical' power station operation (1979-99), which already exceeded 'natural' maximum median flows. At the Gordon above Franklin site, monthly median summer flows have also increased over the pre-Basslink period, but remain within the range of pre-dam median flow levels.

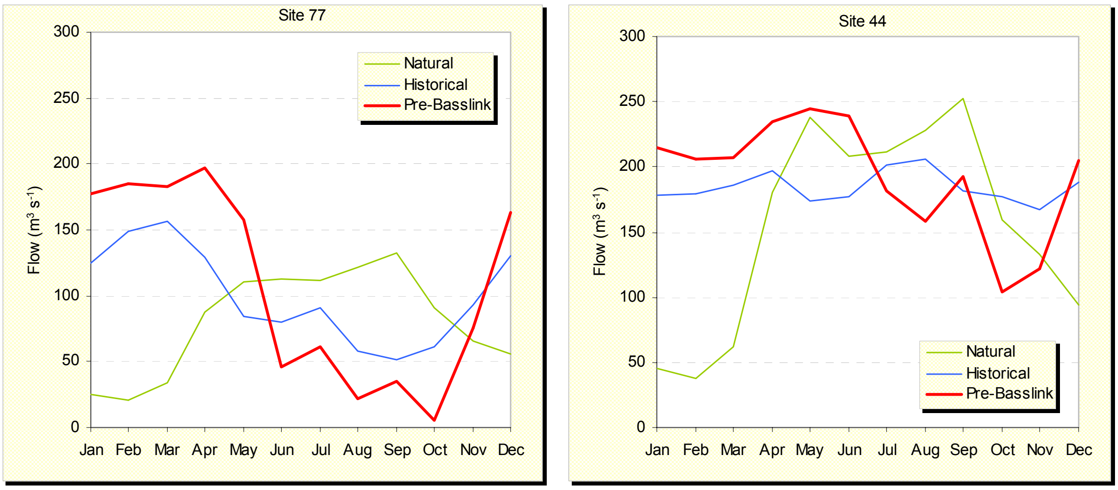

Figure 5.3. Median monthly flow at the Gordon Power Station (site 77, left) and the Gordon above Franklin (site 44, right).

## 5.1.1 Flow duration 2000-05

Flow duration curves for the pre-Basslink period compared to 'historical' operations are presented in Figure 5.4, with the individual monitoring years (2000-05) shown in Figure 5.5. Compared with 'historical' operations, the pre-Basslink period has been characterised by an increase in the duration of flows greater than 100 $m^3s^{-1}$.

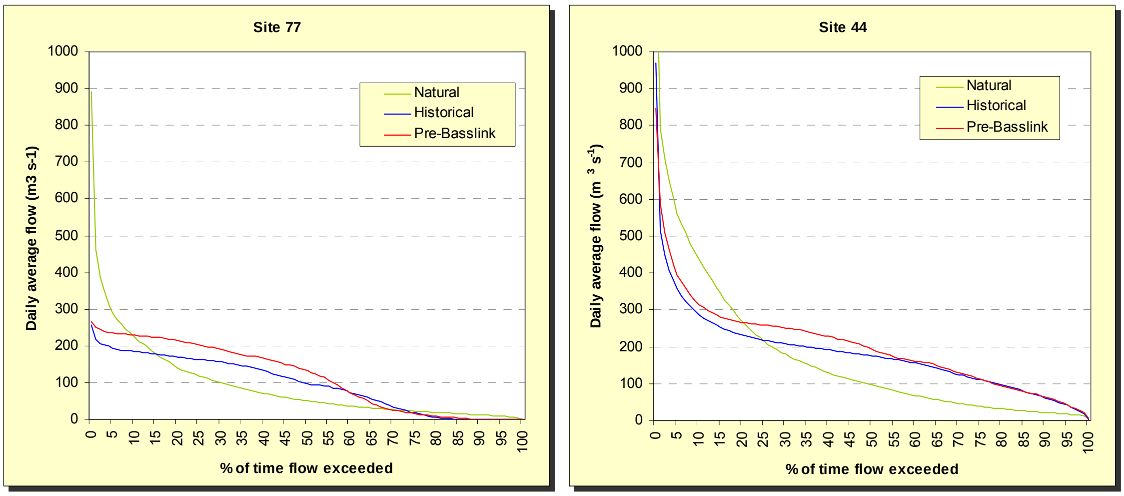

Figure 5.4. Flow duration curves based on average daily discharge for the Gordon at the power station, and Gordon above Franklin River sites, showing natural, 'historical' and pre-Basslink results.

The annual duration curves for 2001-05 for the Gordon Power Station (Figure 5.5) show that there has been considerable interannual variability. All five years show that flows of 200 $m^3 s^{-1}$ or higher have occurred at least 15 % of the time, with 2001-02 having the highest percentage (~ 40 %).

The flow duration results for 2003-04 show the most bi-modal activity, with flows in excess of 25 $m^3 s^{-1}$ occurring only ~50 % of the time, and flows in excess of 180 $m^3 s^{-1}$ (3-turbine operation) occurring almost 25 % of the time. The other years show higher proportions of 1- and 2-turbine power station operation. The long low-flow tail on the 2003-04 curve is attributable to the station being used as 'spinning reserve' in October-November 2003. This resulted in flows of ~10 $m^3 s^{-1}$ from the station.

The 2004-05 duration curve shows the increased use of the power station compared to 2003-04, as well as the proportionally increased use of 2-turbine operation, which is indicated by the 'knee' in the curve at ~50 % and 125 $m^3 s^{-1}$.

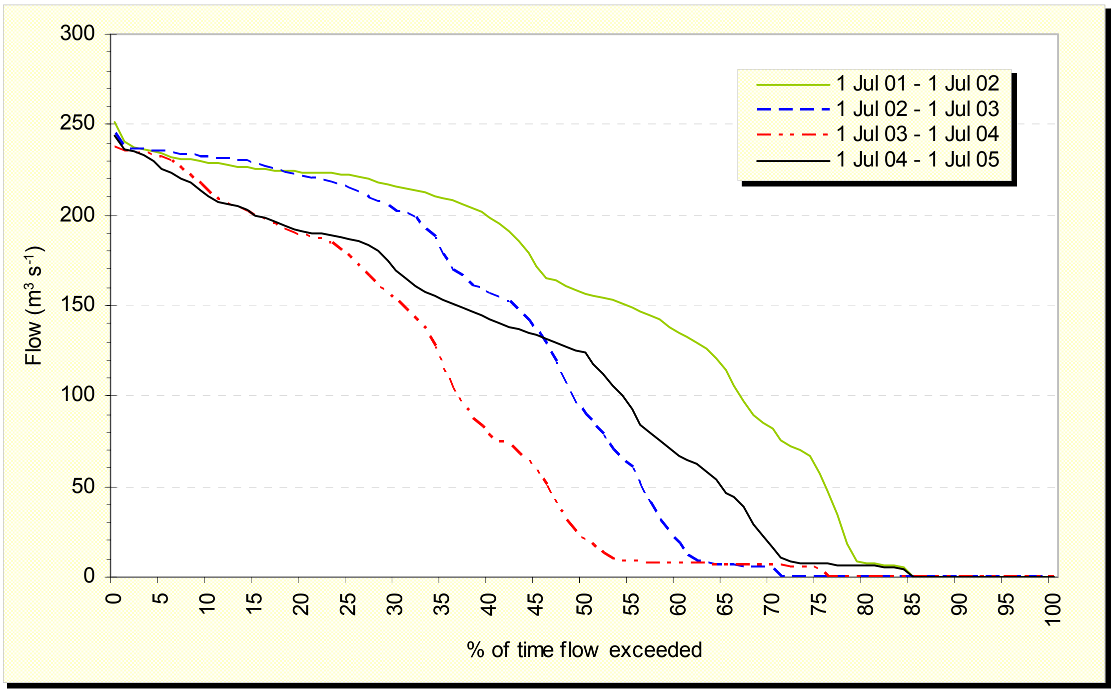

Figure 5.5. Flow duration curves for the 2001-05 Basslink monitoring years.

### 5.1.2 Flow frequency

A summary of flow event frequency for each of the Basslink monitoring years is shown in Table 5.4. The results reflect the variability of operations at the Gordon Power Station with shut-down events, and the number of occasions when the power station was changed to 1- or 2-turbine operation varied by a factor of 2 during the Basslink monitoring years.

Table 5.4. Flow frequency summary of the Basslink monitoring years, 2000-05.

| Flow events | Annual number of events | | | | | |
|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005* |
| Power station shut-downs (no flow) | 114 | 57 | 76 | 61 | 117 | 6 |
| Max discharge <100 $m^3 s^{-1}$ (approx. 1-turbine operation) | 72 | 28 | 43 | 40 | 84 | 0 |
| Max discharge >100 $m^3 s^{-1}$ and <200 $m^3 s^{-1}$ (approx. 2-turbine operation) | 113 | 88 | 76 | 36 | 101 | 11 |
| Max discharge >200 $m^3 s^{-1}$ (approx. 3-turbine operation) | 108 | 79 | 86 | 67 | 98 | 70 |

*data from 01/01/05 to 01/05/05 only.

### 5.1.3 Summary of hydrology during Basslink baseline monitoring

- Since 2000, there has been an increase of ~35 % in the duration of 200 $m^3 s^{-1}$ or greater flows compared to 1979-99. Compared to 'historical' power station operation, the pre-Basslink period is characterised by increased 3-turbine discharge during the summer and autumn periods at the Gordon Power Station;
- During the Basslink monitoring period, 3-turbine power station operation, and shut-downs have occurred for longer durations as compared to the previous 10 years of 3-turbine operation;
- All four pre-Basslink monitoring years had similar flow patterns, with long-duration 3-turbine power station operation dominating flow throughout the middle Gordon in the summer months, large rain events dominating flows downstream of the Denison in the winter, and low or no power station usage during the spring;
- Each year maximum flows downstream of the Denison confluence were associated with large storm events which increased flow (and water level) to two to three times those of regulated discharges;
- In spite of similar annual flow patterns, the frequency of shut-downs and 1-, 2- and 3-turbine power station operation varied considerably over the four years, and do not show any trends when compared to 1996-99 power station operations.

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# 6 Water quality

## 6.1 Chapter summary

The purpose of this chapter is to summarise the findings of the water quality monitoring conducted as part of the Basslink Monitoring Program from 2001-05. Information from earlier water quality monitoring work is included, where appropriate. This chapter and its appendix (appendix 3 Water quality) detail the baseline values, patterns and trends presently in evidence and indicate those which may be useful for comparing post-Basslink conditions.

The summarised findings of the water quality chapter are:

- Both Lakes Pedder and Gordon demonstrated good water quality with parameter values similar to natural lakes in south-western Tasmania. There were no parameters measured in the lakes which would have a detrimental effect on downstream biota;
- Lake Gordon was almost permanently stratified at the power station intake site, and the depth of stratification may have an effect on the quality of water released from the power station;
- During the pre-Basslink period relatively low water levels in Lake Gordon contributed to: a decrease in the incidence of low dissolved oxygen water being released from the power station; and a degree of seasonal variability in the thermal regulation effects of the power station discharge;
- The effects of higher lake water levels on discharged water are unknown, as these conditions have not occurred during the period of study (2001-05);
- In terms of dissolved oxygen, water discharged from the power station over the monitoring period has contained both low and high concentrations. These extremes have shown a marked decrease since 2002 as power station operating procedures were adjusted to reduce their incidence. Extreme values are unlikely to be persistent, as the downstream channel provides ample opportunity for re-oxygenation or de-gassing;
- Thermal regulation produced by the power station discharge is extensive. It is evident downstream of the Denison confluence. Thermal regulation is maintained by power station discharges as low as 10 $m^3 s^{-1}$;
- The regulated thermal regime includes a reduced seasonal pattern and no diurnal or short-term variability. The regulated regime tends to keep temperatures cooler than ambient during September-March and warmer than ambient during April-August;

- The regulated thermal regime is dominant in the reach between the power station and the Denison confluence. Downstream of the Denison, natural in-flows may have an ameliorating effect if power station discharge is low and in-flows are relatively high; and
- Impacts of thermal regulation on the biotic community are now full realized, and the community composition has adjusted to this regulated temperature regime.

## 6.2 Monitoring

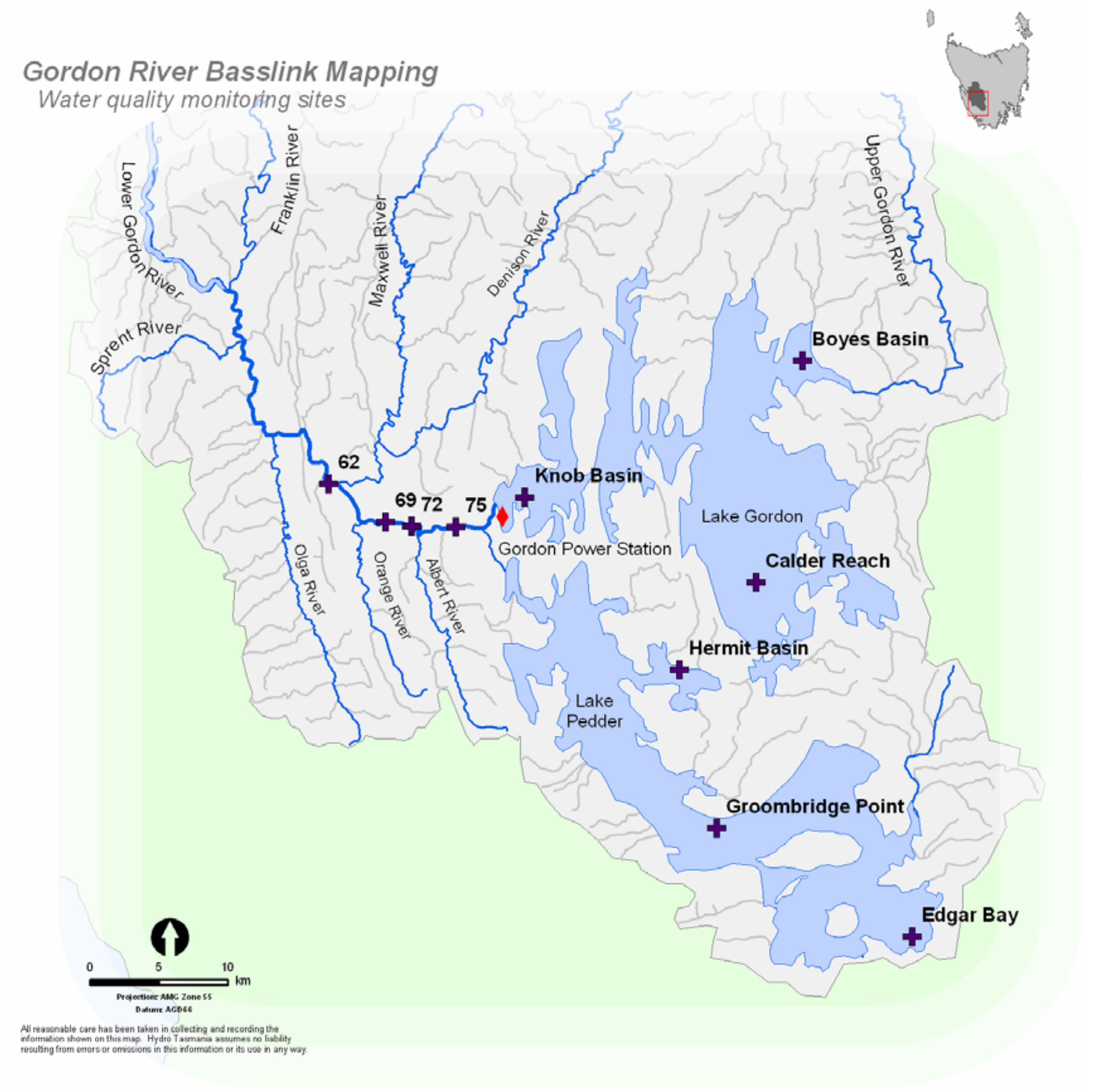
Water quality parameters were monitored in Lakes Pedder and Gordon, which are upstream of the Gordon Power Station, and in the Gordon River, downstream. Map 6.1 shows the Gordon catchment, including the location of the lakes, the power station, and the Gordon River, as well as the monitoring sites. Detailed methods are given in appendix 3 Water quality.

Lakes Pedder and Gordon are both artificial impoundments. Their location within the relatively pristine Tasmanian Wilderness World Heritage Area (TWWHA), and the absence of other land-use impacts, means that their water quality is expected to be similar to that of natural lakes in the western Tasmanian region. The monitoring was conducted to confirm that water quality remained good in the lakes.

Monitoring of water quality downstream of the power station has also been undertaken, to describe the conditions relating to the Gordon Power Station's operations. These include the incidence of both high and low dissolved oxygen concentrations in water discharged from the power station, and downstream thermal regulation.

## 6.3 Findings

Monitoring has indicated that the water quality of the lakes has little effect on downstream water quality. It is only at the intake site in Lake Gordon that the lake's water quality has the potential to impact on downstream conditions. Consequently, this chapter covers lake water quality only in summary. More-detailed results from the lake monitoring are presented in appendix 3, including ranges and trends for the surface parameters and depth profiles for both Lakes Pedder and Gordon.



Map 6.1. Map of the Gordon catchment showing the location of monitoring sites in Lakes Pedder and Gordon and the Gordon River.

### 6.3.1 Lake Pedder surface water quality

The water quality data from the three monitoring sites (Edgar Basin, Hermit Basin and Groombridge Point) indicated no unexpected trends or parameter values in Lake Pedder.

Water temperature and dissolved oxygen values varied seasonally, within a normal range, and were stable over time and throughout the lake. The pH values were relatively even across the lake and through time (*ca* 6.1), although Hermit Basin tended to record generally lower pH values than the other sites (*ca* 5.7). There was no indication of the cause of this persistent trend. Conductivity values were generally even throughout the lake, at *ca* 40 µS $cm^{-1}$, and were consistent over time. Turbidity values were uniformly low at *ca* 1 NTU. The chlorophyll-*a* values were low at *ca* 1 µg $L^{-1}$, and displayed a seasonal pattern, with lower values in winter-spring and higher values in summer-autumn.

Nutrient and metals samples were taken at Groombridge Point in Lake Pedder. The data indicated continuing low nutrient levels in Lake Pedder, with no apparent trends. Alkalinity values showed a long-term pattern of values between 4-6 mg $L^{-1}$. Dissolved organic carbon recorded low values over the winter of 2001 and its long-term pattern of values around 6 mg $L^{-1}$ is also continuing. Sulphate values were relatively stable around the median of 1.1 mg $L^{-1}$.

Several of the metals values were at or below the analytical detection thresholds for these parameters. These included chromium, cobalt, copper, lead, manganese, nickel and zinc. Iron values continued their long-term pattern close to the median value of 0.26 mg $L^{-1}$. Aluminium values were relatively stable over time, close to the median value of 0.11 mg $L^{-1}$.

### 6.3.2 Lake Pedder depth profiles

All profiles recorded at Groombridge Point from March 2001 to April 2005 were uniform to the maximum depth of 16 m. Water temperature values varied seasonally, from 6 °C in July 2004 to 17 °C in March 2001. Dissolved oxygen values ranged from 7.9 to 11.7 mg $L^{-1}$, while oxygen saturation values ranged from 74 to 106 %. The pH values were slightly to moderately acidic, ranging from 5.5 to 6.6. The conductivity values ranged from 33 to 46 µS $cm^{-1}$.

### 6.3.3 Lake Gordon surface water quality

The water quality parameters at the three monitoring sites (Boyes Basin, Calder Reach and the power station intake) showed little indication of unexpected values, patterns or trends in Lake Gordon.

Surface water temperatures and dissolved oxygen concentrations varied seasonally, and no unexpected values were recorded at any of the Lake Gordon sites. The pH and conductivity values were relatively even across the monitoring sites and through time, with median values around 6.3 and 40 µS $cm^{-1}$, respectively. Elevated conductivity values (*ca* 65 µS $cm^{-1}$) were recorded on one occasion in 1996 at the Boyes Basin and Calder Reach sites. The turbidity values were low, with median values between 1.4 and 2.8 NTU. Elevated turbidity (*ca* 9 NTU) was recorded on one occasion in 2002 at the Boyes Basin and Calder Reach sites.

The chlorophyll-*a* values were low and demonstrated a seasonal pattern, with lower values in winter-spring and higher values in summer-autumn. At Boyes Basin, an unusually high chlorophyll-*a* value of 15.1 µg $L^{-1}$ was recorded in February 2004 and a lower value of 5.2 µg $L^{-1}$ in January 2005. In February 2004, the higher concentration was associated with an elevated total phosphorus reading from that site, indicating a possible localised algal bloom. No other site in either lake produced elevated results on these dates.

Nutrient and metals samples were taken at all three sites in Lake Gordon. These indicated continuing low nutrient conditions in the lake. The only reading which stood out as unusual was the elevated total phosphorus reading (0.055 mg $L^{-1}$) at Boyes Basin in February 2004, which is discussed above. In January 2005, total and reactive phosphorus concentrations were lower at 0.006 and 0.002 mg $L^{-1}$, respectively. The amount of reactive phosphorus may influence the amount of algal growth in Boyes Basin. The ranges, median values, and trends of all parameters measured are reported in appendix 3 Water quality.

### 6.3.4 Lake Gordon depth profiles

The water temperature profiles at Boyes Basin and Calder Reach showed a tendency for thermal stratification in the summer and early autumn. Winter and early spring profiles were relatively uniform with depth. Boyes Basin recorded varitations in bottom temperatures which were attributed to the effects of in-flow from the upper Gordon River. Similar effects were also evident in the dissolved oxygen, pH and conductivity profiles at this site. These patterns have no apparent effect on the water at the intake site, and so are not discussed further here. More information is given in appendix 3.

The intake site is the deepest of the three monitoring sites at approximately 100 m. Thermal stratification was seasonal, being most pronounced in summer and early autumn and breaking down to a uniform profile in winter and spring. Figure 6.1 shows the water temperature profiles for the power station intake site since 2001. Surface temperatures ranged from 8-19 °C while bottom temperatures ranged from 7 -9 °C. The stratification depth varied between 10-30 m.

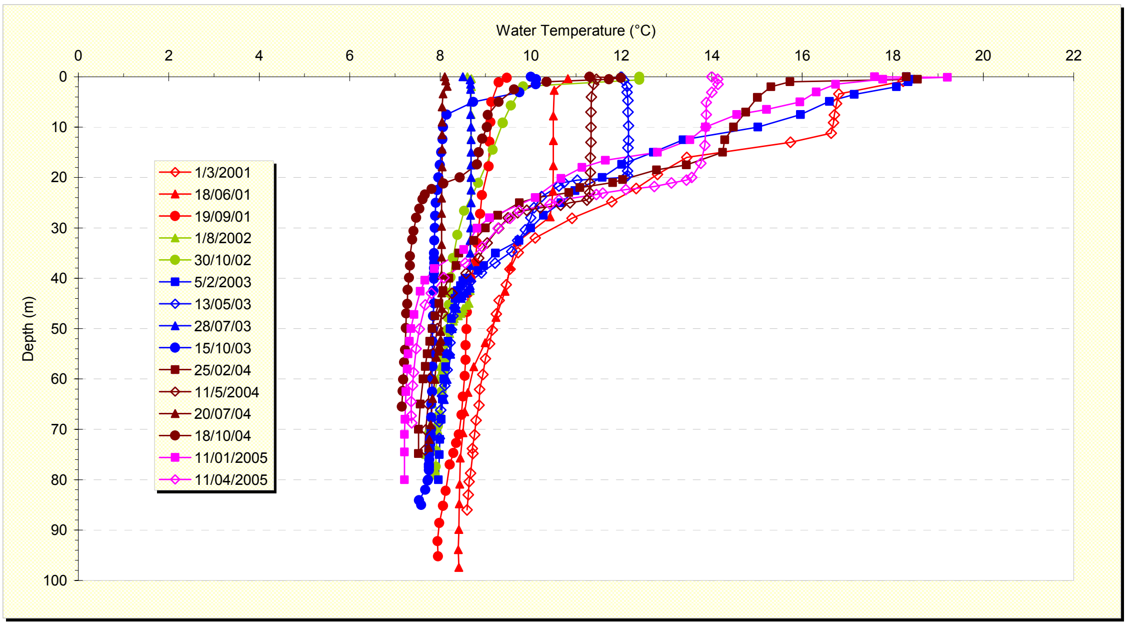


Figure 6.1. Depth profiles of water temperature at the intake site in Lake Gordon. Differing colours indicate years. Filled squares indicate summer profiles, open diamonds: autumn, filled triangles: winter and filled circles: spring profiles.

The Boyes Basin dissolved oxygen profiles indicated varying degrees of stratification, with low dissolved oxygen levels recorded below 20 m in the early autumn of 2001 and the summers of 2003 and 2005. The Calder Reach dissolved oxygen profiles showed distinct oxygen stratification, at around 25 m, in most autumn profiles. Anoxic values (<2 mg L$^{-1}$) were recorded only once (June 2001), although they were approached in most autumn profiles. The stratification was less marked in the summer profiles, and not apparent in the winter and spring profiles. The intake dissolved oxygen profiles were more strongly stratified than either of the other two Lake Gordon sites. Figure 6.2 shows the dissolved oxygen concentration profiles recorded at this site for the four monitoring years. Almost all profiles showed some degree of oxygen stratification, with stratification depth varying from 20 to 70 m. Most profiles recorded anoxic values (<2 mg L$^{-1}$) at depths ranging from 35 to 80 m. In a broadly seasonal pattern, which varied from year to year, stratification tended to develop during the warmer months, extending to its shallowest depths in late autumn. As the surface temperatures decreased over winter, the profile became more vertical, with the oxycline moving to its greatest depths in spring.

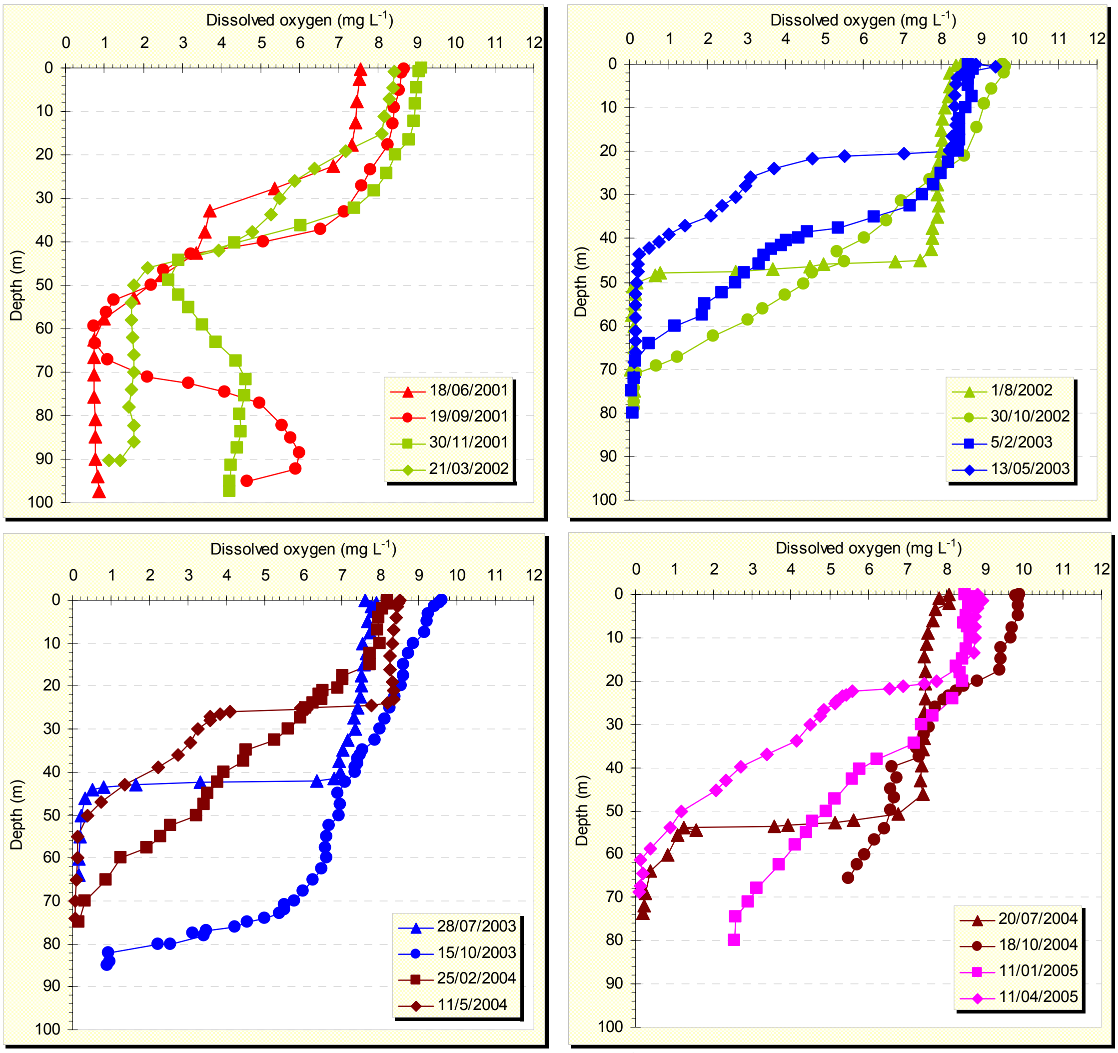


Figure 6.2. Depth profiles of dissolved oxygen concentration (mg L$^{-1}$) at the power station intake, Lake Gordon, for the years 2001-02 to 2004-05.

The dissolved oxygen profile for 19 September 2001 differed from the usual pattern by showing an increase in concentration to 6 mg $L^{-1}$ at a depth of 89 m (Figure 6.2). This is an indication of an 'underflow' effect which was first reported in Steane and Tyler (1982), and is apparently the result of oxygenated Gordon River water flowing down the old river channel below the anoxic layer of the lake. The profile for 30 November 2001 shows this pattern weakening (at about 50 m) and by 21 March 2002, oxygen approached normal levels for this site.

The pH profiles at Boyes Basin were variable. Some summer profiles showed a decline in value with depth at around 15 m, while others displayed variability associated with the unusual dissolved oxygen profiles for this site. Surface values ranged from 5.8 to 6.9 and bottom values ranged from 5.1 to 6.5. The Calder Basin pH profiles reflected the patterns of both water temperature and dissolved oxygen, with clines in pH values evident in most summer and autumn profiles. The site recorded a surface range of 5.5 to 6.9 and a bottom range of 5.1 to 6.2. The intake pH profiles extended the patterns recorded at the other two sites to a greater depth. Figure 6.3 shows the pH profiles recorded during 2004-05, which demonstrate the decline in pH with depth to a depth of around 50-60 m, after which the values began to rise with further depth. Sharp declines in pH were associated with similarly sharp declines in dissolved oxygen concentrations. For the period 2001-05, surface values ranged form 5.4 to 6.4. At 80 m, the values ranged from 4.7 to 5.9.

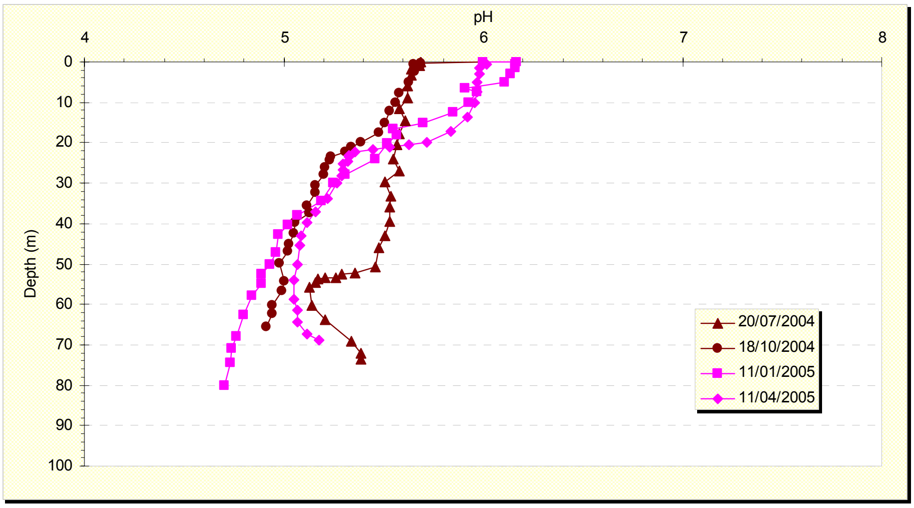


Figure 6.3. Depth profiles of pH at the power station intake, Lake Gordon, during 2004-05.

The Boyes Basin conductivity profiles displayed a large amount of variation similar to those of water temperature and dissolved oxygen at this site. Conductivity values ranged from 28 to 62 µS $cm^{-1}$. The Calder Basin conductivity profiles were even with depth and values ranged from 33 to 44 µS $cm^{-1}$. The intake conductivity profiles were uniform until a depth similar to that at which anoxic conditions were reached. Below this, conductivity tended to rise slightly. Values ranged from 31 to 50 µS $cm^{-1}$.

### 6.3.5 Summary of lake water quality

Both lakes demonstrated good water quality with parameter values similar to natural lakes in south-western Tasmania. The morphology of Lake Pedder is substantially different from that of Lake Gordon. The shallower Lake Pedder showed no indication of stratification and none of the water quality parameters indicated any issues which may impact on the water quality of the Gordon River.

Lake Gordon demonstrated good water quality, with the Boyes Basin site recording one incident of high chlorophyll-*a* and associated total phosphorus values. This was an important finding and will be monitored in the future. None of the water quality parameters indicated any issues likely to impact on downstream water quality. Lake Gordon was almost permanently stratified at the intake site and the depth of stratification may have an effect on the quality of water released from the power station. This aspect is discussed in more detail in section 6.3.6.1. Further information on the lake water quality results is available in appendix 3.

### 6.3.6 Gordon River dissolved oxygen

An important driver of dissolved oxygen concentrations in the Gordon River downstream of the power station is the concentration at the intake in Lake Gordon. This water passes through the power station, where its dissolved oxygen concentration may be modified. Finally, it is released at the tailrace, after which natural processes of entrainment or de-gassing come into play, although the effect of these processes may be influenced by discharge volume (resulting in greater or lesser turbulence) and thermal regulation (affecting the solubility of oxygen in water).

Dissolved oxygen monitoring was conducted quarterly at the intake site in Lake Gordon (see section 6.3.4), and continuously at the power station tailrace, from where it is released into the Gordon River. The intake depth profiles allow an examination of the interaction between the relative depth of the intake, which was subject to seasonal and annual fluctuations in lake level, and the stratification depth, which varied seasonally.

The tailrace data give an indication of the river's dissolved oxygen concentrations which prevail until ambient levels are achieved through downstream processes of entrainment or de-gassing. The distance required for this amelioration is not yet known. It is assumed that the steep and turbulent river channel immediately downstream of the power station promotes rapid restoration of ambient concentrations. A dissolved oxygen probe is due to be installed at site 65 (12 km downstream of the tailrace) during 2005-06, and this will provide some indication of the restoration of dissolved oxygen levels.

### *6.3.6.1 Intake depth*

The water level in Lake Gordon decreased from 300 mASL (metres above sea level) in September 1999 to 275 mASL in July 2003. It has since risen to 279 mASL (September 2005). These fluctuations were seasonal, with the lowest levels occurring in late autumn or early winter and the highest levels in late spring each year.

Given that the lake stratification level varies seasonally, fluctuations in oxycline depth superimposed on a declining water level allow an examination of the interactions between the intake depth and the depth at which anoxia occurs. Figure 6.4 illustrates the relationship between intake level, lake level, and the anoxic threshold since 1999. It shows that, for this period, the intake level has always been above the anoxic threshold (<2 mg L$^{-1}$) at the intake site. In the 1999-2000 year, when the overall water level was at its highest, the intake depth corresponded with dissolved oxygen values of between 2 and 6 mg L$^{-1}$, as shown in Figure 6.4. With the gradual drawdown of the lake, the anoxic threshold has become relatively deeper, so that for successive years the intake has drawn water of increasing dissolved oxygen concentration. Since 2003 only the autumn profiles have indicated that the dissolved oxygen content was less than 6 mg L$^{-1}$. All others indicated that the dissolved oxygen level was greater than this value. Figure 6.4 shows this relationship.

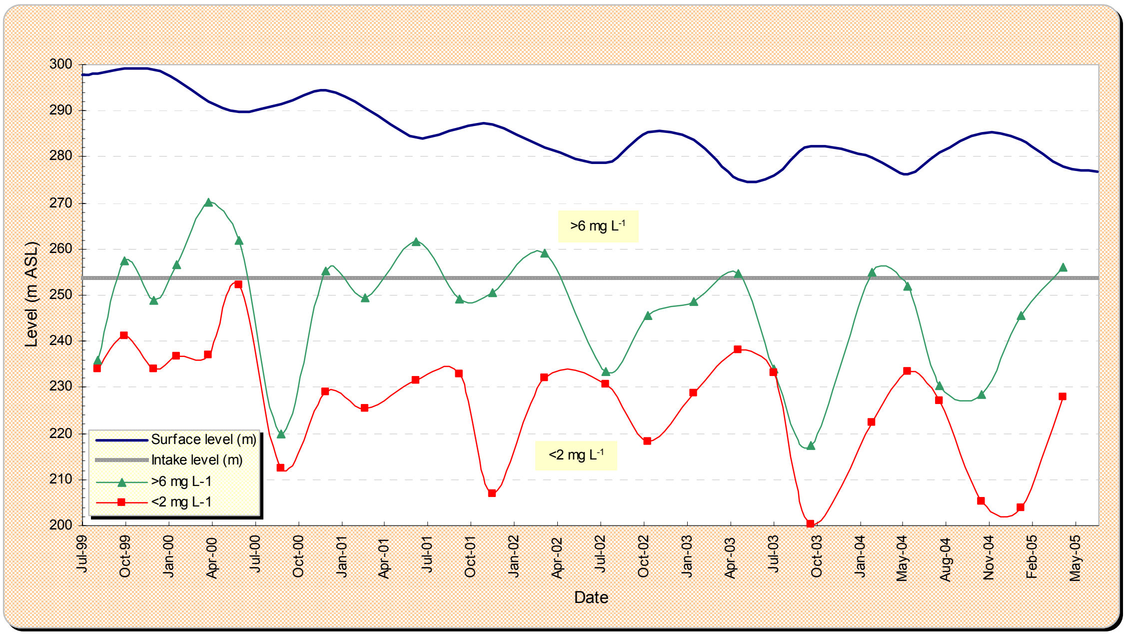


Figure 6.4. The correspondence between surface water level, intake depth and dissolved oxygen ranges at the intake site, Lake Gordon for the period July 1999 to June 2005.

It can be expected that the lake level will increase with time to approach the full supply level (FSL) of 307.85 m. At such levels, the intake may encounter water of low dissolved oxygen content as the oxycline rises relative to the intake level. This may mean that low dissolved oxygen concentrations become more prevalent in the tailrace discharge, although the extent and duration of such conditions is unknown. Should this scenario occur, it will be detected through the monitoring program, investigated and, if practicable, management actions undertaken.

### *6.3.6.2 Tailrace dissolved oxygen*

The dissolved oxygen data recorded at the tailrace are somewhat sporadic, with considerable amounts of missing data due to equipment failure. This is attributable to the harsh operating environment of the tailrace (with discharges ranging from 0 to 240 $m^3 s^{-1}$) and the difficulty involved in reliably powering the site. Table 6.1 gives the percent of readings which were taken each year and shows that reliability has ranged from 52.5 to 95.8 %. Figure 6.5 shows the dissolved oxygen values recorded at the tailrace in 2004-05, when the probe was at its most reliable. The dissolved oxygen values recorded for each monitoring year are presented in appendix 3.

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. For the purposes of this report, a value of 12 mg $L^{-1}$ will be used as an indicator of 100 % oxygen saturation, as this is the saturation value for water at 8 °C, a common temperature recorded in the Lake Gordon water column (see Figure 6.1). High tailrace dissolved oxygen levels occur as a result of air injection during the start-up phase of turbine operation. These levels were generally of a short duration.

Figure 6.5 shows that a period of high dissolved oxygen readings occurred during July 2004 and that few others were recorded during the remainder of the year.

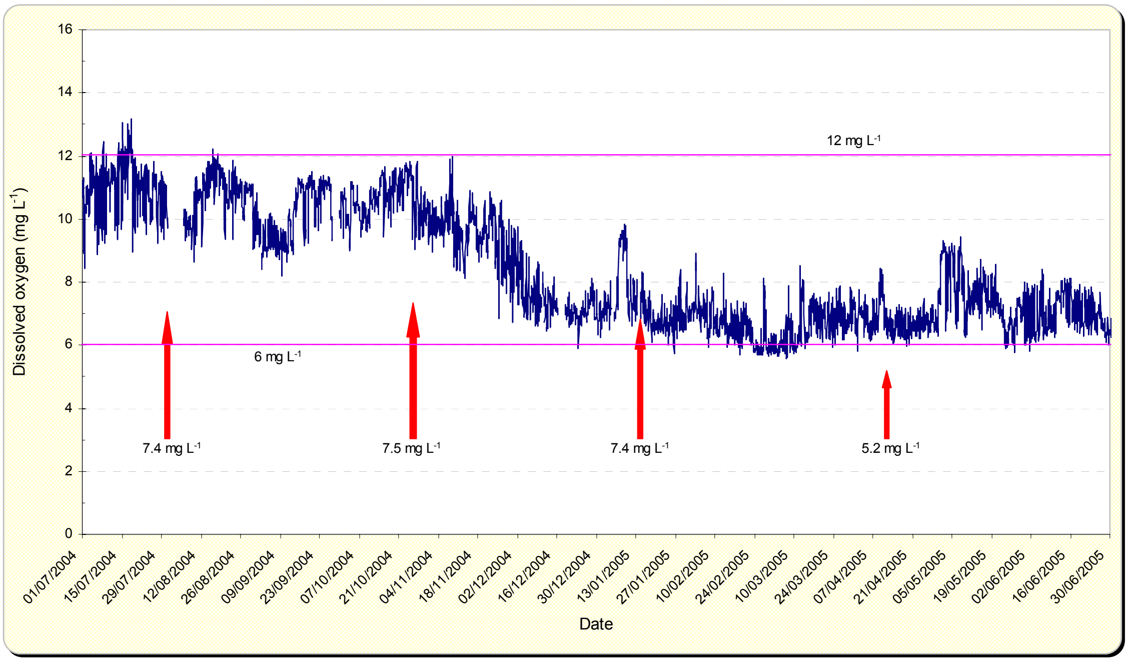


Figure 6.5. Dissolved oxygen concentrations recorded at the power station tailrace, July 2004 to June 2005. The solid lines show the 6 and 12 mg $L^{-1}$ values. The arrows indicate the dissolved oxygen concentrations recorded at the intake depth.

A study undertaken in 2003-04 examined the effects of supersaturated oxygen levels on total dissolved gases (GRBMAR 2003-04). This study found a poor correlation between the two parameters. Despite dissolved oxygen values approaching 120 % saturation, total dissolved gas levels did not exceed 99 % saturation. This finding is relevant to the potential effects of extreme dissolved oxygen concentrations on in-stream biota, as some fish species have been shown to be susceptible to supersaturated total dissolved gas concentrations. The finding indicates that the risk to downstream biota from excessive total dissolved gas concentrations is low.

The results of previous investigations into the relationship between power station operations and dissolved oxygen concentrations have produced improved conditions. Maximum values have decreased and minimum values have increased over time, while the percentages of high and low values have also decreased. Table 6.1 summarises the dissolved oxygen statistics for the period of 1999 to 2005.

Low dissolved oxygen values tend to result from continuous turbine running at efficient load (i.e. without air injection). For the purpose of this report a value of less than 6 mg $L^{-1}$ will be used as the low dissolved oxygen threshold. Figure 6.5 shows the dissolved oxygen values recorded at the tailrace in 2004-05, on which are superimposed the values recorded at the intake site. The intake data indicate that the passage through the turbines added dissolved oxygen to the in-flowing water at the time of monitoring. There was no indication of reduced dissolved oxygen concentrations under these circumstances.

Table 6.1. Annual dissolved oxygen statistics for the Gordon Power Station tailrace site, including: the percent of time that measurements were made; 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 | % measured | Maximum (mg $L^{-1}$) | Median (mg $L^{-1}$) | Minimum (mg $L^{-1}$) | %>12 (mg $L^{-1}$) | %<6 (mg $L^{-1}$) |
|---|---|---|---|---|---|---|
| 1999-2000 | 57.3 | 15.7 | 8.7 | 4.8 | 18.0 | 17.6 |
| 2000-01 | 70.0 | 17.2 | 7.8 | 4.1 | 16.1 | 25.0 |
| 2001-02 | 82.0 | 14.6 | 7.2 | 4.0 | 2.2 | 18.6 |
| 2002-03 | 52.5 | 13.6 | 8.9 | 6.0 | 5.2 | 0.0 |
| 2003-04 | 68.6 | 13.8 | 8.6 | 5.8 | 6.6 | 0.1 |
| 2004-05 | 95.8 | 13.2 | 7.7 | 5.6 | 0.76 | 3.2 |

Any extreme values are unlikely to persist, as the downstream channel is steep and narrow for several kilometres, providing ample opportunity for re-oxygenation or de-gassing. Reducing the frequency and duration of extreme dissolved oxygen events would reduce the area of impact of these events. There is presently no way of measuring either the extent of impact or of improvement. The installation of a dissolved oxygen probe at site 65 will enable the ameliorative effects of the intervening stream distance to be evaluated. Unless the dissolved oxygen levels at site 65 show that recovery of oxygen levels has not occurred, no further investigations are likely to be conducted on this issue.

In summary, under the lake level conditions prevailing during the monitoring period, the intake level has been above the anoxic threshold in Lake Gordon. This factor, combined with improved power station operating procedures, has resulted in the incidence of extreme dissolved oxygen values decrease over the monitoring period. Supersaturated dissolved oxygen levels have been shown to not translate to dangerous total dissolved gas levels. Low dissolved oxygen levels are considered likely to rapidly attain ambient concentrations due to the steep and turbulent river channel downstream of the power station. A dissolved oxygen probe is to be installed at site 65 to measure this recovery.

### 6.3.7 Gordon River water temperature

The Gordon Power Station released water from the Lake Gordon impoundment at a depth of between 35 and 45 m over the period 1999-2005 (see Figure 6.4). Water from such depths has a relatively stable temperature, although it is likely that, for the period of the monitoring program, the lake temperatures have been more seasonally variable than they would have been had the intake level been below the thermocline (see Figure 6.1). Figure 6.1 shows that the recorded water temperatures at the intake depth varied from 7 to 10 °C. This variability represented seasonal, rather than shorter term changes. These characteristics form the basis for the thermal regime which affects the river downstream of the dam.

From January 2000, the tailrace water recorded monthly average values ranging from 7.7 to 12.2 °C. The temperature of tailrace water was lower than that of downstream sites for much of the year. The mean differences in hourly water temperatures between the tailrace and site 75 (2 km downstream, with no significant additional in-flows) were less than 0.1 °C from 1999 to 2003. In September 2003, in an effort to improve the operational reliability of the tailrace, water quality probes were mounted remotely and the water samples were pumped to the probes. One artefact of this was that the water temperature data became much more variable, due to the increased exposure to ambient air temperatures encountered by the water sample. When this system malfunctioned, the water temperature data came to resemble the air temperature data. The lack of similar variation at site 75 indicated that the variability shown at the tailrace site after September 2003 was an artefact of the sampling method rather than an actual increase in thermal variability in the discharged water. Consequently, site 75 data were used as analogues for the tailrace data for post-September 2003 comparisons.

The site 75 temperatures were, at times, up to 3.5 °C warmer and 4.8 °C cooler than those of the tailrace. These extreme differences were usually recorded during power station outages, when no flow was being released. Under these conditions, water temperatures would be subject to local factors, such as orientation, pool depth and size, and ambient air temperature.

The mean water temperature differences between the tailrace and site 62 (downstream of the Denison confluence) were greater than those for site 75. This indicated that there was a warming trend of about 0.3 °C between these sites under the regulated discharge conditions which prevailed for most of the year. The extremes of difference ranged from 6.0 °C warmer to 4.0 °C cooler than the tailrace.

Figure 6.6 and Figure 6.7 show the water temperatures recorded from the tailrace (until September 2003), site 75 (from July 2003) and site 62 (Gordon River downstream of the Denison confluence) for each year of available record. The data from April 2005 onward are not presently available. The dataloggers from these sites are next due to be downloaded in October 2005.

In the warmer months (October-May), the downstream sites recorded warmer temperatures than those of the tailrace. In the cooler months (May-September) downstream temperatures tended to be similar to those of the tailrace or somewhat cooler (see Figure 6.6). This pattern indicates the broad effect of thermal regulation: during the warmer months, the power station discharge keeps downstream water temperatures cooler than ambient; and, during the cooler months, it keeps downstream temperatures warmer than ambient.

The temperature data shown in Figure 6.6 and Figure 6.7 indicate that:

a) the diurnal variability at the tailrace site was constrained for most of the time. When the tailrace data showed greatly increased variability, it was usually the result of a power station shut-down (around October each year);

b) the diurnal variability at site 62 was greater than the tailrace, but still constrained whenever the power station was discharging;

c) there was a seasonal cycle within the regulated water temperatures which peaked at around 12.5 °C in April and declined to around 8.5 °C in September-October; and

d) site 62 temperatures were generally higher (by about 0.4 °C) than the tailrace during the warming months (October-March) and approximately equal during the cooling months (April-August).

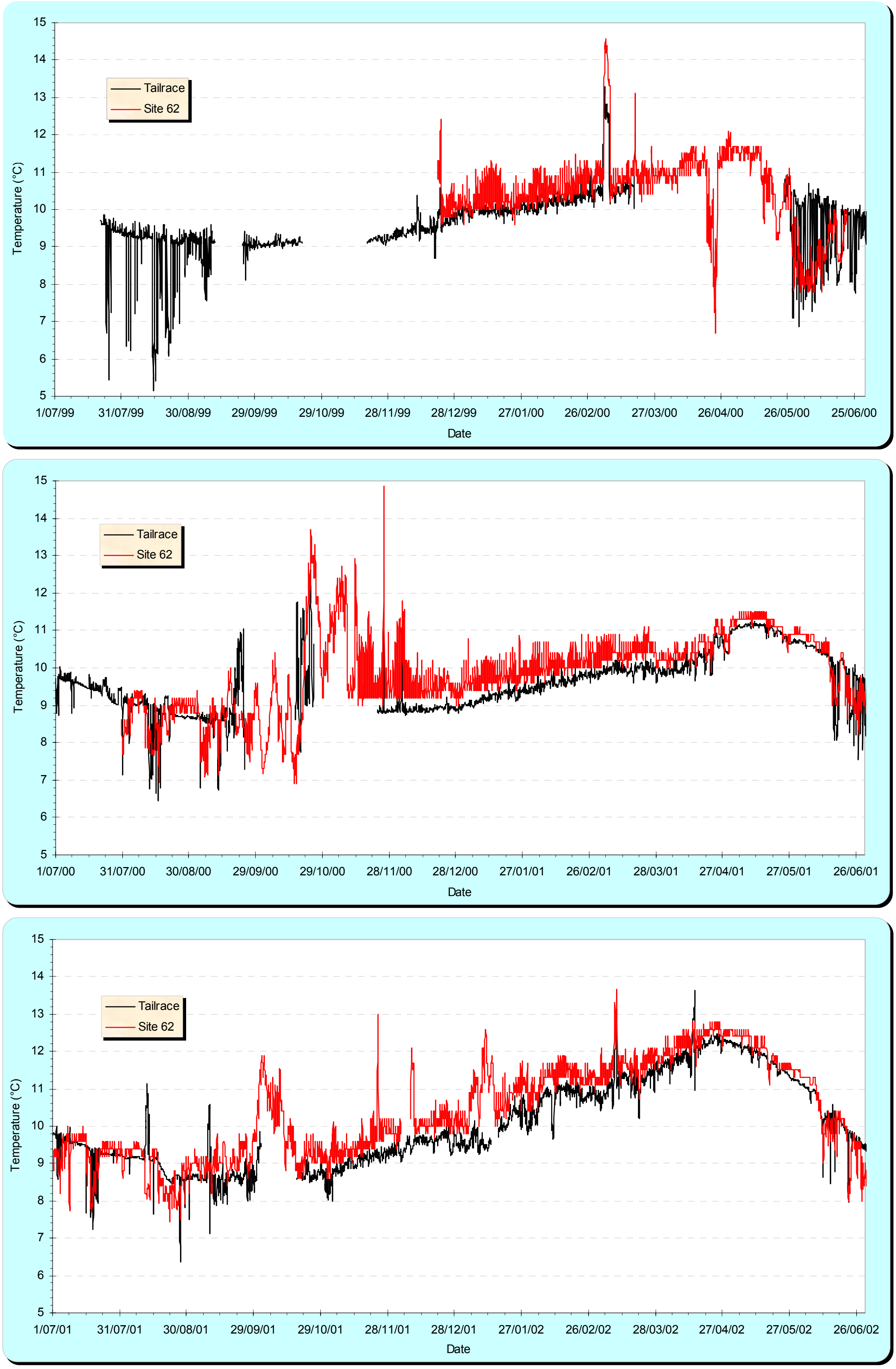
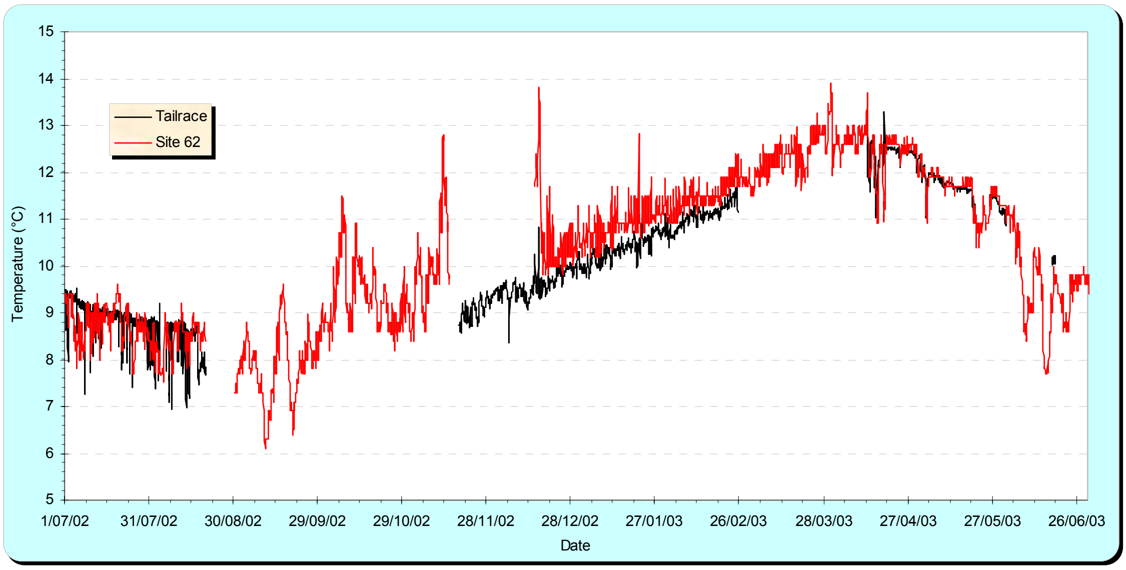
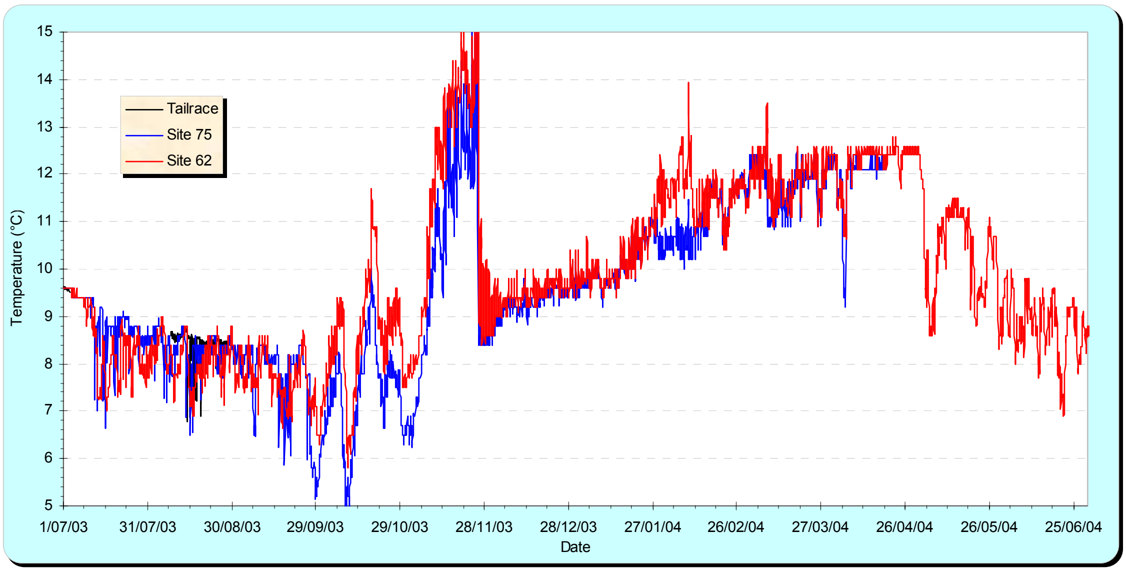


Figure 6.6. Water temperature values for the tailrace and site 62 (downstream of the Denison confluence) for the years 1999-2000 to 2001-02.





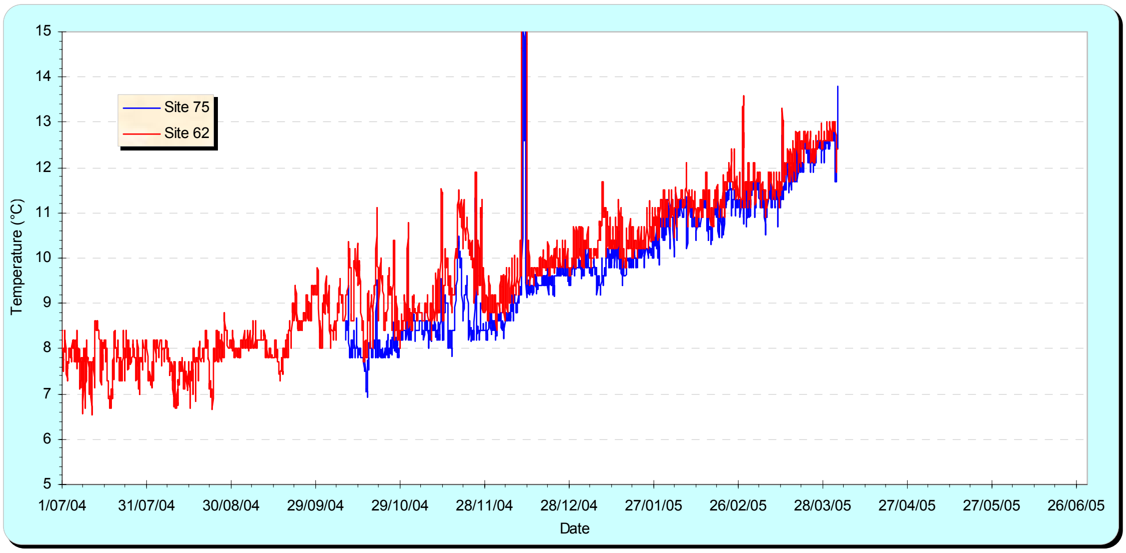


Figure 6.7. Water temperature values for the tailrace (to Sep 2003), site 75 (from July 2003), and site 62 (downstream of the Denison confluence) for the years 2002-03 to 2004-05. Note: the data from April 2005 onward are not yet available.

The patterns described above were driven by two processes: power station discharge, and the seasonality of flows. The hydrology chapter (chapter 5) showed that the discharge from the power station was seasonal and driven by the prevailing rainfall conditions and power demand throughout the state. Generally speaking, the Gordon Power Station was not heavily used in winter-spring when other power stations in the state network were producing power. In most monitoring years, there was an extended period around September-November when maintenance outages occurred at the Gordon Power Station.

In the drier summer and autumn months, the power station was more heavily utilised as runoff decreased throughout the state and the large storages (Lake Gordon and Great Lake) provided more of the state's electricity supply. The usual natural pattern of runoff is one of high discharge during winter-spring and decreasing discharge during the summer-autumn. Subsequently, the Gordon River thermal regime differs from a natural pattern in that:

- it originates from a well-buffered, seasonally varying source which produces a relatively constant temperature free of diurnal or short-term variation (see (a) and (c) above);
- when the power station discharge was greatest (summer-autumn), the thermal influence of natural in-flows was small and decreasing; and
- when the power station was shut-down for extended periods thermal regulation was removed, although natural in-flows were generally small.

The thermal pattern of the Gordon River under each of these operating conditions is examined in the following sections to provide insight into the potential effects of thermal regulation on the river's biota.

#### *6.3.7.1 High power station discharge*

A period of almost continuous 3-turbine operation (discharge of 210-240 $m^3 s^{-1}$) occurred during the warming part of the seasonal cycle in January 2003 (see Figure 6.7), while similar conditions during the cooling phase occurred in June 2002. Figure 6.8 shows the water temperatures recorded during these periods.

During the warming phase, there was a trend for higher temperatures with distance downstream of the station. There was also an indication of a small diurnal temperature increase (up to 1 °C) at the downstream site (site 62). During the cooling phase, the trend for downstream warming was reduced, while diurnal variation was not evident. Thermal variation during the entire seven-day period shown in Figure 6.8 (right) was less than 0.6 °C. These patterns illustrate the strong effect of thermal regulation under high discharge conditions.

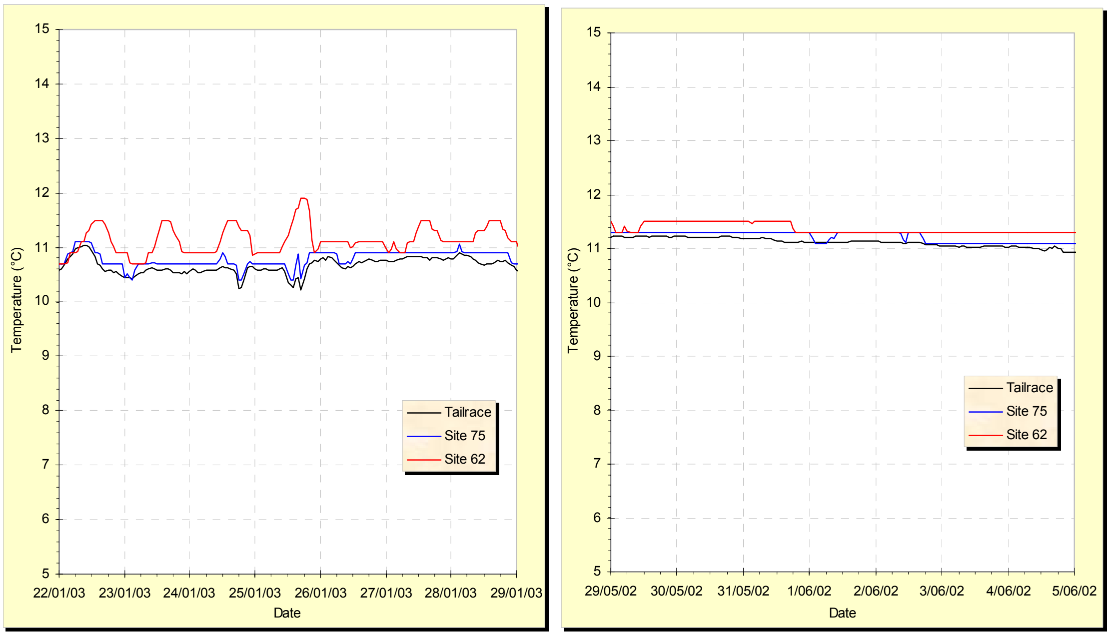


Figure 6.8. Water temperatures recorded at the tailrace, site 75 and site 62 during high volume power station releases. The left figure was recorded during the warming part of the seasonal cycle (January 2003) and the right figure during the cooling phase (May-June 2002).

### 6.3.7.2 *High discharge with short outages*

Given the strong thermal influence of high volume discharges, it is worth looking at the effects that short periods of zero discharge have on the downstream thermal regime. Figure 6.9 shows the thermal patterns recorded during short outages.

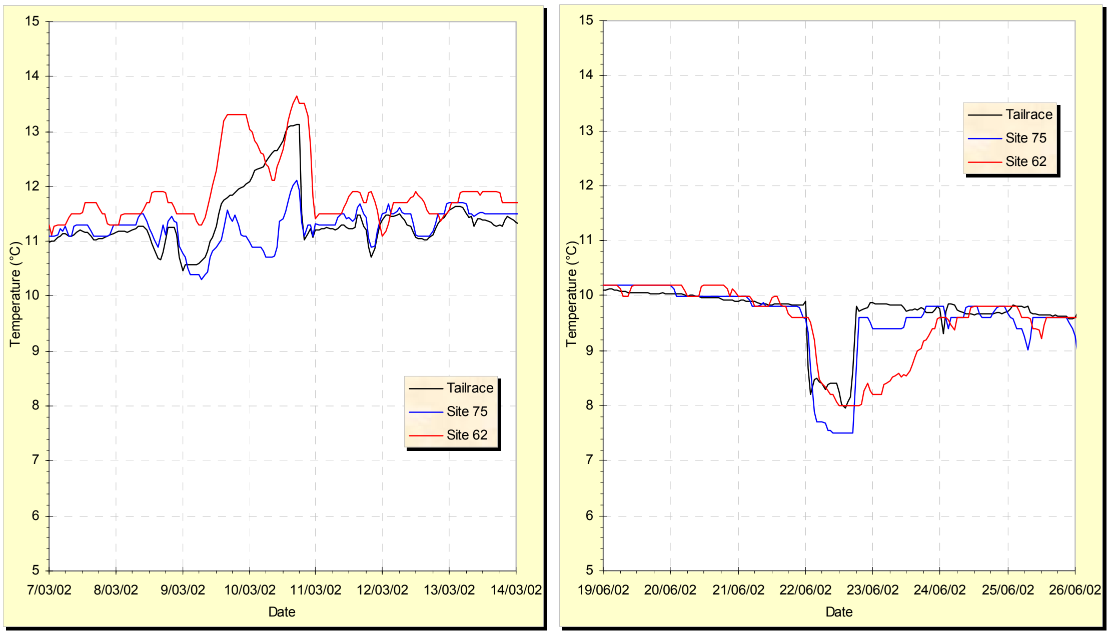


Figure 6.9. Water temperatures recorded at the tailrace, site 75 and site 62 during short (one-two day) outages. The left and right figures represent the warming (March 2002) and cooling phases (June 2002) of the seasonal cycle, respectiively.

During the warming phase of the seasonal cycle a two-day outage (9 -10 March 2002) allowed downstream temperatures to rise by more than 2 °C (Figure 6.9, left figure). The highly regulated thermal pattern is evident before and after this outage. This pattern also suggests that the power station discharge was keeping the water temperature at least 2 °C cooler than would be expected under natural discharge conditions.

During the cooling phase, an outage of less than one day (22 June 2002) followed by a small discharge for a day before a return to high discharge conditions allowed temperatures to fall by around 2 °C (Figure 6.9, right figure). On the initiation of the small discharge, both the tailrace and site 75 immediately resumed a regulated pattern. Site 62 did not regain a regulated pattern until the high discharges re-commenced. The highly regulated thermal pattern is evident before and after this outage. In this case, it appears that the regulated discharge was keeping water temperatures about 2 °C higher than ambient levels. These patterns indicate that short-duration outages of a day or more allow some return to ambient temperatures and increased variability.

### *6.3.7.3 Small power station discharges*

Another relatively common operating pattern is one of short periods of small volume discharge (around 10 $m^3 s^{-1}$), which occur when the power station is on standby. Figure 6.10 shows the thermal patterns recorded during such periods. Note that tailrace thermal data are not available for this period. The thermal pattern at site 75 is considered a sufficient analogue for the tailrace to allow comparisons to be made.

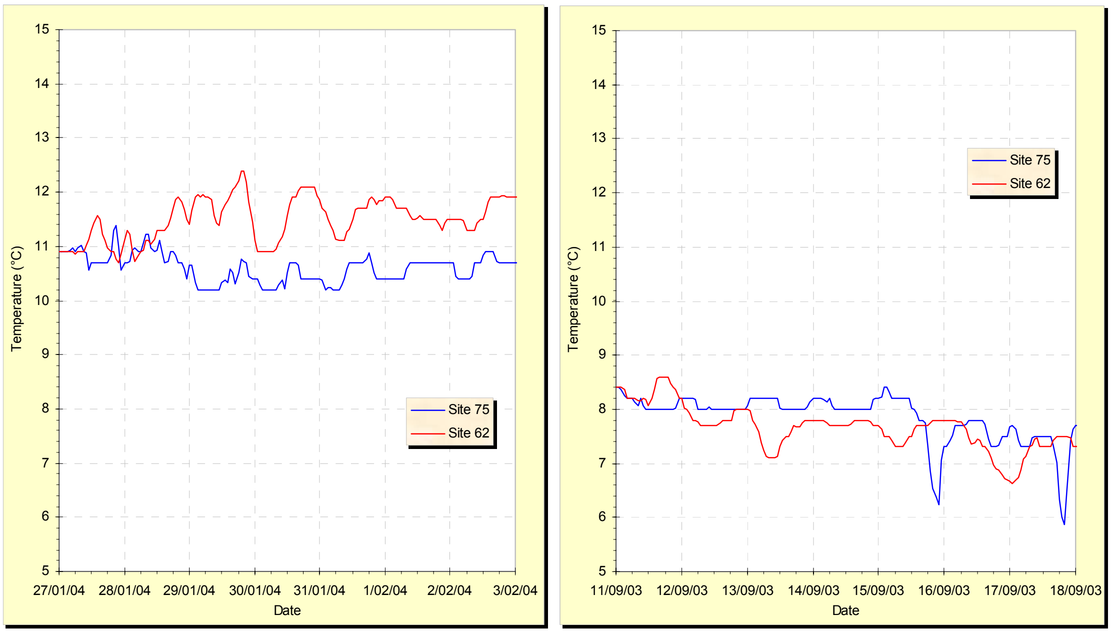


Figure 6.10. Water temperatures recorded at site 75 (as an analogue for the tailrace site) and site 62 during periods of 10 $m^3 s^{-1}$ discharge. The left figure was recorded during the warming part of the seasonal cycle (January-February 2004) and the right figure during the cooling phase (September 2003).

The left figure in Figure 6.10 shows temperatures recorded during the warming phase of the seasonal cycle. The first two days illustrated (27-28 January 2004) were subject to high discharge (160-200 $m^3 s^{-1}$), while the remaining days recorded discharges of around 10 $m^3 s^{-1}$. Even this small discharge was sufficient to maintain thermal regulation, although both temperature and thermal variability increased with distance downstream.

During the cooling phase which was evident in September 2003 the regulated thermal regime was maintained even at a small discharge (Figure 6.10, right panel). Dips in the pattern for site 75 indicate short periods (hours) of complete outage, the effect of which was not evident at downstream sites.

These findings indicate that even small power station discharges were sufficient to maintain thermal regulation. This has implications for the provision of the minimum environmental flow from the power station which must, at a minimum, provide a similar discharge.

### *6.3.7.4 No power station discharge*

The only extended times when the power station was not releasing water were during the maintenance outages, which usually occurred around October. During these outages, Gordon River water temperatures had a chance to achieve ambient levels, although with little tributary in-flow available at that time of year.

Figure 6.11 shows the temperatures recorded in August-October 2002. As this period was during the seasonal warming cycle, temperatures were initially low and increased with time. The tailrace data were not available. Temperatures increased with distance downstream of the power station.

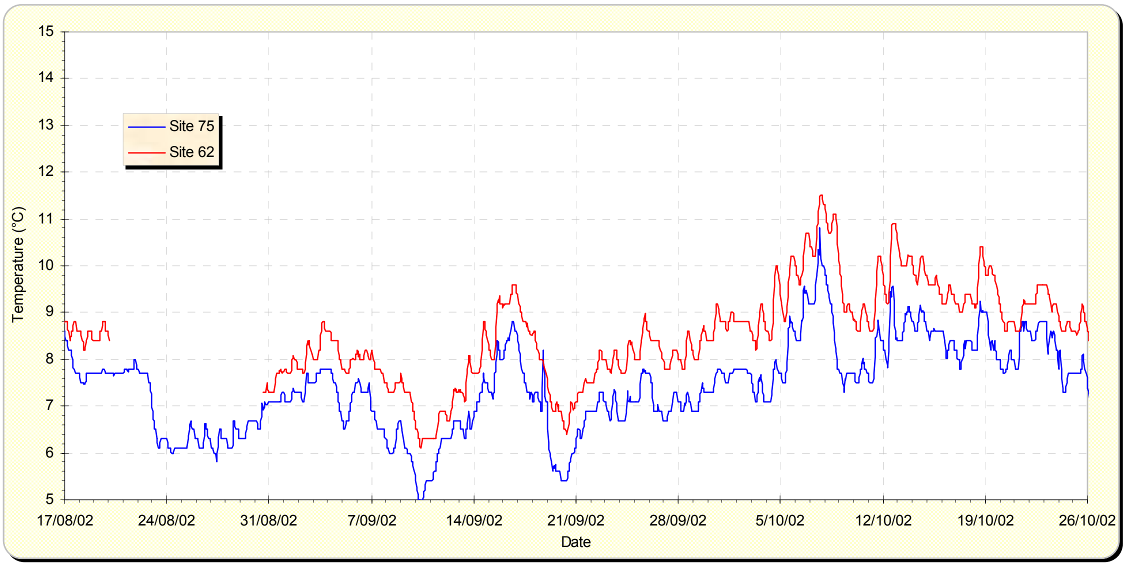


Figure 6.11. Water temperatures recorded at sites 75 and 62 during a period of no discharge from the power station from mid-August to late-October 2002.

Diurnal variation was not constrained by thermal regulation during this period, and ranged around 1-1.5 °C. Also apparent in Figure 6.11 was a series of temperature fluctuations with periods of 5-10 days. These were likely to indicate the effects of passing weather patterns and resulted in variations of as much as 6 °C, and typically about 3 °C per week.

There were no periods of complete outage during the cooling phase of the seasonal cycle.

#### *6.3.7.5 Thermal regulation summary*

Thermal regulation removes the temperature signal of diurnal and weather-related variability and this effect remains strong at least as far as site 62, some 15 km downstream from the tailrace. It is likely that the effects of thermal regulation extend considerably further downstream, although these may be mitigated during the winter period when natural flows are high and power station discharges are reduced. The effects of thermal regulation are evident for most of the year and under all regulated discharge conditions except complete shut-down. During the warming part of the seasonal cycle (September-March) there was a trend for increasing temperatures with distance downstream, while during the cooling part of the seasonal cycle (April-August) temperatures were similar at all sites.

High power station discharges produced complete thermal regulation in the cooling phase (May-September) and allowed only minor downstream warming and diurnal variation during the warming phase (October-April).

Depending on the season, power station shut-downs produced short-term respites from thermal regulation, allowing some return to ambient thermal conditions and increased variability during both the warming and cooling phases. It is unlikely that these were of benefit to downstream biota because of their short duration.

Thermal regulation upstream of the Denison confluence persisted even at low volume discharges of around 10 $m^3 s^{-1}$. The unregulated flows of the Denison River prompted a return to ambient temperatures at site 62 in the presence of small-volume power station discharge. This did not have a mitigating effect on water temperature while the power station was releasing the higher flows associated with power generation.

Power station maintenance outages, which generally occurred once per year around October, allowed the full recovery of ambient thermal patterns for periods of 4-6 weeks. These periods would have some effect on macroinvertebrate productivity, although they occur during periods of low natural flows. They are unlikely to have a great effect on fish or aquatic mammals except to provide short-term increases in prey (macroinvertebrate) abundance.

## 6.4 Analysis and interpretation

### 6.4.1 Key environmental factors

The key factors affecting or being affected by water quality include:

- The relative depth of the power station intake: primarily whether it is above or below the thermocline or oxycline, as this affects dissolved oxygen levels and water temperature in the discharge;
- Operating conditions of the power station: air injection (used during turbine start-up) may cause oxygen supersaturation; steady running at efficient load may deplete oxygen levels;
- Slope and confinement of the river channel immediately downstream of the power station: this is assumed to facilitate recovery from extreme dissolved oxygen conditions;
- In-flowing tributaries help remediate the thermal signal, and their effect is dependant on the volume of power station discharge;
- Reduced thermal variability: this would have been likely to cause a reduction in both number of taxa and individual abundance in affected species; some species, such as *Astacopsis tricornis*, may be advantaged or unaffected; and
- Absence of short-term (diurnal and 5-10 day) temperature fluctuations: may be causing missed migration or reproduction cues for in-stream biota.

Many of these factors are not directly addressable, although their effects need to be considered.

Little can be done about the relative depth of the power station intake.

Operational procedures have been implemented to minimise the frequency and duration of extreme dissolved oxygen levels and these should remain in place post-Basslink. Reducing the frequency and duration of extreme dissolved oxygen events would reduce the area of impact of these events. The recovery of dissolved oxygen levels is to be monitored at the compliance monitoring site (site 65).

There is no direct way of mitigating the thermal regulation effects of the power station: water is necessarily sourced from the impoundment at the intake depth. It would be costly and probably impracticable to retro-fit a multi-level intake to the power station.

Some mitigation of the effects of thermal regulation may be achieved by sourcing the minimum environmental flow from surface waters. This would be likely to introduce unacceptable risks of downstream translocation of pest fish species if sourced from Lake Gordon. Lake Pedder would provide a useable source for the minimum environmental flow, but at considerable expense for the potentially small benefit obtained from short-term relief from thermal regulation. Such a strategy may provide benefits if the minimum environmental flow were released from Lake Pedder during the extended maintenance outages which occur approximately annually.

### 6.4.2 Biotic interactions

Thermal regulation in the middle Gordon River is linked to the distribution and abundance of in-stream biota. The reduced variability of the regulated thermal signal would tend to advantage some species and disadvantage others. Thermal regulation appears to have a more persistent effect over a greater distance than dissolved oxygen effects. Thermal regulation may impact downstream biota's metabolic rates, predation and feeding behaviour, and awareness of environmental cues for migration and reproduction. It would also be a contributing factor to the depauperate macroinvertebrate and fish communities observed in the Gordon River upstream of the Denison confluence.

One invertebrate species apparently not disadvantaged by the thermal regulation is the freshwater crayfish, *Astacopsis tricornis*. Individuals are frequently captured during fish monitoring activities. Large individuals occur throughout the middle Gordon catchment and frequent the deeper pools in the main river channel. The freshwater crayfish, along with short-finned eels, appear to be the only native species present along the entire length of the middle Gordon River. The presence of egg-carrying females suggests that the thermal conditions are suitable for spawning to occur. Smaller individuals tend to be found in steep tributary streams throughout the catchment.

Given the time since thermal regulation began and their comparatively rapid response rate, impacts of thermal regulation on the biotic community are now full realized, and the community composition has adjusted to this regulated temperature regime.

### 6.4.3 Conclusions

In terms of water quality, the middle Gordon River is impacted by thermal regulation and, to a lesser extent, by extremes in dissolved oxygen. It is unlikely that post-Basslink operating conditions will exacerbate the dissolved oxygen extremes, although they may lead to changes in the frequency or persistence of such events.

It is unlikely that post-Basslink water quality conditions will worsen from their present levels, with the possible exception of greater thermal regulation produced by the minimum environmental flow.

Given the limited opportunities for mitigation or remediation of the water quality effects, combined with the overwhelmingly greater effects of flow regulation, it is unlikely that improvements in water quality alone would produce measurable improvements in downstream biotic communities.

## 6.5 Evaluation of the Basslink monitoring program

The current capacity of the BMP for water quality monitoring is generally good, although the tailrace monitoring infrastructure has been unreliable. The method of sampling installed in late 2003 had improved reliability but has also increased the variability of water temperature data. This artefact means that the tailrace water temperature data are no longer directly comparable with those from downstream recorders.

In terms of its breadth, the program is collecting some data which is of little consequence to the middle Gordon River. The near-pristine water quality of Lakes Pedder and Gordon and the absence of potentially disturbing land uses in upstream areas means that it is probably unnecessary to monitor most of the lake sites. It is only the water quality values and stratification pattern at the power station intake site that are important to assess the influence of Lake Gordon on downstream water quality.

These are opportunities to improve downstream water quality monitoring to gain a better understanding of the effects of the power station discharge. Dissolved oxygen is presently only measured at the tailrace site. An additional oxygen probe is planned for installation at the compliance monitoring site (site 65). This will allow some comparison between conditions at the tailrace and site 65 and will give some indication of the mitigating effects of the intervening 12 km of stream flow.

## 6.6 Water quality indicator variables

During the IIAS process, a range of water quality indicator variables were identified to allow post-Basslink evaluation. Defining the indicator variables, and trigger values, forms the first step in a three-step process of evaluation and management action (see chapter 13). Water quality parameters in Lakes Gordon and Pedder and in the Gordon River were examined for suitability as indicator variables, including dissolved ions, dissolved oxygen, gas superannuation and temperature (Koehnken 2001).

Trigger values were set for dissolved oxygen values at the tailrace and for water temperature measured downstream of the power station, as these are the key parameters that may change under Basslink operating conditions, and will consequently affect downstream biota.

Other water quality parameters which may be affected by Basslink operations include the dissolved oxygen and temperature characteristics of the power station in-flow, which are dependent on the relative level of the intake to seasonally variable stratification patterns and longer-term changes in the lake water level. However, it is not considered practicable to define trigger values for these parameters, as similar effects are likely without Basslink. Also, their ultimate impacts (if any) will be indicated by the indicator variables and associated trigger values defined for the downstream parameters.

Unlike the other disciplines, the water quality indicator variables are based on methods presented in the ANZECC/ARMCANZ (2000) guidelines for water quality monitoring and reporting. The trigger values are established at the 20th or 80th percentile of reference site values and a trigger for further investigation occurs when the median value from the test site exceeds the trigger values.

# 7 Fluvial geomorphology

## 7.1 Chapter summary

The purpose of this chapter is to summarise the findings of the ongoing Basslink fluvial geomorphology monitoring project, and provide a baseline against which post-Basslink monitoring results will be compared. A major focus of the investigations and monitoring has been to link the present fluvial geomorphic processes operating in the middle Gordon River to the underlying hydrologic drivers as discussed in the conceptual model (chapter 3). This will provide a framework within which post-Basslink hydrologic changes and fluvial geomorphology monitoring results can be interpreted.

The major findings of the geomorphology monitoring include:

- Flow changes associated with damming, diversion of additional water into the catchment, and flow regulation have lead to channel widening in the alluvial sections of the river, with the planform of the river unaffected due to the large amount of bedrock/boulder control of the river channel. Net bank erosion rates vary by zone, ranging from no net change (zones 1 and 5) to up to ~20 mm/yr in zones 2-4;
- Bank disturbance is generally limited to the area (height) inundated by power station operation, where vegetation was removed through inundation following damming leading to the exposure of the underlying sandy alluvial banks. Upslope of power station-controlled water levels, vegetation has increased, and bank disturbance is limited to flood disturbance downstream of the Denison River. Land slips upslope of power station operating levels have been found to be stable, and revegetate relatively rapidly;
- The erosion pin results indicate erosion of the banks is progressing in a downstream direction, with zone 1 immediately downstream of the power station largely stable, zones 2 and 3 (upstream of the Denison) having stable bank toes with erosion concentrated in the 1-2 and 2-3-turbine bank level, and zones 4 and 5 undergoing erosion of bank toes, with dynamic but stable upper banks (1-2 and 2-3 turbine bank level). Due to the limited duration of pre-Basslink monitoring, it is unknown how much of the erosion is associated with the initial damming of the river, and how much is associated with increased duration 3-turbine power station discharge over the past four years; and
- Limits of acceptable change have been identified based on the present erosion trends in the river as indicated by grouping erosion pins by zones and/or turbine levels, recognizing that, over time, rates are likely to change in the presence or absence of Basslink due to the non-equilibrium condition of the river. Photo-monitoring, bank profiling, observations of

seepage erosion and piezometer results will be used to assist in the interpretation of post-Basslink changes.

## 7.2 Introduction

Fluvial geomorphology investigations in the middle Gordon River were initiated during the IIAS Basslink investigations with findings reported as appendix 4 of the IIAS report (Koehnken *et al.* 2001), and supplementary information provided to the Joint Assessment Panel (JAP). These investigations were the first conducted in the middle Gordon River since damming occurred, and identified impacts associated with the initial regulation of flow as well as identifying potential Basslink-related changes. Ongoing monitoring of fluvial geomorphology in the middle Gordon River was one of the requirements for Basslink to proceed, and a monitoring program was developed and implemented in 2001.

This report summarises the findings of the ongoing Basslink fluvial geomorphology monitoring project, and provides a baseline against which post-Basslink monitoring results will be compared. A major focus of the investigations and monitoring has been to link the present fluvial geomorphic processes operating in the middle Gordon River to the underlying hydrologic drivers as discussed in the conceptual model (chapter 3). This will provide a framework within which post-Basslink hydrologic changes and fluvial geomorphology monitoring results can be interpreted.

## 7.3 Monitoring

### 7.3.1 Approach

The IIAS Basslink investigations were based on observations and characteristics of the river banks in the middle Gordon River, an understanding of the discharge patterns from the Gordon Power Station, the hydrology of the unregulated tributaries in the catchment, sediment transport modelling and the anticipated changes to power generation due to the implementation of Basslink.

Prior to the IIAS investigation, no detailed geomorphic investigations of the middle Gordon River had been completed. This resulted in the IIAS investigations needing to identify processes and trends associated with the initial response of the Gordon River to damming and, more recently, to the installation of a third turbine in 1989, before developing post-Basslink predictions. Investigations focussed on channel widening associated with the increased flow directed down the Gordon since damming, seasonal flow changes, and the water level fluctuations associated with power station operation, as described in the conceptual model (chapter 3).

The approach for the ongoing geomorphic monitoring was established during the IIAS and guided the design of the Basslink Monitoring Program. The initial IIAS field investigations found that upstream of the Denison, the river bed is armoured, and the alluvial reaches of the river are prone to bank erosion as compared to the more resistant vertical cemented cobble banks and bedrock banks. Downstream of the Denison, the bed is more mobile, there is greater sediment input from the unregulated tributaries, and overall the river is more dynamic (Koehnken *et al.* 2001). These findings focussed Basslink investigations on the alluvial banks of the middle Gordon.

Sediment transport modelling completed during the IIAS found that even under conditions of very low flow (power station off) the river has sufficient energy to transport the range of sediment sizes present on the sandy alluvial banks of the middle Gordon River, leading to the conclusion that erosion rates in the Gordon are largely dictated by sediment availability rather than transport. It was also recognised that channel stability would not be achieved until bank toes stabilised, followed by the adjustment of the upper banks. The relatively fixed water levels associated with various turbine output at the power station (especially upstream of the Denison) result in the various bank levels responding to specific operating modes of the power station. Therefore the BMP monitoring was based on the premise that there would be longitudinal (downstream), vertical (up bank slope) and temporal components associated with bank readjustment both before and after the implementation of Basslink. This led to the majority of the monitoring effort being directed at understanding the availability and transport of sediment on the alluvial banks over longitudinal, vertical and temporal scales. Because the sediment transport modelling, based on ~90 sediment samples, found that *all* material present on the sandy alluvial banks is easily transported under any flow condition (even power station off); no additional effort has been directed at the classification of bank materials. This does not mean that small scale variability of sedimentary characteristics at individual sites have no impact on erosion rates, but assumes the impact of bank material variability, along with local variations in hydraulic conditions will be reflected in the data set. As a step towards capturing how bank morphology affects long-term erosion rates, bank profiling at each monitoring site has been completed (see appendix 4) and will be periodically repeated. (For a detailed discussion of the sediment transport model and an environmental flow regime, see section 12.5.1.)

The ongoing monitoring has built on the initial investigations, and continues to document the response of the river to damming and relatively recent increased usage of three turbines, thus providing a baseline for pre-Basslink conditions. Because the river channel is continuing to respond to the present regulated flow regime combined with the natural variability of the unregulated tributaries, the pre-Basslink baseline is not a static, equilibrium condition which can be easily quantified. Rather, the baseline is a collection of processes, rates and trends which can be used to describe and quantify the present condition of the river. The aim of the monitoring has been to provide a coherent and robust picture of these processes and trends against which post-Basslink results may be compared. However, it must be emphasised that as the river banks are not stable, and are continuing to respond to the regulated flow regime, identifying Basslink-related changes as distinct from the ‘natural’ progression of the present processes presents a challenge.

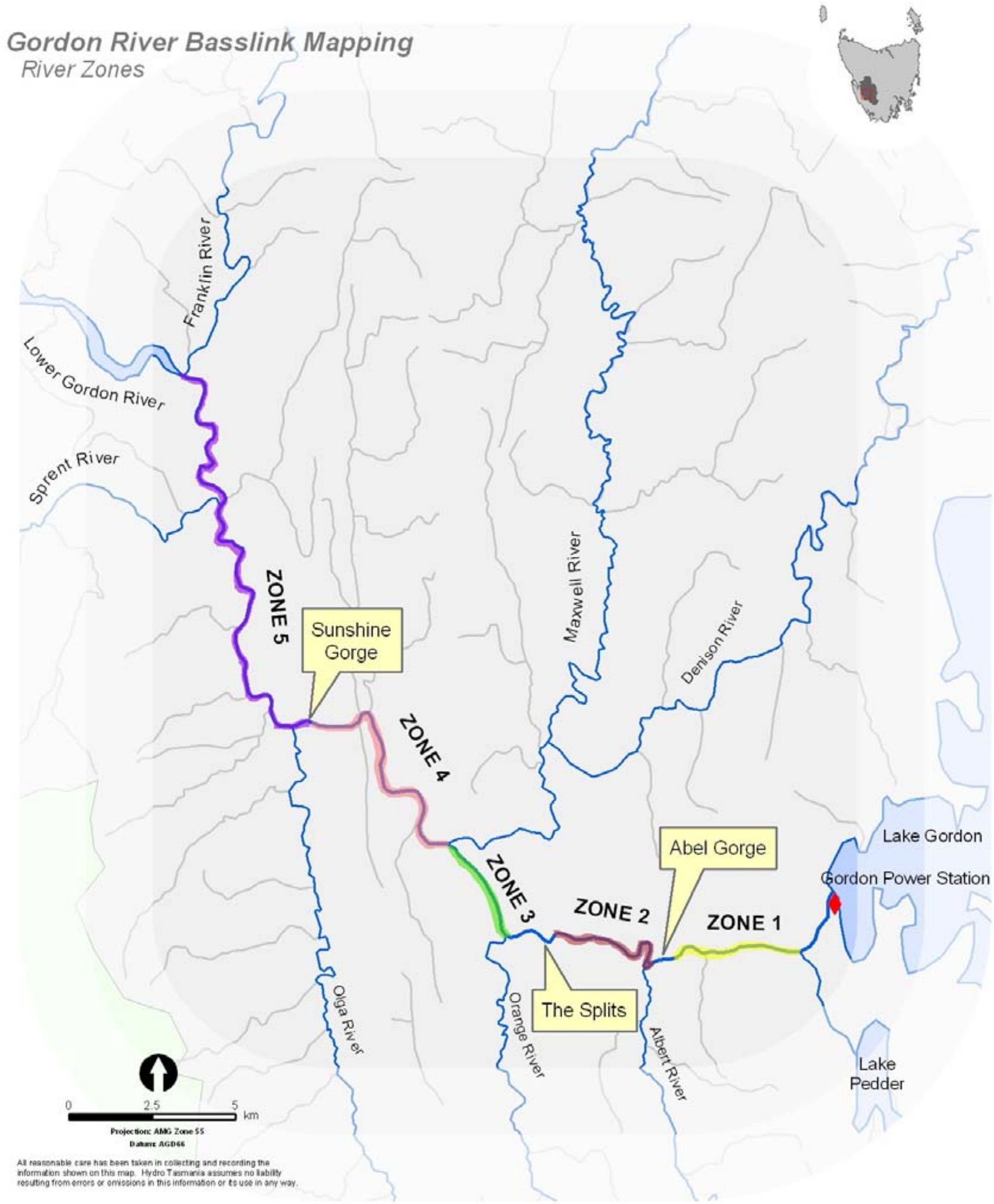
## 7.3.2 Methods

Numerous monitoring approaches have been adopted for the Basslink baseline monitoring which recognise the diversity of materials present in the banks and bed of the river, the different temporal and spatial scales over which processes occur, and the limited access to the river. The following sections provide a brief overview of the methods adopted and the rationale.

### *7.3.2.1 Zones*

The middle Gordon River has been subdivided into five geomorphic zones, as shown in Map 7.1.

- 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.



Map 7.1 The location of the five zones used to investigate the geomorphic processes of the middle Gordon River.

During the IIAS, bank characteristics in these zones were mapped at a broad scale, and used to establish the extent of bedrock, sandy alluvium, cobbles and bedrock or cobbles overlain by sandy alluvium in the study area. The bank mapping results are contained in the IIAS and a summary of the distribution of bank materials is presented in chapter 3.

### *7.3.2.2 Erosion pins*

Initial reconnaissance of the river found that vegetation has been removed from bank faces below the two turbine power station operating level, revealing the underlying bank materials which can generally be classified as bedrock, indurated cobble banks or sandy alluvium. Where the sandy alluvium was exposed, there were signs of fluvial erosion and deposition, and seepage erosion processes associated with the de-watering of the banks following power station shut-down (see chapter 3, Conceptual model, and section 7.4.5 for discussion of seepage erosion).

Due to the resistant nature of bedrock and cobbles compared to sandy alluvium, these sandy alluvial banks are the most susceptible over short timescales to channel widening within the river, and were targeted for monitoring using erosion pins. The erosion pins have been used to determine fluvial deposition and erosion on bank faces, and also detect movement in seepage erosion induced cavities located above the 2-turbine operating level. Combined with field observations, erosion pins have also allowed the observation of the mass-movement of bank materials.

Erosion pin sites are shown on the maps in appendix 4 (Geomorphology A). A total of 46 sites containing over 200 pins have been installed in the middle Gordon, which are measured in October and March each year. The distribution of pins with respect to bank type (alluvial, or alluvium over cobbles or bedrock) and location within the river (inside bend, outside bend, straight reach) is presented in appendix 5 (Geomorphology B).

Pin numbers have varied as some pins have been lost, and others added. Additional readings at some sites have been obtained on an opportunistic basis. Within each zone, sites were chosen to represent the range of bank characteristics present (slope, abundance of large woody debris (LWD), presence/absence of tea tree or other vegetation, presence/absence of seepage erosion), and location within the river channel (inside bend, outside bend, straight reach). A higher density of erosion pin sites was installed in zone 2, where there is a high occurrence of alluvial banks and evidence of channel widening is widespread. Pins were typically placed in a profile up the bank, between power station off low water level, and the initiation of vegetation. At sites prone to seepage erosion, long (2-3 m) pins were driven horizontally into the back walls of cavities. Changes to these pins do not reflect fluvial erosion or deposition, but rather collapse and erosion of the cavity due to seepage processes.

Other pin layouts included longitudinal profiles along banks overlying bedrocks or cobbles, a ‘V’-pattern in a small drainage line below power station water level, and a transect from the river to a backwater. Details of each monitoring site are contained in appendix 4.

Bank profiles at erosion pin sites have been measured using hand levelling equipment. These profiles, which are shown in appendix 4, have been used to estimate the location of pins relative to the 1-, 2-, and 3-turbine power station operating levels.

#### *7.3.2.3 Scour chains*

At 25 of the erosion pin sites, scour chains have been used to obtain additional information about erosion and deposition between monitoring visits. A scour chain is a length of chain approximately 1-1.5 m in length. Approximately half the length of the chain is inserted vertically in a sandy alluvial bank, using a pipe driven into the bank, and the other half is laid horizontally on the surface of the bank. The number of links exposed above ground is recorded. On subsequent visits, the total amount of deposition on the exposed links indicates the total net deposition at the site. Once this depositional material is removed the number of exposed links are counted, which indicates whether scour, which exposes additional links, occurred prior to deposition.

Scour chains were generally inserted on the lower bank face, between the lowest erosion pin on the bank (toe) and next pin on the bank (typically 1-2 turbine water level). Scour chains were measured twice per year during the October and March monitoring, with the results used to assist in the interpretation of erosion pin results, and field observations.

#### *7.3.2.4 Piezometers in zone 2*

In addition to the placement of erosion pins in banks exhibiting signs of seepage erosion, an array of piezometers was installed in zone 2 at the initiation of the IIAS investigations, and upgraded in August 2001 for the ongoing monitoring program. The probes were installed to provide information about the in-bank water levels in relation to power station operation, which was recognized as important for seepage erosion processes. The array consists of five probes placed between the waters edge at low water (power station off, 0 m) and 27 m inland. These probes record the *in situ* water level at 15 minute intervals.

#### *7.3.2.5 Photo-monitoring*

Many fluvial geomorphic features in the middle Gordon River occur over scales of metres to tens of metres, and can be readily monitored using repeat photography. These features include land slips, tree falls, cobble banks and cobble bar profiles and features. Landslips and tree falls were included in the photo-monitoring sites to track the response of a bank following a disturbance.

The locations of photo-monitoring sites are shown on the zone maps in appendix 4. Photo-monitoring sites are visited on an annual basis in March.

#### *7.3.2.6 Aerial photo interpretation*

For the IIAS investigations, aerial photos from 1974 (during dam construction) were compared with photos obtained in 1999. Features such as the drip line, sandy/rocky shoreline, logs, clearings, lateral and mid-stream bars, extent of vegetation were compared for the two maps, and significant differences were identified where possible.

Additional aerial photos of the river were obtained in December 2004, and a similar analysis is being completed by Hydro Tasmania. A summary of this work will be presented in a subsequent annual monitoring report as, as the results are not yet available.

### 7.3.3 Limitations of monitoring

The difficulties associated with access to the middle Gordon River, and the complex nature of the processes operating in the catchment have contributed to limitations of the geomorphology monitoring program.

The low frequency of monitoring (twice per year) and field observations limits the ability to link specific hydrologic flow patterns to bank processes. Because monitoring has been completed at the same time each year (October and March) and the power station has been used similarly in the lead up to monitoring, the results reflect these two ‘modes’ of power station operation only. Bank processes associated with other operating patterns; such as 1- or 2-turbine power station usage combined with high natural inflows during winter have not been able to be recorded. Also, the variability of the banks over distances of metres limits the applicability to extrapolate individual pin results to river reaches. The use of bank profiles to interpret pin results within a site has been adopted to diminish the effect of this local variability on the overall data set.

An additional limitation of the monitoring is the relatively short timeframe (four years) with respect to the length of time since flow in the river was regulated. This four-year record is insufficient to identify where the river is in terms of reaching equilibrium with the regulated flow regime.

Whilst the limited access and monitoring prevent a better understanding of processes occurring in the middle Gordon River, it has been adequate to identify erosion or deposition trends suitable for use as a pre-Basslink baseline as discussed in the next section.

## 7.4 Data analysis and interpretation

### 7.4.1 Analysis of erosion pins and scour chains

Erosion pin results are presented along with bank profiles for each monitoring site in appendix 4. The erosion pin graphs show there is high variability within results from some individual pins, between pins at a given site, between sites in a given zone, and between zones. To identify present trends suitable for use as a pre-Basslink baseline, statistical modelling of results grouped by zone (1-5), placement on the bank (<1-turbine level, 1-2-turbine level and 2-3-turbine level), and by a combination of zones and bank placement (zones 2 and 3, divided into turbine levels and zones 4 and 5 divided into turbine levels) has been completed. There are insufficient data to independently analyse each zone by bank level (<1, 1-2, 2-3-turbine).

The 'zone', 'bank location' and combination groups have been analysed for the following:

- Long-term average erosion and deposition trends have been determined by averaging all pins showing erosion and all pins showing deposition in each group for each sampling interval separately, and comparing the result to the spring 2001 benchmark readings (note, pins are grouped for each monitoring period, and a pin can change groupings if the pin response changes from erosion to deposition, or vice versa). This shows the average erosion and deposition occurring within each group for each monitoring interval in mm;
- Long-term net erosion by averaging all pins (erosion and deposition) in a group for each monitoring interval and comparing the result to the spring 2001 benchmark; and
- Seasonal changes by averaging all pins in a group and comparing the result to the previous monitoring period, rather than the spring 2001 benchmark.

These results show the long-term trends of the erosion pins on a zone or turbine level basis. The same results, normalised to millimetres per year (mm $yr^{-1}$) are contained in appendix 5. Rates of change for individual erosion pins are presented in the annual monitoring reports.

An initial examination of the erosion pin results found that the data associated with the pins located within bank cavities were unsuitable for inclusion in the statistical modelling due to a high incidence of measurement error related to the length of the pin and interference due to hanging tree roots in the cavities, and the fact that both positive and negative results indicated erosion to the bank, but in an unequal and unquantifiable manner (e.g., both erosion and deposition indicated collapse of the back wall of cavities, but the change in readings are not quantitatively linked to the scale of the bank change). The results from these pins are discussed in section 7.4.5 (Piezometer results and seepage erosion).

Following statistical analysis, the results were correlated with hydrological parameters to identify linkages between components of flow and bank response. The hydrological parameters used are listed and explained in Table 7.1

### 7.4.2 Erosion pin results on a zone basis

Figure 7.1 through Figure 7.4 show the results from the statistical analysis of the zone grouping of erosion pin results. Figure 7.1 shows the results separated into erosion and deposition sub-groupings, while Figure 7.2 shows the average net results for the zones. Figure 7.3 presents the ratio of pins showing erosion to pins showing deposition for each zone for each monitoring period, and Figure 7.4 shows net erosion or deposition on a seasonal basis.

There are marked differences between the zones. Zone 1 shows low and similar magnitudes of erosion and deposition (Figure 7.1), resulting in little net change over the monitoring period (Figure

7.2), and with a similar number of pins showing erosion as deposition (Figure 7.3). This is consistent with field observations that suggest the zone is largely stable.

Zones 2 and 3 show the highest rates of erosion over the monitoring period, accompanied by relatively low and variable rates of deposition (Figure 7.1). In these zones there is net erosion over the monitoring period (Figure 7.2) with a similar number of pins showing erosion as deposition (Figure 7.3). Due to the prevalence of seepage erosion processes in these zones, deposition is predominately attributable to the delivery of sediment from upslope of the erosion pin due to seepage processes, rather than from fluvial deposition derived from upstream, and should be interpreted as erosion of the upper bank. The seasonal increase in deposition in zone 2 in autumn (and to a lesser extent in zone 3) is consistent with field observations of increased seepage activity in March, following frequent and extended 3-turbine power station usage over the summer season.

Zones 4 and 5 show similarities in erosion and deposition in Figure 7.2, with erosion in both zones balanced by deposition of a similar magnitude. The net erosion for the zones differs considerably, as shown in Figure 7.2, with zone 4 having a net erosion rate similar to zones 2 and 3. The reason for this is evident from Figure 7.3 which shows that zone 4 has two and half to three and half times as many pins showing erosion as deposition. This ratio differs considerably from the other zones, and indicates that although the relative magnitude of erosion and deposition occurring at sites in zone 4 is similar, erosion is more wide spread. Reasons for this difference are discussed in section 7.5.1.

The low net rate of erosion in zone 5 is attributable to the similarity in magnitude between erosion and deposition occurring in the zone combined with a similar number of pins showing erosion and deposition. These results are also in agreement with field observations of zone 5 displaying attributes similar to a dynamic river, with more typical disturbance patterns for both erosion and deposition, compared with the zones upstream of the Denison confluence. Field observations and erosion pin results from individual sites show, however, that erosion more commonly occurs on bank toes, whereas deposition is greatest in the >1-turbine level of the bank, and above power station-controlled operating levels.

In Figure 7.4, net erosion on a seasonal basis is shown by comparing the averaged erosion pin results to the previous monitoring period. Comparing this graph with the long-term trends in Figure 7.2 demonstrates that the results show strong seasonal changes. This is consistent with field observations which consistently record major differences between the appearance of banks in October and March. Although the erosion pin results show strong seasonal changes, these are not apparent in the long-term trends in Figure 7.2 and suggest that the long-term trends may not be related to seasonal changes in the flow regime on a zone basis.

In order to understand the relationship between hydrologic flow parameters and trends shown in the statistical analyses, correlations were completed as shown in Table 7.1. The table shows that on a zone basis, there are few strong correlations between flow and the erosion, deposition, long-term net trend or seasonal patterns of bank response. This is likely attributable to the variability which occurs within zones, and indicates that there is no dominant flow parameter controlling the behaviour of all levels of the banks in all zones.

Within zone 2, there is a positive correlation between deposition and inflows, and negative correlations between deposition and total power station-derived flow (% power station, 'excess' water relative to pre-dam seasonal medians). This suggests that on a whole-zone basis, there is a tendency for deposition to occur when the power station is not operating, and not occur when it is operating. The positive correlation between deposition and inflows is surprising due to the low natural inflows in the zone, and may be related to seepage-induced or rainfall-induced sediment transport on the exposed banks during extended wet periods when the power station is not operating.

In the long-term and seasonal net erosion results in Table 7.1, zone 5 shows the highest correlations, with erosion positively correlated with the percentage of power station-derived flow, the percentage of flow duration of 2- and 2+3-turbines, and the 'excess' water compared to pre-dam seasonal medians. This finding is consistent with field observations of scoured banks during the summer months when power station-derived flow dominates. The negative correlation with inflow in both the long-term and seasonal analyses also supports field observations of deposition when natural water and sediment inflows are higher and power station usage is low (winter).

On a seasonal basis, zone 4 is the only zone showing strong correlations, with erosion correlated with flow from the Gordon Power Station, and the flow duration of 2+3-turbines. Overall the results suggest that within the zones, the banks are not responding uniformly to the flow regime.

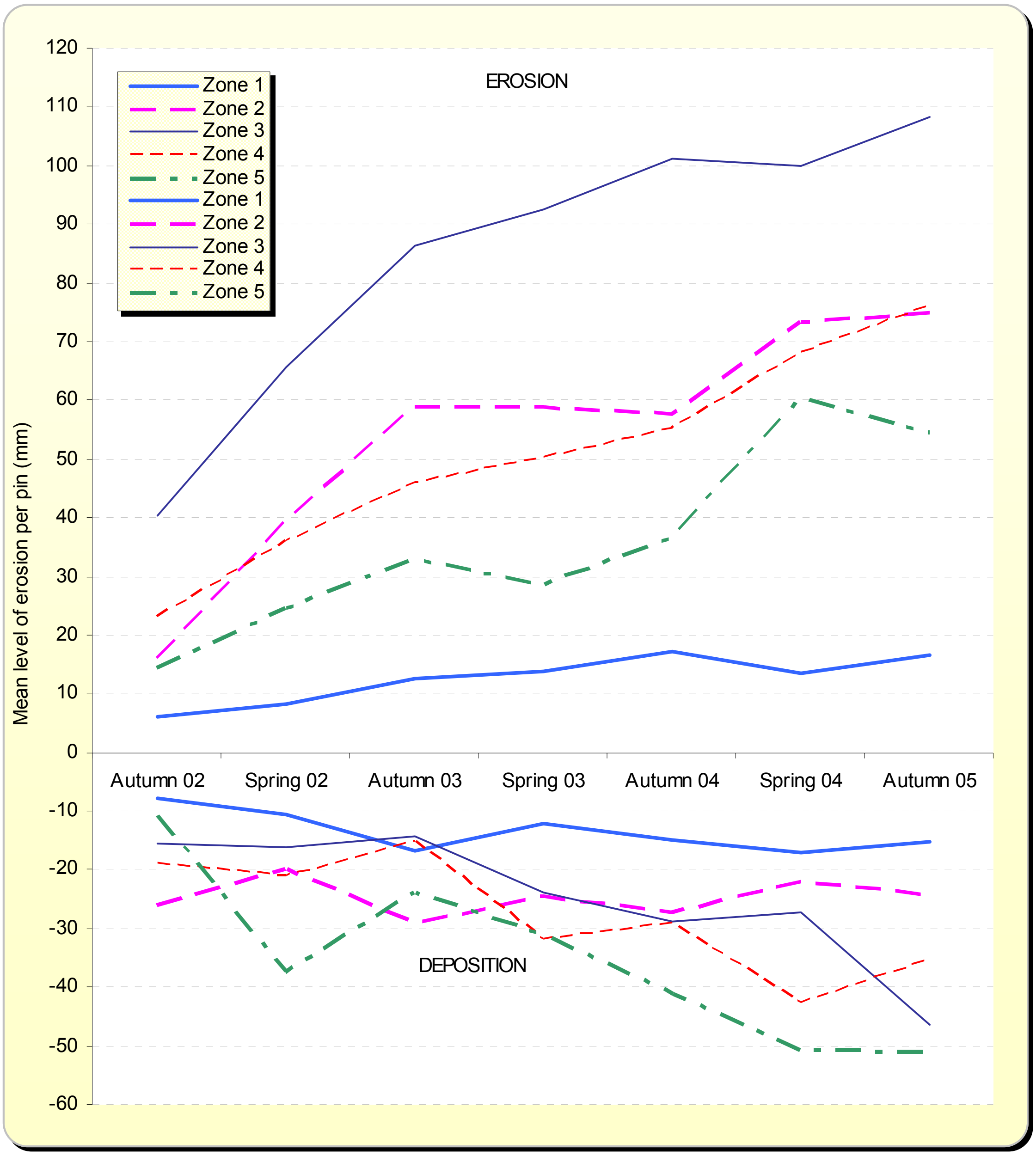


Figure 7.1 Comparison of the mean erosion per pin, in pins that show erosion, to the mean deposition per pin, in pins that show deposition, for each monitoring event compared to spring 2001. [For each monitoring event, pins were grouped according to whether they displayed erosion and deposition, and the mean of each group was calculated].

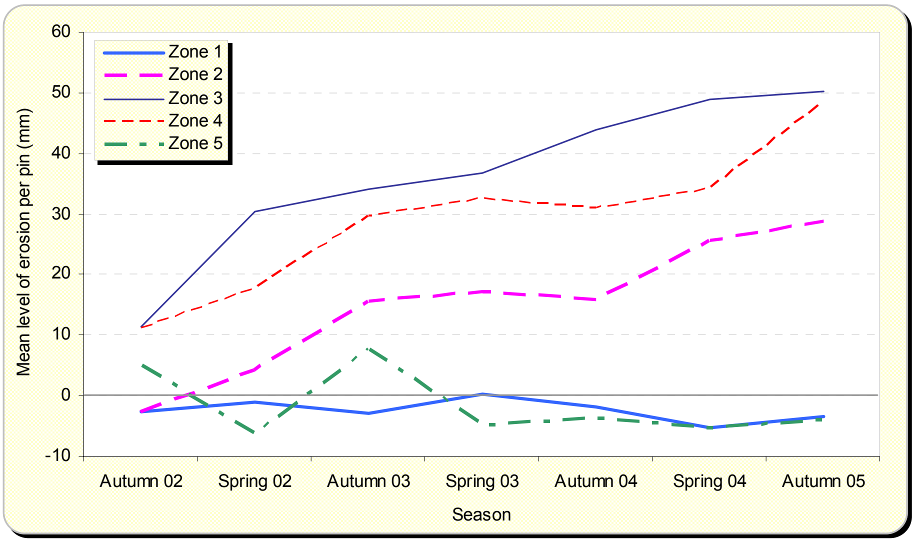


Figure 7.2 Average level of erosion or deposition for all pins in each zone for each season compared to spring 2001.

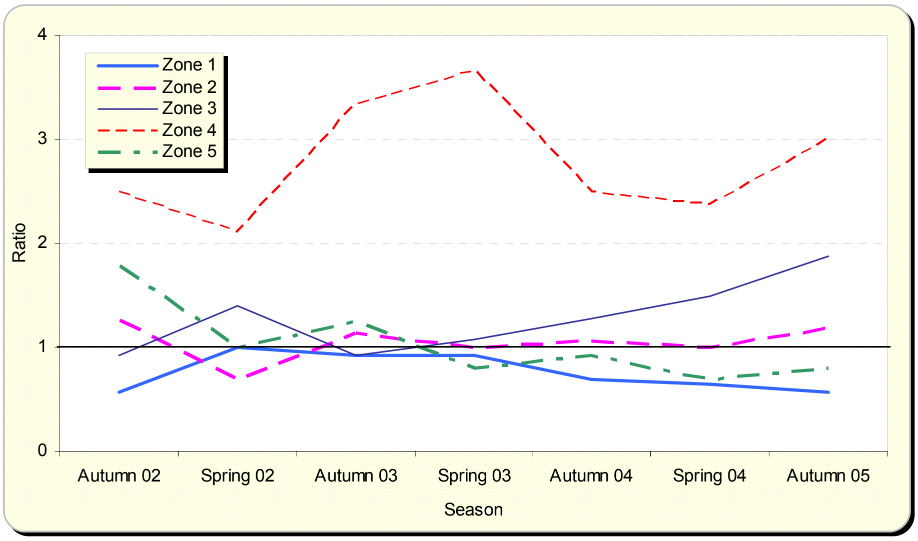


Figure 7.3 Ratio of pins showing erosion to pins showing deposition for each zone compared to spring 2001.

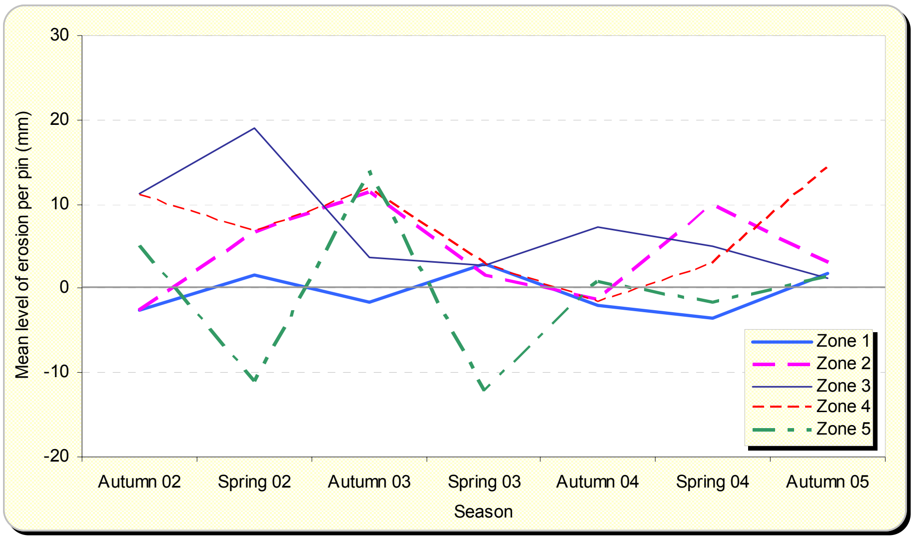


Figure 7.4 Average level of erosion or deposition for all pins in each zone compared to the previous season.

Table 7.1 Summary of correlation coefficients between results of statistical analyses shown in Figure 7.2, Figure 7.3, and Figure 7.4 and hydrologic parameters. Yellow highlight indicates correlation with erosion, and green indicates correlation with deposition.

| **Flow parameter** | **Average erosion in pins per pin showing erosion** | | | | | **Average deposition per pin in pins showing deposition** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Zone** | **1** | **2** | **3** | **4** | **5** | **1** | **2** | **3** | **4** | **5** |
| Gordon Power Station | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | 0.1 | -0.4 | -0.1 | 0.5 | 0.2 |
| Gordon above Franklin | -0.5 | 0.0 | -0.2 | -0.2 | -0.1 | 0.2 | 0.6 | 0.4 | 0.1 | 0.0 |
| Inflow | -0.3 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 | 0.8 | 0.4 | -0.1 | -0.1 |
| % power station | 0.2 | -0.1 | 0.0 | 0.0 | -0.1 | -0.1 | -0.8 | -0.4 | 0.2 | 0.1 |
| No events 1-turbine | -0.1 | 0.3 | 0.2 | 0.2 | 0.4 | -0.2 | 0.6 | 0.2 | -0.4 | -0.3 |
| No events 2-turbines | -0.2 | 0.2 | 0.1 | 0.2 | 0.3 | -0.1 | 0.6 | 0.2 | -0.4 | -0.3 |
| No events 3- turbines | -0.4 | 0.1 | -0.1 | 0.0 | 0.2 | 0.0 | 0.4 | 0.1 | -0.3 | -0.3 |
| No events PS off | -0.1 | 0.4 | 0.2 | 0.3 | 0.5 | -0.2 | 0.6 | 0.1 | -0.4 | -0.4 |
| % Flow duration 1- turbine | 0.2 | 0.4 | 0.4 | 0.4 | 0.4 | -0.1 | 0.7 | 0.1 | -0.4 | -0.3 |
| % Flow duration 2-turbines | -0.4 | -0.3 | -0.4 | -0.2 | 0.0 | 0.1 | -0.5 | -0.1 | 0.0 | 0.4 |
| % Flow duration 3-turbines | 0.1 | -0.1 | -0.1 | -0.1 | -0.2 | 0.0 | -0.5 | -0.3 | 0.3 | 0.0 |
| % Flow duration PS off | -0.1 | -0.1 | -0.1 | -0.3 | -0.3 | 0.1 | 0.2 | 0.4 | 0.3 | 0.0 |
| PS flow - pre-dam median | -0.1 | -0.3 | -0.3 | -0.2 | -0.3 | 0.1 | -0.7 | -0.2 | 0.4 | 0.3 |
| G above F - pre-dam median | -0.3 | -0.5 | -0.5 | -0.4 | -0.4 | 0.2 | -0.8 | -0.1 | 0.4 | 0.4 |
| Flow duration 1- and 2-turbines | -0.1 | 0.2 | 0.1 | 0.2 | 0.4 | -0.1 | 0.4 | 0.1 | -0.4 | 0.0 |
| Flow duration 2- and 3-turbines | -0.1 | -0.3 | -0.3 | -0.2 | -0.2 | 0.1 | -0.7 | -0.3 | 0.3 | 0.2 |
| Flow duration 1-,2- and 3-turbines | 0.1 | 0.1 | 0.1 | 0.3 | 0.3 | -0.1 | -0.2 | -0.4 | -0.3 | 0.0 |

Table 7.1 continued

| Flow parameter | Long-term average net erosion compared to spring 2001 | | | | | Average net erosion compared to previous season | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Zone** | **1** | **2** | **3** | **4** | **5** | **1** | **2** | **3** | **4** | **5** |
| Gordon Power Station | 0.2 | -0.6 | -0.6 | -0.6 | 0.7 | 0.2 | 0.2 | 0.2 | 0.8 | 0.4 |
| Gordon above Franklin | 0.1 | 0.0 | 0.0 | -0.2 | -0.4 | 0.4 | 0.5 | 0.5 | 0.0 | -0.6 |
| Inflow | 0.0 | 0.3 | 0.3 | 0.1 | -0.7 | 0.2 | 0.4 | 0.3 | -0.4 | -0.7 |
| % power station | 0.0 | -0.5 | -0.4 | -0.3 | 0.8 | -0.1 | -0.3 | -0.2 | 0.5 | 0.7 |
| No events 1-turbine | -0.3 | 0.5 | 0.5 | 0.4 | -0.6 | 0.0 | 0.6 | 0.0 | -0.3 | -0.5 |
| No events 2-turbines | -0.3 | 0.5 | 0.4 | 0.2 | -0.6 | 0.0 | 0.6 | 0.1 | -0.3 | -0.5 |
| No events 3-turbines | -0.4 | 0.1 | 0.1 | -0.1 | -0.4 | 0.0 | 0.6 | 0.4 | 0.0 | -0.4 |
| No events PS off | -0.4 | 0.6 | 0.5 | 0.4 | -0.5 | 0.0 | 0.6 | -0.1 | -0.2 | -0.5 |
| % Flow duration 1-turbine | -0.1 | 0.7 | 0.6 | 0.6 | -0.6 | 0.1 | 0.1 | -0.3 | -0.6 | -0.6 |
| % Flow duration 2-turbines | -0.6 | -0.3 | -0.6 | -0.4 | 0.8 | -0.5 | 0.0 | -0.2 | 0.7 | 0.7 |
| % Flow duration 3-turbines | 0.4 | -0.6 | -0.4 | -0.4 | 0.5 | 0.3 | -0.2 | 0.1 | 0.5 | 0.4 |
| % Flow duration PS off | 0.5 | 0.0 | 0.4 | 0.0 | -0.6 | 0.1 | 0.1 | 0.6 | -0.6 | -0.4 |
| PS flow - pre-dam median | 0.0 | -0.6 | -0.6 | -0.5 | 0.8 | -0.1 | -0.2 | 0.0 | 0.7 | 0.7 |
| G above F - pre-dam median | 0.0 | -0.7 | -0.7 | -0.6 | 0.8 | -0.3 | -0.2 | 0.1 | 0.6 | 0.7 |
| Flow duration 1- and 2-turbines | -0.5 | 0.4 | 0.2 | 0.3 | -0.1 | -0.3 | 0.1 | -0.4 | -0.1 | -0.1 |
| Flow duration 2- and 3-turbines | -0.1 | -0.7 | -0.7 | -0.6 | 0.9 | -0.1 | -0.2 | 0.0 | 0.8 | 0.7 |
| Flow duration 1-,2- and 3-turbines | -0.5 | 0.0 | -0.4 | 0.0 | 0.6 | -0.1 | -0.1 | -0.6 | 0.6 | 0.4 |

Description of flow parameters:

- **Gordon Power Station**: Total flow ($m^3 s^{-1}$) from the power station for the monitoring period (Oct-Mar, or Mar-Oct).
- **Gordon above Franklin**: Total flow ($m^3 s^{-1}$) at the Gordon above Franklin gauging site for the monitoring period.
- **Inflow:** Difference between Gordon above Franklin flow and Gordon Power Station flow for the monitoring period.
- **%power station**: The percentage of flow at the Gordon above Franklin gauging site derived from power station releases for the monitoring period.
- **No 1, 2, 3 or off events**: Number of flow releases from the Gordon Power Station for each turbine class during the monitoring period.
- **% duration 1, 2, 3, 1+2, 2+3, 1+2+3 or off events**: Percentage of time power station was operated for each turbine class during the monitoring period.
- **P/S flow - pre-dam median**: The difference between the actual power station discharge for the monitoring period, and the pre-dam median flow for an equivalent period based on pre-dam monthly flow.
- **Gordon above Franklin- pre-dam median**: The difference between the actual flow at the Gordon above Franklin gauging site for the monitoring period, and the pre-dam median flow at the same site for an equivalent period based on pre-dam monthly flow.

### 7.4.3 Erosion pin results grouped by bank placement

The results from the statistical analysis of the erosion pin results grouped by bank placement (<1-turbine, 1-2-turbine level, 2-3-turbine level) are presented in Figure 7.5 and Figure 7.6 in similar plots to the preceding section.

Figure 7.5 shows that erosion is occurring at all levels on the bank, with the <1-turbine level displaying the highest rate (~25 mm $yr^{-1}$). The rates of erosion for the 1-2 and 2-3-turbine levels are similar, at about 20 mm $yr^{-1}$. The erosion in the 1-2 and 2-3-turbine levels is being counter balanced by a uniform ~10 mm yr$^{-1}$, whereas the <1-turbine level displays episodic changes over a 30 mm range. When net erosion (Figure 7.6) rather than the erosional and depositional components are considered, all three bank levels show erosion, with the <1-turbine level greatest, followed by the 2-3-turbine level.

The bank level analysis is refined in Figure 7.7 to Figure 7.9 in which results from zones 2 and 3, and zones 4 and 5 are considered separately. These plots reveal fundamental differences in the erosion activity between these groupings. Figure 7.7 shows that in zones 2 and 3, there is ~13 mm yr$^{-1}$ net erosion in the 1-2-turbine range, and ~20 mm yr$^{-1}$ net erosion in the 2-3-turbine range. In the <1-turbine range, there are fluctuating levels of erosion, but little net change since the initiation of monitoring in spring 2001. The <1-turbine results show a seasonal pattern, of increased erosion during the summer months when the power station tends to be used at full-gate for extended periods, followed by decreased erosion during the winter. The 1-2-turbine level shows an opposite seasonal trend, with higher net erosion occurring during the winter periods, when power station usage is typically characterized by short-duration 1- and 2-turbine operation.

The results for zones 4 and 5 in Figure 7.7 show different trends, with net erosion rates of ~20 mm yr$^{-1}$ in the <1-turbine range, and no net change in the 1-2 and 2-3-turbine levels over the monitoring period. The <1-turbine results also show a seasonal pattern of increased erosion during the period preceding the autumn monitoring. Comparing the zone 4 and 5 results in Figure 7.7 with the zone results discussed in the last section also suggests that the <1-turbine net erosion is dominated by the results from zone 4, where up to four times as many pins show erosion compared to deposition.

These zonal groupings suggest that the <1-turbine level erosion shown in Figure 7.5 is dominated by the results from zones 4 and 5, where as the 1-2 and 2-3 results are related to the higher level of erosion in zones 2 and 3.

Figure 7.8 shows average erosion results for the same groupings on a seasonal basis (i.e., compared with previous season's results rather than the initial 2001 baseline). In zones 2 and 3, the <1-turbine bank level shows strong seasonal changes, with higher erosion rates in autumn, while the 1-2 turbine bank level shows opposite trends, with deposition occurring in autumn. These results reflect scour of the bank toe over the summer associated with extended power station operation, which also leads to deposition in the 1-2-turbine level due to seepage erosion. There are no strong seasonal trends apparent in the 2-3-turbine level.

In zones 4 and 5, there is a similar seasonal trend in the <1-turbine level, with higher erosion rates recorded in autumn. There are no strong seasonal trends in the 1-2 or 2-3-turbine level.

Figure 7.9 shows the ratio of pins showing erosion to deposition for each turbine class for zones 2 and 3, and zones 4 and 5. In zones 2 and 3, the <1-turbine pins show the highest ratio of erosion to deposition, which may be decreasing with time. The ratio of pins showing erosion in the 1-2 and 2-3-turbine levels may be increasing. In zones 4 and 5, both the <1-turbine and 2-3-turbine level show higher numbers of pins recording erosion compared to deposition, with the 1-2-turbine level showing a ratio of ~1. These results were dominated by zone 4, where the number of pins recording erosion exceeded the number showing erosion at all bank levels.

Correlations between flow parameters and the erosion pin results grouped by zone and bank location are presented in Table 7.2 for the long-term trends (Figure 7.7) and Table 7.3) for seasonal results (Figure 7.8). Table 7.2 shows that there are no strong correlations between the long-term erosion pin results and flow parameters. Only erosion in zones 4 and 5 in the 2-3-turbine level of the bank is strongly correlated with power station operation and the combined flow duration of 2+3-turbines.

Strong correlations between flow and erosion pin results are present when the erosion pin results are compared to the previous season, rather than the initial baseline. In zones 2 and 3, erosion of the <1-turbine bank level correlates with the percentage of power station-derived flow, suggesting scour is the major mechanism. Deposition at the same bank level correlates with the 1-turbine flow duration, suggesting deposition occurs when water levels re low, and material transported from upslope is deposited. The 1-2-turbine level in zones 2 and 3 show opposite correlations, with scour having positive correlation with inflows and the number of power station operating events, and deposition associated with power station-derived flows. This supports scour predominating at this bank level when the power station is discharging short-duration flows, with seepage erosion occurring following long-duration power station flows. In the 2-3-turbine bank level, erosion also correlates with the parameters associated with the number of power station-induced water level changes, supporting scour as the dominant erosion process.

Erosion in zones 4 and 5 below the 1-turbine level is similar to zones 2 and 3, with erosion correlating with high flows from the power station and deposition with the duration of 1-turbine discharge. Higher up the bank, in the 1-2-turbine level, erosion correlates with the 2-turbine flow duration, with deposition correlating with the duration of power station shut-downs. Unlike the long-term results, there are no strong correlations between the flow parameters and the 2-3-turbine bank level results.

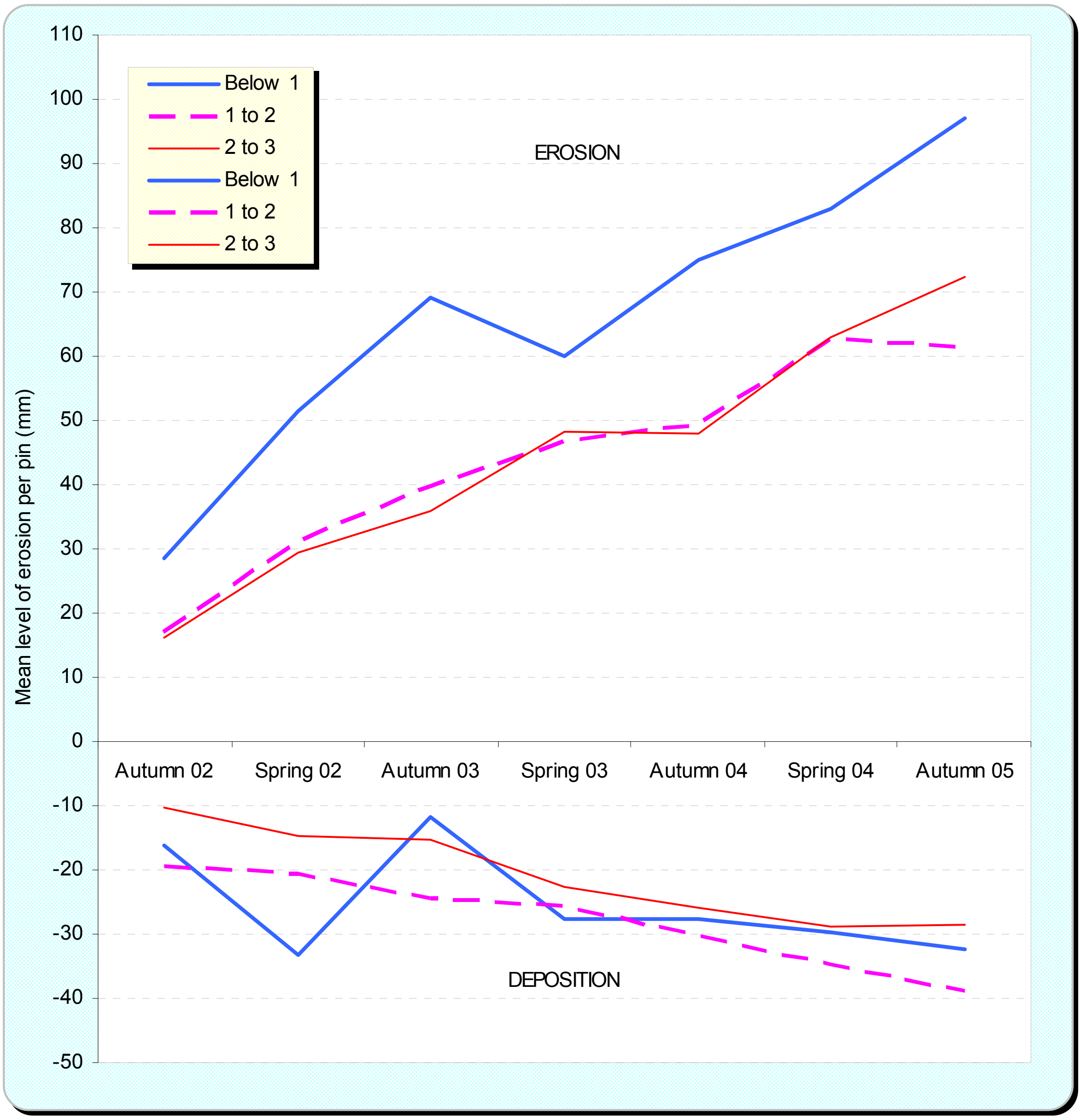


Figure 7.5 Comparison of the mean erosion per pin in pins that show erosion to the mean deposition per pin in pins that show deposition for each monitoring event compared to spring 2001 [for each monitoring event, pins were grouped according to whether they displayed erosion and deposition, and the mean of each group was established].

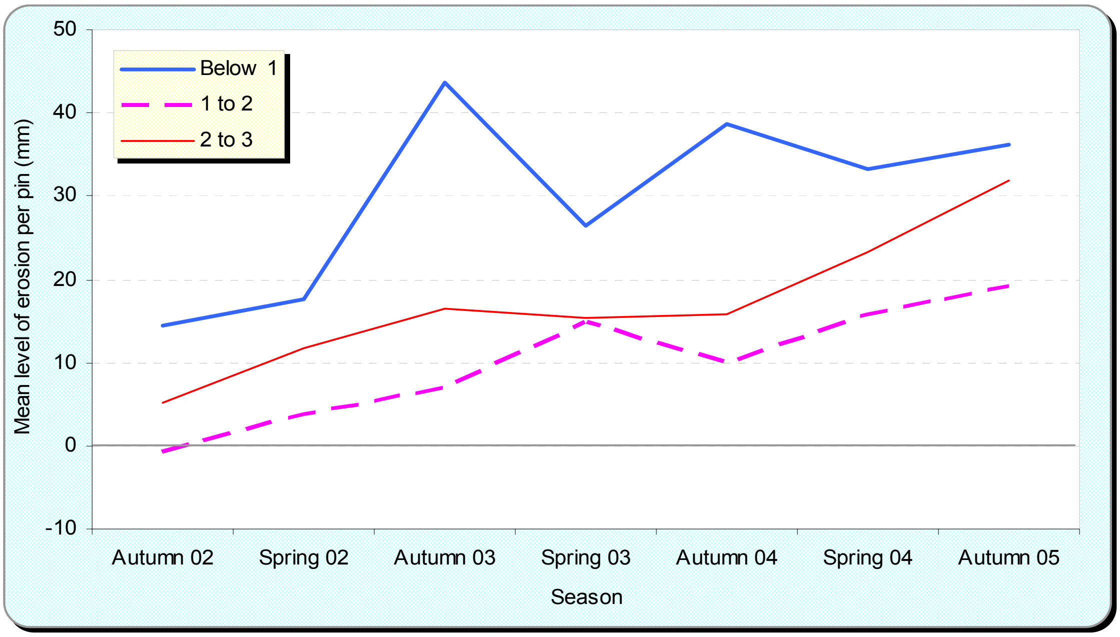


Figure 7.6 Average level of erosion or deposition for all pins by bank placement for each season compared to spring 2001 (long-term trends).

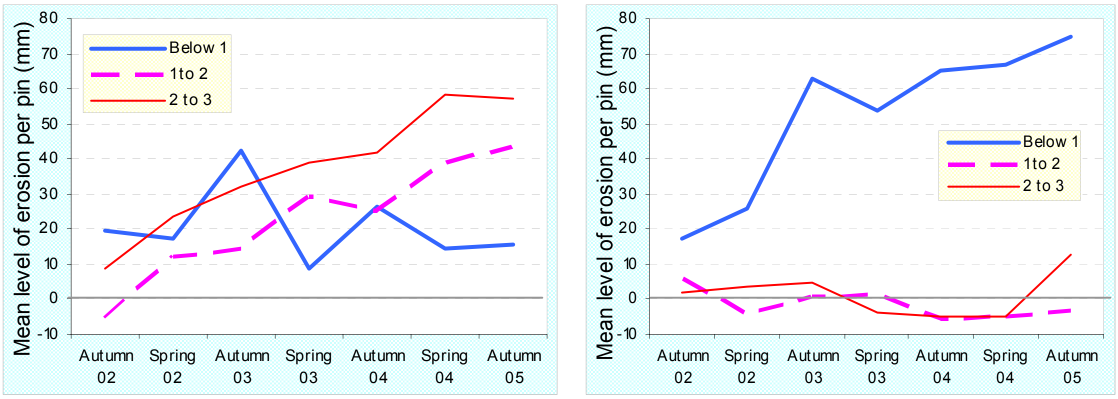


Figure 7.7 Average level of erosion or deposition for all pins in each zone by bank placement for each season compared to spring 2001 for zones 2 and 3 (left) and zones 4 and 5 (right).

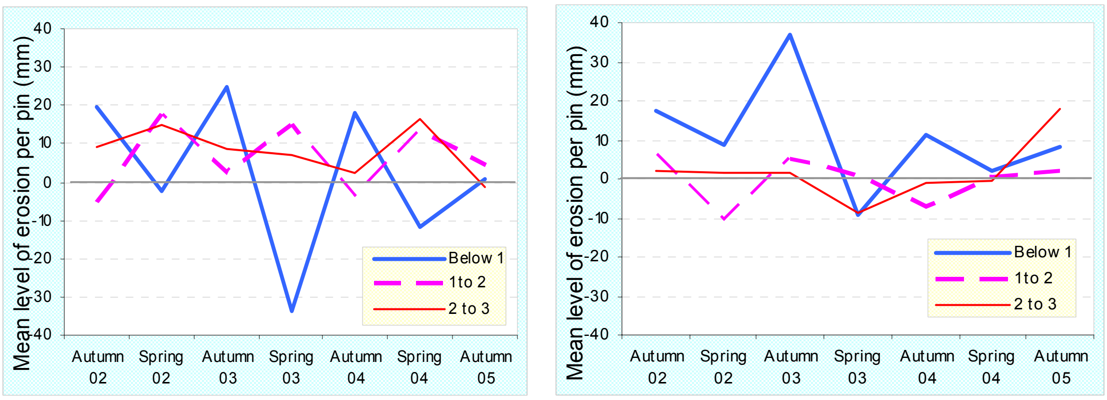


Figure 7.8 Average erosion or deposition for all pins by bank placement on a seasonal basis, compared with the previous season, for zones 2 and 3 (left) and zones 4 and 5 (right).

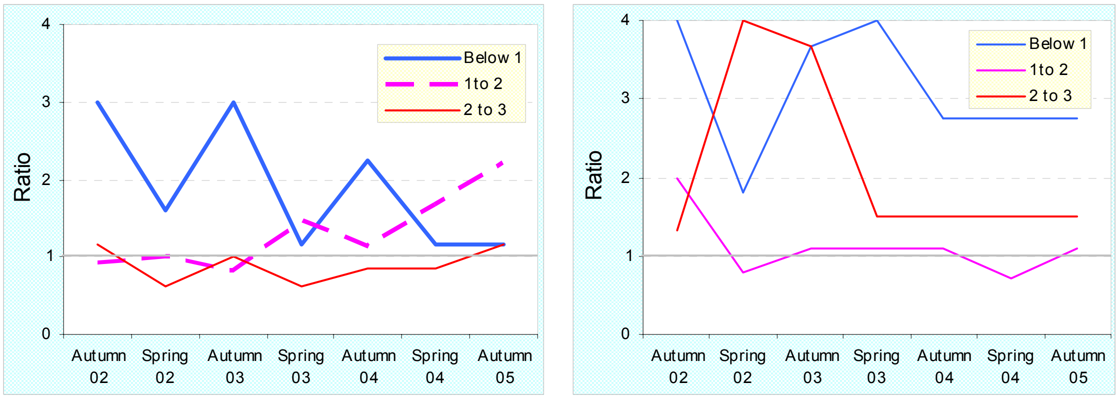


Figure 7.9 Ratio of pins showing erosion to number of pins showing deposition (compared to spring 2001) by bank placement for zones 2 and 3 (left) and zones 4 and 5 (right).

Table 7.2 Summary of correlation coefficients between flow parameters and ‘long-term’ erosion pin results (Figure 7.6 and Figure 7.7) grouped by bank location. Yellow highlight indicates correlation with erosion, and green indicates correlation with deposition.

| **Bank location** | **Zone** | | | | | |
|---|---|---|---|---|---|---|
| | **2 and 3** | | | **4 and 5** | | |
| | **Below 1** | **1 to 2** | **2 to 3** | **Below 1** | **1 to 2** | **2 to 3** |
| Gordon Power Station | 0.5 | -0.4 | -0.4 | -0.2 | 0.2 | 0.9 |
| Gordon above Franklin | -0.3 | 0.0 | -0.1 | -0.3 | -0.1 | 0.0 |
| Inflow | -0.5 | 0.1 | 0.1 | -0.2 | -0.2 | -0.5 |
| % power station | 0.6 | -0.2 | -0.2 | 0.1 | 0.2 | 0.6 |
| No events 1-turbine | -0.5 | 0.4 | 0.4 | 0.1 | -0.3 | -0.4 |
| No events 2-turbines | -0.5 | 0.3 | 0.3 | 0.0 | -0.3 | -0.4 |
| No events 3-turbines | -0.4 | 0.1 | 0.1 | -0.2 | -0.2 | -0.1 |
| No events PS off | -0.5 | 0.4 | 0.4 | 0.1 | -0.3 | -0.3 |
| % Flow duration 1-turbine | -0.6 | 0.5 | 0.5 | 0.2 | -0.2 | -0.6 |
| % Flor duration 2-turbines | 0.3 | -0.3 | -0.2 | -0.2 | 0.6 | 0.4 |
| % Flow duration 3-turbines | 0.5 | -0.2 | -0.2 | 0.0 | 0.0 | 0.7 |
| % Flow duration PS off | 0.1 | -0.2 | -0.2 | -0.2 | -0.5 | -0.5 |
| PS - pre-dam median | 0.6 | -0.4 | -0.4 | -0.1 | 0.3 | 0.7 |
| Gordon above Franklin - pre-dam median | 0.6 | -0.6 | -0.5 | -0.3 | 0.4 | 0.6 |
| Flow duration 1- and 2-turbines | -0.5 | 0.3 | 0.3 | 0.1 | 0.3 | -0.4 |
| Flow duration 2- and 3-turbines | 0.5 | -0.4 | -0.3 | -0.1 | 0.4 | 0.8 |
| Flow duration 1, 2- and 3-turbines | -0.1 | 0.2 | 0.2 | 0.2 | 0.5 | 0.5 |

See Table 7.1 for a description of flow parameters.

Table 7.3 Correlations between flow parameters and 'seasonal' erosion pin results (Figure 7.8). Yellow highlight indicates correlation with erosion, and green indicates correlation with deposition.
See Table 7.1 for a description of flow parameters.

| **Bank location** | **Zone** | | | | | |
|---|---|---|---|---|---|---|
| | **2 and 3** | | | **4 and 5** | | |
| | Below 1 | 1 to 2 | 2 to 3 | Below 1 | 1 to 2 | 2 to 3 |
| Gordon Power Station flow | 0.6 | -0.3 | -0.3 | 0.7 | 0.2 | 0.6 |
| Gordon above Franklin flow | -0.6 | 0.9 | 0.7 | -0.3 | -0.3 | -0.3 |
| Inflow | -0.7 | 0.9 | 0.8 | -0.6 | -0.4 | -0.5 |
| % power station-derived flow | 0.8 | -0.8 | -0.7 | 0.7 | 0.3 | 0.6 |
| No events 1-turbine | -0.7 | 0.9 | 0.8 | -0.5 | -0.1 | -0.4 |
| No events 2-turbines | -0.7 | 0.8 | 0.8 | -0.5 | -0.2 | -0.4 |
| No events 3-turbines | -0.5 | 0.8 | 0.8 | -0.3 | -0.2 | -0.1 |
| No events PS off | -0.7 | 0.8 | 0.7 | -0.5 | -0.1 | -0.3 |
| % Flow duration 1-turbine | -0.9 | 0.6 | 0.4 | -0.8 | 0.0 | -0.5 |
| % Flow duration 2-turbines | 0.5 | -0.5 | 0.0 | 0.5 | 0.8 | 0.4 |
| % Flow duration 3-turbines | 0.6 | -0.5 | -0.7 | 0.5 | -0.1 | 0.6 |
| % Flow duration PS off | 0.0 | 0.3 | 0.4 | -0.1 | -0.8 | -0.5 |
| PS - pre-dam median | 0.8 | -0.8 | -0.5 | 0.8 | 0.3 | 0.6 |
| Gordon above Franklin - pre-dam median | 0.9 | -0.8 | -0.4 | 0.8 | 0.4 | 0.5 |
| Flow duration 1- and 2-turbines | -0.5 | 0.2 | 0.4 | -0.4 | 0.6 | -0.2 |
| Flow duration 2- and 3-turbines | 0.8 | -0.7 | -0.5 | 0.7 | 0.4 | 0.7 |
| Flow duration 1, 2- and 3-turbines | 0.0 | -0.3 | -0.4 | 0.1 | 0.8 | 0.5 |

### 7.4.4 Summary of erosion pin results

The erosion pin results show that all zones have undergone erosion and deposition during the pre-Basslink monitoring period. The changes in zone 1 are small compared to the other zones, and results do not correlate with flow parameters on either a long-term or seasonal timescale.

Zones 2 and 3 display the highest rates of erosion, with relatively lower rates of deposition. The 1-2 and 2-3-turbine levels on the banks have net erosion rates of up to 20 mm $\text{yr}^{-1}$, while the <1 turbine bank level shows seasonal changes correlated with power station usage, but little net change over the monitoring period.

Zone 4 shows similar characteristics to zone 5; in that deposition and erosion occurred at similar rates. However, a greater proportion of pins in zone 4 displayed erosion compared to any of the other zones. Erosion in zones 4 and 5 was concentrated in the <1-turbine level of the banks, with the other bank levels showing no net change over the monitoring period.

The long-term net erosion results from the middle Gordon River show little or no correlation with flow parameters when grouped by zones or bank placement. The correlations increase when the data are grouped by bank placement in zones upstream and downstream of the Denison confluence, and when grouped by season. Generally, deposition in the upstream zones correlates with power station usage and is linked to seepage erosion processes occurring in the 1-2 and 2-3 turbine level of the bank, and erosion is linked to 1- and 2-turbine power station operation which scours the bank but does not promote seepage. In zones 4 and 5, erosion is correlated with total flow discharged from the Gordon Power Station, and deposition is linked to 1-turbine power station usage which allows sediment delivery to the banks during rainfall events.

The erosion pin results show strong seasonal differences. During summer, erosion appears to be linked to the long-duration high discharge power station-derived flows, with little natural input of sediment or water. In contrast, in the winter, when water and sediment inflows are high, erosion is dominated by the number of water level changes in the river.

### 7.4.5 Piezometer results and seepage erosion

Results from the piezometer array at site 71 in zone 2 have been used to monitor the potential for seepage erosion based on in-bank water surface slopes. The IIAS investigations found there is a high risk of seepage-induced bank erosion when in-bank water surface slopes exceed 0.1, and in-bank water levels at piezometer P3 (located 13 m inland) exceeded ~3 m.

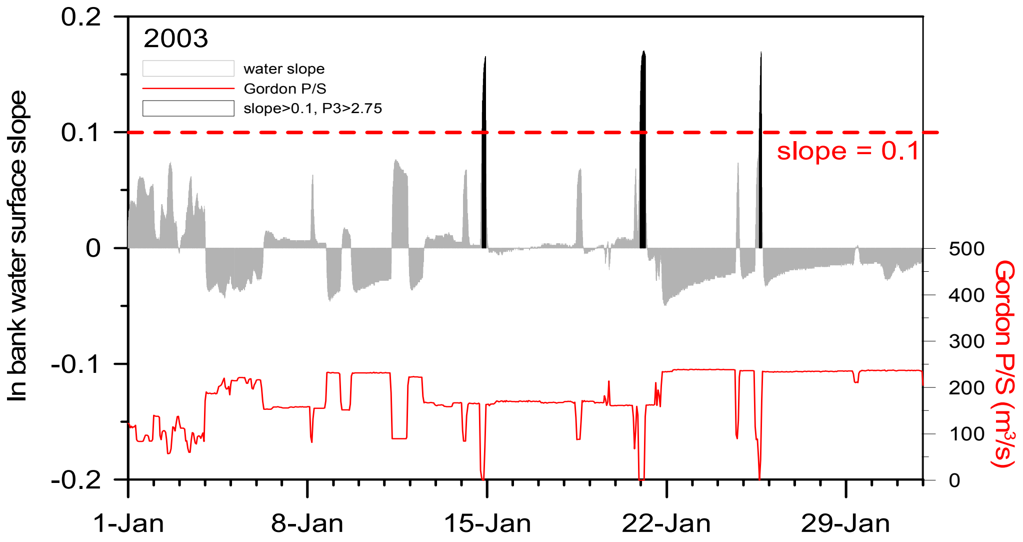


Figure 7.10 Piezometer results from January 2003, showing relationship between power station operation (red line in lower graph) and in bank water surface slopes (grey line). Black lines high light periods when water slopes exceed 0.1.

Figure 7.10 depicts a one month period and shows the relationship between power station operation and in bank water surface slopes. Figure 7.11 summarises the piezometer results for 2002 to mid-2005. The graphs show that periods of high risk of seepage erosion typically correspond to power station shut-down periods, generally following prolonged periods of operation during the summer. Field observations and erosion pin results are consistent with the piezometer results, with evidence of seepage erosion common during autumn monitoring, and less common during spring.

Over the monitoring period, the in-bank water surface slopes remained >0.1 for extended periods when power station shut-down coincided with large rainfall events, such as in June 2002 and the end of January 2004. During the October 2002 monitoring there was field evidence that seepage erosion had occurred on the banks in the <2-turbine level over the wet winter. The piezometer results indicated the water slopes were elevated from mid-June to mid-July, which could have promoted this seepage. However, no observations of the banks were made during this time to verify the bank conditions.

Over the pre-Basslink monitoring period, the piezometer casings have been infiltrated by very fine sediment, eliminating the possibility of verifying the calibration of the probes. There are ongoing inconsistencies between the levels recorded by piezometer 1 and piezometer 2, and the response of the probes has appeared to slow over time, based on a comparison of recent filling and draining rates as compared to initial rates immediately following installation of the probes. This raises questions about the accuracy of the results, but overall the trend of the results is consistent with the understanding of seepage processes in the middle Gordon River.

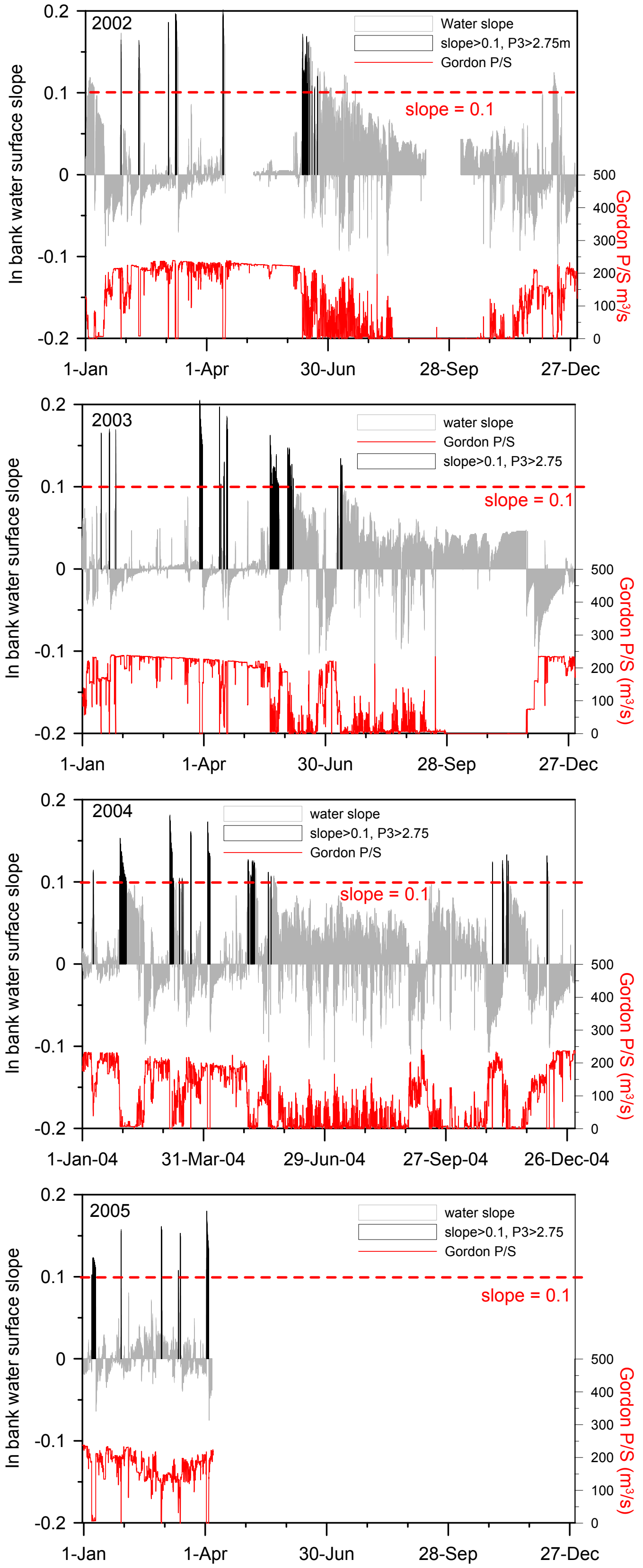


Figure 7.11 Summary of piezometer results for 2002 to mid-2005. Grey line shows water surface slope, with black lines highlighting slopes which exceed 0.1 while the water level at piezometer 3 exceeded 2.75 m. The discharge from the Gordon Power Station is shown in red in the bottom half of the plot.

Figure 7.12 compares the total time in-bank water surface slopes exceeded 0.1 for each monitoring period. Beginning in spring 2003, there was a large increase in the time the piezometers indicated elevated surface slopes. This increase is not due to a higher number of shut-down events, but rather longer-periods of elevated water surface slopes associated with shut-downs. The step change does not correlate with major changes in power station operation, and spring 2003 was also the first monitoring period when the piezometer results were noted to differ from previous results with respect to bank filling and draining rates, and it was hypothesized that infilling by fine-grained sediment was affecting the filling and draining rate of the probes (Koehnken 2002). The piezometers are scheduled for upgrading prior to the initiation of Basslink.

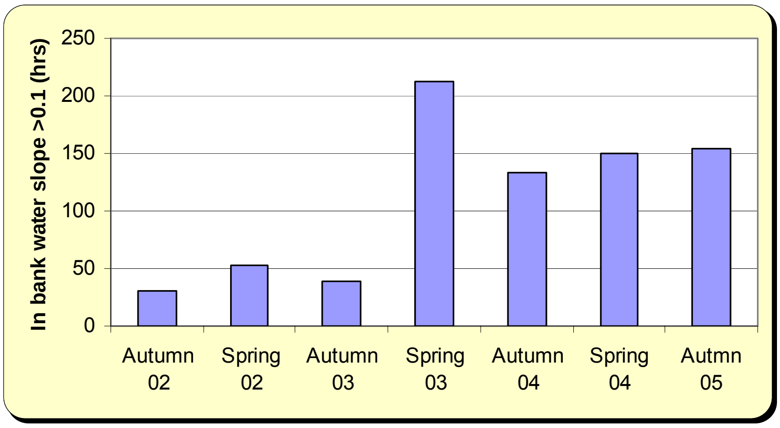


Figure 7.12 Summary of total time (in hours) in-bank water surface slope exceeded 0.1 for each monitoring period based on piezometer results at site 71.

In-bank water slopes are monitored in zone 2 to provide an indication of the potential for seepage erosion. Bank failure through seepage erosion is also monitored using ~25 erosion pins installed horizontally in cavities created by seepage processes in zones 1, 2, 3 and 5. Measurement of the pins is difficult due to the length of the pins (up to 3 m) and interference from plant roots extending through the roof into the cavity. In spite of these difficulties, most cavities showed relatively consistent pin measurements up until the time of failure. Figure 7.13 summarises the cavity collapse history of the monitoring area, and shows that in the first two and a half years of monitoring (spring 2001-autumn 2004), few cavity collapses were recorded. In spring and autumn 2004 this number had increased and, to date, 15 of the original cavities have experienced major collapse.

Overall, the results suggest that cavities persist over periods of several years. Zone 2 has experienced the highest number of collapses, with only one occurring in zone 3. The two collapses which occurred in zone 5 in spring 2004 were at the same site, and followed a very large flood event. There was widespread deposition of sand, branches and other flood debris at and upslope of the bank failure. Because monitoring occurred several months after the flood event, it is not possible to establish the timing of the collapse with respect to the flood event.

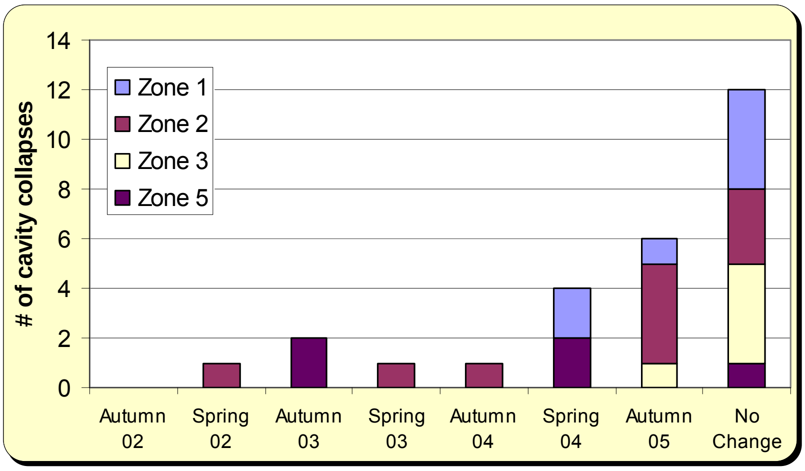


Figure 7.13 Summary of cavity collapses recorded during each monitoring period, and remaining number of in tact cavities since monitoring began in spring 2001.

### 7.4.6 Aerial photo interpretation

Aerial photo interpretation comparing 1974 photos with 1999 photos was completed for the IIAS (Locher 2001). The initial investigation found channel widening had occurred in the river upstream of the Denison confluence, most notably in zone 2. Channel narrowing was evident in zone 1 and zone 5, predominantly due to the establishment of vegetation into areas previously affected by very high flow events.

A new set of aerial photographs were obtained by Hydro Tasmania in December 2004, and an analysis and comparison with previous photos will be completed. At the time of this report preparation, these results are not yet available, and will be summarized in a subsequent annual report.

### 7.4.7 Photo-monitoring

Photo-monitoring was completed four times during pre-Basslink monitoring: March 2002, March 2003, March 2004 and April 2005, allowing comparisons to be made for three periods, March 2002-March 2003, March 2003-March 2004 and March 2004-April 2005. Photo-monitoring focuses on documenting changes to large-scale bank features (metre scale) which are not readily monitored using erosion pins (millimetre scale). Bank disturbance features such as land slips and tree falls comprise the majority of monitoring sites, with other features including cobble banks and bars.

The results from the repeat photo-monitoring are presented in Table 7.4 and appendix 4 and summarised in Figure 7.14 according to categories of change most commonly observed. The results show that poor photo quality was an issue during some monitoring runs, and is attributable to both very bright light and strong shade conditions, and poor visibility due to rainfall. In spite of these constraints, the majority of sites have shown no change over the three monitoring periods. The

50 % of sites in 2003 not showing any change increased to 68 % if the 'poor photo, no apparent change' results are included.

Documented erosional changes include additional tree fall or slip upslope of the initial disturbance site. These slips/falls occurred in the vegetation that remained as an overhang following the initial landslip due to the strength of the root mat and vegetation. The other commonly documented erosional change was the realignment of vegetation with the flow direction of the river and the removal of small branches, leaves and other vegetation deposited at the base of the initial slip or tree fall.

An increase in vegetation on the slip face upslope of the regulated high water level was another common change between photo-monitoring periods, and indicates the initial slip was relatively stable, allowing vegetative colonization.

'Other' changes include additional small tree falls or slips at three sites, an increase in the black weathering coating on a vertical cobble bar in zone 2, and change to the distribution of sand on a cobble bar in zone 4.

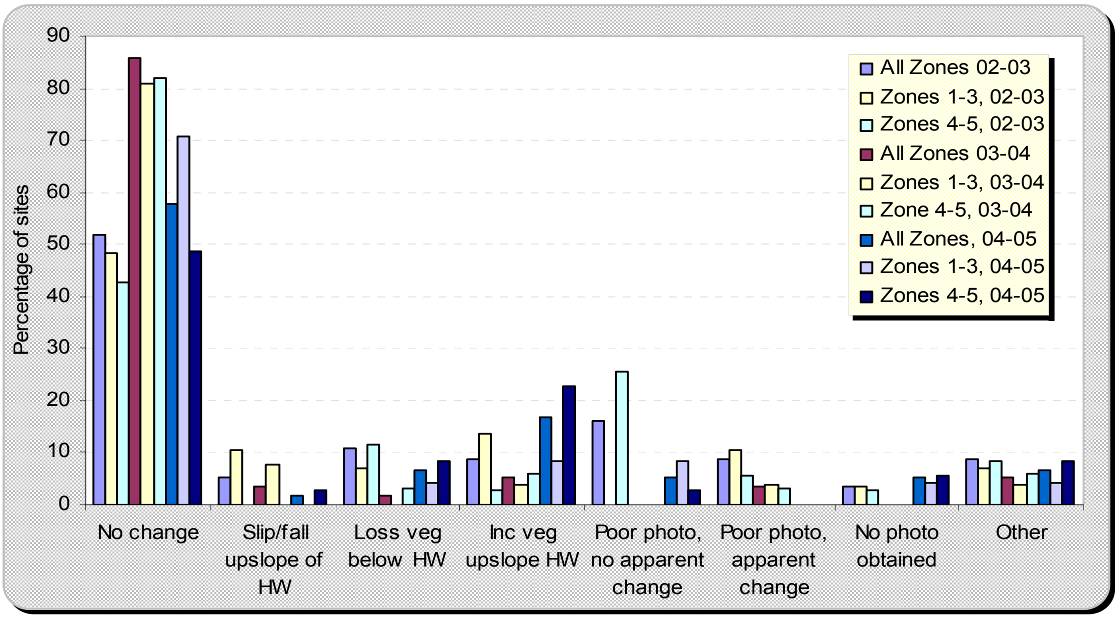


Figure 7.14 Summary of photo-monitoring results for March 2002-March 2003, March 2003-March 2004 and March 2004-April 2005. HW = high water (3-turbine level).

Table 7.4 Photo-monitoring results for sites in zones 1-5 for the periods March 2002-03 (03), March 2003-04 (04), and March 2004-April 2005 (05).

| Site | No apparent change | Slip/ tree fall upslope of HW level | Removal of veg at base of slip | Increased veg on slip upslope of HW level | Poor photo-no apparent change | Poor photo-apparent change | No photo obtained | Other |
|---|---|---|---|---|---|---|---|---|
| P1-1 | 03, 04, 05 | | | | | | | |
| P1-2 | 03, 04 | | | | 05 | | | |
| P1-3 | 03, 04, 05 | | | | | | | |
| P1-4a | 03, 04, 05 | | | | | | | |
| P1-4b | 0, 05 | 03 | 03 | | | | | |
| P1-5 | 03, 04 | | | | 05 | | | |
| P2-1a | 03, 04, 05 | | | | | | | |
| P2-1b | 03, 04, 05 | | | | | | | |
| P2-2a | | 04 | | 03, 05 | | | | |
| P2-2b | 03, 04 | | | | | | 05 | |
| P2-3 | | 04 | 05 | 03 | | | | |
| P2-4 | | 03 | | 03, 04, 05 | | | | |
| P2-5 | 04 | 03 | | | | 03, 04 | | 04 inc tree fall?, 05 small tree fall or accum of debris on toe |
| P2-6 | 04, 05 | | | | | | | 03 inc. coating on cobbles |
| P2-7 | 03, 04, 05 | | | | | | | |
| P2-8 | 03, 04, 05 | | | | | | | |
| P2-9 | 04, 05 | | | 03 | | 03 | | |
| P2-10 | 03, 04, 05 | | | | | | | |
| P2-11 | 04, 05 | | | | | | 03 | |
| P3-1 | 04, 05 | | 03 | | | | | |
| P3-2 | 03, 04, 05 | | | | | | | |
| P3-3 | 03, 04, 05 | | | | | | | |
| P3-4 | 04, 05 | | | | | 03 | | 03 may not be same site |
| P3-5 | 03, 04, 05 | | | | | | | |
| P4-1 | 03, 04, 05 | | | | | | | |
| P4-2 | 04 | | | | 03 | | | |
| P4-3 | 05 | | 03, 04 | | | | | |
| P4-4a | 03, 04, 05 | | | | | | | |
| P4-4b | 03, 04, 05 | | | | | | | |
| P4-4c | | | | | | | | 04, change to dist'n of sand on cobble bar |
| P4-5a | 03, 04, 05 | | | | | | | |
| P4-5b | 03, 04, 05 | | | | | | | |

Table 7.4 continued. Photo-monitoring results for sites in zones 1-5 for the periods March 2002-03 (03), March 2003-04 (04), and March 2004-April 2005 (05).

| Site | No apparent change | Slip/ tree fall upslope of HW level | Removal of veg at base of slip | Increased veg on slip upslope of HW level | Poor photo-no apparent change | Poor photo-apparent change | No photo obtained | Other |
|---|---|---|---|---|---|---|---|---|
| P4-6 | 03, 04 | | | | 05 | | | |
| P4-7 | 04 | | | 05 | 03 | | | |
| P4-8 | 04, 05 | | | | 03 | | | |
| P5-1 | 04, 05 | | | | | 03 | | 03 extra slip? |
| P5-2 | 03, 04 | | 05 | | | | | |
| P5-3 | 04 | | | 05 | 03 | | | |
| P5-4 | 03, 04, 05 | | | | | | | |
| P5-5 | 05 | | | | | 04 | | 04, additional small tree fell |
| P5-6 | 04 | | | 05 | 03 | | | |
| P5-7 | 04 | | 05 | | 03 | | | |
| P5-8 | 04 | | | 05 | 03 | | | |
| P5-9 | 03, 04, 05 | | | | | | | |
| P5-10 | 04, 05 | | 03 | | | | | |
| P5-11 | 03, 04 | | | 05 | | | | 05 inc veg below high WL |
| P5-12 | 04, 05 | | 03 | | | | | |
| P5-13 | 03, 04, 05 | | | | | | | |
| P5-14 | 03, 04 | | | | | | | |
| P5-15 | 04, 05 | | | 03 inc. in veg on bar | | 03 | | |
| P5-16 | | | 03 | 04, 05 | | | | 03 movement of branch downslope |
| P5-17 | 03, 04 | | 05 | | | | | |
| P5-18 | 04, 05 | | | | | | | 03 may not be same site |
| P5-19 | | | | 04, 05 | 03 | | | |
| P5-20 | 04, 05 | | | | 03 | | | |
| P5-21 | 04 | | | | | | 03, 05 | |

## 7.5 Discussion and synthesis

### 7.5.1 Erosion pins

The pre-Basslink geomorphology monitoring results show that between 2001-05 the middle Gordon River was active and continuing to adjust to the regulated flow regime, with channel widening processes predominating. The bank area below the regulated water level was most active, with all zones affected by scour, and the zones upstream of the Denison confluence affected by seepage erosion processes as well. The statistical analyses of the pre-Basslink monitoring results are consistent with the field observations and results collected and reported over the monitoring period, have added additional insights into the processes affecting the banks, and have provided an indication of the present trends.

Zone 1, closest to the power station, shows the least amount of change over the monitoring period, with changes unrelated to flow patterns. This is interpreted as the steep, narrow bedrock-dominated zone being in relative equilibrium with the regulated flow regime. This is in contrast to the overall findings for the middle Gordon. Changes in zone 1 during the monitoring period have been largely limited to the loss of root mats overlying bedrock and cobbles from below the regulated water level. Above the regulated water levels, there has been widespread channel narrowing, due to the encroachment of rainforest species into what was previously (pre-power station) the riparian zone. The relative bank stability of the zone is attributable to its steep slope, high occurrence of bedrock and proximity to the power station. The steep slopes have resulted in high energy flows which have scoured the river to bedrock and cobbles over most of the channel in the years since power station initiation. The absence of unregulated inflows and sediments results in the zone being subjected to one flow and sediment regime, with no opportunities for the banks to readjust to unregulated flows and sediment inputs as appears to be occurring downstream.

The remaining four zones show net erosion, but with different trends common upstream and downstream of the Denison confluence. Upstream, in zones 2 and 3, bank toes are active, show seasonal changes in response to power station operating patterns, but show relatively low levels of net erosion (~20 mm) over the three-year monitoring period. Erosion of the <1-turbine level correlates with the percentage of power station usage, and the 'excess' water released from the power station compared to pre-dam seasonal medians.

The banks in the 1-2 and 2-3-turbine range in zones 2 and 3 show consistent net erosion rates of 20-30 mm $yr^{-1}$. This net erosion correlates with high discharge from the power station, namely the flow duration of 2- and 3-turbines, and the 'excess' water released from the Gordon Power Station compared to pre-dam seasonal medians. Based on field observations, these flows lead to the transport of bank material downslope following cessation of prolonged 3-turbine power station operation, which is scoured by subsequent flows. The data may be indicating that the number of erosion pins in the 2-3-turbine bank level showing erosion have increased over the monitoring period. This suggests that the occurrence of erosion is increasing through time, but the length of monitoring is too short to confirm this trend. These results are also consistent with the hypothesis that the river is actively responding to increased flows due to the greater use of the three turbines in the Gordon Power Station. As discussed in chapter 5, in 2000-05, median monthly flows at the Gordon Power Station exceed pre-dam median monthly flows by up to 50 $m^3 s^{-1}$, an increase of 50 %.

The difference in net erosion rates between the 1-2 and 2-3-turbine bank level in zones 2 and 3 (Figure 7.7) is related to seepage-induced deposition reducing net erosion rates in the 1-2-turbine level, with the material largely derived from the 2-3-turbine level. This may imply that slowing seepage processes will result in a decrease in net erosion in the 2-3-turbine zone (due to a reduction in seepage events), with an increase in net erosion in the 1-2-turbine bank level due to reduced deposition. This is supported by the erosion pin results in the 1-2-turbine bank level which consistently show erosion, with lower net summer rates due to the increased sediment supply from the upslope seepage processes.

Zones 4 and 5 show different patterns of net erosion, with the <1-turbine level results indicating continuous erosion, accompanied by little net change in the 1-2 and 2-3-turbine bank levels. Field observations have found deposition occurs on the upper banks in these zones during periods of low or no power station discharge and high tributary inflows. This deposition is ‘balanced’ on the upper banks by scour, with erosion well correlated with power station discharge.

Although both zones 4 and 5 show similar magnitudes of erosion and deposition when the processes are considered independently, net erosion in zone 4 is substantially higher than in zone 5 due to the greater number of pins which recorded erosion in the zone. The reason for this is unknown. The monitoring sites were initially selected based on the same criteria for all zones, with the aim of including the range of alluvial bank types present in the zone (inside bend, outside bend, steep bank, shallow slope, high/low percentage of LWD). It must also be recognised that the deposition recorded by many pins in zones 2 and 3 is due to seepage erosion processes, rather than fluvial deposition, masking the true extent of bank erosion in the zone, so the higher ratios in zone 4 may reflect the impact of scour in the absence of seepage erosion.

The high ratio of erosion to deposition in zone 4 indicates that although the unregulated inflow of the Denison River is delivering sediment to the zone (as shown by the depositional component in Figure 7.1), the combined net effect of the power station-derived flow and natural inflows is erosion. The higher erosion rate of toes in zones 4 and 5 compared to zones 1-3 may be due to higher flows (inflows) eroding the banks downstream of the Denison confluence. It may also be that the toes in zones 1-3 have already adjusted to the regulated flow, with zones 4 and 5 continuing to adjust. Unfortunately, inflow from the Denison River is not available as an independent flow variable for testing some of these hypotheses.

Because the processes operating in zones 4 and 5 appear very similar based on field observations, the differences in net erosion rate may be attributable to the slope of the river and/or the relative input of unregulated flow. The slope of zone 4 is about 0.007 whereas the river slope decreases an order of magnitude downstream of the confluence with the Olga River to <0.0001. The additional flow input from the Olga River and other tributaries increased unregulated flows from 30 % in zone 4 to 40 % in zone 5 on an annual basis. The increase in sediment input is unknown, as no sediment budget is available for the middle Gordon. The statistical analysis found that deposition in zones 4 and 5 correlates with low or no power station usage, with erosion correlated with power station usage. This is consistent with the hypothesis that the sediment being eroded from zones 2 and 3 by power station-derived flows is not being deposited on banks in zones 4 and 5, and that sediment associated with tributary inputs is the main source of deposition in the zones downstream of the Denison confluence.

Net changes in zone 5 are near neutral, with deposition and erosion occurring at similar rates. This is consistent with field observations which found zone 5 to be dynamic, and displaying typical fluvial characteristics associated with flood disturbance. However, some individual sites are showing bank steepening through toe scour and the fluvial deposition of sand on the upper bank. Based on the pre-Basslink monitoring results, it is not possible to predict whether this zone will remain dynamic yet stable, or whether it will begin to respond similarly to zone 4.

The erosion pins show that the middle Gordon River is continuing to respond to the regulated flow regime, and is undergoing channel widening, with most erosion occurring in zones 2-4. Zones 1 and 5 are relatively stable with respect to bank erosion, although for different reasons. Generally, river channels reach equilibrium with altered flow regimes through the initial adjustment of bank toes, followed by adjustment and stabilisation of the higher bank faces. Viewing the middle Gordon River erosion pin results within this context suggests that upstream of the Denison, bank toes have stabilised, and erosion has progressed to the upper banks, whereas downstream of the Denison, the toes have yet to adjust to the regulated flow. This supports the idea of an erosional wave progressing down the river, with toe erosion in zone 4, upper bank erosion in zones 2 and 3, and stability in zone 1. This scenario raises some questions about the future response of the Gordon River:

- Where, in the channel widening process, is the present river, and how has the rate changed with time - is it approaching equilibrium or is it decades away from equilibrium?
- Will the processes remain the same in the future, or will the progression observed in the downstream direction occur within each zone?
- Is the stability in zone 1 permanent, with the erosional front having passed through this zone?
- Will the stability in zone 5 continue due to the high unregulated water and sediment inflows and low river slopes, or will erosion increase over time?

### 7.5.2 Photo-monitoring

The photo-monitoring results show that large-scale bank disturbances are generally stable, and do not propagate along banks once initiated. Only one site (zone 2 site 5) which is a large tree fall on an inside bend, has shown signs of ongoing disturbance. Since the initial tree fall occurred in March 2000, the bank failure has continued to propagate upstream with numerous additional small tree falls occurring.

The revegetation of landslips or tree falls appears to take one or more years to commence but, once established, grows rapidly above regulated high water level. This lag time in revegetation may be due to seed availability or lack of moisture during the summer. Banks below the regulated water level have not shown signs of revegetation.

Cobble banks are the most active features based on the results of the photo-monitoring, with the most common change being land slips in the overlying fine-grained deposits, and loss of vegetation from over-hangs remaining from the initial failure. Of the nine cobble banks monitored, five have shown changes over the monitoring period, with four showing change over both the 2002-03 and 2003-04 periods. Three of the five sites showing activity are located in zone 2, along the same reach.

The cemented cobble bars in the middle Gordon River show evidence of erosion in some areas, but the sites included in the photo-monitoring have not shown change over the three years of monitoring.

### 7.5.3 Summary

Baseline monitoring results document ongoing erosion of banks, with activity occurring at all levels of bank below the regulated high water levels and within all zones.

Results show that the river is not in equilibrium with the present flow regime. Bank toes continue to respond to even small power station discharges, with the 2-3-turbine operation range responding to higher flows. The river is responding both upstream and downstream of the Denison confluence, with channel widening in zones 2 and 3 concentrated in the 1-2 and 2-3-turbine bank level, and driven by high power station releases. Bank toes upstream of the Denison confluence are active, but overall show low levels of net erosion.

Downstream of the Denison confluence, the highest rates of erosion are associated with bank toes, with deposition and erosion occurring at similar rates on the upper banks leading to little net change. These results show that although the Denison River contributes a large unregulated sediment rich flow; there is insufficient deposition on bank toes to counter the erosive force of high power station discharges.

## 7.6 Evaluation of the Basslink monitoring program

The pre-Basslink monitoring has yielded results which document how various levels of the bank respond to the existing power station operations, and how the river is responding on a zone by zone basis. This has provided a baseline against which future results can be compared on a statistical basis. The results of the Basslink monitoring program have also documented the dynamic, non-equilibrium condition of the present river system, which needs to be recognised when interpreting post-Basslink monitoring results. Within the context of establishing a baseline for the detection of future changes, the monitoring program has achieved its goal, and is considered adequate. Continued analysis of the results and integration of results between disciplines is planned, which will further enhance the understanding of the pre-Basslink condition and potential Basslink changes.

Although the present monitoring regime has established a pre-Basslink baseline, a limitation has been the inability to form an in-depth understanding of the processes operating in the middle Gordon River to be gained due to the limited opportunities for field observations and low frequency of monitoring. Because the river has been repeatedly monitored in March and October only, with monitoring following similar power station operating patterns each year, there is a good understanding of the status of the banks in March and October, but not during the other months.

A major gap is what occurs during the wet winter period when power station operation is intermittent, typically involving 1- or 2-turbines and natural inflows are high. During this time of year there is a large difference in flow regimes between the zones upstream of the Denison and those downstream of the Denison. There is some evidence that under high natural inflows, the direct impact of rainfall on the exposed bank combined with seepage erosion may be affecting the banks in the 1-2-turbine bank level in zones 2 and 3, but there are no field observations to substantiate the evidence. The piezometer results in zone 2 have not been useful in interpreting winter bank conditions, because of doubts about the accuracy of the results due to changes in response rates resulting from the infilling of the bores by fine grained sediment.

Additional field access and erosion pin monitoring would also increase the understanding of processes operating in zone 3, where the recent installation of the compliance site has confirmed that the entire zone experiences backwater effects during periods of high flow in the Denison coinciding with power station shut-down. Obtaining erosion pin measurements in this zone before and after such an event would provide information about the role deposition from the Denison and Orange Rivers under backwater conditions plays in the overall bank dynamics of the zone, and assist in the understanding of some of the high rates of change documented in this zone.

Downstream of the Denison, where bank toes have a high net erosion rate, presumably due to scour from both the power station and natural inflows, winter monitoring would help identify what conditions are contributing to erosion, and how winter deposition from natural inflows varies between zone 4 and zone 5. This would assist in understanding the differences in rates documented between the two zones. Presently it is particularly difficult to interpret results from zones 4, as no flow information from the Denison River is available.

Understanding seepage erosion will be critical for interpreting post Basslink results and evaluating the efficacy of the ramp-down rule. Monitoring of the 2-3-turbine bank where seepage cavities are prevalent has proven difficult in zones 1-3 due to difficulties associated with measuring erosion pins placed in cavities, and the ambiguous results provided by the cavity pins due to the non-quantitative relationship between pin measurement and bank changes (any change in pin length indicates bank disturbance, but the change is not proportional to the change in-bank). This difficulty is being addressed by continuing to observe the behaviour of cavities, and increasing monitoring of bank slopes upstream and downstream of selected monitoring pins and cavities. The density of monitoring pins in the 2-3-turbine level not associated with cavities has also been increased so that the statistical power of the present monitoring regime will be maintained even if some of the present erosion pins are lost. This additional monitoring began in December 2004 during a non-routine monitoring trip, and will allow the collection of March 2005 and October 2005 results prior to the initiation of Basslink. Improving the piezometer array in zone 2 would also assist in interpreting post-Basslink seepage processes.

### 7.6.1 Planned improvements to monitoring program

To address some of the issues associated with limited field access, an investigation into the applicability of photo-electric erosion pins (PEEPs) for monitoring bank changes has been initiated. PEEPs are continuously recording erosion pins, however, commercially available units require considerable bank disturbance during installation associated with the laying of cable between the pin and the logger, located upslope of high water level. In the Gordon River, this level of bank disturbance would reduce the usefulness of the results to unacceptable levels. Hydro Tasmania is investigating options for installing commercially available PEEPs with minimal bank disturbance, and assessing whether the probes can be modified to auto-log results.

A second planned improvement to the monitoring program is the upgrading of the piezometer array in zone 2. Each of the bores will be re-drilled, and new casings which are less prone to sediment infilling will be installed. This will result in a piezometer array in which the probes will be able to be periodically removed for checking and calibration.

Opportunities for field observations outside of the scheduled Basslink monitoring periods will be provided by Hydro Tasmania on an opportunistic basis. With the establishment of a second helipad at the compliance site in zone 3, it is anticipated additional field excursions will be possible in the future which will enhance the understanding of processes affecting the banks outside of the regularly scheduled monitoring periods.

## 7.7 Fluvial geomorphology indicator variables

During the IIAS process, a range of indicator variables relating to fluvial geomorphology were identified to allow post-Basslink evaluation. Defining the indicator variables, and associated trigger values, forms the first step in a three-step process of evaluation and management action (see chapter 13). The key aspects of the post-Basslink changes with implications for hydrological stability in the middle Gordon River are the increase in the percentage of time of full capacity discharge, and the increased on-off fluctuations of the power station more fully utilising the range of flows.

Hydrological and erosional processes in the five fluvial geomorphology zones of the Gordon River were examined for suitability as indicator variables (Koehnken *et al* 2001), and erosion or deposition averages from sites within the five zones were set as indicator variables.

The diversity of processes occurring in the river and longitudinal heterogeneity, coupled with the limited length of the pre-Basslink monitoring period, has led to the need to pool data across sites within zones. Further pooling has been necessary either across turbine levels to allow zonal comparisons, or across zones to allow comparisons of turbine levels. This pooling restricts the capability to build verifiable stochastic models that are necessary to construct reliable limits on the range of values expected as a result of chance variation.

A further complication is the evidence of possible ongoing systematic change in many erosion indicators. Given that there are only four years of data, there is limited information on which to base a mathematical formula for a trend line. Yet another concern is the possibility that part of the trend may be a consequence of the changing pattern of use of the third turbine over the pre-Basslink monitoring period, a changing pattern that would continue even if Basslink were not implemented.

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# 8 Karst geomorphology

## 8.1 Chapter summary

The purpose of this chapter is to report on the findings of the Karst Geomorphology investigations of the Basslink monitoring program which have been in progress since 2001 following the initial investigation phase. The Gordon-Albert karst area in zone 2 and the Nicholl's Range karst area in zone 4 were targeted in the monitoring program as the areas which may be affected by the Basslink regime. In the Gordon-Albert karst area, the sites of interest include a backwater channel, two dolines and a newly discovered cave GA-X1, while in the Nicholl's Range karst area, two caves - Kayak Kavern and Bill Neilson Cave - were monitored.

The summarised findings of the karst chapter are:

- In general, the sediment processes in the caves reflect the typical river sediment processes of summer erosion occurring when the power station flow is high and the contribution from natural flow in tributaries is low, and winter deposition when the power station contribution is small and the sediment rich tributary flow is high;
- The key ecosystem component that may be affected by Basslink is the sediment transfer processes in the caves which are driven by the hydrological regime. Changes to the regime could affect the trends and rates of sediment transfer and change the geomorphic development of the caves;
- There are six different potential drivers of change to the hydrological regime, some artificial relating to power station operations and some natural. The measured changes in sediment that occur as a result of this complex hydrological regime are on average very small (average change at all pins in sediment banks 5.5 mm). It is difficult to assign the changes to specific power station operations and changes due to Basslink will need to be reasonably distinctive and significant in the context of all the other potential sources of change before they will be identifiable as specific Basslink changes;
- Limits of acceptable change are expressed as trigger values which, if exceeded will signal the need for investigation and, if necessary, the development and application of adaptive management actions. In the sediment banks, the indicator variables are current range and average changes at erosion pins, and current long-term trends. An additional indicator variable in the Bill Neilson Cave is the current percentage of the time that the pins in the dry sediment bank are inundated, both on a long-term basis and on an average seasonal basis, together with the current maximum height of inundation in the cave. In the dolines, the trigger is a change in distances between the pins of more than 20 mm.

## 8.2 Monitoring

### 8.2.1 Location of study sites

Based on the findings of the initial karst investigations as part of the Basslink Integrated Impact Assessment (Deakin *et al.* 2000), the Gordon-Albert karst area and the Nicholl's Range karst area (Map 8. 1) were targeted in the karst monitoring program as the areas most likely to be affected by the Basslink regime. Within the Gordon-Albert karst area, the program focussed on cave GA-X1, two dolines and a backwater channel. Within the Nicholl's Range karst area, the monitoring sites were 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. Detailed maps of each of the study areas can be found in Deakin *et al.* (2000).

### 8.2.2 Program objectives

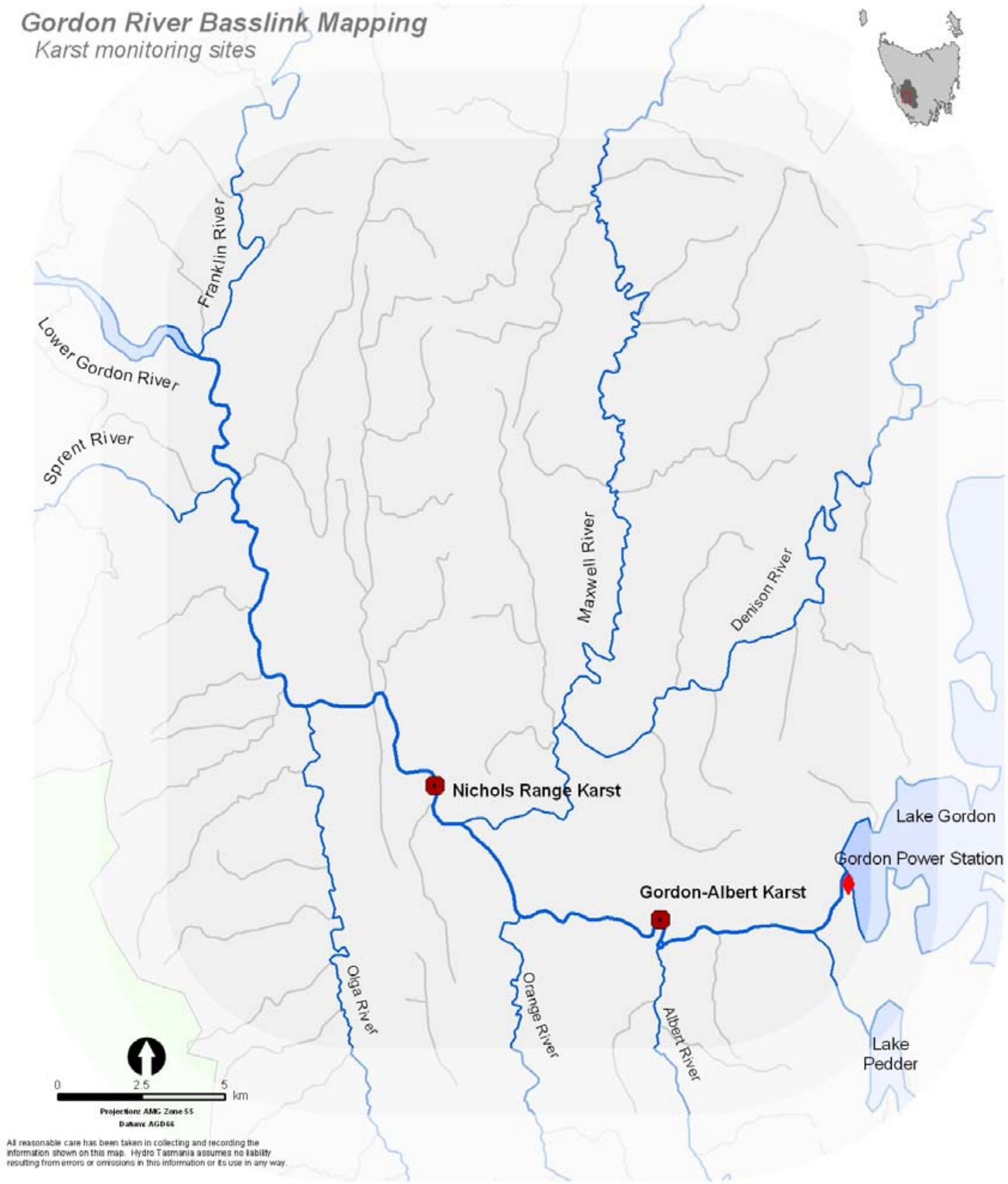
The primary objective of the monitoring program was to gain an understanding of the inundation regimes in the caves due to the back flooding of the Gordon River water, and the sediment fluxes within the caves which are dependent on those inundation regimes, particularly those caused specifically by power station operations. In the Bill Neilson Cave, two wet sediment banks in the entrance chamber and a dry sediment bank 175 m into the cave were the subject of the monitoring program.

In the dolines, the focus of the monitoring program was to determine whether there are any changes in the features under current power station operations, and what the rates of any changes are relative to power station operations.

An additional, lower priority element to the program in the Gordon-Albert karst area was to monitor the sediment changes in a backwater channel (Channel Cam) which is located directly behind a sediment flow feature in the upper part of the right hand bank of the Gordon River. It was not known conclusively in the original investigation stage whether these channels contributed sediment to the sediment flow features in the banks of the river via buried karst conduits. The objective of this relatively minor part of the program was to continue monitoring sediment changes in the channel and to determine whether they were significant enough to be providing a sediment source for the sediment flow.

It is possible that partially filled karstic channels may be conduits for groundwater that influence sediment flows along the banks in karstic sections of the river. This is not specifically monitored in the karst monitoring program, and would lend itself more to a one-off experimental exercise, for example using dye-trace although with considerable logistical difficulties.

Further information on the program rationale is provided in appendix 1.



Map 8. 1. Location of the karst study area.

### 8.2.3 Sampling strategy and methodology

A number of different sampling techniques were used throughout the monitoring program including water level monitoring in Bill Neilson Cave and GA-X1 to measure inundation by the Gordon River; erosion pin measurements in Bill Neilson Cave, Kayak Kavern, GA-X1 and Channel Cam to measure sediment transfer processes; and regular surveying in the dolines and Kayak Kavern to measure larger scale structural changes. Basic observation and photo-monitoring were also used to support the technical data. Further information on the sampling methodology is provided in appendix 6. Rainfall at Strathgordon, Gordon River water levels (site 77 (tailrace), site 72 (G5), site 71 (G5a), site 62 (Gordon below Denison)) and power station output were also recorded. Geomorphology data was also useful for the comparison of sediment transfer processes in the main river channel and in the cave environments.

Each site was visited twice annually in March and October, to collect sediment flux data representing spring-summer and autumn-winter conditions. Water level recorders collected data continuously throughout the year and were downloaded during each trip. Other observations such as high water level marks and vegetation changes in the Bill Neilson Cave were also noted.

## 8.3 Findings

The findings of the monitoring program are presented below under the headings of each of the sites being monitored. Further information, where appropriate, is provided in the appendix 6.

### 8.3.1 Channel Cam

Channel Cam is located high above the Gordon River. Surveys to the nearby gauging station and analysis of the water level data, show that the channel is only inundated by river water when the power station is operating with 3-turbines, at a flow of approximately 230-235 $m^3 s^{-1}$ (Figure 8.1). The depth of water in the channel with the inundation was typically less than 0.2 m, although a maximum depth of approximately 0.7 m occurred in April 2003.

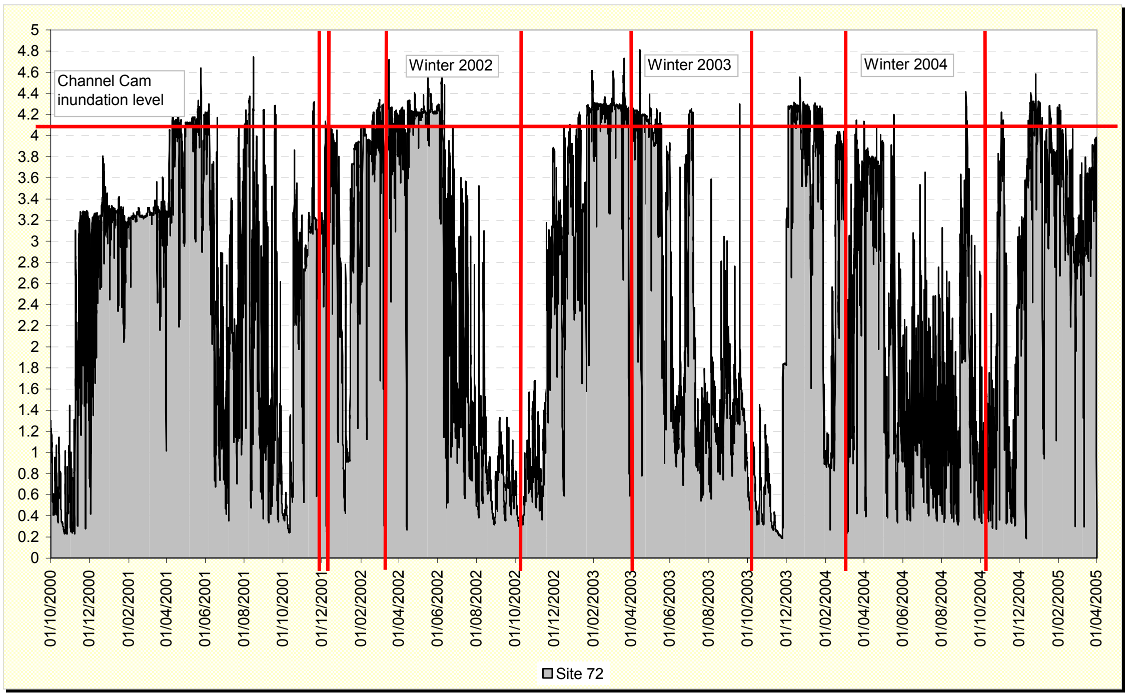


Figure 8.1. Water level data for the site 72 (G5) gauging station showing the level at which Channel Cam is inundated overlain by the sampling periods. All data in metres above an arbitrary reference level.

Two erosion pins were located at or about the level that the relatively horizontal channel was first inundated. The change in sediment at each of the pins in each of the sampling seasons relative to when the pins were first emplaced is shown in Figure 8.2.

The pin data show that there has been slight net erosion of fine grained muddy sediment in Channel Cam over the sampling program, due for the most part to the relatively large decrease in sediment during just one season, the summer 2004-05 period (9 to 13 mm). The changes during any one season ranged from 13 mm of erosion to 8 mm of deposition.

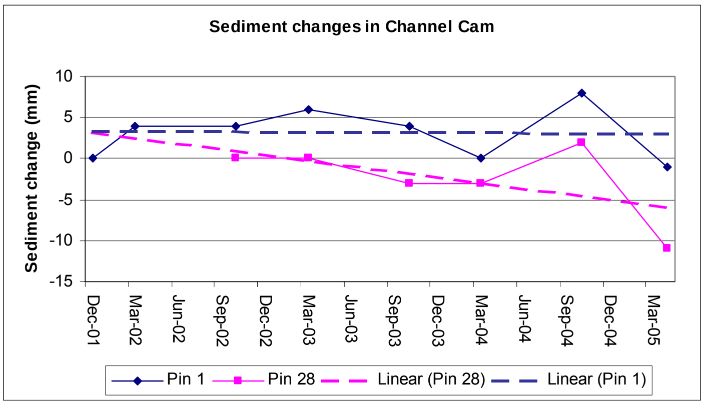


Figure 8.2. Sediment changes at the two erosion pins in Channel Cam. Graph shows the changes in sediment levels relative to the time when the pins were first installed. Note that pin 28 was not installed until October 2002.

Analyses of the site 72 (G5) river level data show that Channel Cam was inundated for approximately 16 % of the time between October 2000 and October 2004. Inundation most often occurs during the summer periods when the frequency of 3-turbine operations is typically highest (Table 8.1). Inundation during the winter periods has been as little as less than 1 % of the time (e.g. during the 2004 winter period).

Table 8.1. Seasonal changes in sediment in Channel Cam at each of the erosion pins together with the % of time that season that the channel was inundated. Pin data are relative to the levels on the preceding sampling trip and are measured in mm.

| Date | Channel Cam | | % of time inundated |
|---|---|---|---|
| | No. 1 | No. 2 | |
| Summer 01-02 | 4 | n/a | 9 |
| Winter 02 | 0 | n/a | 32 |
| Summer 02-03 | 2 | 0 | 36 |
| Winter 03 | -2 | -3 | 15 |
| Summer 03-04 | -4 | 0 | 20 |
| Winter 04 | 8 | 5 | <1 |
| Summer 04-05 | -9 | -13 | 12 |

### 8.3.2 Dolines

The two dolines are located above the maximum level of inundation of the Gordon River water and are not directly affected by the power station operations. There is however, potential for indirect impacts to be occurring below the surface at depth which could impact on the visible parts of the features in time.

Measurements of the lengths of the erosion pins in the dolines, and the distances between them, were made throughout the program. The data show that there has been a net accumulation of debris in the features over time (Figure 8.3 and Figure 8.4). The movement tends to happen in a consistent pattern over time at all levels in the feature but it is not strictly seasonal.

The erosion pins in the dolines however are more usefully used as markers for surveying whether any structural changes are occurring in the features. The pins have been established in a vertical array from the bases of the dolines to the rims and the distances between the pins have been regularly measured (see Table 8.2). The surveys show that, within the level of accuracy of the measurements, there has been no appreciable change in the structure or shape of the features since the program commenced.

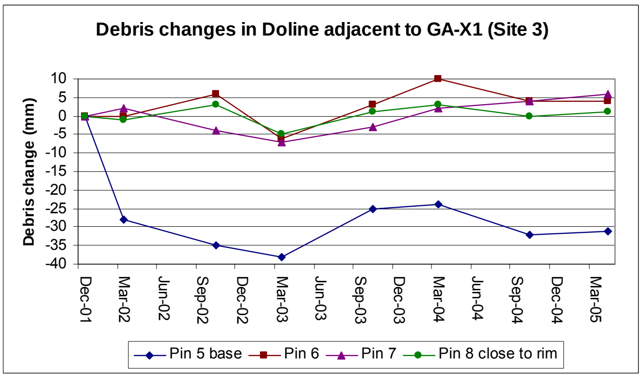


Figure 8.3. Changes in debris and leaf litter at the erosion pins in the doline at site 3.

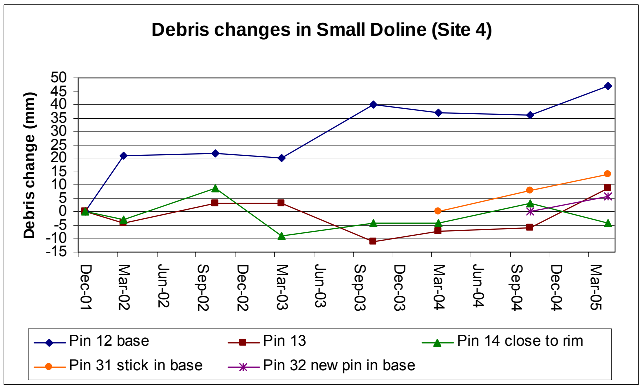


Figure 8.4. Changes in debris and leaf litter at the erosion pins in the doline at site 4.

Table 8.2. Distances between the erosion pins in the dolines since the beginning of the program.

| Site No. | Pins measured | Distance between pins (m) | | | | |
|---|---|---|---|---|---|---|
| | | 06/10/02 | 30/03/03 | 15/10/03 | 06/03/04 | 09/10/04 |
| 3 | Photo-monitoring peg to Pin 5 | 3.28 | 3.295 | 3.295 | 3.295 | 3.298 |
| | Pin 5 to Pin 6 | 1.055 | 1.055 | 1.05 | 1.055 | 1.05 |
| | Pin 6 to Pin 7 | 1.35 | 1.345 | 1.345 | 1.355 | 1.359 |
| | Pin 7 to Pin 8 | 1.85 | 1.85 | 1.85 | 1.845 | 1.852 |
| | *Sum Pins 5 to 8* | *4.255* | *4.25* | *4.245* | *4.255* | *4.261* |
| 4 | Photo-monitoring peg to Pin 12 | 2.62 | 2.62 | 2.63 | 2.625 | 2.628 |
| | Pin 12 to Pin 13 | 1.515 | 1.515 | 1.515 | 1.515 | 1.522 |
| | Pin 13 to Pin 14 | 1.435 | 1.435 | 1.435 | 1.435 | 1.44 |
| | Pin 13 to stick (Pin 31) | n/a | n/a | n/a | 1.505 | n/a |
| | Pin 12 to Pin 31 | n/a | n/a | n/a | n/a | 530 |
| | Pin 12 to Pin 32 | n/a | n/a | n/a | n/a | 722 |
| | *Sum Pins 12 to 14* | *2.95* | *2.95* | *2.95* | *2.95* | *2.962* |

### 8.3.3 GA-X1 Cave

Surveying and manual recording of water level rises in GA-X1 Cave has shown that the sump of the cave is located at or about the level of the Gordon River when the power station is off, and that the cave is inundated, although never completely, each time the power station is switched on. The water level recorder data from the cave have been calibrated with the water level data from the nearby permanent river gauging station at site 72 (G5) to gain a better picture of the full inundation regime in the cave. The site 72 (G5) data have also been compared with the power station operations to determine the relationship between power station activity and inundation of the cave (Figure 8.5).

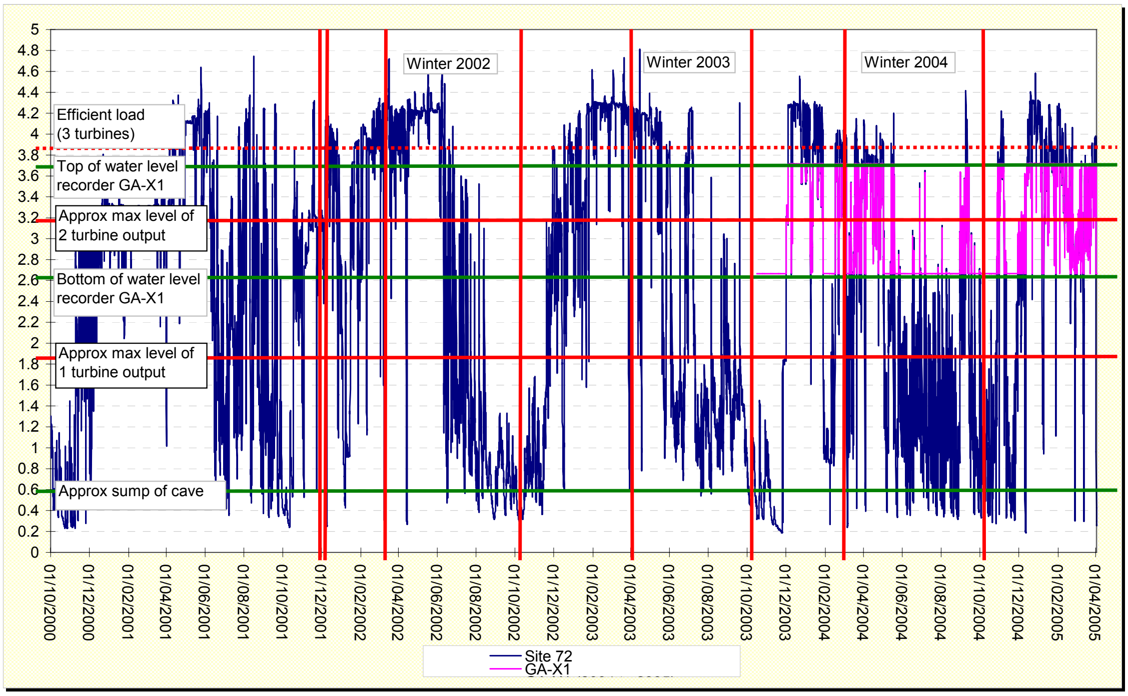


Figure 8.5. Water level data from site 72 (G5) (1 October 2000 to 2 April 2005) overlain by water level data from GA-X1 Cave (1 December 2003 to 2 April 2005 only). The graph also shows the river level at which water begins to enter the cave (Sump level in GA-X1). All data in metres above a single arbitrary reference level.

The river water begins to rise in GA-X1 when the power station is switched on. The 80 $m^3 s^{-1}$ of flow which is released when just 1-turbine is operating causes the river level at site 72 (G5) to rise to approximately 1.9 m which is below the level of the water level recorder in the cave. Pin 4, the lowest of the three erosion pins in the cave, is located within this zone. The flow when 2-turbines are in operation reaches a maximum of 3.2 m at site 72 which is at or about the middle of the 1 m range of the water level recorder. Pin 2 is located within this range. Efficient load at 3-turbine operation, results in a water level rise to 3.8 m at site 72 which is just above the maximum range of the water level recorder in the cave. Full-gate operations results in a water level rise of just over 4.2 m on the site 72 gauge, and together with any natural pickup in the catchment from the tributaries, it is still not capable of flooding out the cave completely. Pin 3 is installed above the water level recorder, at or about the highest level of the river water inundation at full-gate operation.

It was observed during an event when the power station was being turned on that the water level in the cave rises at a lower, steadier rate than that in the river. The lag time between the rise in the river and the rise in the cave was approximately 17 minutes when the power station was first turned on. The corresponding head difference was 0.35 m. The head difference and the lag time had significantly reduced within the next half hour to hour however, and equilibrium was reached after approximately five hours. This indicates that there is some sort of sediment buffer through which the river water seeps before reaching the cave. This is in contrast to an open rock conduit which would be expected to respond immediately to rise in river level.

The change in sediment at each of the pins in each of the seasons is shown in Table 8.3.

Table 8.3. Seasonal changes in sediment in GA-X1 Cave (pins 2-4) and leaf litter and debris in the doline at the cave entrance (pins 9, 10). Data show the changes that occurred over the relevant seasonal period at each erosion pin and are relative to the levels on the preceding sampling trip. All changes measured in mm.

| **Date** | **GA-X1 Cave** | | | | |
|---|---|---|---|---|---|
| | **No. 2** | **No. 3** | **No. 4** | **No. 9** | **No. 10** |
| Summer 01-02 | 11 | 1 | -7 | 1 | 0 |
| Winter 02 | 1 | -4 | 1 | -7 | -15 |
| Summer 02-03 | -6 | -2 | -3 | 3 | 3 |
| Winter 03 | 2 | -1 | 4 | -2 | -1 |
| Summer 03-04 | -3 | 2 | -6 | -5 | 1 |
| Winter 04 | -3 | 0 | -3 | 23 | 7 |
| Summer 04-05 | -3 | 0 | 0 | -14 | -3 |

Figure 8.6 shows graphically the sediment changes relative to when the pins were first emplaced. The changes at pins 9 and 10 represent the changes in leaf litter and debris in the doline at the entrance to the cave (Figure 8.7).

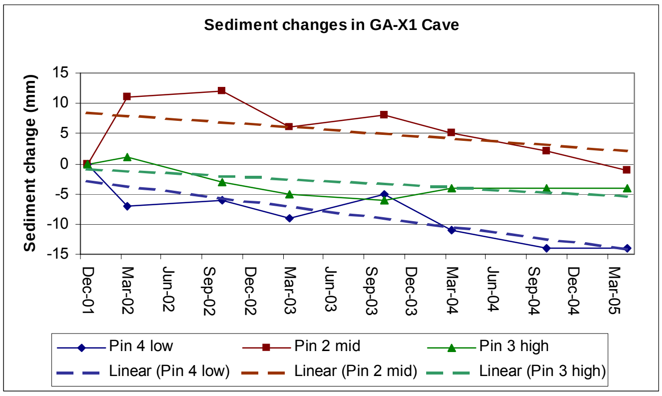


Figure 8.6. Sediment changes at the three erosion pins in GA-X1. Graphs show the changes in sediment levels relative to the time when the pins were installed.

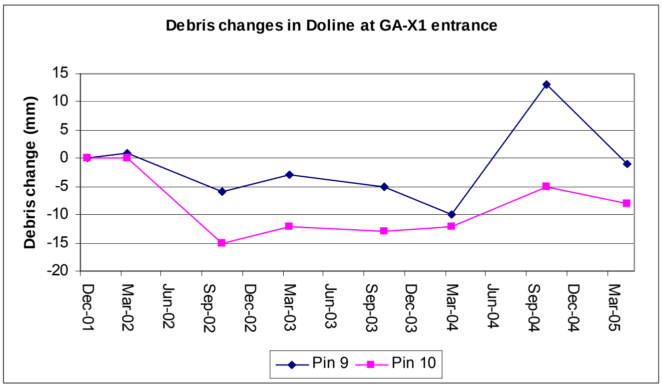


Figure 8.7. Leaf litter and debris changes at the two erosion pins in the doline at the entrance to GA-X1. Graphs show the changes in sediment levels relative to the time when the pins were installed.

The erosion pin data from within the cave show that there has been a gradual loss of sediment at all levels since the program began, although the middle pin experienced a relatively large increase in sediment during the first summer sampling period. The lowest pin, pin 4 shows the greatest loss of material over time (-14 mm), followed by the upper pin with -4 mm and finally the middle pin with -1 mm. Excluding the initial sampling period, the loss of sediment at the middle pin over the remainder of the program was -10 mm.

Pins 9 and 10 in the doline at the entrance to the cave, which are exposed to the elements, show that there is movement of at least the leaf litter and debris over time. The cave is immediately downslope of the pins and so is likely to be receiving the material. The distance between the pins (2.072 m) has not changed significantly since the beginning of the program which indicates that there has been no significant sediment or structural change.

### 8.3.4 Kayak Kavern

Kayak Kavern is inundated by the Gordon River at all flow levels. The sediment bank within the cave has an active slope to the front which plateaus out on top to a primarily horizontal surface and fills the base of the cave. Pins are located on the active slope and on top of the sediment bank.

Using the river as a common reference point between Kayak Kavern and the Gordon River below the Denison stream gauging site, it has been estimated that the top of the sediment bank at pin 18 is inundated when the river level at the gauging site is higher than approximately 2.5 to 2.6 m. Pins 17 and 19 are inundated when the river is higher than approximately 1.9 m. The two new pins located at mid levels on the active slope (pins 29 and 30) are affected when the level is higher than approximately 1.5 m[1].

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[1] While correlations of this kind are not entirely accurate due to differences in river channel profile between the two sites, given the proximity of the sites to one another, a rough estimate is considered possible within the level of accuracy required.

Interpretation of the water level data suggest that when the contribution of tributary flow to the river is low, it takes 3-turbine power station operations to inundate the top of the sediment bank and submerge pin 18, and 2-turbine operations to inundate Pins 17 and 19 on the active slope. However, when the power station is off, the entire sediment bank can also become completely submerged from the effects of tributary flow only, as in September 2002 for instance (Figure 8.8). As the Denison contributes a considerable proportion of the flow in the river during the winter/spring months (more than 50 % during the spring), it is difficult to relate sediment changes at the pins to specific changes in power station flow during these periods.

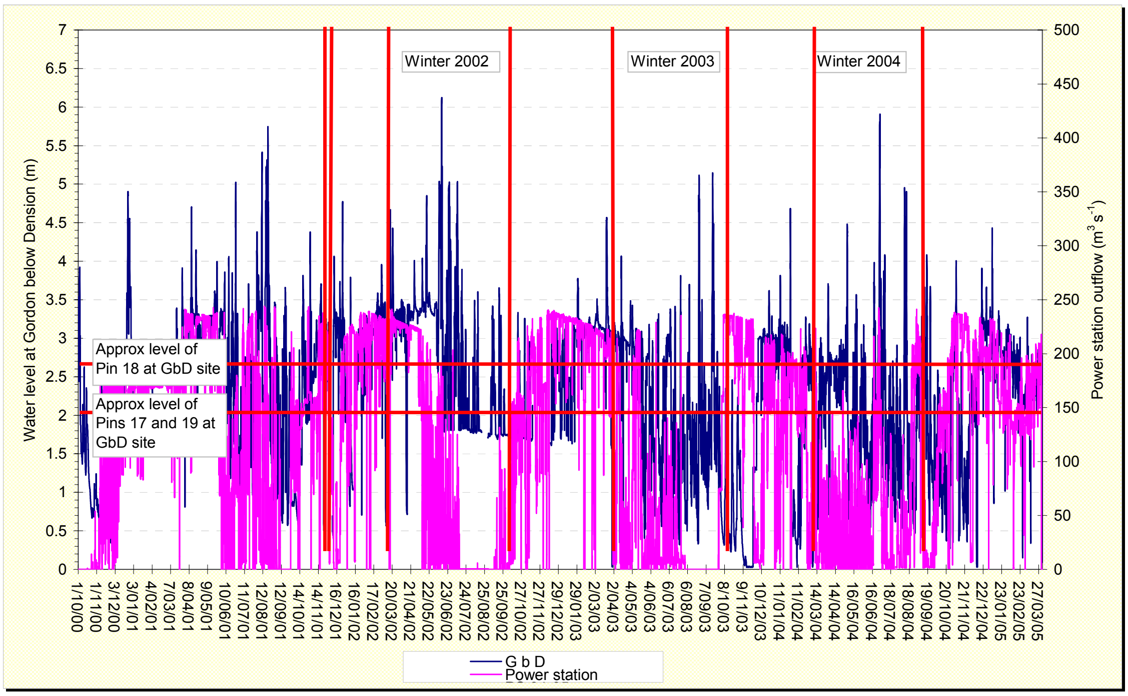

Figure 8.8. Water level data for the Gordon below Denison gauging site with power station outflow. Approximate estimates of the heights of the erosion pins in Kayak Kavern relative to the Gordon below Denison data are also shown.

The sediment changes at each of the pins for each of the sampling seasons are shown in Table 8.4, and graphically relative to when the pins were first emplaced in Figure 8.9. The results of the transect surveys of the sediment profile carried out between March 2003 and October 2004 to support the pin data are shown in Figure 8.10.

Table 8.4. Seasonal changes in sediment in Kayak Kavern at all pins. Note that pins 29 and 30 were only installed towards the end of monitoring program to assist in the post-Basslink monitoring program and no results are yet available. Data show the changes that occurred over the relevant seasonal period at each erosion pin and are relative to the levels on the preceding sampling trip. All changes measured in mm.

| **Date** | **Kayak Kavern** | | | | | |
|---|---|---|---|---|---|---|
| | **No. 16** | **No. 17** | **No. 18** | **No. 19** | **No. 29** | **No 30** |
| Summer 01-02 | 1 | 2 | 1 | 4 | n/a | n/a |
| Winter 02 | -11 | 7 | 11 | -26 | n/a | n/a |
| Summer 02-03 | -40 | -4 | -8 | 4 | n/a | n/a |
| Winter 03 | n/a | -51 | 5 | 42 | n/a | n/a |
| Summer 03-04 | n/a | -45 | 6 | 5 | n/a | n/a |
| Winter 04 | n/a | 35 | -4 | -2 | n/a | n/a |
| Summer 04-05 | n/a | 29 | -15 | -10 | n/a | n/a |

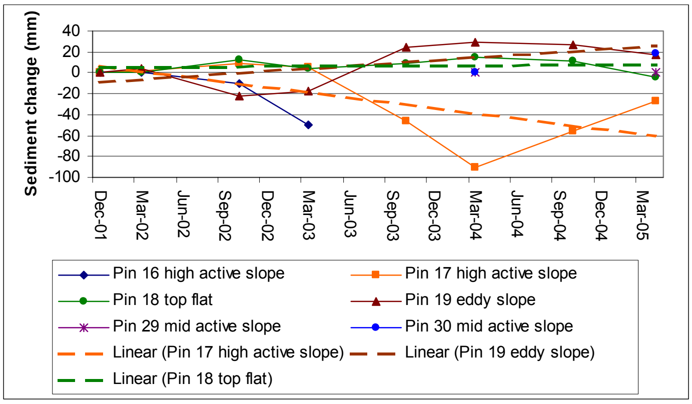

Figure 8.9. Sediment changes at the erosion pins in Kayak Kavern. Graphs show the changes in sediment levels relative to the time when the pins were installed. Note that pin 16 has fallen out and while pins 29 and 30 were installed in March 2004, they were submerged in October 2004 and no readings were obtained.

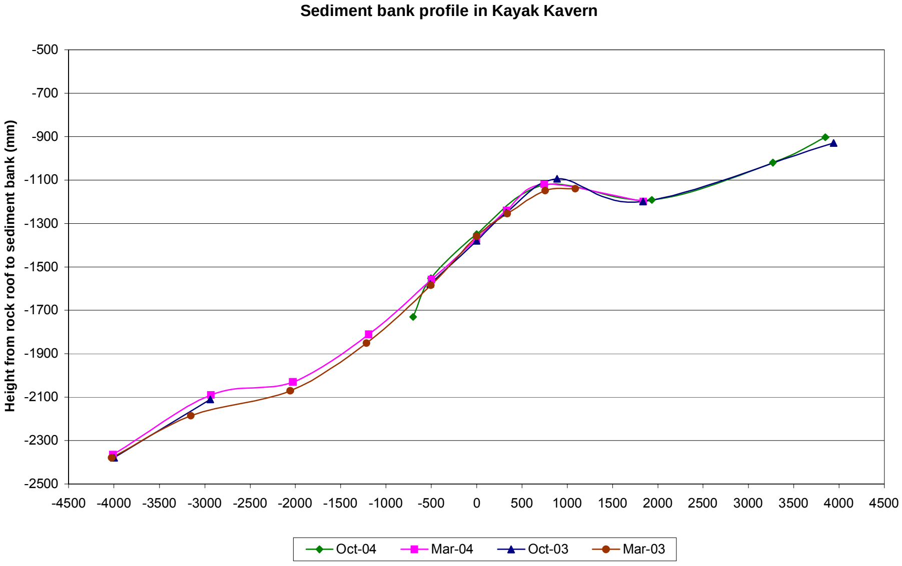

Figure 8.10. Results of the transect surveys of the sediment profile in Kayak Kavern between March 2003 and October 2004. Note that the shape of the trace is not the actual profile of the sediment bank because the vertical heights are relative to the rock roof and have not been corrected to a zero reference point. What is of most interest is the relative differences between surveys. All measurements in mm.

The transect survey data suggest that there have been no macro scale changes in the sediment bank over the 19 month period that the surveys have been carried out. On a micro scale however, more significant changes have taken place, particularly on the active slope area. At the northern end of the slope, pin 16 lost 50 mm of sediment and has been eroded out, and there has been some significant erosion at pin 17 (a maximum of -91 mm recorded in March 2004). To the southern end of the slope, pin 19 almost always exhibits the opposite trend and has experienced overall deposition (+17 mm).

### 8.3.5 Bill Neilson Cave

The entrance to Bill Neilson Cave is located at approximately the same level as the Gordon River, but as the cave is in the region of 500 m long with an average gradient of <0.015, it is only partially inundated with river water, depending on the height of the river and the size of the flow in the cave stream. The higher the cave stream flow, the higher the flow in the Gordon needs to be before it can reach a given point in the cave. The range of this variation appears to be of the order of 0.2-0.3 m (approximately 13-20 m horizontal distance in the cave) based on the flows observed during the sampling period.

The maximum distance within the cave to which the Gordon River back flooded during the sampling program was approximately 350 m from the entrance or to a height of 3.9 m RL[2]. This occurred during a flood event in June 2002 when high flows in the Denison coincided with 3-turbine power station operations and caused the river to reach a height of 6.1 m on the Gordon below Denison gauge. The median river level at the gauge during the sampling period however, was just 2.5 m which gives rise to inundation in the cave to a height of approximately 0.32 m RL or to a distance of approximately 115 m from the entrance.

The direct influence of the power station operations on the cave is difficult to determine because of the large contribution the tributary flows make to the overall flow in the river. When the Denison is very low and the flows in the river are controlled by the power station output, 1-turbine operation causes maximum back flooding in the cave to a height of approximately -0.88 m RL which reaches about 35 m into the cave or just into the large entrance chamber; 2-turbine operations inundates to a maximum of approximately 0.02 m RL or a distance of approximately 95 m into the cave; while 3-turbine operations can affect the cave to a height of 0.82 m RL or a distance of approximately 150 m from the entrance. When the power station is off however and the Denison River is high, the natural river flows can inundate the cave to higher levels than that caused by 3- turbine operations alone. The greatest impact in the cave is felt when the power station output and the Denison flow are both high.

The erosion pins in the sediment banks in the cave are positioned at various different heights and are inundated under a range of flow conditions (Figure 8.11). When the Denison River is low, the two lowest pins in the wet sediment banks (pins 20 and 25) are not inundated until the power station is operating with at least 2-turbines. The middle 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 efficient load or higher, 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 have been inundated just over 1 % of the time throughout the sampling program, almost all of which has been during the winter periods.

The sediment changes at each of the pins during each of the sampling seasons are shown in Table 8.5, and graphically relative to when the pins were first emplaced in Figure 8.12 and Figure 8.13. The data for the wet sediment banks at the entrance to the cave show that there has been net erosion at the lower level (-14 mm and -9 mm), while the middle levels has experienced little change

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[2] All reference points in the cave have been surveyed in to a single common reference point (0 m RL) and are described in meters above or below this point. The reference point is located at the base of a protruding piece of rock 1.41 m above the cave floor in the main entrance chamber.

(-0 mm and -1 mm), and there has been minimal net deposition at the upper levels (+1 mm and +5 mm).

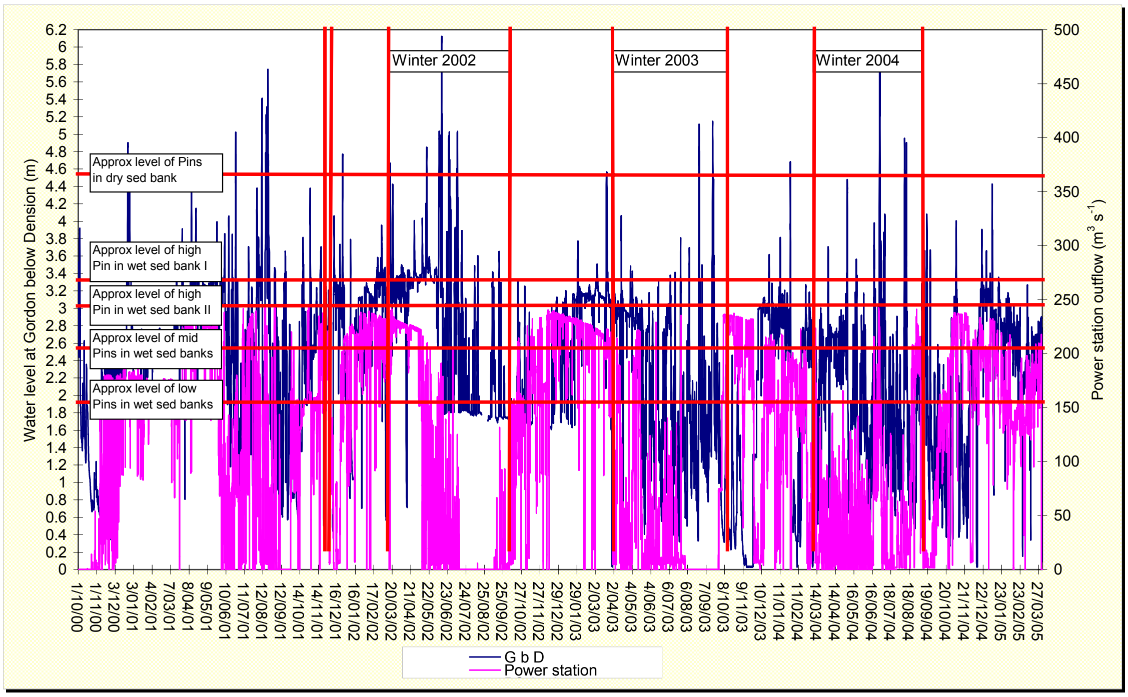
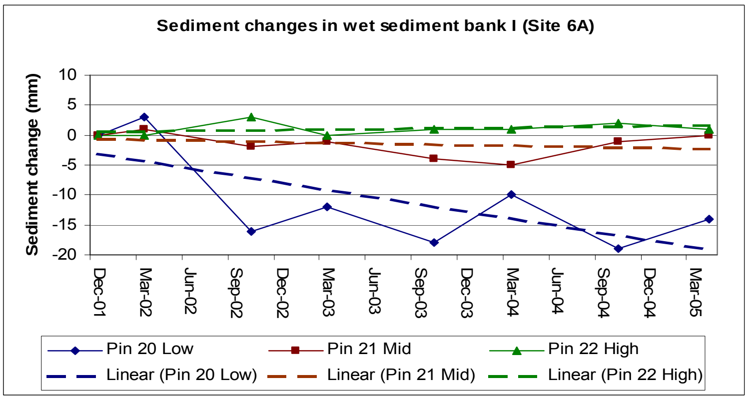


Figure 8.11. River levels at the Gordon below Denison stream gauge with power station flow. The approximate levels of the erosion pins in BIll Neilson Cave relative to the Gordon below Denison data are also shown.

Table 8.5. Changes in sediment at the three sites in Bill Neilson Cave. Data show the changes that occurred over the relevant seasonal period and are relative to the levels on the preceding sampling trip. All changes measured in mm.

| Date | Bill Neilson Cave | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Site 6A | | | Site 6B | | | Site 6C | |
| | No. 20 | No. 21 | No. 22 | No. 25 | No. 26 | No 27 | No 23 | No 24 |
| Summer 01-02 | 3 | 1 | 0 | -1 | 0 | -1 | 0 | 1 |
| Winter 02 | -19 | -3 | 3 | 0 | 1 | 2 | 2 | 24 |
| Summer 02-03 | 4 | 1 | -3 | 0 | 0 | 1 | -3 | -1 |
| Winter 03 | -6 | -3 | 1 | -3 | 0 | 1 | 0 | 0 |
| Summer 03-04 | 8 | -1 | 0 | 0 | -2 | 4 | 1 | 0 |
| Winter 04 | -9 | 4 | 1 | -7 | -2 | -2 | 0 | 0 |
| Summer 04-05 | 5 | 1 | -1 | 2 | 2 | 0 | 0 | 0 |



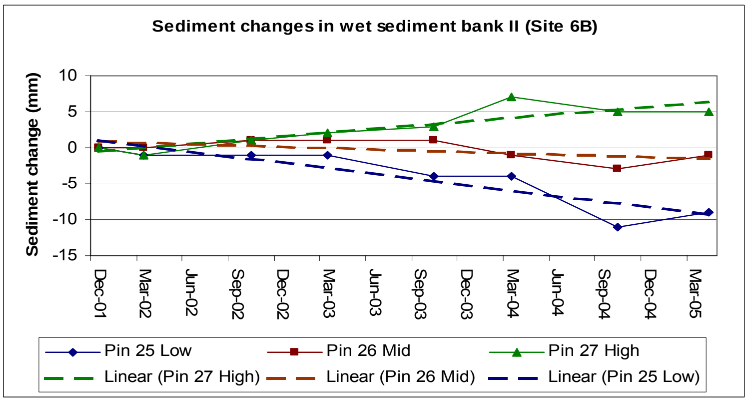


Figure 8.12. Sediment changes at the two wet sediment bank sites in Bill Neilson Cave. Graphs show the changes in sediment levels relative to the time when the pins were emplaced.

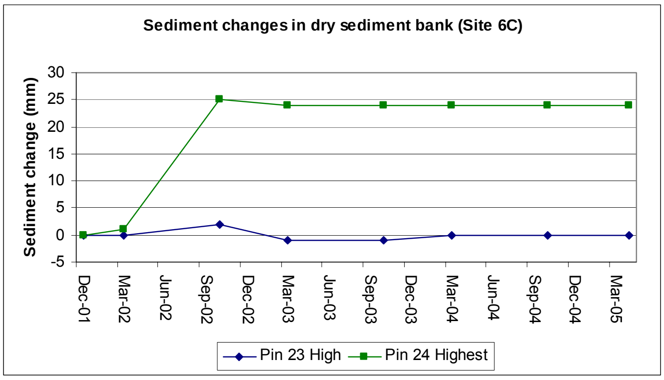


Figure 8.13. Sediment changes at the dry sediment bank in Bill Neilson Cave. Graphs show the changes in sediment levels relative to the time when the pins were first emplaced.

## 8.4 Analysis and interpretation

As discussed in the Conceptual model chapter, winter periods in the Gordon River are for the most part characterized by relatively low power station operations and high flows in the Denison River with associated sediment input to the system. These periods are typically periods of deposition in the river catchment. Summer periods on the other hand, are usually periods of high power station flow, with high river velocities, scour during water level rise events and a lack of sediment input which results in net erosion.

These trends are also generally reflected in the sediments in the caves. However, there are three main exceptions. Firstly, while these typical power station operation regimes give rise to broad scale seasonal trends in the sediment transfer data for the caves, there are occasionally short periods within the seasons when flows do not fit the trend due to river and power station events (appendix 6). The effects of these events on the apparent changes in sediment transfer when they occur prior to a monitoring trip need to be taken into consideration in the interpretation of the data. Secondly, the sediments at the lower levels in Bill Neilson Cave are more strongly influenced by the actions of the cave stream which is independent of the river. Thirdly, some of the sediments in Kayak Kavern, particularly those on the active slope face, are considered to be affected by localized eddy processes which do not reflect general flow conditions in the river itself.

The interpretation of the findings for each site is described below.

### 8.4.1 Channel Cam

Sediment changes in Channel Cam appear to be related to 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.

Given the relatively small changes in the channel throughout the monitoring period and the nature of the substrate being more muddy than the sandy material found in the sediment flows, it is considered that the channel is not a source of material for the sediment flow located immediately down gradient in the main river channel.

### 8.4.2 Dolines

Data collected throughout the program have shown that there has been no appreciable structural change in either of the dolines within the level of accuracy of the measuring technique.

The principal issue in determining any likely effects of the Gordon River fluctuations on the dolines is the nature of the hydraulic connection with the river. While the levels of the bases of the features are higher than the level of the river, the development of karst in this area is down to the current level of the river (e.g. GA-X1), so it is likely that the subsurface rock structure of the dolines has developed to similar depths. Analysis of the piezometer data from site 71 (G5a) (appendix 6) shows the degree to which the impacts of fluctuations in river level are likely to be tempered by in-filled sand. It is probable that in general, the higher and more frequent the fluctuations in river level, the greater the influence they will have on the dolines. However, they are probably relatively small.

The movement of leaf litter and forest debris into the dolines is not caused by river level fluctuations or power station operations and is probably more closely correlated with rainfall or other climatic or external terrestrial influences.

### 8.4.3 GA-X1

Despite the presence of the sediment buffer between the cave and the Gordon River, the water levels in the cave correlate well with the water level data from the site 72 (G5) gauging station, and much better than with the water level regime at the sediment bores at site 71 (G5a), which suggests that the hydraulic connection between the cave and the river is perhaps a structured rock channel which is in-filled in parts with sediment.

Seasonal trends are evident at the pins inside the cave. In general, sediment erosion occurs during the summer periods at the lower levels (pins 2 and 4) while the winter periods are typically periods of deposition. This is likely to be because the water level inundation regime during the summer months is typically one of higher and more consistent inundation, due to longer periods of 3-turbine flows, and the sediments become water logged and destabilised when the power station is turned off. The winters on the other hand are characterised by a much greater proportion of 1- or 2-turbine power station flows and extended periods when the flows do not inundate as high as the level of the pins. The slight deposition during these periods is likely to be due to the movement of sediment into the cave from rainfall in the surrounding area. The winter 2004 period was an exception to this trend, probably because of the uncharacteristic power station operations immediately preceding the sampling trip.

With the exception of the initial sampling period when the middle pin (pin 2) gained an uncharacteristically large 11 mm of sediment, the sediment transfer trends at the pins can be roughly correlated with the lengths of time the sediment at the pins is inundated: longer the sediment is inundated, i.e. in the lower parts of the cave, the more that is eroded.

While the sediment at pin 3 has changed relatively little compared to the other pins, if there is a trend it is typically opposite to that at the lower pins. This is probably a consequence of the height at which the pin is installed above the level of influence of the majority of power station flows. It is also close to, and directly down-gradient of the second smaller entrance to the cave and so may be receiving sediment from, or being effected by, rainfall events on the surface.

In summary, the erosion pin data suggest that there has been a net erosion of sediment from around the pins over the duration of the monitoring program but that there are also seasonal trends to the changes which are generally stronger in the lower parts of the cave that are more often influenced by power station operations. The more the pins are inundated, the more sediment that is removed: this leads typically to erosion occurring during summer and deposition during winter. The size of the changes inside the cave was relatively small however, with neither the net change, nor any individual seasonal changes at any of the pins greater than approximately 15 mm. At this stage it is not clear where the sediment is moving to, whether it is being removed from the cave through the sump or being recycled and moved around with the inundation events.

### 8.4.4 Kayak Kavern

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 as occurs in GA-X1 and Bill Neilson Cave. The differences in sediment transport between the pin locations is thought to be due to very localized affects of the Gordon River water swirling in the major eddy at the cave entrance. Pin 18 on top of the sediment mound, with its net loss of 4 mm since the program began, is probably most representative of more general sediment transport conditions in the cave.

Seasonal sediment transfer trends are not particularly strong but it appears that they fit the general river trends of summer erosion and winter deposition. The pin data suggest that there is a relatively high degree of sediment change occurring on the active slope. Pin 17 for instance has been eroded back to -91 mm relative to the starting point, but subsequently regained 64 mm of sediment over the following two monitoring periods. Sediments in the eddy area and on top of the mound are experiencing overall little net change. The effects of the changes to power station operations and Denison River flows in the lead up to the March and October 2004 sampling trips is evident in the data with overall net changes contrary to the norm during those periods.

### 8.4.5 Bill Neilson Cave

The lower levels of wet sediment banks are heavily influenced by the cave stream which erodes the banks when the Gordon River level is low, and deposits its sediment load when its velocity is reduced on meeting the backwaters from the Gordon when the river level is high. This is reflected in a strong seasonal trend of winter erosion and summer deposition. The mid levels of the wet sediment banks show a similar but weaker trend, with the exception of the two sampling periods in 2004 which were affected by unusual flow conditions prior to the trips. These pins, being higher up in the profile, are less affected by the cave stream and more affected by the Gordon River inundation regime than the lower levels. The upper levels of the wet sediment banks appear unaffected by the cave stream and sediment changes are primarily due to the effects of the back flooding from the Gordon River. Deposition at these levels occurs in winter when the sediment load is higher due to the higher contribution of flow from the Denison, while erosion occurs in summer when the flows are dominated by power station output. Pin 22, being the higher of the two pins at this level, is inundated less and has accumulated slightly less sediment as a result. Pin 18 in Kayak Kavern is located at a height equivalent to between the middle and upper level pins in Bill Neilson Cave and supports the conclusions drawn.

The net result is that at the first wet sediment bank, the erosion appears to be generally balancing the deposition, notwithstanding that there are one or two outliers in the data. The second wet sediment bank however is experiencing a slight divergence in the data: the lower levels of the banks are generally eroding over time, albeit at a low rate, while the upper levels are generally gaining sediment. The lower parts of the dry sediment bank are only rarely inundated at present (just over 1 % of the time) and have experienced little change over the course of the monitoring program.

The Gordon River affects all levels of the sediment banks being monitored, including the dry sediment bank, regardless of the power station output. Specific effects of the station operations can only be identified in summer when the natural flows are low. These summer events do not tend to impact the dry sediment bank unless the 3-turbine flows coincide with a reasonable additional contribution from the Denison River. Should this occur however, this is the period when the greatest impacts are likely to occur as the power station contribution to the flow will be relatively high and inundation is likely to be more intense than it would otherwise be with a Denison River dominated flow.

## 8.5 Impacts of changes to power station flow

The key karst ecosystem component that is likely to be affected by Basslink is the sediment transfer processes in the caves which are driven by the hydrological regime. 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 in the caves and their food sources, and change the geomorphic development of the caves. The current and future sources of change to the hydrological regime are complex. It is difficult to isolate the effects of the power station flow only on the sediments such that any future changes to that component of the hydrological regime only can be identified.

It has been determined in the conceptual model (chapter 3) that the sediment transfer processes in the Gordon River have not yet reached equilibrium from when the dam was constructed and power station operations commenced, so the ‘baseline’ condition determined at present in the river is not a stable baseline. This relatively long-term stability issue is likely to be the same for the cave environments as they are heavily influenced by the river regime. There are also shorter term changes to power station operations that have occurred more recently in the years since 2000, which have influenced both the hydrological regime and the sediment transport processes in the caves. On an even shorter term scale, there are the changes that occur due to isolated events in the power station operating regime in the weeks immediately prior to the sampling trips. On a more natural timescale, there are also the changes and fluctuations which will always occur in dynamic natural environments such as caves, and those that occur in response to particular natural changes in climatic conditions. Finally, once Basslink comes on line, there will be a further change to the operating regime which will also introduce a certain degree of change to the system. From these potential sources of ongoing change in the system, it is the effects of only one, the Basslink change, that are to be isolated and considered.

From the relatively limited evidence available over the course of the four-year monitoring program, it appears that there is a slight net gain in sediment at higher levels in the caves but a slight net loss at the lower levels which are more affected by the frequent low level power station operations, the mid range natural flows, and the cave stream in Bill Neilson Cave. The only sediment bank that registered negligible gross change over the course of the program was the dry sediment bank in Bill Neilson Cave and this was primarily due to the lack of inundation at that level. Some of the other sites however, registered significant gross changes but little net changes, indicating that the erosion and deposition processes may trend towards cancelling each other out over a longer timeframe. GA-X1 was the only site where the measurements at all pins consistently point towards removal of material over the course of the program.

The degree of change at all sites ranged from 0 mm in a number of locations to a maximum of 51 mm at pin 17 in Kayak Kavern on the active eddy slope. The median change at all sites over the course of the program, excluding the dolines, was 2 mm, the average was 5.5 mm and the standard deviation was 9.6 mm. In the context of all the potential forces of change that are present in the system, these are very small changes, particularly given the level of accuracy in the measuring technique.

It is not possible within the scope of this program to quantitatively ascribe accurate proportions of the measured changes to each of the potential forces of change, and in particular to the power station. At best, from the reasonable knowledge that has now been gained of how the sediment banks react to the hydrological regime, it is possible to qualitatively relate seasonal power station activity with changes in the caves. Any future changes due to Basslink will need to be reasonably distinctive in the context of all the other potential drivers of hydrological change before they will be specifically identifiable as Basslink changes, and not for instance a change in climatic conditions or pre-sampling weather conditions.

## 8.6 Evaluation of the Basslink monitoring program

The relatively limited number of karst monitoring sites has meant that the karst team has been able to collect some detailed quality data which has good repeatability. There has also been time and scope to make improvements and additions to the monitoring program along the way which will benefit the post-Basslink monitoring phase, such as adding new erosion pins, moving water level recorders and resurveying caves and dolines. As such, the karst monitoring program is considered adequate for the Basslink Monitoring Program.

Nonetheless there are a number of limitations with the monitoring program which are described below under each of the sampling techniques used.

### 8.6.1 Photo-monitoring

The photo-monitoring has produced mixed results throughout the program, although on balance it has been worth while and should be retained for the post-Basslink phase. Taking photographs inside caves and in low light environments is difficult at the best of times and this, with the substantially different quality outputs produced by the different photographic establishments which have been used throughout the program, has meant that comparison of photos has at times not been all that useful. However, now the same photographic paper and the same photograph developer are consistently used and photographs are digitally processed which can later be enhanced.

In the context of the monitoring program, the photo-monitoring is more useful for comparing macro-scale changes than micro-scale changes, principally because the micro-scale changes are so small that they are not picked up by the photographs and need to be actually measured. The photos are also useful for picking up other changes which have occurred in the caves which are not specifically the focus of the technical measuring program and may be missed in the dark during the site visit (e.g. new fallen tree branches which have the potential to interfere with erosion pin data and new inundation marks within the caves). Some additional photo-monitoring sites were added to the program as it progressed to concentrate more on the macro scale than micro scale.

### 8.6.2 Water level monitoring

It is a weakness in the program that the karst water level recorders, which are critical to understanding the water level regime in the caves, are inherently unreliable instruments and measure water levels over a relatively narrow range (up to a maximum of 1.8 m) which is much smaller than the change in river level (more than 3.5 m). There have been three failures where a full season's dataset has been unrecoverable from recorders, two of which occurred in Bill Neilson Cave over the same sampling period.

However, the monitoring program has worked well within these constraints by keeping a number of recorders in operation, by regularly moving them around to measure different parts of the hydrograph, and by continually striving to make correlations with the permanent water level recording stations in the Gordon River. Under the circumstances, there is now a fairly good understanding of the water level regime in the caves and the current situation is considered adequate for the post-Basslink monitoring phase. Given the nature of the caves, it is not possible, nor desirable from a cave conservation perspective, to install more permanent reliable monitoring stations, and in any case such a measure would not be considered warranted from a cost-benefit perspective.

### 8.6.3 Erosion pin data

Having access to the erosion pins twice per year makes it difficult to determine exactly how the sediment fluxes in the caves respond to the Gordon water level regime, as the changes measured on the day are strongly influenced by relatively recent flow events but yet are also representative of the cumulative changes over the previous six months. This reduces the usefulness of this data to only being able to provide qualitative information about net changes on a long-term basis.

However, given the relatively small nature of the changes in the sediment fluxes in the caves (usually less than 10 mm and frequently 0-4 mm) in the context of the level of accuracy of the measuring technique, a more regular sampling period would be unlikely to return more conclusive results. Ideally the sampling would be flow event based but this is an impractical approach given the remoteness of the area and the need for a power station shut-down to access all the sites. The current approach of generalising the Gordon River flow data to suit the level of sediment transfer information is probably the most realistic. The six-monthly sampling regimes for measuring erosion pins are considered adequate.

Measuring the heights of the erosion pins in the dolines as required under the original contract is not a useful task. The primary purpose of the pins in the dolines is to act as marker or reference points for identifying any major structural changes in the features and it is therefore the distances between the pins which is of interest, rather than the heights of the pins themselves. Both sets of measurements were recorded and reported on throughout the program but for the post-Basslink phase, the objective of the doline monitoring could be amended to focus on the structural aspects.

In the initial stages of the program, the pins were marked with yellow fluoro tape which unfortunately attracted the attention of wildlife. The early data collected in the program were affected by these disturbances but this was quickly remedied by removing or not replacing tape where appropriate.

### 8.6.4 Surveying

Surveying in the dolines and in Kayak Kavern is a useful sampling methodology to measure large-scale structural changes. A weakness with it in Kayak Kavern however, is that it was only added to the monitoring program in the second year and there are therefore only a limited number of datasets with which to determine the baseline conditions. However, as the data obtained are supporting the erosion pin data rather than replacing it or measuring a different parameter, it is considered that any data that can be recovered will be useful and the practice should continue.

### 8.6.5 Other issues

#### *8.6.5.1 Limitations due to human-induced impacts*

The relatively high sensitivity of the cave environment in GA-X1 to human disturbance means that the monitoring program is probably causing more damage with each visitation than there are benefits gained. The safety risk assessment has also shown that GA-X1 is the highest risk site in the karst program. The water level monitoring in GA-X1 could be ceased for the post-Basslink monitoring phase, once the correlation with the water level recorder at site 72 (G5) has been confirmed under Basslink operations. Disturbance could be minimised by only one person entering the cave to read the erosion pins.

#### *8.6.5.2 Statistical variability*

The issue of statistical variability is discussed in more detail in chapter 4 but two specific issues arise with reference to the karst monitoring.

In a normal karst environment, major structural changes in dolines are just as likely, if not more so, to be catastrophic as they are gradual. If a catastrophic event occurs at one of the monitoring sites after the Basslink flow regime has commenced, it will be difficult to determine objectively whether it is a Basslink related event or simply one that might have happened anyway. The strength of the doline monitoring program in the pre-Basslink phase is that it has determined that there are no significant gradual changes occurring under pre-Basslink conditions. Monitoring for gradual change should continue in the post-Basslink phase.

There are three major sources of water that together contribute to the inundation regime in Bill Neilson Cave and hence the sediment transfer processes: (a) the cave stream which is governed by the climatic conditions in the cave's local catchment area; (b) the Denison River and other major tributaries downstream of the power station which are controlled by the climatic conditions in their regional catchment areas; and (c) the output from the power station which depends on a number of external factors. Isolating the specific impacts of the power station operations from the impacts of the other sources of water, to the extent of being able to objectively determine the impacts of any future changes to operations under Basslink, is statistically difficult as the datasets are limited and the effects of each source of water are combined in different relative proportions preceding each sampling trip. A similar situation applies to Kayak Kavern and GA-X1, however with the exclusion of a cave stream. This means a quantitative approach to defining the effects of Basslink is not possible and qualitative assessments are most appropriate for analysing the data and considering the results.

Notwithstanding all the limitations of the data, the current karst monitoring program is considered to have been adequate to achieve its objectives although the results and conclusions can only realistically be qualitative rather than quantitative. Comparisons with the post-Basslink monitoring data will need to focus on identifying and accurately attributing any large-scale changes that may occur, as the potential origin of any smaller scale changes is likely to be difficult to determine.

## 8.7 Karst geomorphology indicator variables

The consequences of change in the sediment transfer processes in the caves are difficult to determine because the changes and impacts to the sediment banks generally happen at a relatively slow rate, and in both positive and negative directions thereby resulting in minor net change. It is difficult to define at what point any changes may become significant. The six potential drivers of hydrological change in the caves (see section 8.5) may all lead to changes to the sediments, so any future changes that may be Basslink-related will need to be reasonably distinctive.

There are no known significant karst biological considerations in the caves because the impact zones are not ones favoured by troglobitic (true cave adapted) species (Doran *et al.* 2000).

The significance of any changes also depends on the features and processes at work under current operations. It is difficult to assess the significance of Basslink impacts when it is not really known what the impacts of the present power station operations are, relative to the pre-power station impacts. For instance, it appears from the present monitoring program and initial investigation in 2000, that the power station operations are creating an overall net increase in sediment in Bill Neilson Cave and Kayak Kavern and that this may potentially switch to net erosion with Basslink in place. Comparison of the present cave surveys with pre-power station surveys suggests that before the power station was in place there was less sediment in the caves than there is today. Therefore, if sediment is removed under Basslink operations this may be a beneficial outcome.

In general terms, any future level of change would be considered to be acceptable if it is not inconsistent with the current range of change at each of the monitoring sites. There may also be scope for increasing the level of change without any significant impact but the degree to which this would be possible is not known. Any changes that fall outside the current range would need to be assessed to see whether any of the other five drivers of change apart from Basslink are also contributing to the effect. It is considered that the best approach will be to measure the degree of change if and when it occurs, assess the possible drivers of the change, identify what the consequences of the change might be and then determine whether or not it is acceptable. With this in mind, indicator variables have been determined, along with trigger values at which any future changes should be assessed for Basslink implications. Trigger values have been determined for:

- sediment transfer processes in the caves;
- inundation of the dry sediment bank; and
- structure of the dolines.

For assessing the changes to the sediment transfer processes, each erosion pin will be considered individually and collectively where appropriate, e.g. in Kayak Kavern, Channel Cam and in the wet sediment banks in Bill Neilson Cave. Three principal indicator variables will be used: the current maximum range of change, the current average rate of change, and the long-term trend since the pins were first installed Relatively large changes to the average rate of change are anticipated because the data are for individual pins and as such, are subject to the influences of extreme events.

To assist in determining any future significant changes to the dry sediment bank in Bill Neilson Cave, an additional indicator variable will be added, namely the current percentage of the time that the pins in the bank are inundated, both on a long-term basis and on an average seasonal basis. The current maximum height of inundation in the cave will also be considered.

In the dolines, while there has been no appreciable structural change to date, the level of accuracy of the measurement technique is ±10 mm so the trigger will be an increase in the sum of the distances between the erosion pins of more than 20 mm, with consideration given to whether the pins could have been disturbed by wildlife.

# 9 Riparian vegetation

## 9.1 Chapter summary

This chapter summarises the results of the three years of baseline data collected from April 2002 to April 2005, and provides a baseline with which post-Basslink monitoring results will be compared. The main focus of the monitoring has been to understand the seasonal and spatial patterns of extant vegetation and to understand the processes that may be driving change in this vegetation.

The summarised findings of the riparian vegetation chapter are:

- This study has found that the vegetation within the Gordon River over the past three years has generally been stable in terms of abundance and diversity;
- The main factor that controls the extent of the vegetation is flow regulation and the subsequent level of disturbance and inundation. This has led to the mature vegetation being highly stratified up the bank of the river resulting in a distinct Plimsoll line, below which few species are able to survive;
- Below the Plimsoll line there are a reduced number of trees, shrubs and ground cover species with only those species that are highly tolerant of inundation of leaves and waterlogging of roots persisting;
- The germination and recruitment of seedlings shows a similar pattern. Seedlings are germinating at most bank levels over the spring and summer but are not persisting or developing into larger plants;
- Soil analyses have shown that dieback (*Phytophthora cinnamomi*) is present in the Gordon River. Since the inception of Basslink investigative studies and the monitoring program, Hydro Tasmania has addressed the risk of *Phytophthora* introduction by implementing hygiene measures as recommended by DPIWE; and
- A number of indicator variables are used as a basis for comparison between pre- and post-Basslink monitoring periods, most of which are measures of abundance or density of flora species, seedlings or ground cover conditions. The major criterion for suitable indicators is that they will be able to detect real change within the middle Gordon River. This change may or may not be attributed to pre-Basslink changes and will thus require further analysis for detection of causal relationships.

## 9.2 Introduction

The Basslink riparian vegetation monitoring program aims to monitor the present conditions and underlying processes operating on the riparian vegetation of the middle Gordon River. The program has been designed to obtain three years of pre-Basslink data and six years of post-Basslink data.

The riparian vegetation monitoring program has collected data on the cover and abundance of existing vascular riparian plants at permanent plots located both in the middle Gordon River and in two reference rivers, the Franklin and Denison. Map 9.1 shows the location of the monitoring sites. Analysis of these data will provide:

- a greater understanding of the existing processes, trends and condition of riparian vegetation within the middle Gordon River;
- datasets to quantify any potential Basslink-related effects; and
- a scientific basis for adaptive management.

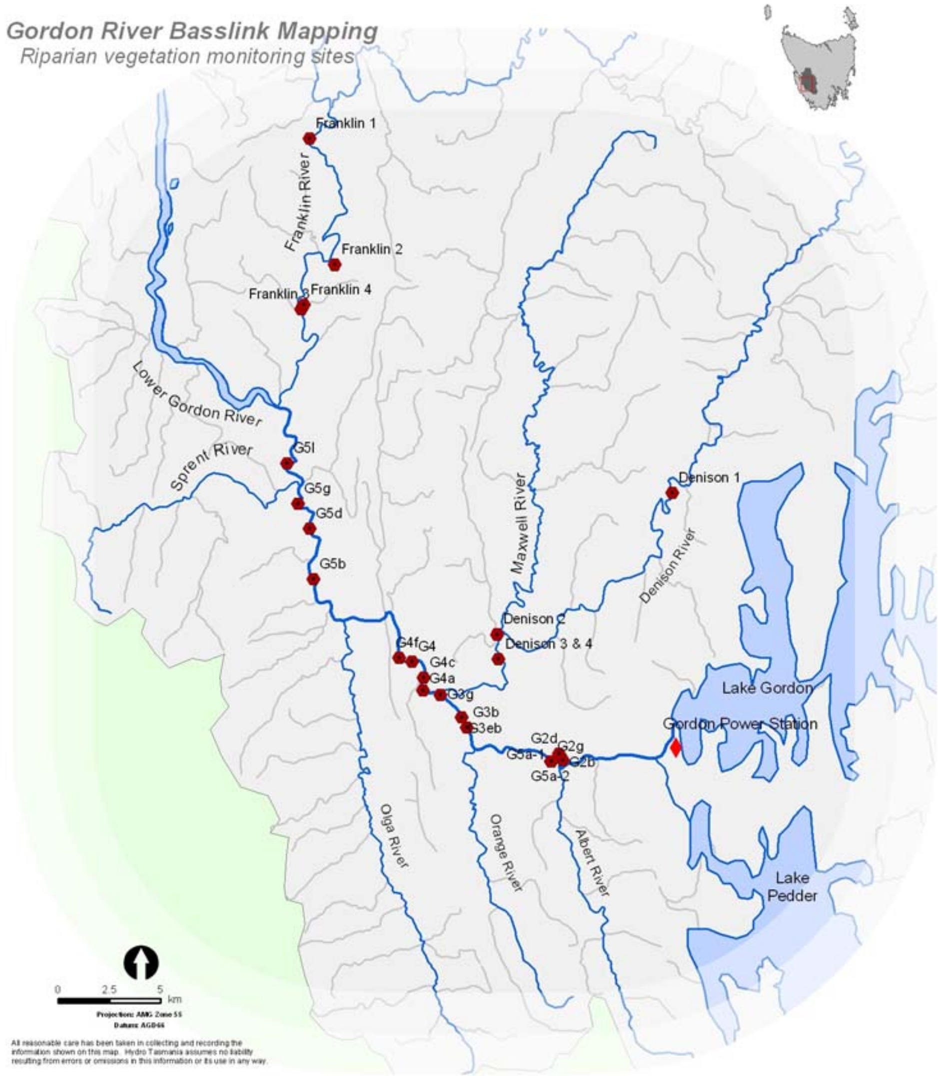
## 9.3 Monitoring

The riparian vegetation monitoring comprises two methods of assessment: permanent quadrats and transects; and photo-monitoring sites. Permanent quadrat monitoring comprises assessment of ground species cover, shrub and tree stem density, seedling numbers and ground conditions.

Seedling recruitment monitoring is undertaken in the Gordon River twice yearly, in autumn and summer, to obtain seasonal recruitment patterns. Photo-monitoring and all quadrat studies are undertaken concurrently in the Franklin and Denison Rivers. The monitoring program schedule, covering both seasons for all rivers, is presented in Table 9.1.

### 9.3.1 Quadrat location

Quadrat sites were located along river banks adjacent to sites established for geomorphic studies to enable investigation of correlation between geomorphic investigations and vegetation processes. All vegetation sites are co-located within 5-10 m of geomorphology sites, except in areas of overhangs or active scour. See Table 9.2 for a list of permanent quadrat sites established in the Gordon, Franklin and Denison Rivers.



Map 9.1. Riparian vegetation monitoring sites on the Gordon River and tributaries. Monitoring zones are indicatedin the Gordon River site labels: e.g. site G2d is in zone 2; site G5g is in zone 5, etc.

Bank sampling sites were established in four of the five zones of the Gordon River (see Map 9.1). These zones correspond with those determined in initial geomorphic studies (Koehnken *et al.* 2001) which divided the middle Gordon River into five zones based on the presence of hydraulic controls, such as gorges or the confluence of tributaries. No bank sites were established in zone 1, the zone closest to the power station, as it is dominated by bedrock substrate with little substrate suitable for vegetation.

Site selection within the Denison and Franklin Rivers was largely dictated by logistical constraints; only those sites accessible by helicopter under a range of flow levels (except very high flows) were selected for quadrat sites. This resulted in all bank monitoring sites being adjacent to, or accessible from, cobble bars.

Table 9.1. Riparian vegetation monitoring program schedule.

| | Season | | Monitored variable / method of assessment | | |
|---|---|---|---|---|---|
| **Sites** | **Autumn** | **Summer** | **Quadrat studies** | **Seedling recruitment** | **Photo-monitoring** |
| Gordon zones 2-5 | | * | | ✓ | ✓ |
| Gordon zones 2-5 | * | | ✓ | ✓ | |
| Tributary sites | * | | ✓ | ✓ | ✓ |

Note: Quadrat studies include species cover, root exposure and tree and shrub stem counts.

Table 9.2 List of permanent quadrat sites established in the Gordon, Franklin and Denison Rivers showing distance from tailrace, presence of a co-located geomorphology site and substrate type at site.

| Zone/river | Site Name | Distance from tailrace (km) | Co-located geomorphology site? | Substrate type |
|---|---|---|---|---|
| 2 Gordon | G2b | 5.5 | Y | Alluvial |
| 2 Gordon | G2d | 6 | Y | Alluvial |
| 2 Gordon | G2g | 6.8 | Y | Alluvial |
| 3 Gordon | G3b | 13 | Y | Alluvial and cobble |
| 3 Gordon | G3eb | 13.7 | Y | Alluvial and cobble |
| 3 Gordon | G3g | 15.8 | Y | Alluvial |
| 4 Gordon | G4a | 16.8 | Y | Alluvial |
| 4 Gordon | G4e | 17.4 | Y | Alluvial |
| 4 Gordon | G4f | 19.4 | Y | Alluvial |
| 5 Gordon | G5b | 27.2 | Y | Alluvial |
| 5 Gordon | G5d | 30.45 | Y | Alluvial |
| 5 Gordon | G5g | 32.3 | Y | Alluvial and cobble |
| Denison | D 1 | N/A | N | Alluvial |
| Denison | D 2 | N/A | N | Alluvial and cobble |
| Denison | D 3 | N/A | N | Alluvial and cobble |
| Denison | D 4 | N/A | N | Alluvial and cobble |
| Franklin | F 1 | N/A | N | Alluvial and cobble |
| Franklin | F 2 | N/A | N | Alluvial |
| Franklin | F 3 | N/A | N | Alluvial and cobble |

### 9.3.2 Sampling design

#### *9.3.2.1 Quadrat sites*

At each site one permanent transect, comprising eight 1-m square quadrats was established. Quadrats were offset by 0.5 m from the transect line to avoid trampling impacts, and located with reference to the high water mark as shown in Figure 9.1. At most of the quadrat sites the high water mark was delineated by a star picket previously installed during three-turbine operation. At sites where there was no delineation of high water mark, this was estimated by changes in litter cover and ground disturbance. Sites were permanently marked.

Monitoring within these sites included assessment of ground species cover, seedling numbers, density of trees and shrubs, health of vegetation and habitat variables including substrate and aspect, as discussed in appendix 7.

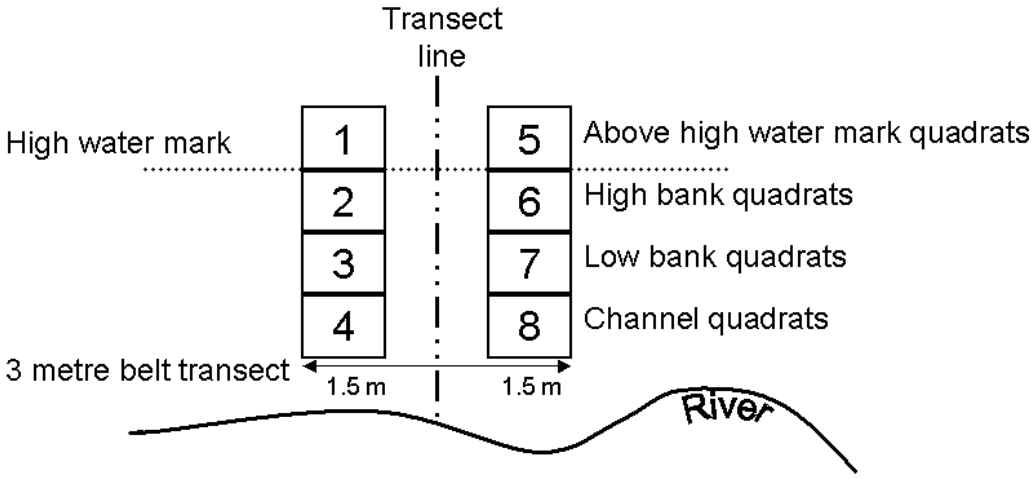


Figure 9.1 Diagrammatic representation (plan view) of quadrat positions along transects in Gordon, Franklin and Denison Rivers.

#### 9.3.2.2 *Photo-monitoring sites*

Photo monitoring sites were established at representative sites covering all substrate types within the major reaches to obtain representative data on patterns and processes within the rivers (see Table 9.3). These photo monitoring sites enabled accurate, objective measurements of canopies of shrub and tree species, presence/absence of ground layer species, and assessment of health indicators. The following factors were considered in taking oblique photographs to reduce distortion and variation (Magill, 1989):

- Photos have been taken using the same focal length;
- Range poles were placed on permanent markers at a 5 m interval (parallel to the river);
- Photos have been taken in the same season to avoid seasonal changes.

Photo-monitoring provided additional monitoring sites. Analysis of photos included assessment of canopy expansion or contraction, ground cover expansion or contraction, and combinations of these changes. Reported changes have a minimum magnitude of ±10 %.

Table 9.3 Number of permanent photo-monitoring sites established in each zone in the Gordon River.

| Zone | Number of photo-monitoring sites |
|---|---|
| Gordon 2 | 12 |
| Gordon 3 | 8 |
| Gordon 4 | 7 |
| Gordon 5 | 8 |
| **Total** | **35** |

## 9.4 Results for the Gordon River

### 9.4.1 Vegetation communities and meta-disturbances

The riparian vegetation communities of the Gordon River are somewhat atypical compared with the tributaries. Riparian vegetation in the unregulated rivers extends laterally from the boundary of low summer flows to the peak flood level where it grades into the adjacent rainforest community (Davidson and Gibbons 2001). Riparian vegetation in the middle Gordon River is greatly reduced, in terms of both abundance and species richness, due to physical disturbance, bank collapse, waterlogging, and inundation.

Pre-damming peak flows in the Gordon River were typically short-duration, high magnitude events that varied between seasonal baseflows, exacerbating seasonal influences. The post-dam regulated flow regime has led to broadly reversed seasonality and a higher frequency of high flows of greater duration. Further downstream of the power station, in zones 3 and 4, tributary inputs led to more natural flows in winter, with summer flows still being dominated by power station operation. Concomitant with these natural flows and flood events are inputs such as plant propagules, large-scale disturbance and sediments contributing to conditions more typical of natural riparian systems.

Flow regulation has resulted in altered disturbance regimes and the removal of much of the typical riparian community. Extended durations of high flows have resulted in the loss of vegetation within the power station-controlled range of water levels, resulting in a distinct Plimsoll line. Photo 9.1 shows the Plimsoll line at a zone 4 site. The level of the line varies according to local hydrology. It generally decreases in delineation with distance from the power station and increasing natural flows.

The reversed seasonality of the present regulated flow regime has exacerbated these impacts, with high summer flows restricting photosynthetic activity in what is typically the peak growth season. Inundation of leaves is further damaging due to the dark-coloured waters, effectively reducing the euphotic depth of the water (the depth at which plants can obtain enough light to carry out photosynthesis). Most plants cannot respire or photosynthesise when inundated and require sufficient daylight hours free of inundation to maintain growth. The impacts of this reduced metabolic effort and energy may include a diminished seed production, growth and capacity to withstand stress.

The riparian vegetation of the middle Gordon River is largely thamnic rainforest with an edge of light-tolerating species or occasional copses of the inundation and waterlogging tolerant species *Leptospermum riparium* (tea tree). Rainforest species include *Anopterus glandulosus* (native laurel), *Richea pandanifolia* (pandani), *Nothofagus cunninghamii* (myrtle) *Eucryphia lucida* (leatherwood), *Lagarostrobos franklinii* (huon pine) and *Atherosperma moschatum* (sassafras).

Photo 9.1. Riparian vegetation along Gordon River in zone 4 showing the distinct Plimsoll line and bank butressing by large woody debris.

### 9.4.1.1 *Tree falls and landslips*

Tree falls and land slips frequently occur along the banks of the Gordon River. Landslips result in the inundation of vegetation and large trees, often up to five or more metres into the bank. Following such events, bare soil surfaces above the high water mark are colonised by disturbance-tolerating ruderal species such as *Baloskion tetraphyllum*, *Gnaphalium* spp., *Acaena* spp. and *Ehrharta stipoides*. Secondary colonists may include some of the more light-requiring tree species such as *Acacia verticillata* and *Pomaderris apetala*. There is often only limited re-colonisation of areas below the high water mark.

#### *9.4.1.2 Community dynamics shown in photo-monitoring*

Photo-monitoring was undertaken at thirty-five sites during the pre-Basslink monitoring: in December 2002, November 2003 and December 2004. This allowed comparisons to be made between years providing assessment of coarser scale patterns, such as decreases or increase of abundance of strata within the vegetation. The results for the 2002-03 and 2003-04 sampling pairs are presented in Figure 9.2.

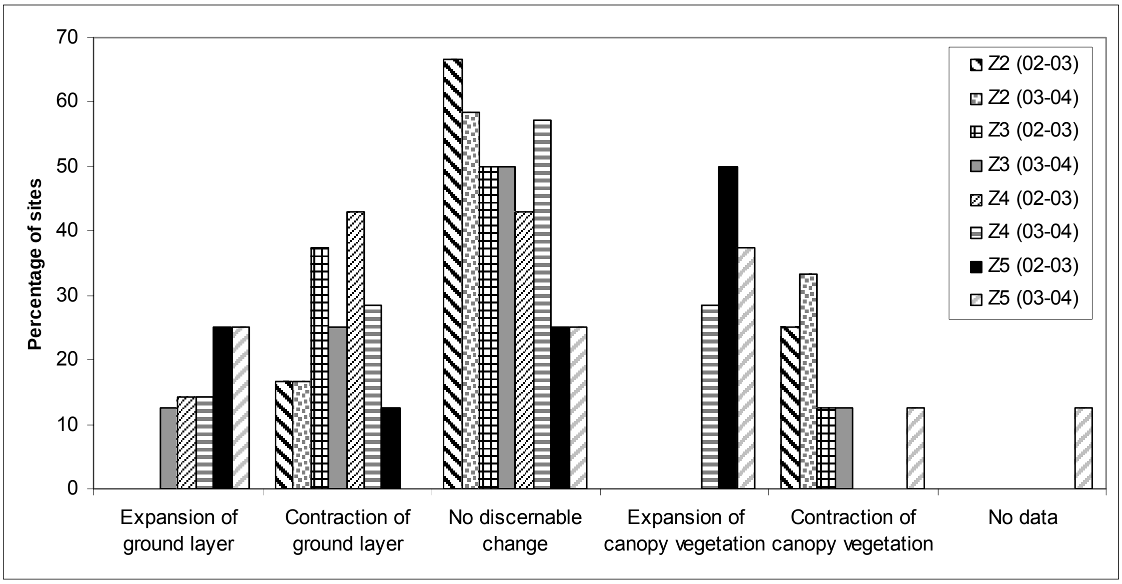


Figure 9.2 Summary of photo-monitoring results in zones 2-5 for middle Gordon River, December 2002-November 2003 and November 2003-December 2004.

Most photo-monitoring sites showed no discernable change (approximately 10 % for most variables) over the monitoring period (see Figure 9.2). The dominant pattern of change over both periods of analysis was the contraction of ground layer vegetation that occurred at numerous sites in all zones. Much of this contraction was the result of thinning of ferns such as *Blechnum* spp. and grass species. However, the inverse pattern of ground cover expansion was the next most commonly recorded pattern in the photo-monitoring. This too was the result of changes in fern cover, most of which occurred in zone 5. The expansion of the canopy vegetation in zones 4 and 5 was due to thickening of existing tree canopies, largely *Pomaderris apetala*. Contraction of the canopy vegetation in zones 2-4 for this time period reflected continuing thinning of Leptospermum riparium shrubs and retreat of the bottom of the canopy to a higher level; this latter effect is a response to increased periods of inundation. Photographs showing examples of listed changes are presented in section A7.3 in appendix 7.

## 9.4.2 Species diversity and cover

### 9.4.2.1 *Trees and large shrubs*

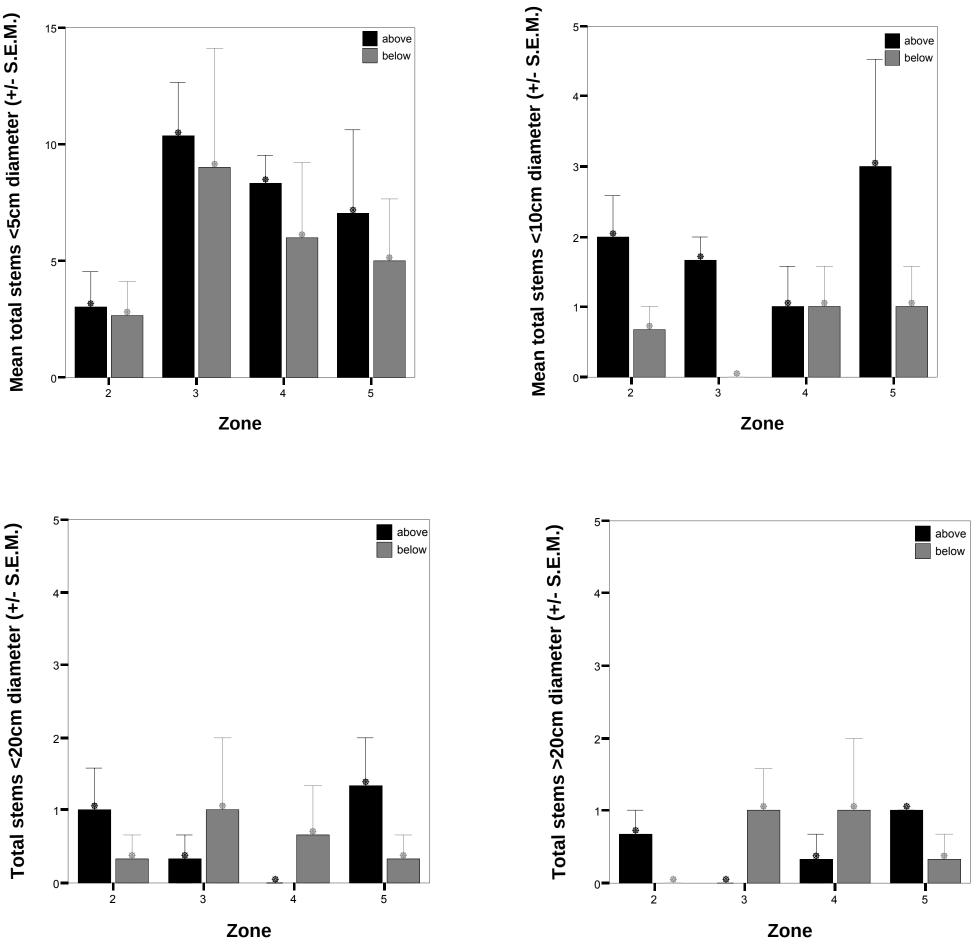
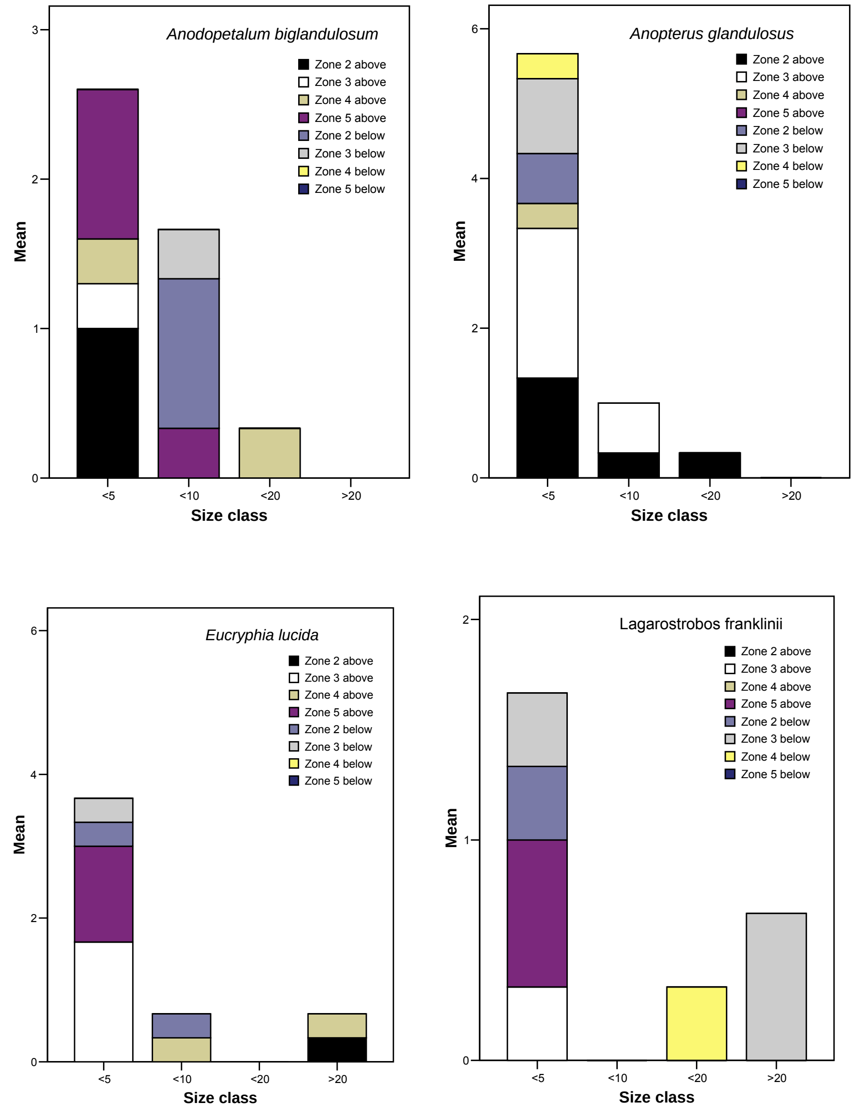


Figure 9.3. Stem density (per 9 $m^2$) of tree and large shrub species in 'above regulated level' and 'below regulated level' quadrats in four size classes in the Gordon River by zone (note different scale). Data for individual sites is presented in appendix 7.

Figure 9.3 shows the total number of trees in each of the four size classes for each zone, separated by location above or below the regulated flow level. The density of trees <10 cm in diameter was significantly higher in the area above regulated flow in zone 3 and for consolidated data of all zones. Patterns of differences varied between the zones for large trees (those <20 cm and >20 cm). Mean numbers of trees above the regulated flow level were greater in zones 2 and 5; the reverse is the case in zones 3 and 4. This pattern is due to the presence of larger individuals of *Leptospermum riparium, Lagarostrobos franklinii* and *Nothofagus cunninghamii* at the sites within zones 3 and 4.

Simper analysis showed that through all of the zones, higher abundance of smaller (<5cm) *Leptospermum riparium, Richea pandanifolia* and *Acradenia franklinae* trees distinguished between the region below regulated flow level and that above. *Leptospermum riparium* is recognised as an important inundation tolerant species (Reid et al. 1999) and is also a good indicator of the region below regulated flow level. *Acacia verticillata* and *Pomaderris apetala* individuals (<5cm) were a good indicator of the region above regulated flow level indicating that these areas are well illuminated as the former species is generally intolerant of shade and the later is a gap opportunist that grows readily on disturbed sites.

Species composition was varied within the different size classes. A total of 21 taxa were recorded. Of these, most species were present in the smaller size classes with some species reaching their maximum expected diameter in these classes (such as *Anopterus* and *Richea*). Size class distributions of the most abundant species are given in Figure 9.4. These distributions show the larger size classes to be dominated by longer-lived trees such as *Nothofagus* and *Lagarostrobos* (Read 1999). Size class distributions of the most abundant species within the zones are given in Figure 9.4.



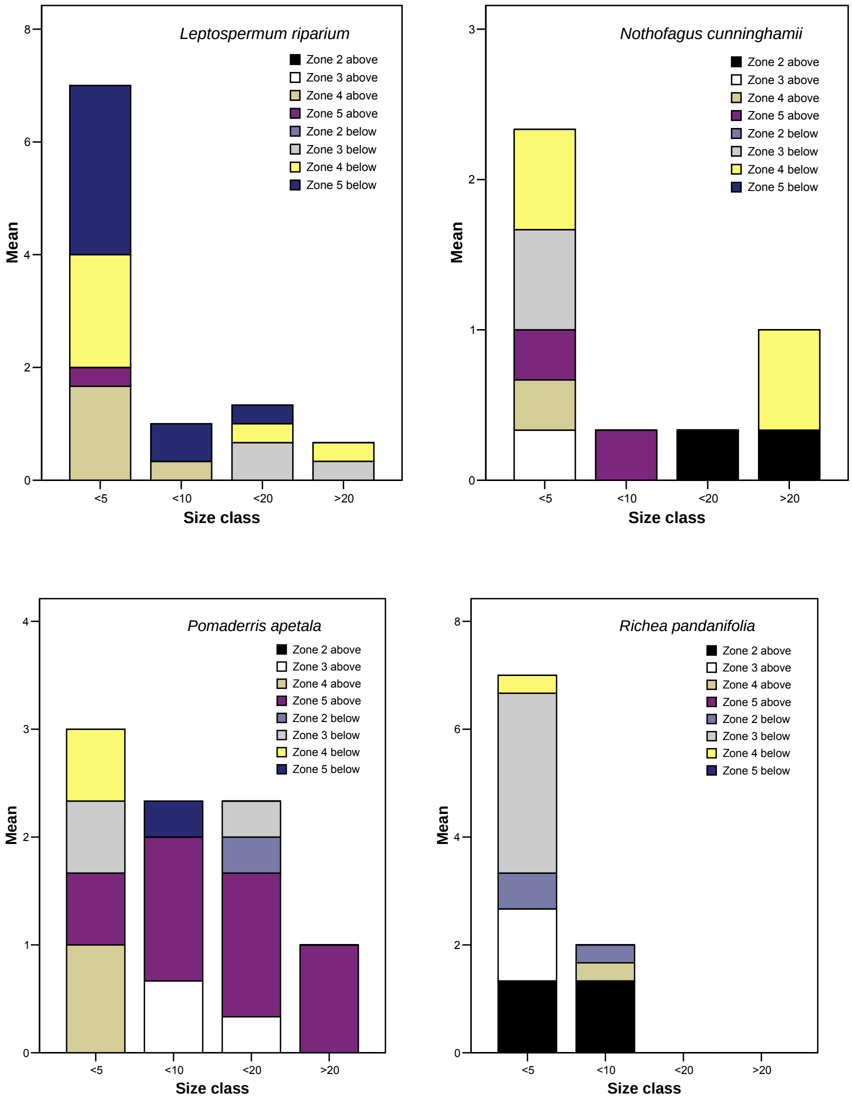


Figure 9.4 Mean size class distribution (cm) of the most abundant tree and shrub species measured in belt transect for ‘above regulated water level’ (above) and ‘below regulated water level’ (below) quadrats by zones along the middle Gordon River.

Simper analysis showed few species to be clear indicators of differences *between* the zones in either region. *Acradenia franklinae* and *Richea pandanifolia* was more abundant in zone 3 than all other zones, *Anopterus glandulosus* was more abundant in zone 2 than all other zones whilst *Leptospermum riparium* was more abundant in zones 4 and 5.

Repeated monitoring showed less than 2 % tree mortality over the monitoring period, most of which occurred below the regulated flow level. This included *Leptospermum riparium, Richea pandanifolia* and *Anopterus glandulosus* predominantly in the <5 cm size class. Total numbers of species counted in the above and high areas are presented in Figure A7.1 in appendix 7.

#### *9.4.2.2 Total vegetation cover*

Total vegetation cover, the sum of cover for all species, showed no differences between zones or over time in the 'high' and 'low' quadrats (Figure 9.5). There were significant differences in the 'above' quadrats. Total vegetation cover differed more in the 'above' quadrats between the zones than over the years (Table 9.4) reflecting the continually higher cover in zone 3 compared to all other zones. There was a weak pattern of change between 2002 and 2005. A summary table of these variables for each zone is presented in Table 7.1 in appendix 7.

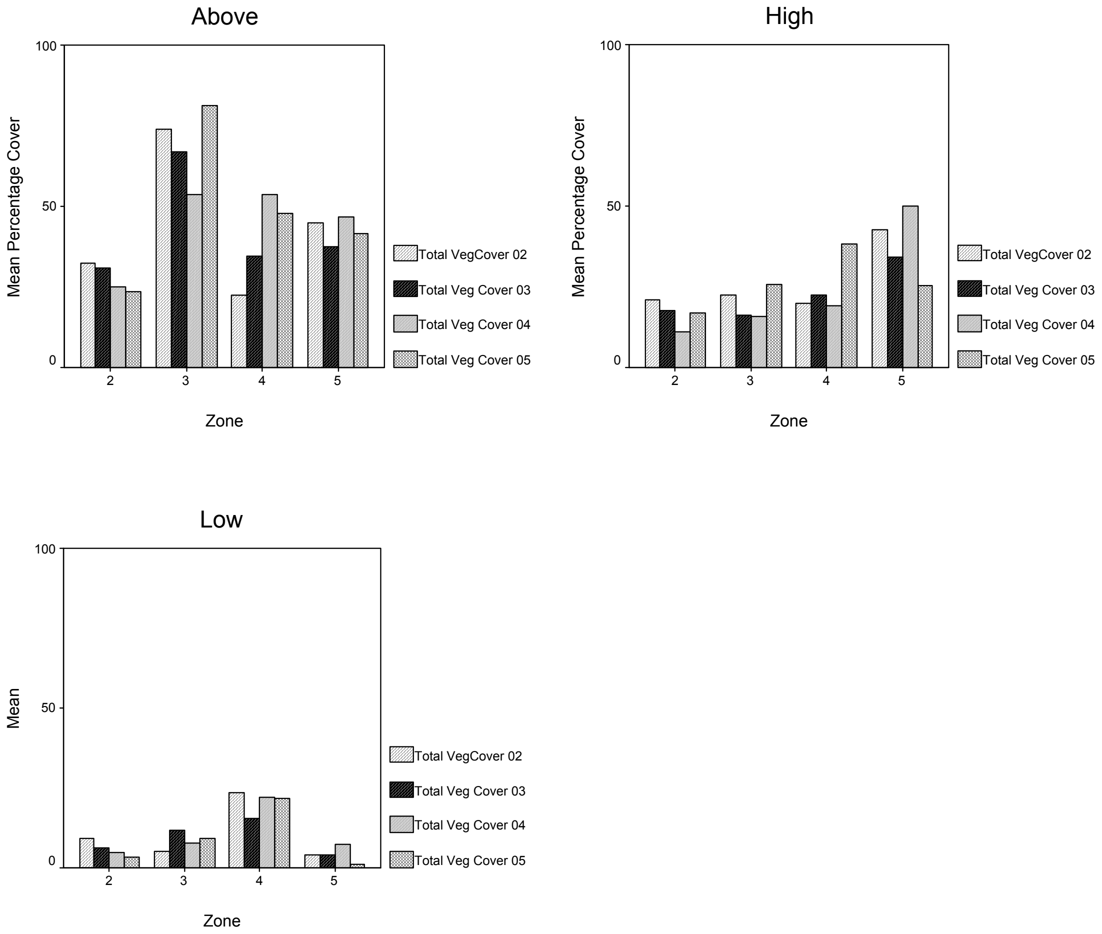


Figure 9.5 Mean percentage cover of total vegetation cover at all sites by zone for 'above', 'high', and 'low' quadrats in the middle Gordon River.

#### *9.4.2.3 Bryophytes, ferns, small shrubs, graminoids, grasses and herbs*

Bryophytes (mosses and liverworts) were the most abundant vegetation life form in all quadrats except in the 'low" quadrats in 2002 (Figure 9.6). Ferns and small shrubs were generally the next most abundant life forms. Zone 5 had reduced fern cover, with graminoids and small shrubs increasing in relative importance. The other life forms; graminoids, grasses, herbs and trees had low abundance and frequency in all quadrat types and were not analysed further.

Table 9.4 Results of ANOVA of percentage cover data of major life forms measured in the Gordon River from April 2002 to April 2005. Significance ratings NS: not significant; *= P<0.05; **=P<0.01; ***=P<0.001.

| Variable | Quadrat type | Year | Year x Zone |
|---|---|---|---|
| Bryophytes | Above | NS | NS |
| | High | NS | NS |
| | Low | NS | NS |
| Ferns | Above | NS | NS |
| | High | NS | NS |
| | Low | NS | * |
| Small shrubs | Above | NS | NS |
| | High | NS | NS |
| | Low | *** | * |
| Total vegetation cover | Above | * | *** |
| | High | NS | NS |
| | Low | NS | NS |

Differences of vegetation life form abundance were apparent between quadrats (see Figure 9.6). Shrub species had the greatest relative cover compared to other life forms in the 'low' quadrats followed by fern species, although mean cover was low for both life forms. Graminoid species, such as sedges and lilies were almost absent from these lower quadrats. Tree cover in these quadrats was largely the result of low (<1m) overhanging branches rather than trees rooted in the quadrats. Alternatively, in the 'above' quadrats, ferns followed by shrubs had the greatest relative cover.

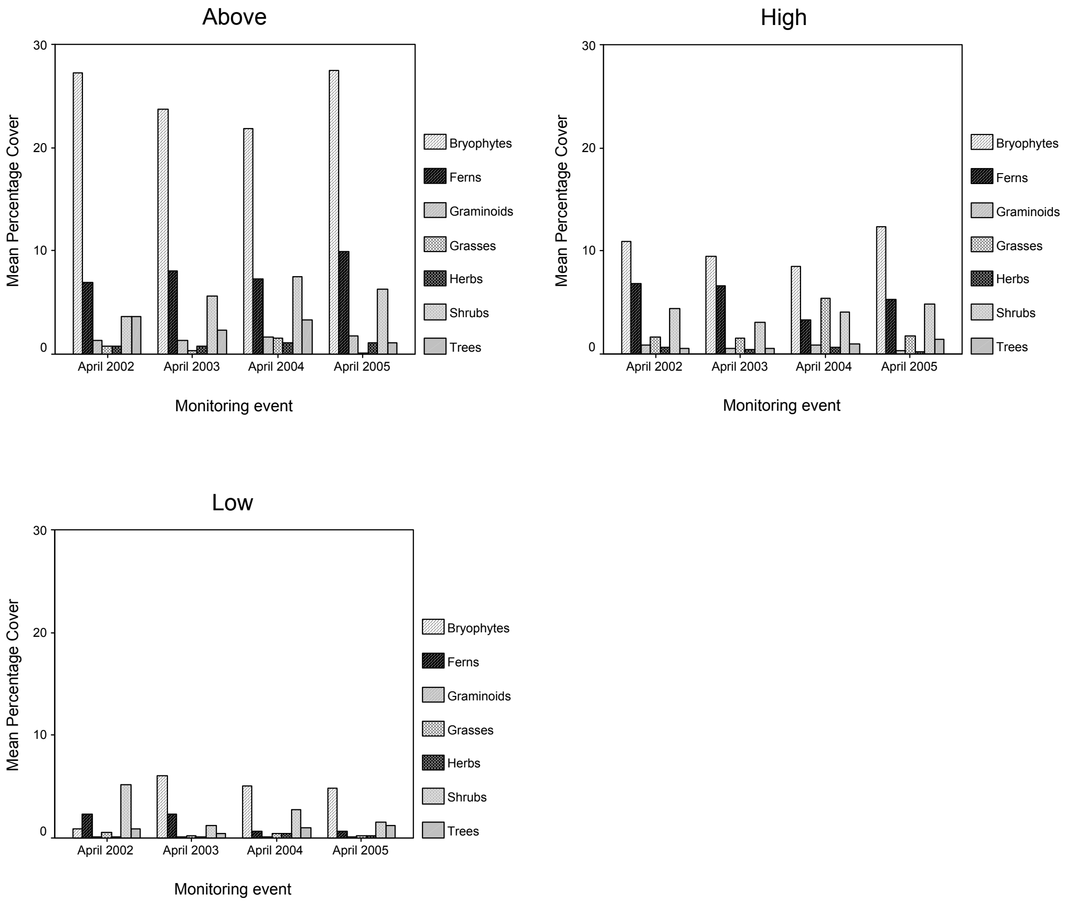


Figure 9.6 Mean percentage cover of vegetation life forms in all zones and sites by monitoring event for ‘above’, ‘high’, and ‘low’ quadrat types in the middle Gordon River.

The abundance of vegetation life forms was generally stable between 2002 and 2005 in all zones. One exception was the abundance of small shrubs in the ‘low’ quadrats that declined over time (Table 9.4) and showed weak differences between zones. The decline was largely due to a decrease in shrub cover at one site in zone 4, where a minor slip had reduced the cover of *Leptospermum riparium* and *Pultenaea juniperina.* Fern cover also showed a weak difference in the low quadrats between years and zones; reflecting a decrease in cover of *Blechnum* spp. in zones 2 and 3. No further analyses were undertaken on the other life forms due to the paucity of data.

### *9.4.2.4 Ground cover*

Ground cover metrics including bare substrate, coarse woody debris and litter showed numerous patterns and interactions over the monitoring period and between the zones for both the ‘above’ and ‘high’ quadrats reflecting the flow-driven, dynamic nature of these variables. Analysis of total bare substrate (a composite of root exposure and bare ground) showed very strong differences between the years and a weak difference between zones and years (Table 9.5). Changes in total bare substrate differed more between the years than between the zones. While the differences were significant from year to year, there was no discernible pattern apparent (see Figure 9.7).

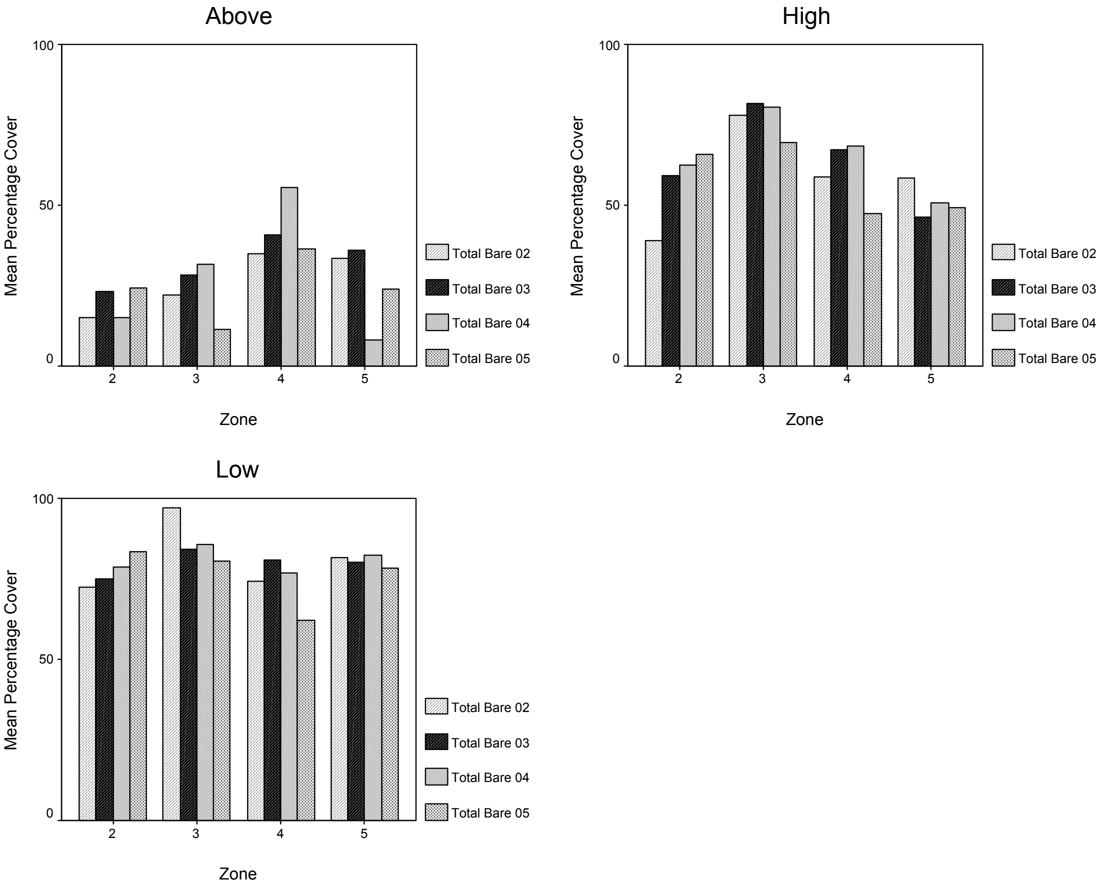


Figure 9.7. Mean percentage cover of total bare substrate at all sites by zone for ‘above’, ‘high’, and ‘low’ quadrat types in the middle Gordon River.

Table 9.5 Results of ANOVA of percentage cover data of major ground cover groups measured in the Gordon River. Significance ratings NS: not significant; *= P<0.05; **=P<0.01; ***=P<0.001

| Variable | Quadrat type | Year | Year x Zone |
|---|---|---|---|
| Coarse woody debris | Above | NS | NS |
| | High | ** | ** |
| | Low | NS | NS |
| Litter | Above | * | * |
| | High | * | NS |
| | Low | NS | NS |
| Total bare substrate | Above | *** | * |
| | High | NS | NS |
| | Low | NS | NS |

Coarse woody debris cover was stable in the ‘above’ and ‘low’ quadrats. However, this was significantly different between years and between the zones in the high quadrats. Litter cover also showed differences between the zones and the years for the ‘above’ quadrats and between years for the ‘high’ quadrats. Both these variables are very dynamic and strongly influenced by the flows immediately preceding the monitoring period. While the differences were significant between years and zones, there was no discernible pattern apparent either between the zones or between the years. This reflects the influence of floods, local overland flow, and other factors on these variables. It also reflects the differences in flood frequency and intensity between those zones with natural flows (zones 4 and 5) and those largely restricted to regulated flows (zones 2 and 3). A summary table of cover values for these variables is presented in table A7.2 in appendix 7.

#### *9.4.2.5 Species richness, diversity and composition*

Species richness was relatively stable over the monitoring period, showing no significant *within* zones across the sampling period. However, there were some differences apparent *between* some of the zones. Tests between zones within the monitoring events showed overall (grouped) species richness in zone 4 to be significantly higher than zone 2 in April 2002 and zones 2 and 3 in April 2004 and April 2005 ($p<0.05$). There were no significant differences in species richness between the monitoring events. Figure 9.8 shows species richness for each quadrat type within the zones between the years of the sampling period.

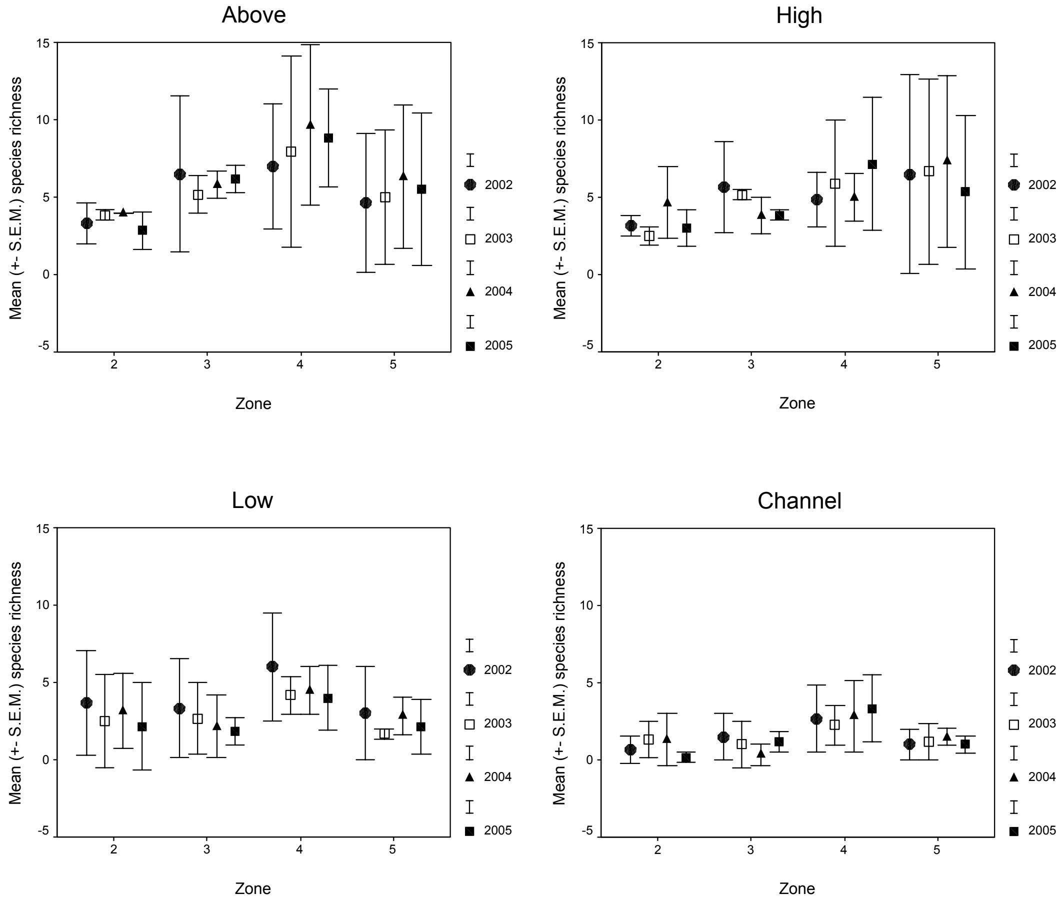


Figure 9.8. Mean (±S.E.M.) species richness for all quadrat types for each monitoring event and each zone.

Species richness was most strongly influenced by the quadrat type (i.e. 'above', 'high' or 'low') in zones 2 and 3 (Table 9.6). These zones continued to show the strong influence of proximity to the dam with lower richness, therefore fewer species, persisting below the Plimsoll line in the 'low' and 'channel' quadrats. Increased inundation and waterlogging, altered flows and the predominantly alluvial nature of the banks led to significantly lower species richness in the 'low' and 'channel' quadrats.

Although distinct stratification in terms of *vegetation cover* was apparent between quadrats at different levels on the bank in zones 4 and 5, *species richness* did not reflect such strong patterns. This indicates that, although the disturbance regime in the lower quadrats continued to limit vegetation cover more than 17 km from the tailrace, species richness was not as strongly affected. The species composition in these quadrats was stable, showing little change over the monitoring period. This reflects the growth of disturbance-tolerating species such as *Bauera rubioides* in these lower quadrats, which may have originated from propagules introduced to the Gordon River from the tributary inflows.

Table 9.6 Significant differences of species richness *between quadrat types* within zones for each monitoring event. Significance ratings NS: not significant; * = 0.01<P<0.05; **=0.001<P<0.005; ***=P<0.001.

| Zone | April 2002 | April 2003 | April 2004 | April 2005 |
|---|---|---|---|---|
| 2 | * | * | * | * |
| 3 | * | *** | *** | *** |
| 4 | NS | NS | NS | NS |
| 5 | NS | * | NS | NS |

### *9.4.2.6 Floristic patterns in quadrats*

Ordination analysis (by non-metric multidimensional scaling – NMS) of quantitative species data for all zones within the middle Gordon shows two broad groupings, one of which is showing variation around the above quadrats and another that is showing a gradient of the high, low and channel quadrats (Figure 9.9) on axes 1 and 2. This gradient is reflecting the increasing disturbance down the bank as represented in Figure 3.3 in the chapter 3. Simper analysis showed that the taxa most important in separating the above quadrats from the others were litter, *Blechnum wattsii* and bryophytes; all having higher abundance in the above quadrats. Likewise the taxa most important in distinguishing the lower quadrats are coarse woody debris (BLS), root exposure and bare ground. These taxa are shown in Figure 9.9 in relation to the position of the sample units in ordination space.

Simper analysis of above and high quadrats between the zones showed that the taxa most important in separating zone 2 from the other zones were *Blechnum wattsii* and bryophytes; both of which were more abundant in zone 2. Abundance of *Blechnum nudum* was a distinguishing feature of zone 3 which had a higher abundance than both zones 2 and 5 but a lower abundance than zone 4. Zone 4 sites were distinguished by higher abundance of *Leptospermum riparium*.

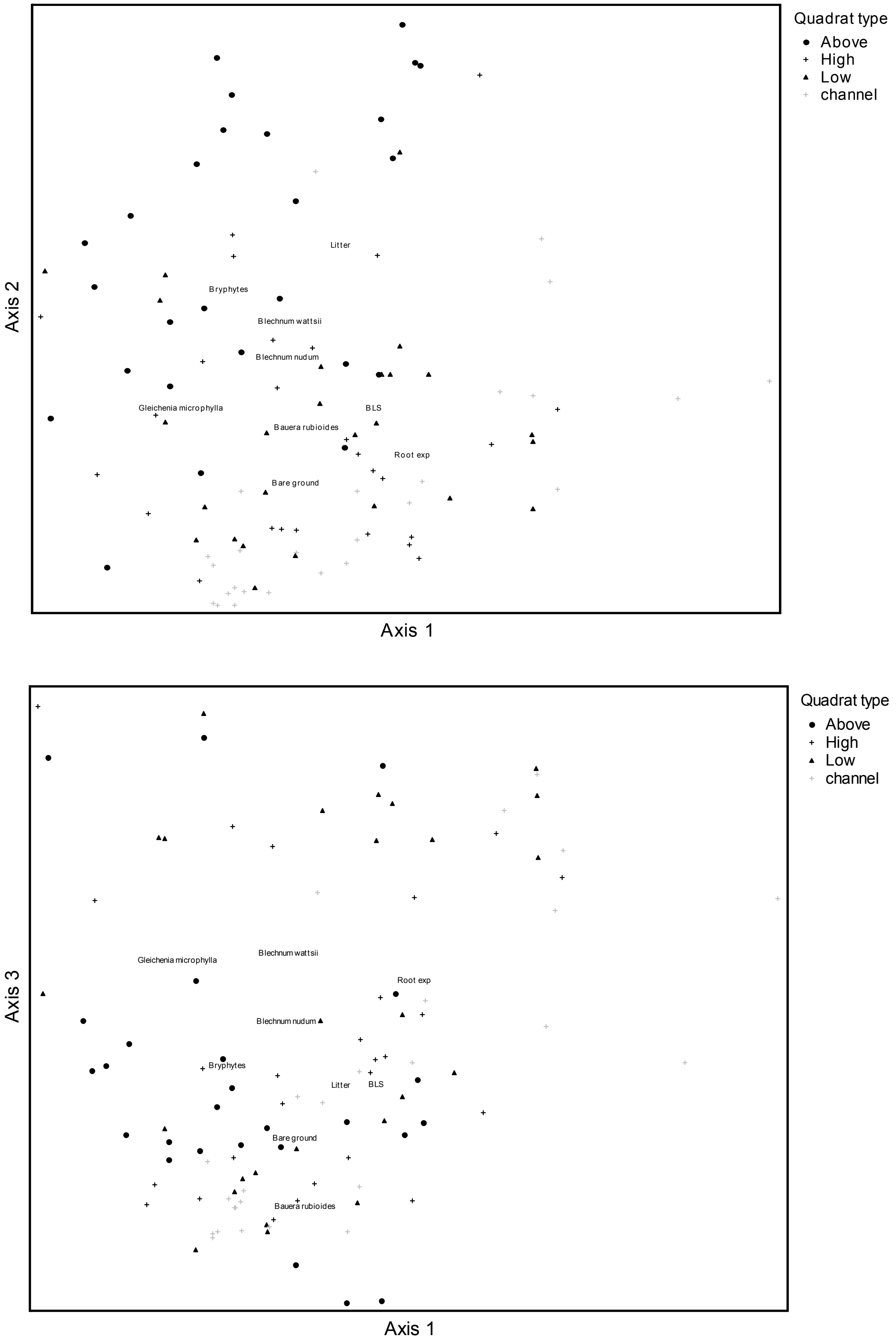


Figure 9.9 NMS ordination of quadrat data for all Gordon River sites in all zones showing distribution of quadrat types and major species or taxa that distinguish the different quadrat types (see text for discussion). Stress = 14.1.

### 9.4.3 Seedling recruitment

Total seedling abundance over the monitoring period showed complex interactions for all quadrat types, with year and seasonal effects apparent. The seasonal effect was expected as seedling numbers peaked in the summer period and then subsequently died as a result of waterlogging and inundation. The variation between years is likely to be a reflection of the alterations in power station operating regimes, flows and extended shut-downs over the monitoring period. The following discussion highlights the general trends in these data for each zone. Statistical analyses are presented in section 9.4.4.

Zone 2 mean seedling numbers generally followed the established pattern of a peak in the summer monitoring events in all quadrats, and reduction in the autumn in all quadrat types (Figure 9.10). The exception to this pattern was evident in the 'channel' quadrats in December 2004. Mean seedling numbers in all other quadrat types were higher in the December 2004, continuing a trend of increasing seedling numbers over the summer monitoring periods. However, April 2005 also showed a substantial increase in the 'above' quadrats.

The increase in mean seedling numbers in the 'above' and 'high' quadrats were the result of large numbers of *Acacia* spp, *Nothofagus cunninghamii, Leptospermum riparium* and *Anopterus glandulosus* seedlings at numerous sites. *Nothofagus cunninghamii, Anopterus glandulosus, Leptospermum riparium* and *Blechnum nudum* seedlings at two sites contributed to the large numbers in the 'low' quadrats.

The most abundant seedlings in zone 2 over the monitoring period, in descending order of total abundance, were the tree *Nothofagus cunninghamii* (myrtle) (<5 cm), the small herb *Drymophila cyanocarpa* (Native Solomon's Seal) (<5 cm), and unknown dicotyledon and monocotyledon seedlings (<5 cm). These taxa all had mean occurrences of greater than 1 for all quadrats. *Nothofagus* were the most abundant seedlings in all quadrats, including the 'channel' quadrats.

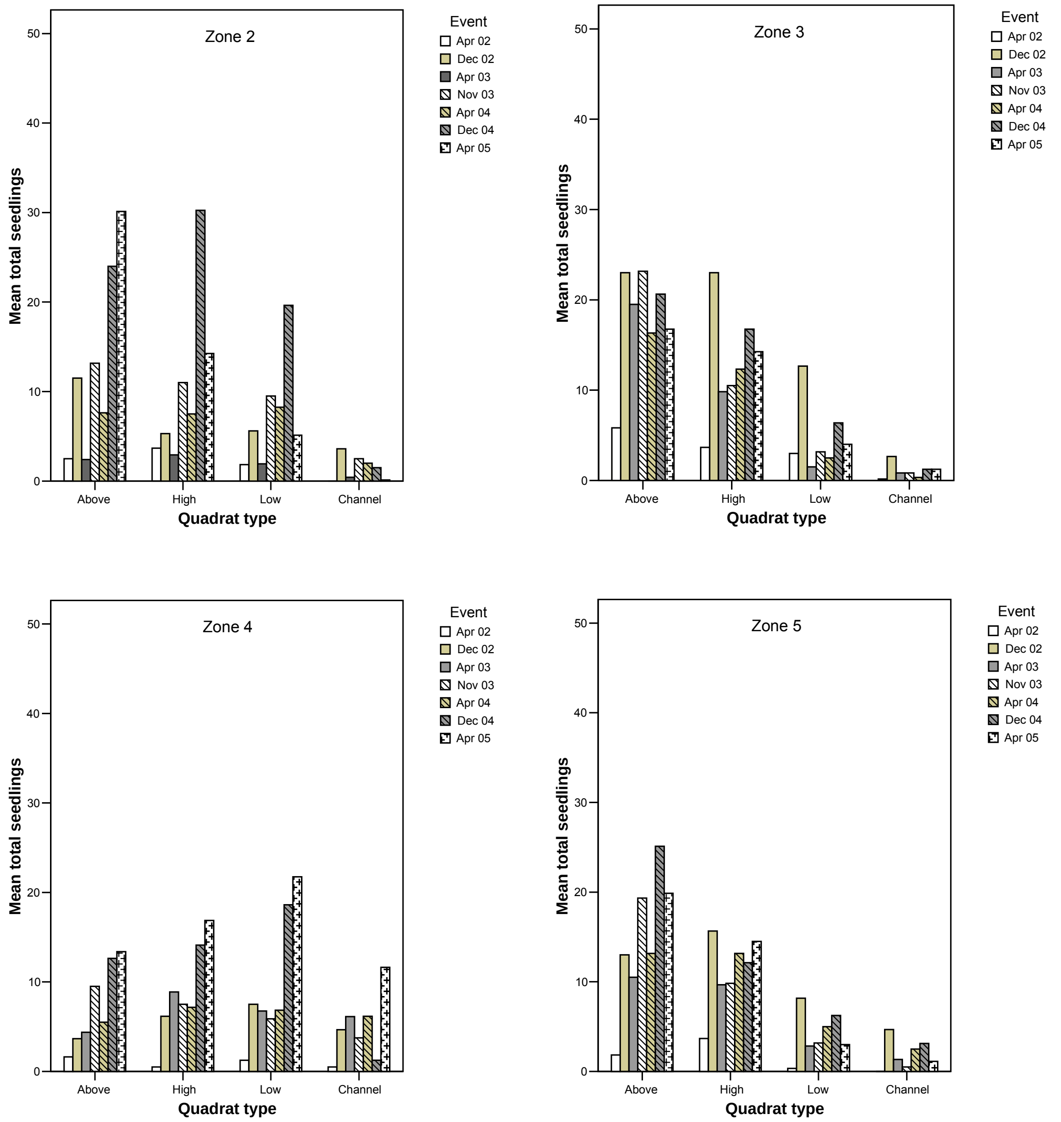


Figure 9.10. Mean number of seedlings per quadrat by quadrat type for each zone over the seven monitoring events.

Seedling numbers have generally been increasing throughout the monitoring period, with the exception of November 2003 which showed a small decrease. *Drymophila cyanocarpa* was more abundant in the 'above' quadrats than all other quadrats. This is likely to indicate that this species is not tolerant of high disturbance for germination and the periods of shut-down provided conditions stable enough to allow for germination in lower quadrats. This conclusion is supported by the dramatic decline in seedlings in the lower quadrats recorded in April 2004 following resumption of power station operation after a long outage in October- November 2003, and the low abundance of seedlings in December 2004 that did not have the same antecedent conditions.

Seasonal patterns in zone 3 were not as pronounced as those displayed in zone 2, although the stratification between the quadrats above high water and those below high water levels was more pronounced. Seedling numbers in the 'above' quadrats were higher, indicating a more favourable environment for establishment. When compared with quadrats at 'equivalent' heights in other zones, the mean seedling numbers were generally much higher. The most abundant seedlings in zone 3 over the monitoring period in descending order of total abundance were the trailing herb *Clematis aristata* (Clematis) < 5 cm, *Nothofagus cunninghamii* (myrtle) (<5 cm), unknown dicotyledons and monocotyledons <5 cm and *Anopterus glandulosus* (native laurel) <5 cm. *Clematis aristata* is a trailing herb that often had high numbers of seedlings present and few adult plants. Seedlings were most abundant in the upper, less disturbed quadrats with few individuals in lower quadrats. However, the presence of some individuals on vertical faces in the lower channel quadrats in April 2003, after a summer of relatively high power station operation, indicates that this species is highly tolerant of inundation and mechanical stress. Seedlings also persisted in 'channel' quadrats in November 2003 and December 2004. The next most abundant seedling, *Nothofagus cunninghamii,* followed the quadrat stratification pattern displayed in zone 2, with the same substantial reduction in seedlings in November 2003 and increase in abundance in April 2004. *Anopterus glandulosus* is a tall shrub to small tree that is commonly found on the banks in the middle Gordon River in all life stages. The seedlings often form dense clusters on bare mineral soils in shaded environments. The seedlings present in zone 3 also showed stratification of abundance by quadrat type with few or no seedlings present in the 'low' or 'channel' quadrats. This is indicative of a species less tolerant to disturbance. Seasonal patterns were not apparent.

Seedling abundance in zone 4 displayed a number of patterns over the monitoring period. This zone is more variable and the patterns between the quadrat types were not as distinct as in the upstream zones. This conclusion is supported in all data collected from this zone, including the cover data for all species, and reflecting the more natural flows in this zone. This zone receives inflows from the Denison River and significant winter flows. The most abundant seedlings in zone 4 over the monitoring period, in descending order of total abundance, were *Nothofagus cunninghamii* (<5 cm), unknown dicotyledon and monocotyledon seedlings (<5 cm), *Clematis aristata* (<5 cm) and the shrub *Coprosma quadrifida* (native currant) (<5 cm). All the major seedling species in zone 4 showed less stratification by quadrat types, with higher numbers of all species being present in the 'channel' quadrats. Again, *Nothofagus* seedlings were well represented in most monitoring events except April 2002 and November 2003. *Clematis* seedlings were recorded in most quadrat types in the later monitoring events. *Coprosma* abundance was highly variable between the seasons and the quadrat types in this zone.

Zone 5 seedling abundance showed less seasonal influence than other zones. This zone receives natural inflows from the Denison and Olga Rivers with power station inflows having only moderate, and seasonal, influence. The most abundant seedlings in zone 5 over the monitoring period, in descending order of total abundance, were unknown dicotyledon and monocotyledon seedlings (<5 cm), *Nothofagus* <5 cm, *Clematis aristata* (<5 cm), *Coprosma quadrifida* (<5 cm). As in zones 2 and 4, *Nothofagus* seedlings were present in all quadrat types for most monitoring events as was *Coprosma*. The significant bank stabilising species *Leptospermum riparium* (tea tree) was more abundant in zone 5 compared with other zones for all monitoring periods except December 2004 when it was not recorded. This species is known to store seed in the canopy and requires large disturbance events for seedling recruitment.

### *9.4.3.1 Erosion, deposition and seedling recruitment*

Seedling numbers increased with increasing erosion in the low quadrats (at the 1-2 turbine level) in spring 2003 in all zones of the river with numerous species colonising (Table 9.7). However, this pattern reversed in zones 2 and 3 in autumn 2005 and zones 4 and 5 in spring 2002. This correlation corresponded with areas of alluvial deposition that were colonised by *Leptospermum riparium* seedlings in zones 4 and 5 and *Acacia* spp. and *Nothofagus cunninghamii* seedlings in zones 2 and 3.

Erosion and seedling density were not as frequently or strongly correlated in the high quadrats (at the 2-3 turbine level). Again, this relationship was a negative correlation where alluvial deposition corresponded with a high number of seedlings of *Acacia* spp, *Anopterus glandulosus*, *Clematis aristata* and *Leptospermum riparium* seedlings, most of which were less than 5 cm tall.

Table 9.7 Summary of correlations between seedling density per quadrat and total erosion change over the previous season for low and above quadrats in each monitoring period. Analysis is based on the geomorphic groupings of zones presented in chapter 7.

| **Quadrat type** | **Low quadrats 1-2 turbine** | | **High quadrats 2-3 turbines** | |
|---|---|---|---|---|
| | Zones 2&3 | Zones 4&5 | Zones 2&3 | Zones 4&5 |
| Autumn 2002 | | | | |
| Change previous season | 0.250 | 0.761 | 0.348 | 0.359 |
| Spring 2002 | | | | |
| Change previous season | 0.029 | -0.821 | 0.143 | -0.300 |
| Autumn 2003 | | | | |
| Change previous season | -0.464 | 0.400 | 0.377 | 0.400 |
| Spring 2003 | | | | |
| Change previous season | 0.928 | 0.800 | 0.600 | 0.154 |
| Autumn 2004 | | | | |
| Change previous season | 0.667 | -0.500 | 0.235 | 0.667 |
| Spring 2004 | | | | |
| Change previous season | 0.543 | -0.300 | -0.257 | 0.100 |
| Autumn 2005 | | | | |
| Change previous season | -0.912 | 0.120 | -0.300 | -0.800 |

### 9.4.4 Analysis of seedling data to allow for seasonal and year effects

The variability in the seedling recruitment data proved problematic for assessment of pre- and post-Basslink changes. Therefore, to test for differences between pre-and post- Basslink conditions, the *degree* (or ratio) of changes between the relatively unaffected 'above' quadrats and the 'high' and 'low' quadrats are used. In this way, the high quadrats act as a 'control' for the changes that may occur post-Basslink.

Analysis of the ratio data showed season to be the dominant effect with no effect for the year of sampling (Table 9.8). Because a year is not a significant effect with the ratio data, these provide a suitable means for measuring a change between pre- and post Basslink conditions.

Table 9.8 Results of analysis of raw total seedling data for Gordon River. Significance ratings NS: not significant; * = 0.01<P<0.05; **=0.001<P<0.01; ***=P<0.001*.

| Quadrat | Seedling size | Year | Year*Zone | Season | Season * Zone | Year*Season | Zone |
|---|---|---|---|---|---|---|---|
| Above | <5 cm | ** | NS | *** | NS | * | NS |
| | All | * | NS | *** | NS | * | NS |
| High | <5 cm | - | NS | - | NS | ** | NS |
| | All | * | NS | ** | NS | ** | NS |
| Low | <5 cm | * | NS | *** | NS | * | NS |
| | All | * | NS | *** | NS | * | NS |

### 9.4.5 Population structure and seedling persistence

Seedlings in all zones continued to be limited to high numbers of individuals in the smaller size classes reducing substantially in the larger size classes (Figure 9.11). This pattern is a similar, although more exaggerated, example of the reverse 'j-curve' that generally characterises a population structure such as this (see Kirkpatrick *et al.* 2002 for a description of methods).

The lack of larger size classes, and therefore older individuals, supports the conclusion that while conditions were amenable for germination of many species in the higher quadrats, they were not suitable for seedling persistence. The factors most likely responsible are the frequent disturbance of substrate and the total inundation of leaf and stem material precluding, or severely inhibiting, photosynthesis and carbohydrate production and storage.

Few species have seedlings recorded in the 5-10 cm or 10-15 cm size classes. The most abundant species in the larger size classes included *Acacia* spp. (5-10 cm), *Clematis* (5-10 cm), *Acacia* spp. (>10 cm), *Leptospermum riparium* (5-10 cm), *Leptospermum riparium* (>10 cm), *Coprosma quadrifida* (5-10 cm) and the snow berry *Gaultheria hispida (5-10 cm).* These species still generally demonstrated the classic j-curve pattern, although the *Acacia* spp. seedlings had greater survival than most other species (Figure 9.12).

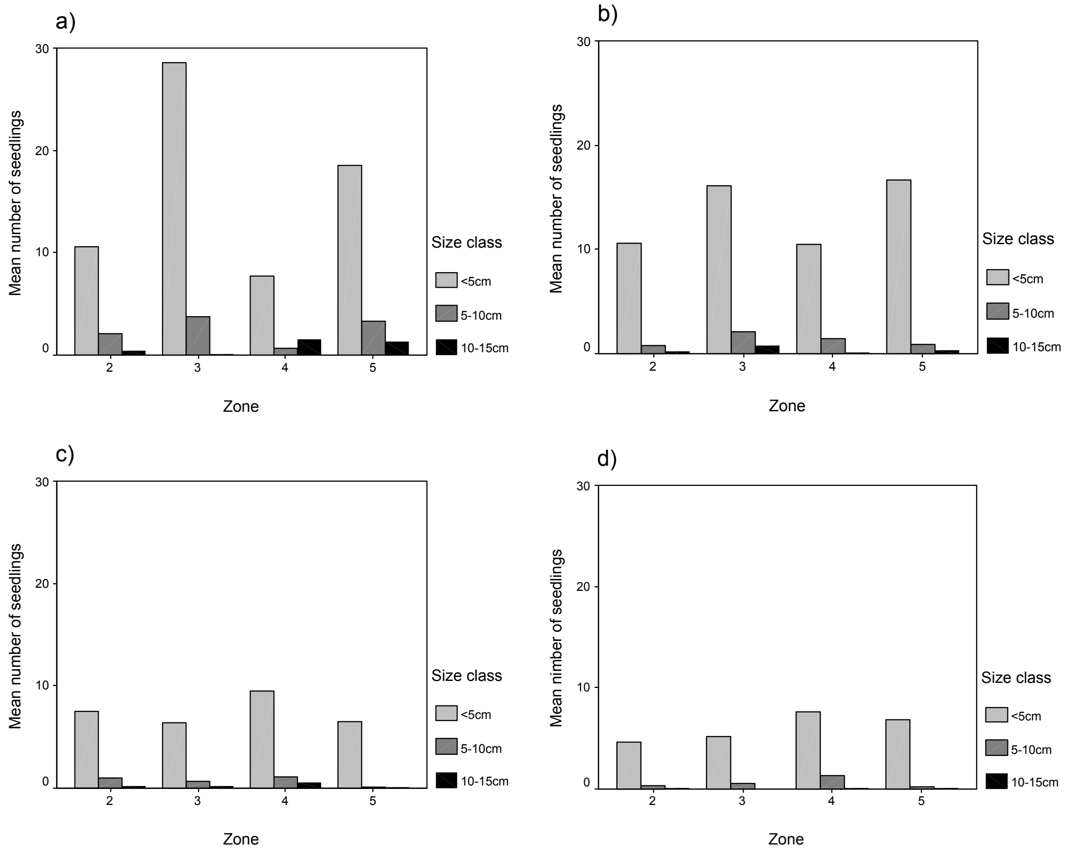


Figure 9.11. Mean number of seedlings per quadrat in three size classes by quadrat type for all monitoring events in all zones of the Gordon River: a) 'above'; b)' high'; c)' low', and d) 'channel' quadrats.

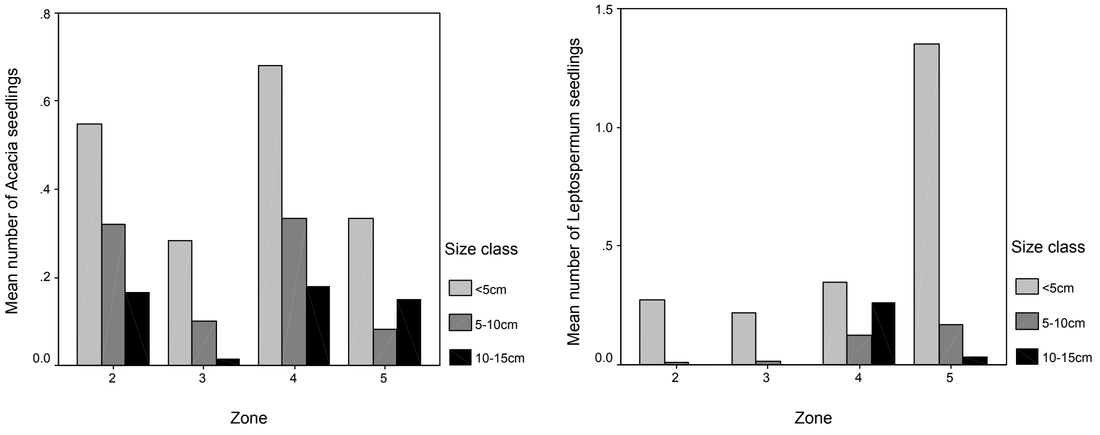


Figure 9.12. Mean number of *Acacia* spp. and *Leptospermum riparium* seedlings for three size classes by zone in the Gordon River - grouped data for all monitoring events.

## 9.5 Results for the Franklin and Denison Rivers

Tributary monitoring was included in the program to provide a 'reference' for seasonal, regional-scale, variables such as drought or climatic changes. These sites should not be viewed as a 'control' for post- Basslink comparisons due to the very different nature of the rivers and substantially different processes affecting the vegetation. The following data have been included in this report to provide an assessment of their use as a reference.

Vegetation communities in the Denison and Franklin Rivers were typical of riparian vegetation in undisturbed rivers. Vegetation community dynamics are a reflection of the natural disturbance regimes (see section A7.1 in appendix 7) and the responses of species to these disturbances. A broad band of riparian vegetation persists from the boundary of low summer flows to the limits of the recent flood events. Species richness is high, with numerous vegetation life forms represented. A complete description of the vegetation of these rivers and the differences with the vegetation of the Gordon River is presented in the IIAS study undertaken by Davidson and Gibbons (2001). The following discussion refers to the quadrats in the studies as 'above', 'high', 'low' and 'channel'. Whilst these quadrats relate to different positions up the banks in the reference rivers, they do not reflect the distinct bank stratification that they do in the Gordon River, where they are responding to different regulated flow levels. The nomenclature used here is consistent with the Gordon River to enable easier comparisons.

### 9.5.1 Total vegetation cover

Total vegetation cover (a composite of all life-form data) was variable over the sites, quadrat types, and monitoring periods and showed no significant trends (Figure 9.13).

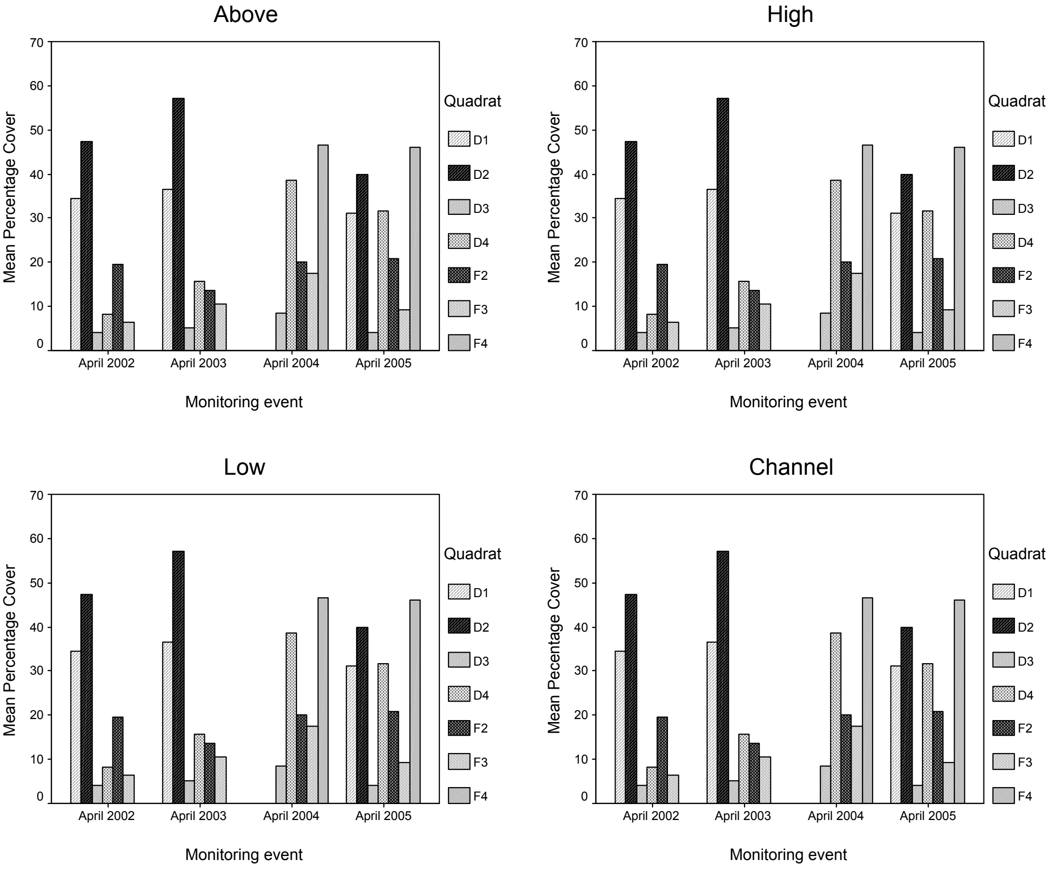


Figure 9.13. Mean percentage total vegetation cover at all sites by monitoring event for sites in the Denison and Franklin Rivers. D1= Denison site 1; D2= Denison site 2; D3= Denison site 3; D4= Denison site 4; F2=Franklin 2; F3=Franklin 3; F4=Franklin 4.

### 9.5.2 Bryophytes, ferns, small shrubs, graminoids, grasses and herbs

Bryophyte cover was the most consistent and abundant life form in all quadrat types in the Franklin and Denison Rivers (Figure 9.14). Analyses of grouped bryophyte cover data showed this cover did not change significantly between zones or by the type of quadrats (Table 9.9). Fern cover was also relatively abundant in all quadrat types; with a higher diversity of species present than in the Gordon River. Species frequently recorded in addition to the common *Blechnum nudum* were: *Blechnum fluviatile, Blechnum chambersii, Blechnum penna-marina* and *Doodia caudata*. Analyses of grouped fern cover data showed this cover did not change significantly between zones or by the type of quadrats. Other vegetation cover recorded in the quadrats included moderate abundance of herbs and shrubs. In contrast to the Gordon River, there was little cover of graminoid and grass species.

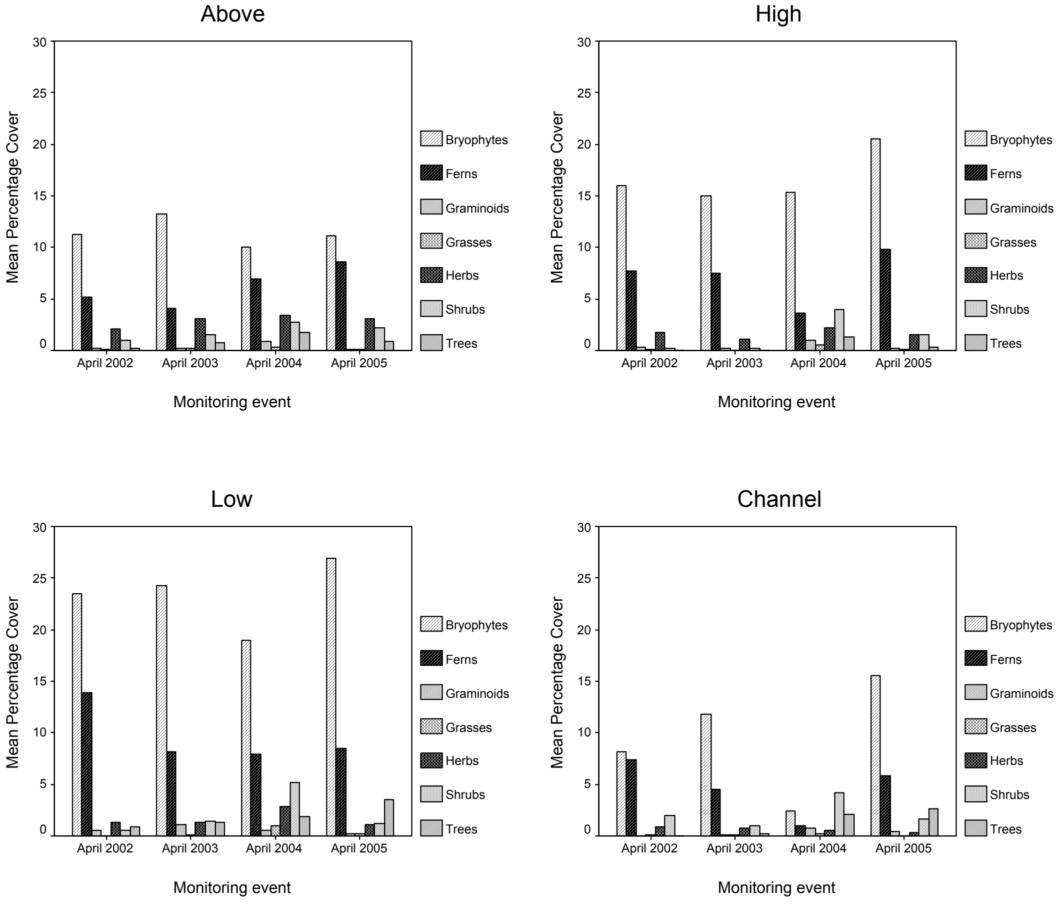


Figure 9.14. Mean percentage cover of vegetation life forms in the Franklin and Denison Rivers by monitoring event.

Table 9.9 Results of ANOVA of percentage cover data of major life forms measured in the Franklin and Denison Rivers from April 2002 to April 2005. Significance ratings NS: not significant; *= P<0.05; **=P<0.01; ***=P<0.001

| Variable | Year | Year x Type |
|---|---|---|
| Bryophytes | NS | NS |
| Ferns | NS | NS |
| Small shrubs | NS | NS |
| Total vegetation cover | NS | NS |

### 9.5.3 Ground cover

Cover of coarse woody debris and litter were highly variable in space and time in both rivers, similar to that found in the Gordon River. As previously mentioned, these data are affected by the flows immediately preceding the monitoring event, in addition to large flows. There were no significant interactions detected in these data (Table 9.10). Total bare substrate showed a weak linear year interaction (Figure 9.15). This highlights a decline in total bare cover from 2003 to 2005.

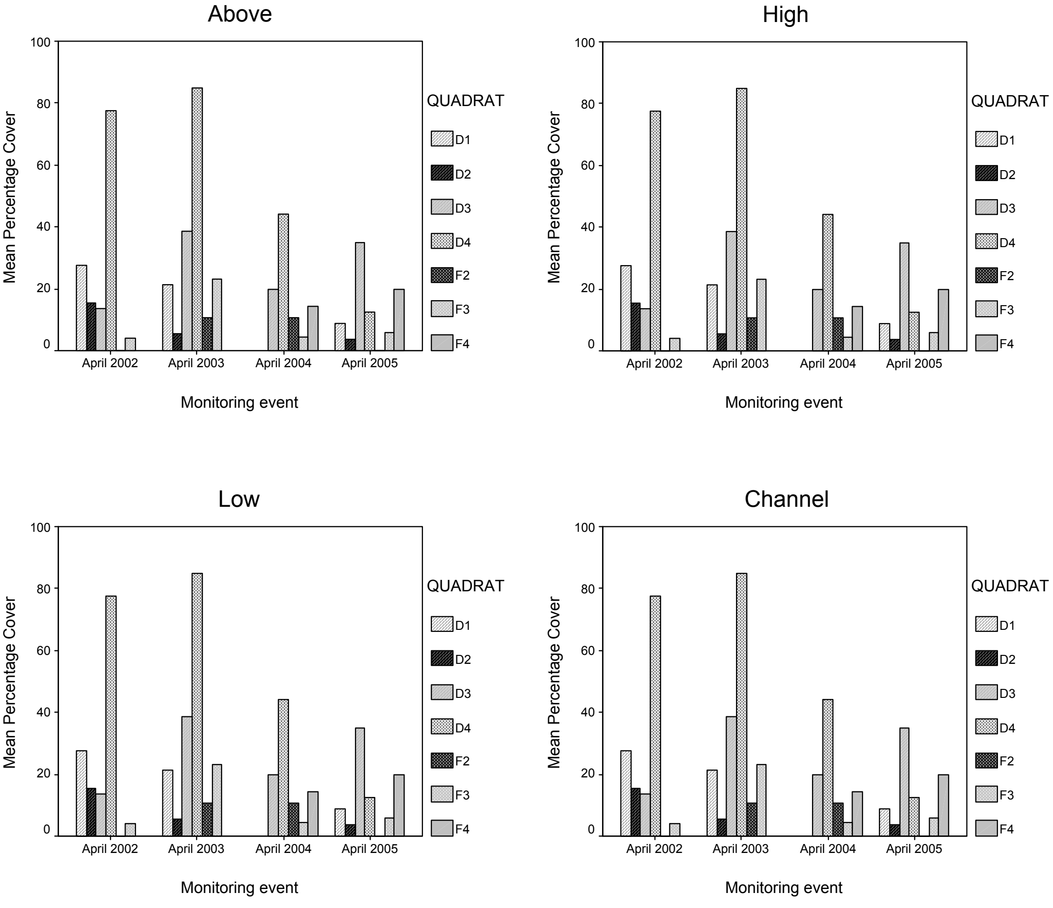


Figure 9.15. Mean percentage cover of total bare substrate at all sites by monitoring event.

Table 9.10. Results of ANOVA of percentage cover data of ground cover variables measured in the Franklin and Denison Rivers from April 2002 to April 2005. Significance ratings NS: not significant; *= P<0.05; **=P<0.01; ***=P<0.001

| Variable | Year | Year x Type |
|---|---|---|
| Litter | NS | NS |
| Coarse woody debris | NS | NS |
| Total bare substrate | * | NS |

### 9.5.4 Seedling recruitment

Mean seedling numbers for most quadrats were very high for all monitoring events in the Franklin and Denison Rivers, especially the latter (Figure 9.16). Seedling counts in the Denison River were very high in all quadrats including the ‘channel’ quadrats. The seedlings included an abundance of *Acacia* sp. and *Clematis aristata* seedlings in all quadrat types. *Coprosma moorei, Nothofagus cunninghamii, Leptospermum riparium* and ‘unknown dicotyledon’ seedlings were also widespread but not as prolific as the *Acacia* sp. and *Clematis aristata* seedlings. All these species are frequent colonisers in the Gordon and Franklin Rivers; however, they are generally not as abundant. At many sites, substantial numbers of *Tasmannia lanceolata* occurred. This species is an infrequent seedling in the Gordon River.

Most of the seedlings in the Denison River occurred in the <5 cm seedling size class with few *Leptospermum* sp. seedlings also occurring in the 5-10 cm seedling size class (Figure 9.17). The Franklin River data had more numerous seedlings in the 5-10 cm size class, a spread not frequently recorded the Denison or Gordon Rivers.

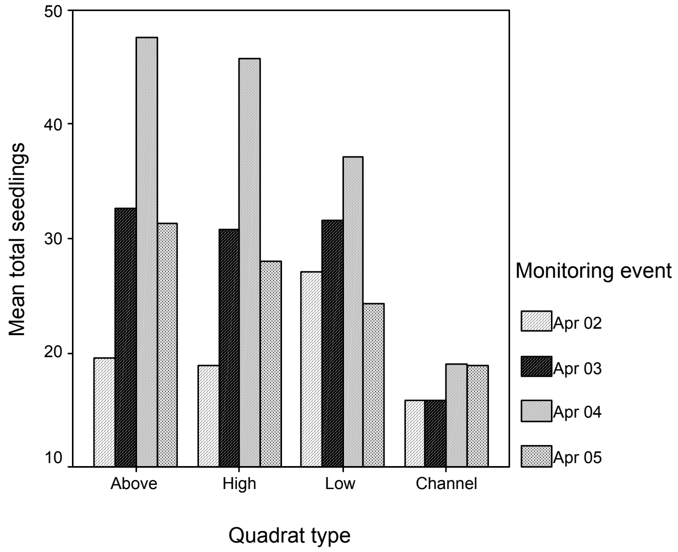


Figure 9.16. Mean seedling count by quadrat type for the Franklin and Denison Rivers over the monitoring period for all seedling size classes.

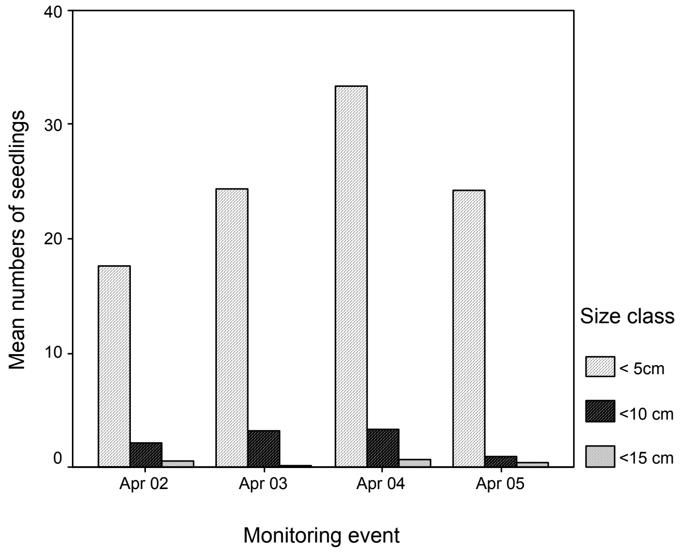


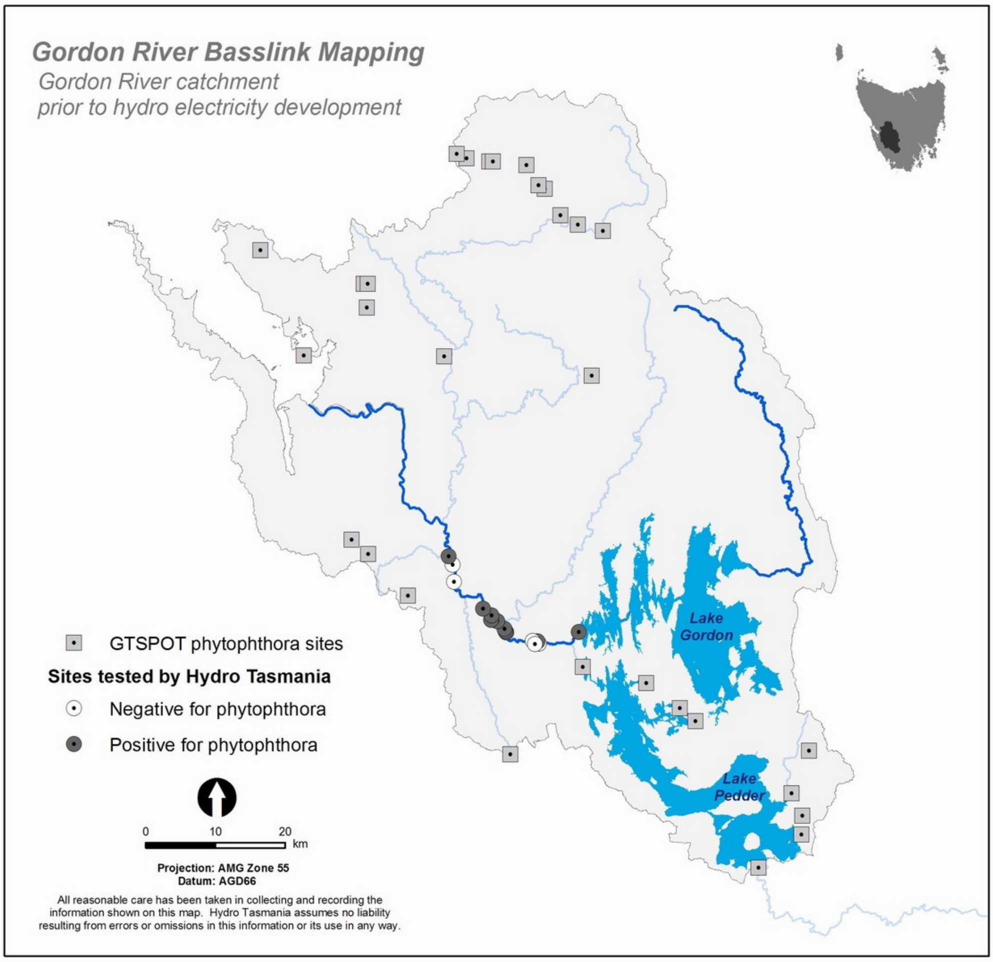
Figure 9.17. Mean number of seedlings per quadrat in three size classes over the four monitoring events for the Franklin and Denison Rivers.

## 9.6 Presence of *Phytophthora cinnamomi* in the Gordon River.

There was substantial dieback of *Richea pandanifolia* (pandani) in a number of areas along the middle Gordon River. From Abel Gorge down to the Franklin confluence there has been mortality of clumps of *Richea pandanifolia*. This species is highly susceptible to *Phytophthora cinnamomi*, commonly known as dieback. *Phytophthora cinnamomi* is a soil-borne pathogen in the kingdom Chromista which affects the roots of susceptible plants, starving them of nutrients and water.

Conclusive identification of a *Phytophthora* infection required laboratory analysis of soil or root sample, which were undertaken on samples from 14 vegetation monitoring sites along the river and at the Knob helipad. The results of these analyses showed that the disease is present at sites in all zones along the Gordon River (see Map 9.2) and is the most likely cause of dieback of *Richea pandanifolia* in a number of sites (Photo 9.2).

Not all areas of *Richea pandanifolia* dieback were the result of infection, as soil samples taken directly from the roots have tested negative to *Phytophthora.* In these cases, it is likely that localised scour and physical disturbance associated with flow regulation is more likely to have caused this mortality.



Map 9.2. Map of historic and newly-tested Phytophthora sites within the Gordon River catchment.

Other *Phytophthora*-susceptible species may be showing the effects of infection. Dieback of *Anopterus glandulosus* has been recorded in some plots (see 9.4.2.1). Other species that occur along the river which have been recorded as being susceptible include *Lagarostrobos franklinii, Bauera rubioides, Nothofagus cunninghamii, Trochocarpa cunninghamii* and *Cyathodes juniperina.* These species represent a substantial component of the flora of the middle Gordon River, including many of the larger trees that occur below the present regulated flow level. Further spread of *Phytophthora* downstream may have a significant impact on the vegetation of the riparian strip and the stability of the banks. It is believed that *Phytophthora* does not persist in rainforest communities due to low soil temperatures. Soil temperatures along the well-illuminated, sparsely vegetated banks of the Gordon River are evidently warm enough for the pathogen to persist. It is not certain how far into the vegetation and colder soils, the pathogen may invade, therefore the width of impact has not been ascertained.

Photo 9.2. Photo-monitoring in zone 3 (site 6) showing distinct dieback of *Richea pandanifolia* between November 2003 (left) and December 2004 (right).

Long-distance spread of *Phytophthora* is principally by the transfer of infected soil or plant material by vehicles, people or animals. Dispersal of spores over short distances may occur via water movement in soil or along water-courses. However, spread along water courses does not always occur as the pathogen needs a means to exit the water. Some old infections in the Huon River have shown no evidence of longitudinal spread (Tim Rudman, pers comm).

*Phytophthora cinnamomi* has been recorded extensively in the Gordon Power Scheme region for the many years (see Map 9.2). The identified infection may have originated from these sources, however, it is probable that the introduction to the middle Gordon River is a consequence of increased access for the Basslink Monitoring Program.

Currently there is no treatment that has been shown to work with any degree of efficacy on the scale required. To date, Hydro Tasmania has addressed the risk of *Phytophthora* introduction by implementing hygiene measures recommended by DPIWE. This has included ensuring field equipment is free of loose dirt and washing down waders and small field equipment with ‘Phytoclean’, the chemical registered for hygiene use.

Given the spread of the infection to the middle Gordon River, a reassessment of these hygiene procedures was undertaken. The main priority is to ensure that the pathogen does not spread to the tributaries, many of which are remote, have few others accessing them, and have not had previous records of infection. Strict hygiene measures include:

- scheduling all tributary work before that undertaken in the Gordon itself;
- 'Phytoclean' wash-down of waders and equipment at each monitoring site;
- wash-down of the helicopters skids, boats and other large field equipment; and
- incorporating additional recommendations for access to remote areas, using DPIWE guidelines.

## 9.7 Discussion and interpretation

The riparian vegetation monitoring has shown the existing vegetation to be stratified in terms of abundance up the banks of the Gordon River in response to varying degrees of regulated flow-induced disturbance. This disturbance restricts vegetation growth and recruitment in the lower quadrats with effects reducing in areas above, or subject to, shorter periods of regulated flows.

The banks below the regulated water level have reduced abundance and cover of trees and shrubs in smaller size classes (<5 cm and <10 cm diameter) and ground cover species. The extant woody vegetation is characterised by a higher abundance of smaller trees including *Leptospermum riparium* in zones 4 and 5. Some larger tree species (<20 cm and >20 cm diameter) also occur in the area below regulated flows. These species are able to resist the mechanical disturbance of high flows and are high enough up the bank to not be totally inundated, allowing them to photosynthesise during high flows. It is this inundation of leaves, coupled with waterlogging of roots that can lead to reduced vigour and fewer carbohydrate reserves decreasing the capacity of plants to tolerate stress, and which may eventually lead to plant death. The other life form that is persistent on the bank below the regulated water level is ferns; these too have shown significant decline over the monitoring period. Other life forms such as grasses, herbs and graminoids had only limited cover. Grouped vegetation cover data and the total bare substrate data did not show any significant trends in the banks below the regulated flow level.

The banks above the regulated water level had increased abundance of tree and shrub species in smaller size classes (<5 cm and <10 cm diameter) and ground cover species. Tree and shrub species richness and abundance was higher in areas above regulated flow reflecting the reduced impacts of inundation and disturbance. There were still some changes in this vegetation over the monitoring period, including changes in total vegetation cover. These changes were largely due to changes in bryophyte cover.

Disturbance influences are also apparent in the floristics of the river. Species that are tolerant or even requiring, of disturbance are prevalent in many areas such as *Leptospermum riparium*. This species holds seed in the canopy until released by a disturbance event and then readily germinates on areas of alluvial deposition, therefore it is prevalent in the zones downstream of sediment-laden inflows and those with large flood events (i.e. zones 4 and 5). These zones are also the only areas where this species is surviving into larger age classes. However, this species has shown signs of decline over the monitoring period in zones 2 and 3, and to a lesser extent zone 5, with reduced canopy extent and cover apparent in much of the photo-monitoring. The leaves on many plants are dying, resulting in a contraction of the canopy from the bottom, indicating a stress response to increased inundation of leaves at a higher level; a factor likely to reflect the effects of the recent power station operating regime.

Seedling recruitment and persistence of all species within the Gordon River was primarily influenced by location on the bank in the upstream zones, followed by seasonal effects. The relative influence of both bank stratification and season decreased with distance downstream from the dam. The reduced influence of season in the downstream zones was the result of the more-natural flows and increased sediment transfer that allowed pulses of seedling recruitment to occur such as those by *Leptospermum riparium*. Episodic or 'pulse' germination of seedlings is common in most environments because the conditions that favour germination are limited in time and space and often require a form of disturbance. The principal agent of disturbance in riparian systems is flood, which is largely absent in the upstream zones of the middle Gordon River. The increased tributary inflows and incidence of flood events in zones 4 and 5 has created more opportunities for seedling recruitment on the banks by the creation of gaps and regeneration niches.

Observations as part of this study, and by Davidson and Gibbons (2001), have indicated that seedling recruitment often occurs on bryophyte mats which are only abundant above regulated flow levels in the Gordon River. Successful recruitment is further hindered by the limited periods free of inundation (enabling photosynthesis), cooler temperatures due to substantial shading and an often saturated oxygen-deprived substrate. It is these factors, as opposed to a lack of seed *availability* as reported in other studies (Andersson *et al.* 2000), that is likely to be limiting seedling recruitment. This is apparent from the substantial recruitment that has occurred in some locations when conditions may have been ameliorated sufficiently to allow recruitment. One example of this is in zone 2 at the site 72 (G5a) cobble bar where a large stand of even-aged *Leptospermum riparium* seedlings exist. Despite this, seed *diversity* is likely to be reduced in zones 2 and 3 due to the lack of inflows and the low possibility of seedlings persisting in flows from the dam.

Size class analysis of seedling recruitment indicates that while germination occurs in most areas, including the highly impacted areas below the Plimsoll line, seedlings do not persist. Periodic waterlogging, inundation, localised scour and mechanical disturbance prove too frequent or intense to allow continued growth. This pattern is less severe, but still apparent, at the furthest downstream site which is 32 km downstream of the dam.

These results all show that while bank stratification is the dominant influence on a small scale; spatial differences in species dynamics, recruitment and abundance also occur at the reach and zonal scale.

## 9.8 Evaluation of the Basslink Monitoring Program

The riparian vegetation monitoring program has been successful in developing a greater understanding of vegetation processes such as recruitment, species richness and abundance, and how the degree of regulated flow-induced inundation affects these parameters. These data quantify the changes that have occurred over this period and provide baseline data with which post-Basslink comparisons can be made, following consideration of some of the limitations outlined below.

The major difficulties associated with the monitoring program are the limited pre-Basslink period and the limited number of sites that could be monitored due to access and logistical constraints. Coupled with the low frequency of monitoring, these data are limited in the amount of variability that can be measured and the degree to which this variability can be correlated with natural seasonal, year-to-year or longer-term patterns.

The paucity of sites can lead to significant effects being recorded in analyses that may be limited to one site, such as minor slips and individual tree mortality. These data therefore need to be carefully interpreted in association with larger-scale vegetation health monitoring such as photo-monitoring and general observations.

The lack of data over a longer time frame can lead to questions as to how representative these data are of riparian vegetation processes. For example, were the past three years ‘typical’ in terms of climatic conditions? Were some of the seedling recruitment numbers the result of a mass seeding event, as in known to occur with *Nothofagus cunninghamii*? How can future, stochastic events affect the interpretation of these data?

In addition to natural variability of the system, the data sampling may indicate ongoing adjustment to a third turbine that was added in 1988. This turbine increased river height and maximum flow output substantially and it is likely many of the longer-lived species on the upper banks are still adjusting to increased inundation and waterlogging. This variation is also likely to be affecting the geomorphology of the river banks, a factor that is explicitly linked with riparian vegetation processes (see chapter 3, Conceptual model and chapter 7, Fluvial geomorphology).

The riparian vegetation program has monitored sites in two ‘reference’ rivers. Although processes in these rivers can be quite different to those in the Gordon (see section 9.5), they provide a useful comparison for larger-scale regional variation that may occur, such as drought or other climatic influences.

Further to the use of the reference rivers to explain possible variation associated with the monitoring, analysis of the data has been undertaken in a way to use the impacted plots themselves as ‘controls’. Seedling data has been collected at four locations up the bank associated with turbine use. One of the quadrats is located at the position above power station operation. Data analysis has used the ratio of seedling numbers in this plot to those affected by power station flows. In this way, changes in the *relative recruitment* can be assessed. These data have been used to produce a model that is showing no significant differences between the zones over the monitoring period for any variables other than season. Power analysis has shown these data to have the power to detect changes in the order of 40 % reduction or increase in seedling recruitment for grouped data. (see chapter 4, Design and inference, for further discussion of power analysis of riparian vegetation data).

The baseline monitoring program allows for detection of changes in:

- seedling recruitment numbers for grouped data only (all <5 cm) at the site and zone level;
- seasonal patterns of mean, grouped seedling abundance at site and zone level;
- abundance of life forms at the site and zone level; and
- the presence or absence of tree species at site and zone level.

In addition to the design issues associated with physical variation of the system, physical changes can impact substantially on the program itself. The program uses permanent plots to monitor vegetation change, a widespread technique in plant ecology (Bakker *et al.* 1996). However, given the dynamic nature of the river and the frequent tree falls and landslips, these sites may be at risk. To reduce the impact of future site loss and still enable analysis at the zone level, the number of sites monitored was increased to four within each zone. A minimum of three sites is necessary to calculate a variance and enable analysis at the zone level.

The riparian vegetation monitoring program is adequate to fulfil the program’s aims of providing baseline data for comparisons on seedling recruitment and species abundance and richness and allow cautious interpretation of these data to detect a post-Basslink effect. Quantification of these impacts is not likely to be achieved given the natural variation in the system, however, the power to detect changes is relatively high (see chapter 13, Indicator variables).

## 9.9 Riparian vegetation indicator variables

The riparian vegetation monitoring program has been developed to detect possible post-Basslink effects and interpret these data within pre-Basslink defined indicator variables in accordance with the step-wise process outlined in chapter 13. There are a number of indicator variables that can be used as a basis for comparison between pre- and post-Basslink monitoring periods, most of which are measures of abundance or density of flora species, seedlings or ground cover conditions. The major criterion for suitable indicators is that they will be able to detect real change within the middle Gordon River. This change may or may not be attributed to pre-Basslink changes and will thus require further analysis for detection of causal relationships.

The baseline monitoring program detects changes at different spatial and temporal levels, namely smaller-scale seasonal seedling monitoring and longer-scale ground cover and life form monitoring. By including a selection of these variables, both short- and long-term changes at the zone level should be detected.

The use of the third turbine may also influence riparian vegetation regardless of post-Basslink changes. Consequently, the indicator variables have been defined to consider the use of the third turbine. Abundance and ground cover variables are presented as ratios of values from above the 3-turbine level ("above") to (a) corresponding values between the 2- and 3-turbine levels ("high") and (b) corresponding values between the 1- and 2-turbine levels ("low").

The shorter-term indicator variable is seedling density. Seedling density is a highly seasonal measure that responds quickly to changes in suitability of environmental conditions for establishment, such as increased inundation or mechanical disturbance. Due to the variable and seasonal nature of these data that may change on a local scale, the indicator variable has been developed as a measure of the ratio of the seedlings in the area above regulated flow compared with those below. This variable is measured in spring and summer.

Longer term indicator variables include abundance measures of bare ground, bryophytes, ferns, shrubs and total vegetation cover. Other life form data were excluded due the paucity of data and high variability on the zone level. These variables are measured annually giving four pre-Basslink measures to compare the post-Basslink results.

The monitoring program has been designed to enable analysis of the data at the zone level with each zone having at least three sites monitored to enable calculation of a variance. Data have been initially explored at the zone level and later grouped for the whole of the Gordon River when no significant or relevant trends were apparent. These data are presented within the results section of the report grouped by River where appropriate with the zone summaries are presented in Appendix 7.

Due to the limited period of pre-Basslink data and the possibility of ongoing systematic change or seasonal aberrations leading to values outside those defined in the trigger values, these values must be considered following the guidance outlined in chapter 13.

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# 10 Macroinvertebrates and algae

## 10.1 Chapter summary

This chapter provides an overview of the current state of in-stream benthic macroinvertebrates and aquatic moss and algae in the middle Gordon River, with an emphasis on how post-dam flow conditions continue to influence in-stream biological condition. The history of sampling in the middle Gordon River is described, as are the downstream trends in benthic macroinvertebrates and algal characteristics, and the likely nature of changes following Basslink.

The summarised findings of macroinvertebrate and algal monitoring are:

- The middle Gordon River is less diverse than reference sites in the tributaries and the greatest differences occur upstream of the Denison confluence. Density and abundance upstream of the Denison confluence were also less than at reference sites. Further downstream diversity was approximately 25 % lower than at the reference sites, and taxonomic composition differed (more simuliids, fewer beetles, mayflies and worms). Densities within the Gordon River upstream of the Olga confluence and downstream of the Denison confluence were between 20-50 % of the reference stream densities.
- Several taxa occur in the upper middle Gordon sites at higher abundances than in reference river sites. Simuliids (blackfly larvae), Grypoptyerygid stoneflies and worms numerically dominated the middle Gordon River sites. Aphroteniid chironomids, Ceratoponid chironomids and freshwater worms tended to be widespread at reference sites and were observed rarely or at lower abundances in the middle Gordon River. Orthoclad chironomids, Janiirid isopods, Hydropsychid caddisfly, Diamesinid chironomids and amphipods were found at higher abundances in the upper middle Gordon than in reference sites.
- The gradient of increasing diversity and abundance downstream of the power station is likely to be a product of reduced severity of velocity changes, reduced area of channel dewatering and probability of stranding mortality, increased availability of food resources, increased input of colonisers from tributary rivers, adult insect reproduction, and increased availability of substrate interstices.
- There was a general trend of O/E values increasing with distance downstream of the power station. O/E values for reference sites were consistently high falling within A or X bands on all occasions. Values for the middle Gordon River generally fell in the B or C bands upstream of the Denison confluence and in the A band downstream of the Denison confluence.

- Benthic algal and moss cover was relatively high (15-30 % of the total bed stream) downstream of the power station. These levels equated to 100 % cover of the wetted stream bed during periods of low flow and power station shut-downs. Cover decreased to very low levels (typically < 2 %) for sites downstream of the Denison confluence. Assessment of algal cover for the reference sites only commenced in spring 2004, revealing an average of 1.3 % cover across all sites. The lower cover in reference sites may be due to low nutrient levels, or low light availability (high colour) coupled with bed instability during large floods. Temporal variation in cover is between seasons and years and with the timing and duration of power station shut-downs. Spatial variation in cover is evident across the river channel and with distance along the Gordon River.
- A range of indicator variables have been selected for benthic macroinvertebrates, which provide data on the status of abundance, diversity and community composition. Changes are possible in all three areas following commencement of Basslink operations. Any changes in benthic algae and moss post-Basslink are expected to manifest primarily in overall cover and position within the channel. Accordingly, total in-channel percentage cover of algae and moss are the two core indicators to be reported and analysed during Basslink monitoring and assessment.
- All benthic macroinvertebrate, algal and moss data will be analysed at site level initially. The potential and need for data aggregation (to reach or zone levels) has been explored, and will be evaluated in detail during the major post-Basslink data analysis stages (years 3 and 6). Formal analysis may also include assessment of changes in the whole of river downstream spatial trends in selected indicators with distance from the dam. The form of such analyses has yet to be evaluated.

Previous investigations (Coleman 1978, Davies *et al.* 1999, Davies and Cook 2001) have documented the benthic macroinvertebrate assemblages of the middle Gordon River and discussed how these have responded to hydrologic changes associated with damming and flow regulation. Both the physical presence of the dam and the changed flow regime are believed to be major drivers of the observed changes in benthic biological condition and processes, with benthic algae also responding to these changes and mediating some aspects of benthic macroinvertebrate assemblages. The current level of conceptual understanding in relation to responses of benthic macroinvertebrates and algae to regulated flow-induced changes in the middle Gordon River is described in chapter 3.

## 10.2 Monitoring

Biological sampling of the middle Gordon River and its tributaries was first conducted in 1977 and 1978, consisting of quantitative sampling of benthic macroinvertebrates in summer (Coleman

1978). Benthic macroinvertebrate sampling was subsequently repeated at Coleman's original sites in the mid- and late-1990's (Davies *et al.* 1999, Davies and Cook 2001). The historical timing of all benthic sampling conducted in the middle Gordon is illustrated in relation to hydroelectric development in Figure 10.1.

Routine monitoring of benthic macroinvertebrates, algae and moss for the pre-Basslink Gordon River monitoring program commenced in late 2001. Map 10.1 shows the location of the monitoring sites for benthic macroinvertebrates and Map 10.2 shows those for benthic algae and moss within the Gordon River catchment. These locations are further detailed in Table 10.1.

### 10.2.1 Benthic macroinvertebrate sampling

The Basslink Monitoring Program was initiated in mid-2001, with nine of the middle Gordon River sites previously established by Davies and Cook (2001) and six of the reference sites selected for sampling. Sampling was conducted once in each spring and autumn of 2001-02, 2002-03, 2003-04 and 2004-05. Both rapid biological assessment (RBA) and quantitative (surber) sampling has been conducted on each sampling occasion. Ten surber sample units and two RBA samples have been collected from mid-channel riffle habitat at each site during low flows in the Gordon (during power station shut-down).

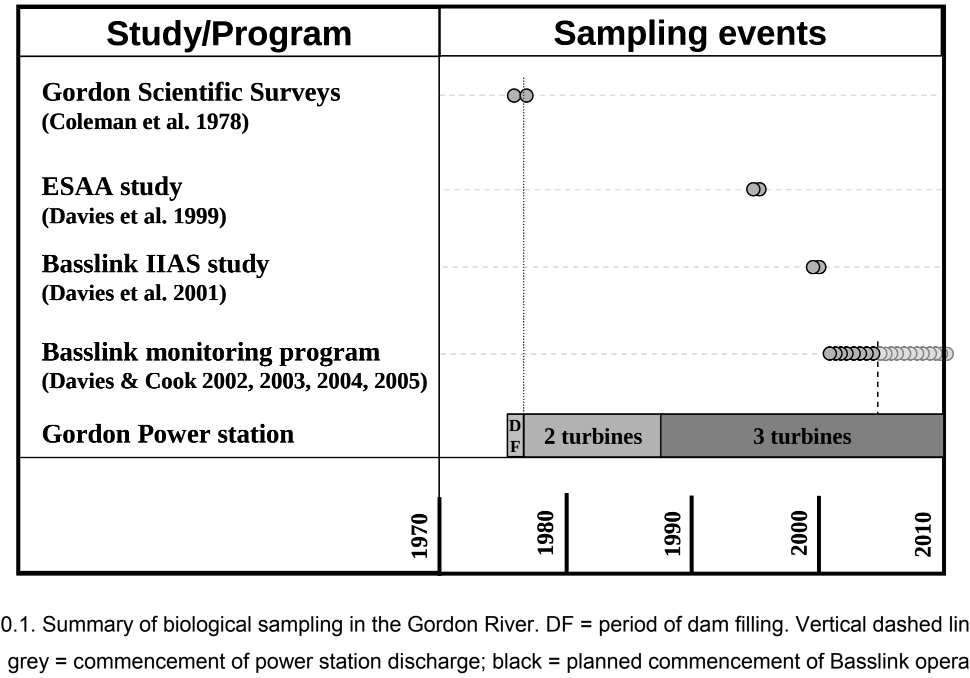


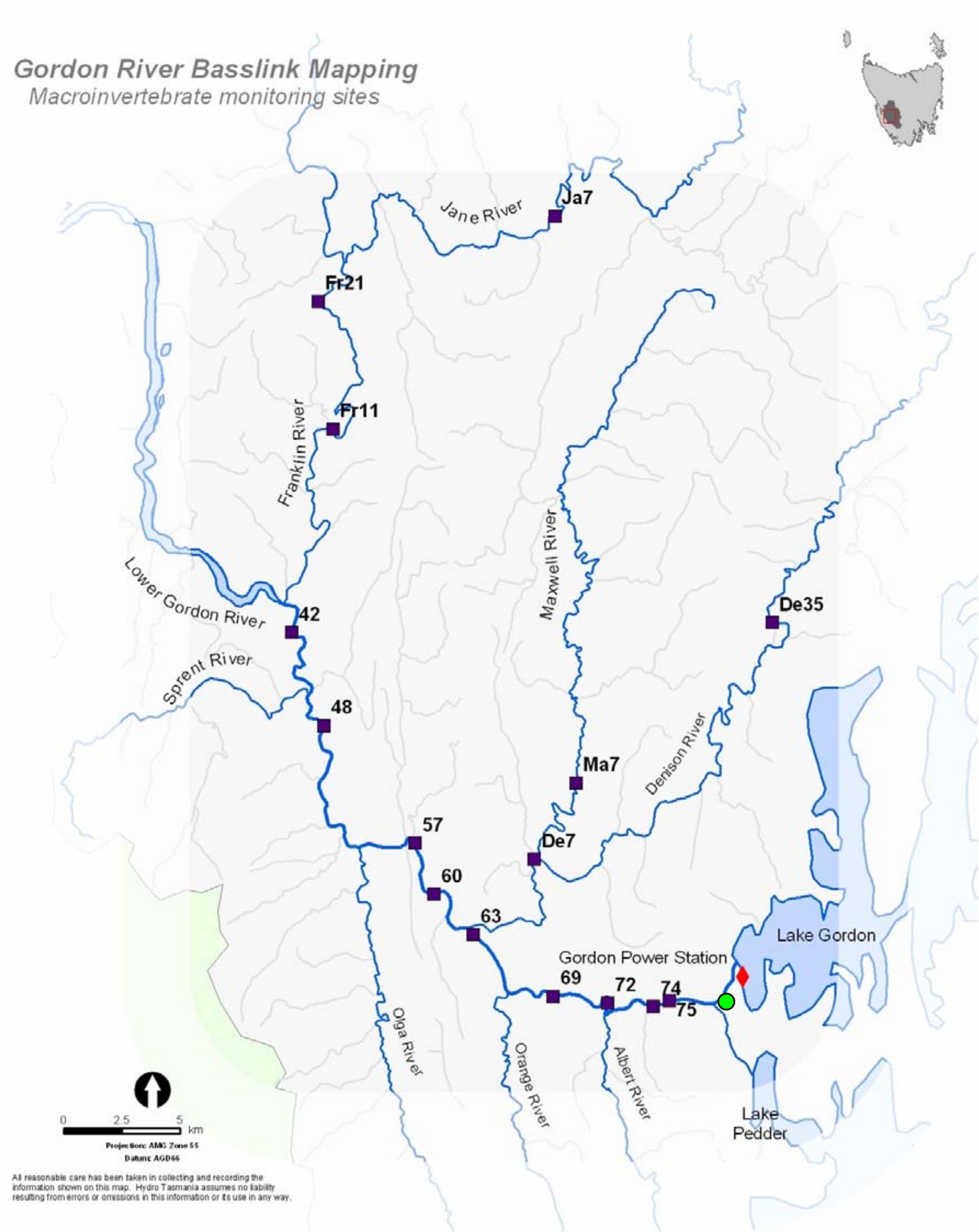
Figure 10.1. Summary of biological sampling in the Gordon River. DF = period of dam filling. Vertical dashed lines indicate: grey = commencement of power station discharge; black = planned commencement of Basslink operations. Circles indicate sampling events: dark grey = past sampling; light grey = planned 'post-Basslink' sampling.

The sampling methodology for macroinvertebrates is provided in appendix 8. Identification is to 'family' level for all samples, with all individuals identified to family level with the exception of oligochaetes, Turbellaria, Hydrozoa, Hirudinea, Hydracarina, Copepoda and Tardigrada, and with

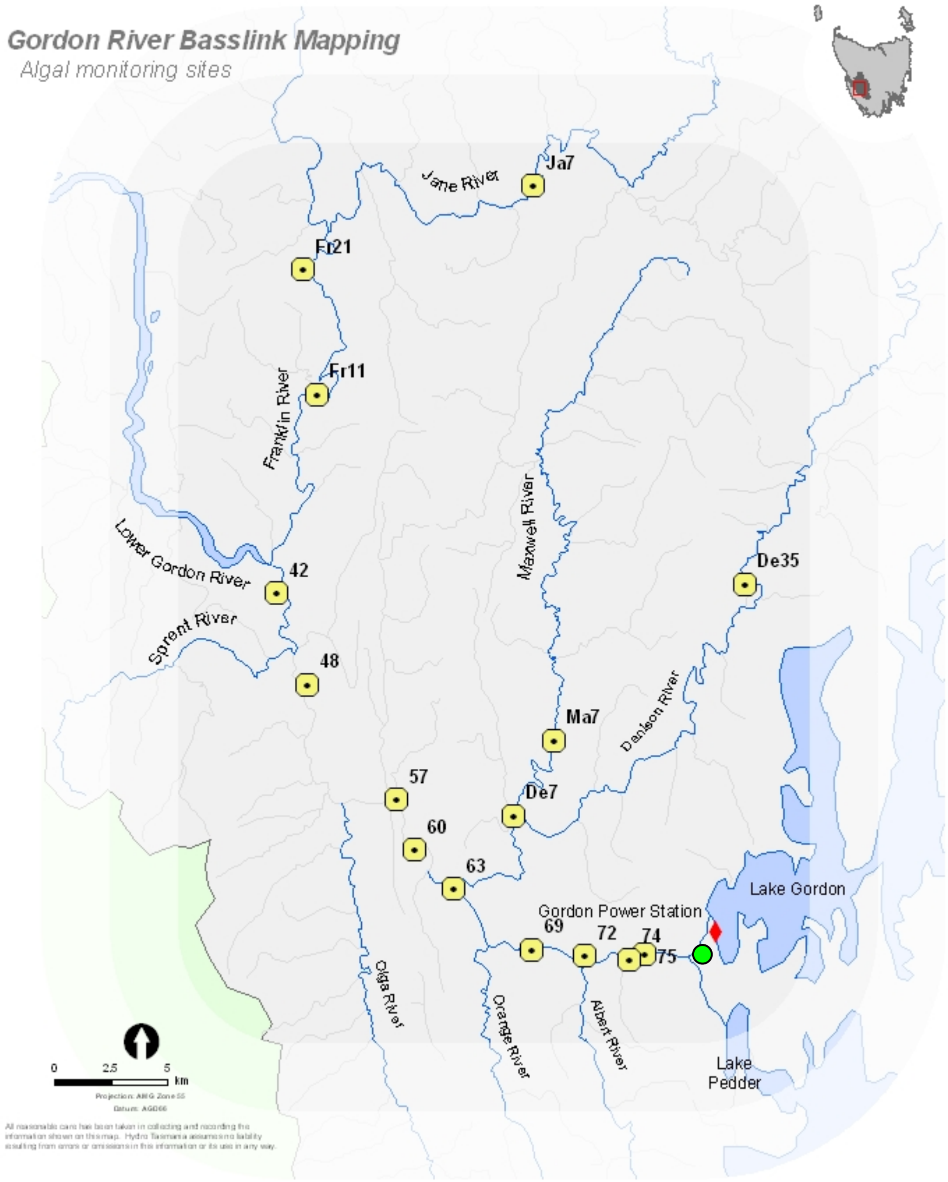
Chironomids identified to sub-family. Individuals in the following groups: Ephemeroptera, Plecoptera, Trichoptera, Coleoptera and Crustaceae - collectively known as 'EPTCC' - are also identified to species/genus level for surber samples.

Several variables are used to describe the macroinvertebrate assemblages in the middle Gordon River, derived from data collected using the two different sampling methods:

- Quantitative sampling - total density, number of taxa, density of individual taxa, and the Bray Curtis index (a measure of assemblage similarity between sites/samples) - using 'family' and/or 'EPTCC species' level data; and
- RBA sampling - the observed to expected ratio (O/E) derived using dedicated Hydro Tasmania AUSRIVAS models, and based on either presence-absence family level data (O/Epa) or on rank abundance family level data (O/Erk).



Map 10.1. Map of Gordon River catchment showing benthic macroinvertebrate monitoring sites. Gordon River zones for benthic biota are as follows: zone 1 - power station tailrace to Orange confluence (sites 69-75), zone 2: Denison confluence to Franklin confluence (sites 42-63). Red diamond indicates power station. Green circle indicates location of tailrace discharge.



Map 10.2. Map of Gordon River catchment showing benthic algal monitoring sites. Gordon River zones for benthic biota are as follows: zone 1 - power station tailrace to Orange confluence (sites 69-75), zone 2: Denison confluence to Franklin confluence (sites 42-63). Red diamond indicates power station. Green circle indicates location of tailrace discharge. Note that monitoring of reference sites commenced in 2004 and are not reported in this report.

Table 10.1. Macroinvertebrate and algal sampling sites. Under site code, Gn in parentheses denotes the original code for sites sampled by Coleman (1978).

| River | Site Name | Site Code | Distance from power station (km) | Easting | Northing |
|---|---|---|---|---|---|
| Gordon | Gordon R d/s Albert Gorge | 75 (G4) | 2 | 412980 | 5266630 |
| | Gordon R d/s Piguenit R | 74 (G4a) | 3 | 412311 | 5266383 |
| | Gordon R in Albert Gorge | 72 (G5) | 5 | 410355 | 5266524 |
| | Gordon R u/s Second Split | 69 (G6) | 8 | 408005 | 5266815 |
| | Gordon R u/s Denison R | 63 (G7) | 14 | 404584 | 5269469 |
| | Gordon R d/s Denison R | 60 (G9) | 17 | 402896 | 5271211 |
| | Gordon R u/s Smith R | 57 (G10) | 20 | 402083 | 5273405 |
| | Gordon R d/s Olga R | 48 (G11a) | 29 | 398178 | 5278476 |
| | Gordon R @ Devil's Teapot | 42 (G15) | 35 | 396804 | 5282486 |
| Franklin | Franklin R d/s Blackman's bend | Fr11 (G19) | - | 398562 | 5291239 |
| Franklin | Franklin R @ Flat Is | Fr21 (G20) | - | 397939 | 5296733 |
| Denison | Denison d/s Maxwell R | De7 (G21) | - | 407206 | 5272718 |
| Denison | Denison R u/s Truchanas Reserve | De35 (D1) | - | 417400 | 5282900 |
| Jane | Jane R | Ja7 (J1) | - | 408100 | 5300400 |
| Maxwell | Maxwell R | Ma7 (M1) | - | 409011 | 5276009 |

The AUSRIVAS analyses of RBA sample data resulted in assessments of ‘test’ sites with the following outputs:

- a biological index (O/E, or the ‘observed to expected’ ratio) which describes the proportion of 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). This is an index of biological impairment benchmarked against natural conditions, and which accounts for natural spatial variations in community composition. O/Epa is the O/E value calculated using an AUSRIVAS model based on presence-absence data. O/Erk is the O/E value calculated based on rank abundance category data.; and
- an impairment band, designated by the letters X, A, B, C, D, accompanied by a standardised description of the degree of impairment, whose bounds are based on statistically defined ranges of the O/E scores.

O/Erk is more sensitive to flow changes than O/Epa (Davies *et al.* 1999). Both indices are used in the Basslink monitoring program. The O/E bands used to report the condition of benthic macroinvertebrate communities are shown in Table 10.2, along with the O/E ranges relevant to each band in the two (combined season) Hydro Tasmania AUSRIVAS models developed by Davies *et al*. (1999). A single 'combined season' O/Epa and O/Erk value is derived for each year of sampling. Single season Hydro Tasmania AUSRIVAS models have also been developed for this program, allowing derivation of an O/Epa and O/Erk score for each sampling occasion (season).

Table 10.2. Impairment bands used for the O/E outputs of the Hydro Tasmania PA (presence/absence) and RK (rank abundance) combined season AUSRIVAS models developed by Davies *et al*. (1999).

| **Band** | **Bounds: PA model** | **Bounds: RK model** | **Description** |
|---|---|---|---|
| X | > 1.15 | > 1.11 | More diverse than reference* |
| A | 0.79-1.15 | 0.78-1.11 | Equivalent to reference. *Unimpaired.* |
| B | 0.43-0.79 | 0.44-0.78 | Less diverse than reference. *Significantly Impaired.* |
| C | 0.07-0.43 | 0.10-0.44 | Much less diverse than reference. *Highly Impaired.* |
| D | 0.000-0.07 | 0.000-0.10 | Extremely less diverse than reference. *Extremely impaired.* |

* denotes may occur for sites of exceptional natural diversity, or due to slight nutrient enrichment.

### 10.2.2 Benthic algae and moss

Quantitative observations have been made of the aerial cover of river substrate by benthic algae and moss on each site visit since the Basslink Monitoring Program began in mid-2001. Data collection has been focussed on assessing changes in cover of filamentous algae and moss that may be associated with Basslink-related effects. Each spring and autumn, algal cover has been recorded at close intervals across a single fixed transect (using quadrats, at three locations per interval) at each site. In addition, qualitative sampling of algal assemblages has been conducted, and 'zones' of algal-habitat features recorded. The sampling methodology is provided in appendix 8.

### 10.2.3 Indicator variables

The following indicator variables have been derived from the macroinvertebrate, algal and moss data for the assessment of the effects of Basslink operations:

**Benthic macroinvertebrates:**

1. Total density - density per unit area of all benthic macroinvertebrates
2. Total density* - density per unit area of all benthic macroinvertebrates excluding simuliids and oligochaetes (two taxa with high temporal/spatial variability at the site scale)
3. N families - total number of 'family' level taxa
4. N EPTCC species - total number of species within the EPTCC group.
5. Density Ephemeroptera - density of all ephemeroptera (mayflies) in the sample
6. O/Epa (single season)
7. O/Erk (single season)
8. O/Epa (combined season)

9. O/Erk (combined season)
10. Proportion EPTCC - the ratio of density of EPTCC to total density
11. Mean Bray Curtis Similarity of community composition to all reference sites - the average of the Bray Curtis similarity of the sample to all reference sites sampled on the same occasion. Calculated using square-root transformed density data for the EPTCC group only.

**Algae and moss:**

12. % algal cover - mean % cover of filamentous algae across the entire river channel from bank toe to bank toe.
13. % moss cover - mean % cover of mosses as above.

Variables 1 and 2 provide information on total macroinvertebrate density, while variables 3 and 4 provide information on taxon richness. Variables 6-9 and 11 provide information on community composition relative to reference conditions, while variables 5 and 10 provide information on the status of 'sensitive' (EPTCC) taxa. Variables 12 and 13 provide means of overall cover across the channel at fixed locations. These variables are all derived and reported on a seasonal (autumn and spring basis), with the exception of the combined season O/E indicators. These are derived using combined (summed) autumn and spring macroinvertebrate data, and are therefore reported on an annual basis.

Data analysis is done on a site and a zone basis, with two zones defined for macroinvertebrates (Map 10.1) and algae and moss (Map 10.2). Zone 1 is upstream of the Denison confluence to the power station tailrace discharge, not including site 63 (i.e. sites 75, 74, 72 and 69). Zone 2 is downstream of the Denison River to the Franklin confluence (sites 60, 57, 48 and 42).

Examination of the monitoring findings (see below) indicated that site 63 is transitional between the two zones, and experiences influences from both upstream and from backwater effects from the Denison River. Data from site 63 is therefore excluded in any analyses conducted by zone.

The consequences of post-Basslink values falling outside the trigger values (given in chapter 13) are as follows:

- *If variables fall above the trigger value maximum,* this implies an improvement in habitat quality above pre-Basslink levels, and a general shift toward natural reference condition (with the exception of algae and moss), with the following symptoms:
  - For variables 1 and 2 above - total density of macroinvertebrates has increased above pre-Basslink levels, probably linked to a rise in abundance and secondary productivity;
  - For variables 3 and 4 - taxon richness has increased above pre-Basslink levels;

  - For variables 6, 7, 8, 9 and 11 - O/E and similarity to reference has increased significantly above pre-Basslink levels;
  - For variables 5 and 10 - an increased representation of 'sensitive' (EPTCC) taxa, above pre-Basslink levels; and
  - For variables 12 and 13 (algal and moss cover) - an increased cover of filamentous algae and moss above pre-Basslink levels, implying an increase in low flows and a further shift away from natural reference conditions.

- *If values fall below the trigger value minimum,* this implies a decline in habitat quality below pre-Basslink levels and a further shift away from natural reference levels (with the exception of algae and moss), with the following symptoms:
  - For variables 1 and 2 above - total density of macroinvertebrates has decreased below pre-Basslink levels, probably linked to a decline in abundance and secondary productivity;
  - For variables 3 and 4 - taxon richness has decreased below pre-Basslink levels;
  - For variables 6, 7, 8, 9 and 11 - O/E and similarity to reference has decreased significantly below pre-Basslink levels;
  - For variables 5 and 10 - a decrease in representation of 'sensitive' (EPTCC) taxa below pre-Basslink levels; and
  - For variables 12 and 13 (algal and moss cover) - a decreased cover of filamentous algae and moss below pre-Basslink levels, implying a decrease in low flows and a shift toward natural reference conditions.

## 10.3 Findings

### 10.3.1 2001-05: Benthic macroinvertebrates

#### *10.3.1.1 Taxonomic composition and diversity*

The benthic macroinvertebrate fauna of the middle Gordon is currently less diverse than in reference rivers (Figure 10.2 and Figure 10.3, Table 10.3). The greatest differences occur upstream of the Denison confluence. However, the diversity at sites 48 and 42 (far downstream) is still 25 % lower (*ca* 5-7 families fewer) on average than at reference sites, and taxonomic composition differs (more simuliids, less beetles, mayflies and worms).

Table 10.3. Number of taxa (N taxa) and total density (T abund) of benthic macroinvertebrates from quantitative (surber) sampling of middle Gordon and reference river sites in 2001-02 to 2004-05. N = 10 surber sample units per sampling event, numbers are n per 0.18m$^2$ of river bed.

| | 2001/02 | | | | 2002/03 | | | | 2003/04 | | | | 2004/05 | | | | 2001/02 | | 2002/03 | | 2003/04 | | 2004/05 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Spr01 | | Aut02 | | Spr02 | | Aut03 | | Spr03 | | Aut04 | | Spr04 | | Aut05 | | Mean | | Mean | | Mean | | Mean | |
| | N taxa | T abund | N taxa | T abund | N taxa | T abund | N taxa | T abund | N taxa | T abund | N taxa | T abund | N taxa | T abund | N taxa | T abund | N taxa | T abund | N taxa | T abund | N taxa | T abund | N taxa | T abund |
| **Middle Gordon River** | | | | | | | | | | | | | | | | | | | | | | | | |
| 75 | 3 | 11 | 5 | 28 | 10 | 107 | 5 | 79 | 15 | 275 | 6 | 29 | 9 | 35 | 14 | 47 | 4 | 19.5 | 7.5 | 67.5 | 7.5 | 93 | 11.5 | 41 |
| 74 | 12 | 75 | 12 | 40 | 14 | 187 | 16 | 91 | 23 | 347 | 11 | 85 | 9 | 38 | 15 | 52 | 12 | 57.5 | 13 | 113.5 | 15 | 139 | 12 | 45 |
| 72 | 14 | 30 | 9 | 31 | 17 | 130 | 15 | 203 | 23 | 137 | 9 | 48 | 18 | 270 | 16 | 96 | 11.5 | 30.5 | 13 | 80.5 | 16 | 166.5 | 17 | 183 |
| 69 | 9 | 26 | 14 | 57 | 24 | 226 | 11 | 50 | 16 | 164 | 20 | 207 | 6 | 14 | 14 | 30 | 11.5 | 41.5 | 19 | 141.5 | 17.5 | 138 | 10 | 22 |
| 63 | 22 | 232 | 19 | 227 | 16 | 183 | 21 | 272 | 27 | 371 | 12 | 64 | 22 | 527 | 21 | 239 | 20.5 | 229.5 | 17.5 | 205 | 18.5 | 227.5 | 21.5 | 383 |
| 60 | 19 | 1472 | 14 | 78 | 22 | 335 | 19 | 233 | 17 | 332 | 17 | 747 | 26 | 558 | 11 | 164 | 16.5 | 775 | 18 | 206.5 | 20.5 | 284 | 18.5 | 361 |
| 57 | 18 | 115 | 30 | 417 | 17 | 134 | 18 | 122 | 20 | 188 | 22 | 246 | 21 | 516 | 18 | 374 | 24 | 266 | 23.5 | 275.5 | 17.5 | 128 | 19.5 | 445 |
| 48 | 21 | 709 | 15 | 81 | 17 | 167 | 21 | 148 | 14 | 192 | 15 | 129 | 17 | 152 | 17 | 209 | 18 | 395 | 16 | 124 | 19 | 157.5 | 17 | 180.5 |
| 42 | 24 | 605 | 25 | 439 | 16 | 172 | 16 | 88 | 20 | 217 | 16 | 127 | 22 | 197 | 12 | 159 | 24.5 | 522 | 20.5 | 305.5 | 16 | 130 | 17 | 178 |
| **Reference rivers** | | | | | | | | | | | | | | | | | | | | | | | | |
| Fr11 | 22 | 690 | 27 | 430 | 24 | 501 | 23 | 400 | 18 | 445 | 17 | 379 | 26 | 712 | 19 | 449 | 24.5 | 560 | 25.5 | 465.5 | 23.5 | 450.5 | 22.5 | 580.5 |
| Fr21 | 20 | 462 | 18 | 351 | 23 | 408 | 33 | 1016 | 23 | 312 | 25 | 624 | 24 | 469 | 27 | 303 | 19 | 406.5 | 20.5 | 379.5 | 28 | 712 | 25.5 | 386 |
| De7 | 13 | 336 | 21 | 348 | 22 | 220 | 22 | 326 | 22 | 246 | 26 | 430 | 23 | 336 | 24 | 359 | 17 | 342 | 21.5 | 284 | 22 | 273 | 23.5 | 347.5 |
| De35 | 23 | 606 | 26 | 445 | 22 | 246 | 24 | 635 | 18 | 451 | | | 23 | 388 | 21 | 411 | 24.5 | 525.5 | 24 | 345.5 | | | 22 | 399.5 |
| Ma7 | 37 | 852 | 27 | 548 | 20 | 269 | 26 | 384 | 31 | 637 | 33 | 1083 | 29 | 461 | 28 | 490 | 32 | 700 | 23.5 | 408.5 | 23 | 326.5 | 28.5 | 475.5 |
| Ja7 | 23 | 781 | 19 | 643 | 21 | 376 | 25 | 1013 | 20 | 392 | 24 | 913 | 27 | 735 | 21 | 609 | 21 | 712 | 20 | 509.5 | 23 | 694.5 | 24 | 672 |

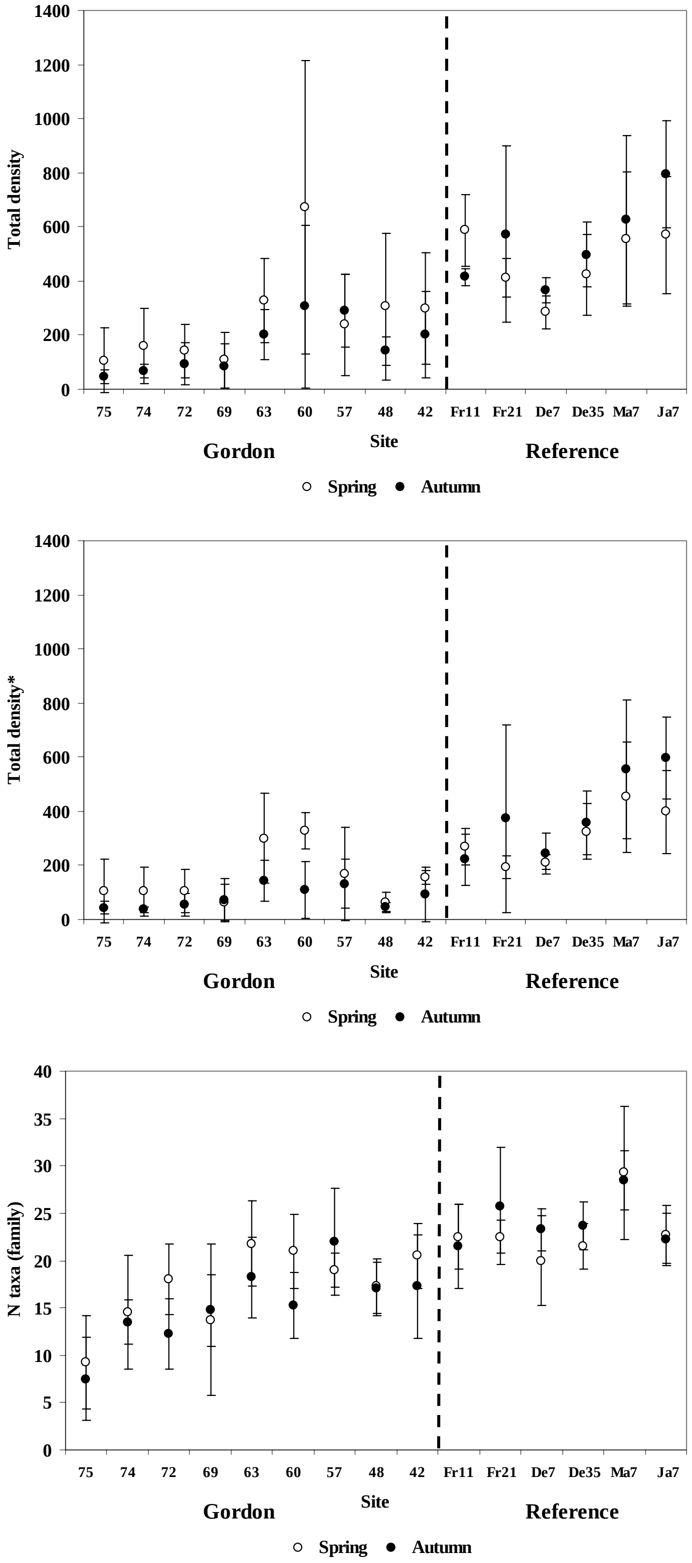


Figure 10.2. Mean spring and autumn values for benthic macroinvertebrate density, both total density and total density* without worms and simuliids, and number of taxa (at family level) at all sites in the Gordon River, and at reference sites in all four years sampled to date (spring 2001 to autumn 2005). Bars indicate standard deviation around means. Density in n individuals per 0.18m$^2$

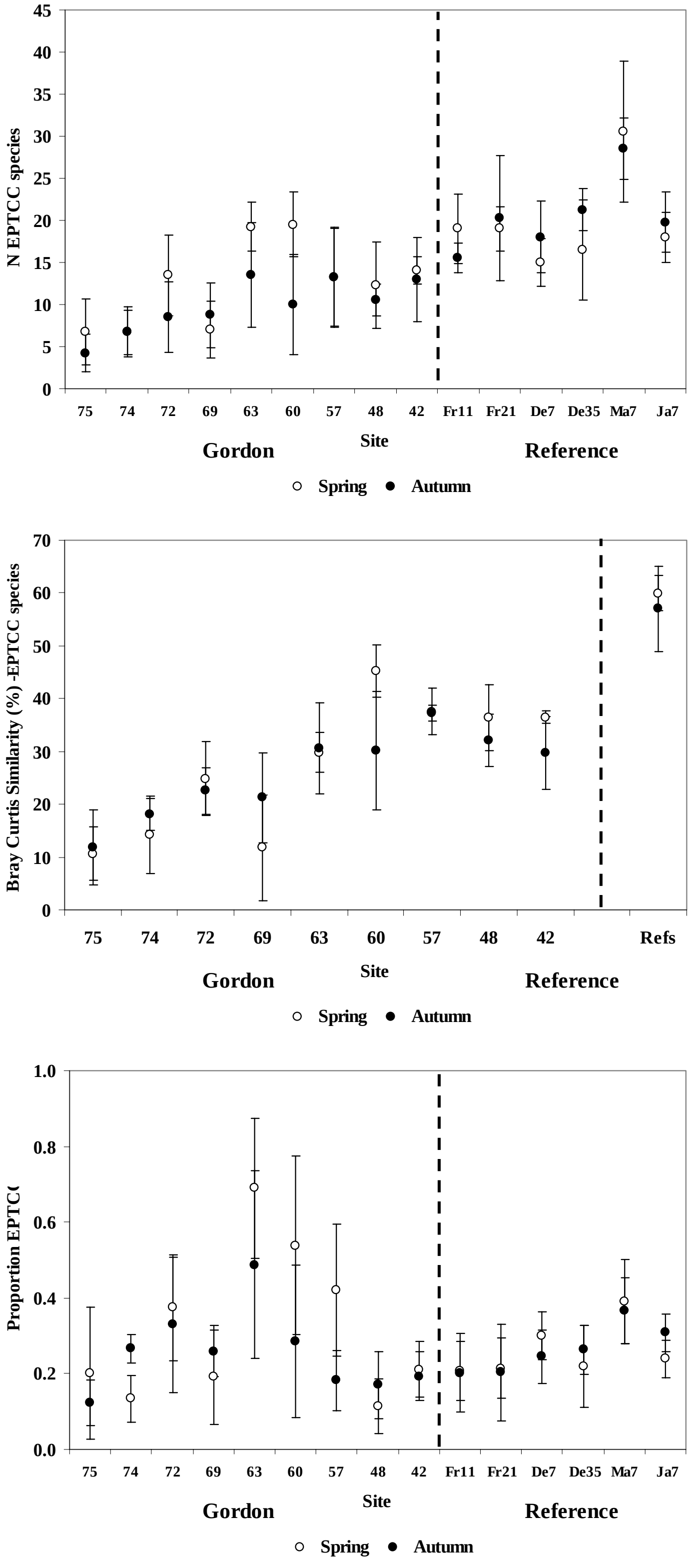


Figure 10.3. Mean spring and autumn number of EPTCC species, the Bray Curtis Similarity of Gordon to reference sites (derived from data on EPTCC species composition), and the proportion of total density represented by EPTCC species, at all sites in the Gordon River, and at reference sites in all four years sampled to date (spring 2001 to autumn 2005). Bars indicate standard deviation around means.

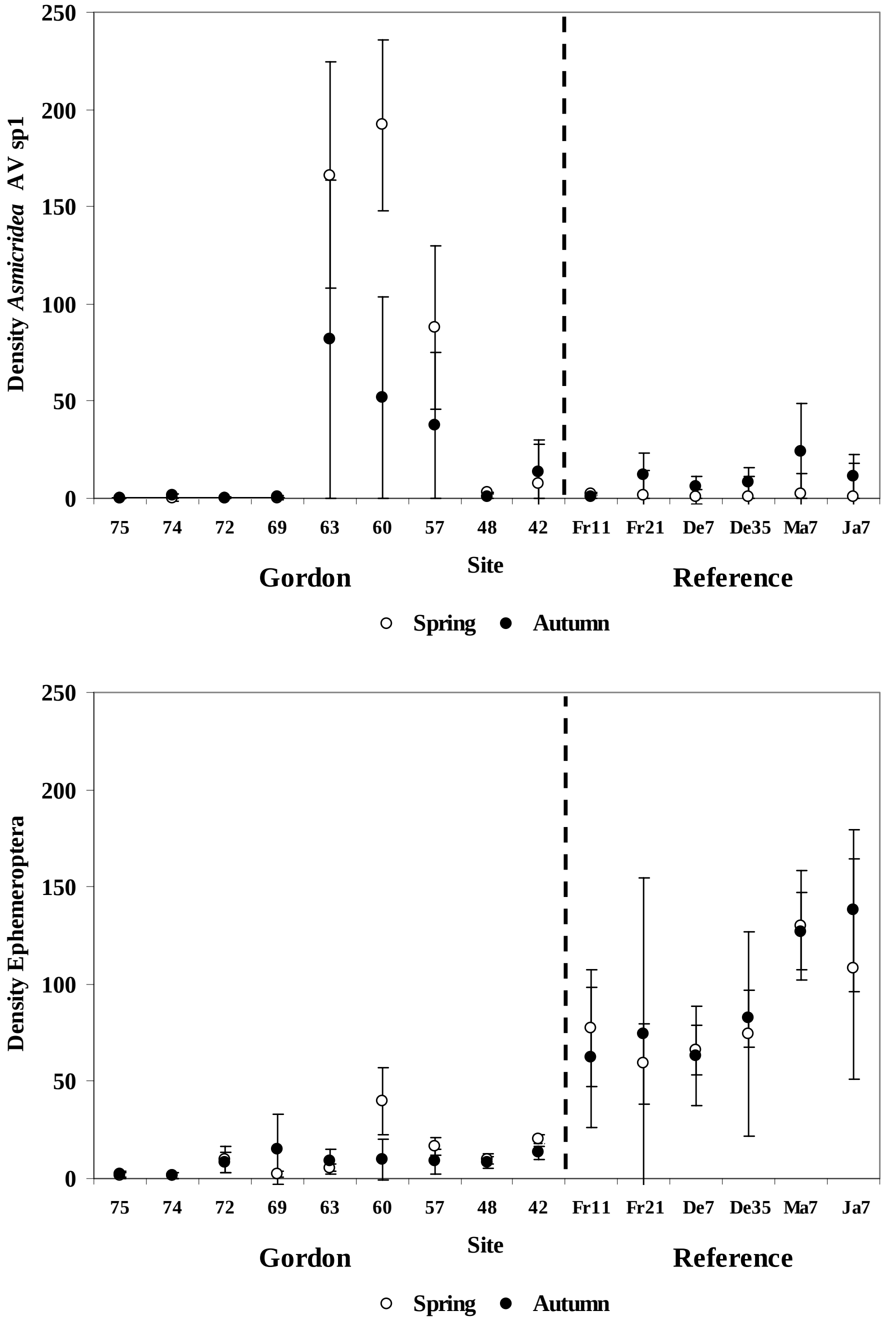


Figure 10.4. Mean spring and autumn density of the hydropsychid caddis Asmicridea AV sp. 1 and of Ephemeroptera at all sites in the Gordon River, and at reference sites in all four years sampled to date (spring 2001 to autumn 2005). Bars indicate standard deviation around means. Density is n individuals per 0.18m2.

There are several taxa occurring in the upper middle Gordon (sites 75-69) at higher abundances than in reference river sites. These include:

- Orthoclad chironomids and Janiirid isopods - taxa favoured by low flows and filamentous algal growth;

- Hydropsychid caddisfly, especially *Asmicridea* sp AV1 - a taxon favoured by conditions of low hydraulic disturbance and constant fine, suspended particulate food supply, especially in the vicinity of the Denison confluence (Figure 10.4);
- Diamesinid chironomids (observed at 75-74 only) - which are colder water algal grazers; and
- amphipods (both Parameletidae and Neoniphargidae) - which, in mid-channel, prefer slower flowing conditions with abundant algae.

Ordination analysis of quantitative benthic macroinvertebrate data from the middle Gordon (by multidimensional scaling) results in a two-dimensional ordination (Figure 10.5) with:

- the first (x) axis describing the downstream trend in assemblage composition (dominated by changes in overall density and diversity), approaching but not reaching reference site composition;
- the second (y) axis relating to seasonal differences in composition (again relating to changes in overall density).
- sites close to the power station (75, 74) being distinct from others; and
- sites becoming more similar in a downstream direction;, with the exception of sites 60 and 57 and occasionally site 69 - these differences are discussed below.

#### *10.3.1.2 Density and abundance*

Middle Gordon sites have lower mean overall benthic macroinvertebrate density and abundance than reference river sites (Figure 10.2, Table 10.4), especially above the Denison confluence, where sites average 20 % of reference site densities. Upstream of the Denison there is also a significantly reduced biomass resulting from the combination of reduced density and the predominance of smaller larval (instar) stages of aquatic insects (Davies and Cook unpub. data).

Benthic macroinvertebrate densities upstream of the Olga confluence and downstream of the Denison are between 20-50 % of reference stream densities. Total benthic macroinvertebrate density just upstream of the Franklin confluence at 48 and 42 are still lower than those of reference sites (*ca* 65 % on average).

Table 10.4. Most abundant (dominant) taxa in the Gordon River upstream and downstream of the Denison confluence and in reference river sites. % are means of overall total density derived from all quantitative (surber) data collected between 2001-02 and 2004-05.

| Area | % | Sites | % | Sites | % |
|---|---|---|---|---|---|
| **Upstream Denison** | | **74 - 75** | | **69 - 72** | |
| **Simuliids** | 18.93 | Janiiridae | 30.55 | Gripopterygidae | 20.59 |
| **Stoneflies** | 17.96 | Simuliidae | 17.52 | Simuliidae | 20.34 |
| **Janiriids** | 17.03 | Gripopterygidae | 12.05 | Orthocladiinae | 13.06 |
| **Oligochaetes** | 8.29 | Diamesinae | 11.07 | Oligochaetae | 9.92 |
| **Mayflies** | 5.50 | Orthocladiinae | 7.29 | Leptophlebiidae | 8.98 |
| **Caddis** | 3.26 | Oligochaetae | 6.66 | Podonominae | 3.58 |
| **Beetles** | 1.41 | Leptophlebiidae | 1.75 | Janiiridae | 3.52 |
| **Downstream Denison** | | **57 - 60** | | **42 - 48** | |
| **Simuliids** | 38.04 | Simuliidae | 40.29 | Simuliidae | 35.79 |
| **Oligochaetes** | 16.17 | Hydropsychidae | 26.56 | Oligochaetae | 24.66 |
| **Mayflies** | 5.48 | Oligochaetae | 7.68 | Chironominae | 8.88 |
| **Beetles** | 4.32 | Leptophlebiidae | 5.30 | Leptophlebiidae | 5.38 |
| **Stoneflies** | 3.71 | Gripopterygidae | 2.97 | Gripopterygidae | 3.18 |
| **Caddis** | 1.15 | Elmidae (L) | 2.66 | Hydropsychidae | 3.01 |
| **Janiriids** | 0.74 | Elmidae (A) | 1.71 | Elmidae (L) | 3.01 |
| **Reference rivers** | | **All Reference sites** | | | |
| **Beetles** | 31.41 | Simuliidae | 20.84 | | |
| **Simuliids** | 20.84 | Elmidae (L) | 19.89 | | |
| **Mayflies** | 17.73 | Leptophlebiidae | 13.81 | | |
| **Oligochaetes** | 10.89 | Oligochaetae | 10.89 | | |
| **Caddis** | 6.91 | Elmidae (A) | 6.72 | | |
| **Stoneflies** | 2.23 | Scirtidae | 4.33 | | |
| **Janiriids** | 0.99 | Baetidae | 3.93 | | |

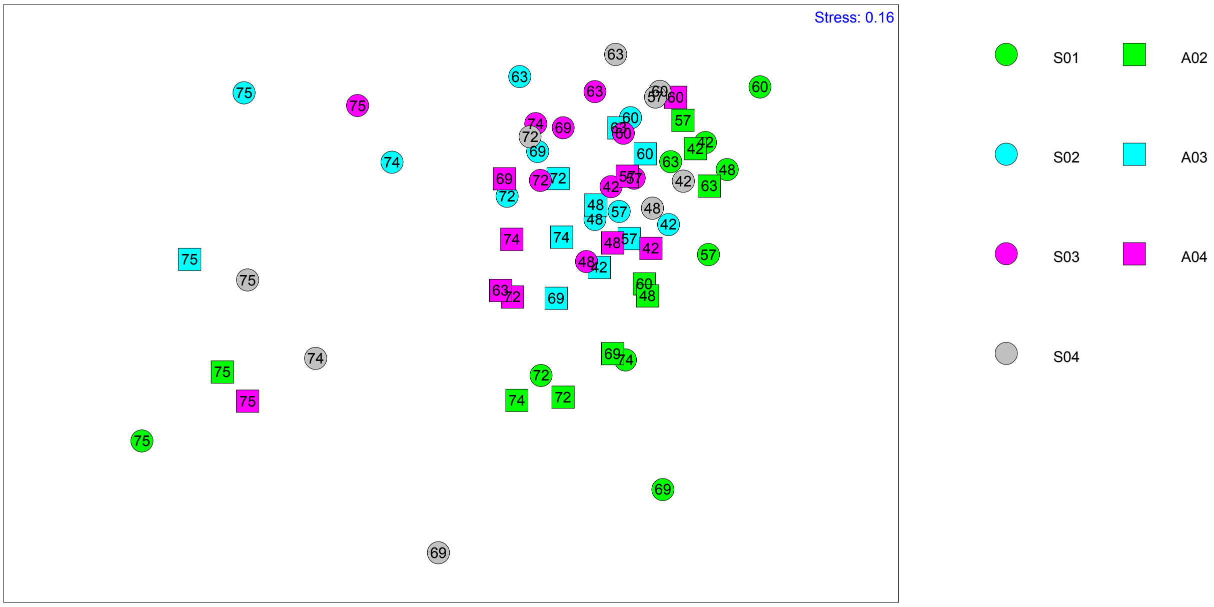


Figure 10.5. Ordination of quantitative benthic macroinvertebrate data for all Gordon river sites for all seasons. Squares = autumn, circles = spring. Light green = 2001-02, light blue = 2002-03, pink = 2003-04, grey = 2004-05. Horizontal axis differentiates sites primarily on basis of density and diversity (lower values to the left), vertical axis differentiates sites largely by season (with exception of spring 2001).

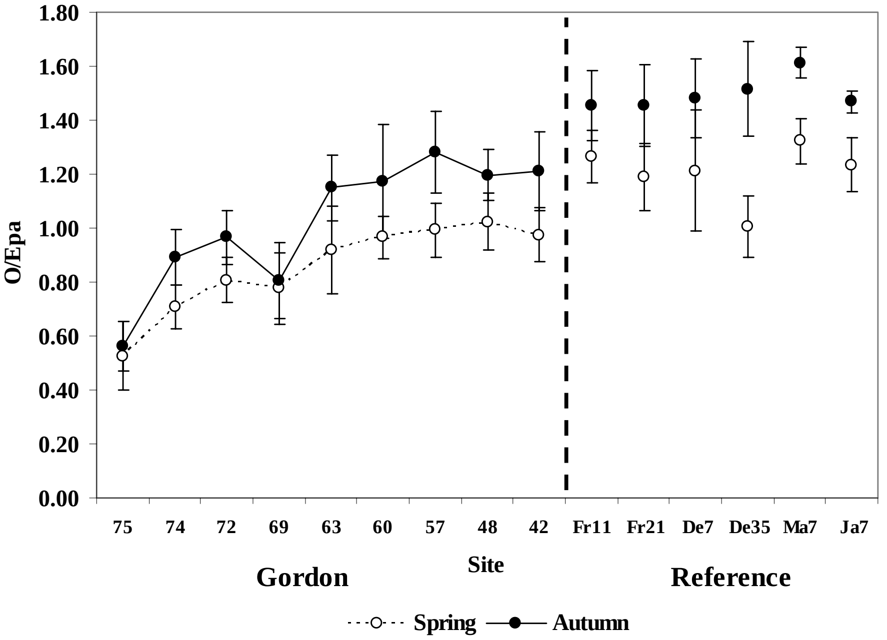
### *10.3.1.3 O/E values*

O/E values derived for each season's sampling are presented in Table 10.5, and plotted by site and season in Figure 10.6. O/Epa and O/Erk values for both zones of the Gordon River upstream of the Denison confluence fell below those for reference sites on average, with values for zone 1 falling below reference site values on all sampling occasions (all $p < 0.05$ by repeated measures ANOVA). There is a general trend of low O/E values downstream of the power station, increasing with distance toward the Franklin confluence.

O/E values for reference sites were consistently high, falling within the A or X bands on all occasions. Values for the middle Gordon River generally fell in the B or C (significantly to severely impaired) bands upstream of the Denison confluence, and in the A band downstream of the Denison.

Table 10.5. O/Epa and O/Erk values for each sampling occasion to autumn 2005 at all middle Gordon and reference river sites. Values are means of two for each sampling event from autumn 2002 onward. Blanks indicate occasions when sampling could not be conducted.

| | **Year :** | **2001** | | **2002** | | **2002** | | **2003** | | **2003** | | **2004** | | **2004** | | **2005** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Season :** | **Spring** | | **Autumn** | | **Spring** | | **Autumn** | | **Spring** | | **Autumn** | | **Spring** | | **Autumn** | |
| | **OE output :** | **OEpa** | **OErk** | **OEpa** | **OErk** | **OEpa** | **OErk** | **OEpa** | **OErk** | **OEpa** | **OErk** | **OEpa** | **OErk** | **OEpa** | **OErk** | **OEpa** | **OErk** |
| **River** | **Site** | | | | | | | | | | | | | | | | |
| **Gordon** | 75 | 0.68 | 0.71 | 0.59 | 0.61 | 0.38 | 0.60 | 0.49 | 0.43 | 0.49 | 0.58 | 0.68 | 0.56 | 0.56 | 0.58 | 0.49 | 0.56 |
| | 74 | 0.66 | 0.64 | 0.88 | 0.66 | 0.81 | 0.61 | 1.03 | 0.83 | 0.63 | 0.73 | 0.88 | 0.73 | 0.74 | 0.88 | 0.78 | 0.50 |
| | 72 | 0.87 | 0.97 | 0.88 | 0.71 | 0.69 | 0.77 | 0.88 | 0.73 | 0.80 | 0.92 | 1.03 | 0.73 | 0.87 | 0.83 | 1.08 | 0.86 |
| | 69 | 0.91 | 1.12 | 0.98 | 0.73 | 0.68 | 0.61 | 0.78 | 0.74 | 0.87 | 0.81 | 0.83 | 0.68 | 0.64 | 0.76 | 0.64 | 0.47 |
| | 63 | 1.04 | 1.16 | 1.27 | 1.11 | 1.08 | 1.06 | 1.17 | 0.95 | 0.82 | 0.94 | 1.17 | 1.03 | 0.74 | 0.68 | 0.98 | 0.81 |
| | 60 | 0.90 | 1.12 | 1.37 | 1.11 | 0.90 | 1.14 | 1.17 | 0.83 | 1.05 | 1.02 | 1.27 | 0.91 | 1.01 | 0.96 | 0.88 | 0.58 |
| | 57 | 0.97 | 1.06 | 1.08 | 0.86 | 1.05 | 1.12 | 1.27 | 1.08 | 0.86 | 0.85 | 1.42 | 1.03 | 1.09 | 1.06 | 1.37 | 0.96 |
| | 48 | 0.96 | 0.98 | 1.27 | 0.95 | 0.92 | 1.17 | 1.08 | 0.93 | 1.04 | 0.98 | 1.17 | 0.93 | 1.16 | 1.23 | 1.27 | 0.85 |
| | 42 | 1.12 | 1.17 | 1.37 | 1.01 | 0.90 | 1.13 | 1.03 | 0.85 | 0.94 | 0.96 | 1.17 | 0.86 | 0.94 | 0.90 | 1.27 | 0.88 |
| **Reference** | | | | | | | | | | | | | | | | | |
| Franklin | Fr11 | 1.35 | 1.40 | 1.57 | 1.01 | 1.31 | 1.17 | 1.52 | 1.16 | 1.12 | 1.20 | 1.27 | 0.93 | 1.27 | 1.20 | 1.47 | 1.16 |
| | Fr21 | 1.20 | 1.18 | 1.66 | 1.21 | 1.35 | 1.17 | 1.47 | 1.18 | 1.05 | 1.03 | 1.32 | 1.13 | 1.16 | 1.23 | 1.37 | 1.11 |
| Denison | De7 | 0.91 | 1.00 | 1.66 | 1.36 | 1.18 | 1.14 | 1.42 | 1.13 | 1.37 | 1.23 | 1.52 | 1.19 | 1.40 | 1.29 | 1.32 | 1.16 |
| | De35 | 1.11 | 1.03 | 1.66 | 1.21 | 1.11 | 1.01 | 1.32 | 1.14 | 0.91 | 1.04 | | | 0.91 | 0.83 | 1.56 | 1.19 |
| Maxwell | Ma7 | 1.35 | 1.41 | 1.66 | 1.21 | 1.43 | 1.04 | 1.66 | 1.14 | 1.24 | 1.22 | 1.56 | 1.13 | 1.28 | 1.22 | 1.56 | 1.13 |
| Jane | Ja7 | 1.34 | 1.15 | 1.47 | 1.06 | 1.26 | 1.07 | 1.47 | 1.19 | 1.11 | 1.16 | 1.52 | 1.24 | 1.22 | 1.16 | 1.42 | 0.96 |



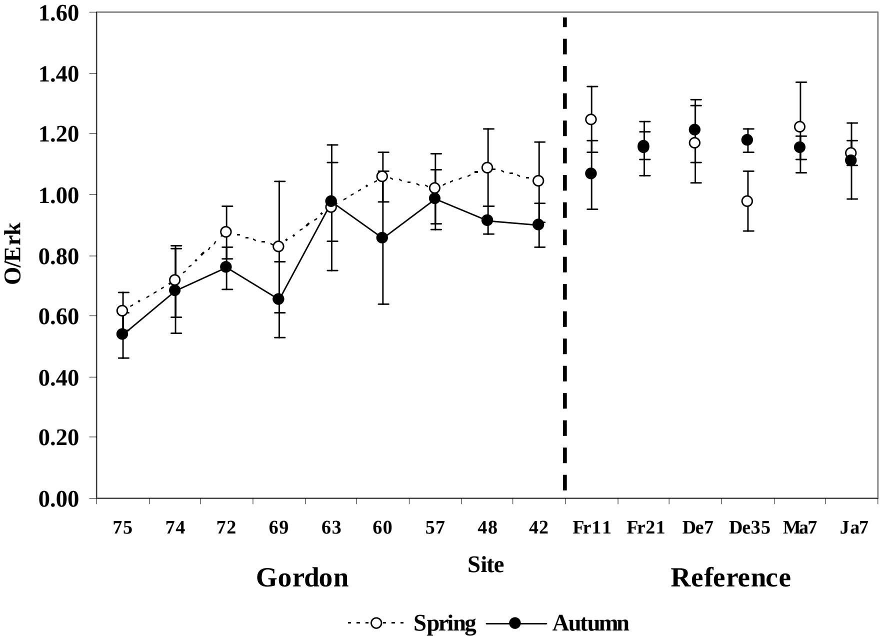


Figure 10.6. Mean spring and autumn season O/Epa and O/Erk values at all sites in the Gordon River and at reference sites over all four years sampled to date (spring 2001 to autumn 2005). Bars indicate standard deviation around means.

### 10.3.2 Sources of variation in macroinvertebrate data

The results of twice-yearly sampling in 2001-02, 2002-03, 2003-04 and 2004-05 revealed variation in density, diversity and community composition by year, river, location and season, summarised below. More detailed description and interpretation is provided in subsequent sections.

#### *10.3.2.1 Year*

The degree of interannual variation was small for all macroinvertebrate variables, with no substantive trends detected over the study period. There were however, some significant interannual variations for particular sites within the Gordon.

A two-way analysis of variance (year, location) revealed significant differences between years for total density in spring, but not autumn. The between year differences in density were due to significantly higher total density in spring 2001 at sites downstream of the Denison confluence. A large peak in density of simuliid (blackfly) larvae was observed at sites downstream of the Denison confluence in early 2001 (Figure 10.7). This was accompanied by higher simuliid density in reference sites in the Denison River. This was therefore probably a natural event in which a major increase in simuliid recruitment occurred in the Denison, and presumably led to colonisation by drift in the reaches of the Gordon downstream of the Denison confluence. Site 57 maintained low simuliid densities, possibly due to a backwater effect from Ewarts Gorge (see below). This was not observed in subsequent years, and was not preceded by unusual flow conditions. Local climatic conditions in 2000-01 may have contributed to higher levels of blackfly recruitment.

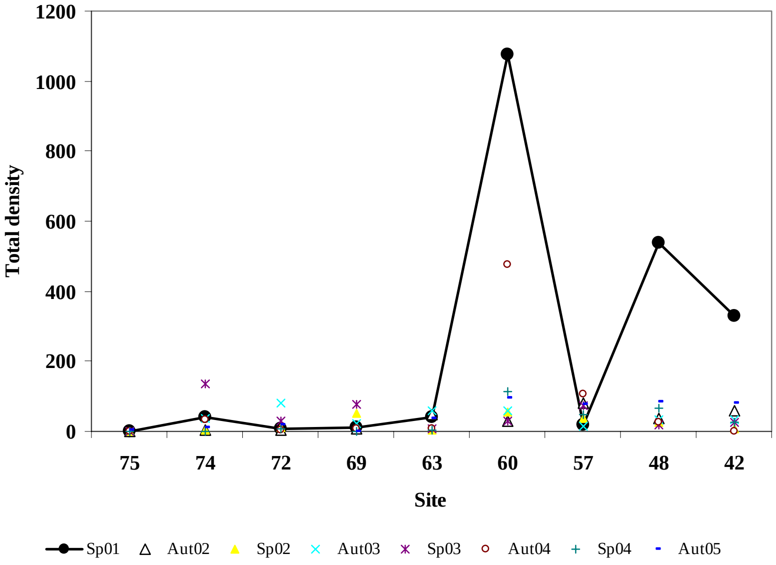


Figure 10.7. Density of simuliid larvae in Gordon sites on all sampling occasions, highlighting the spike in density in spring 2001 at sites 60, 48 and 42.

Marked fluctuations in total density were observed between years at sites upstream of the Denison (sites 75 to 67). This was a result of synchronous variation in density of several dominant taxa, including *Trinitoperla zwicki*, *Heterias pusilla*, *Nousia* sp AV7. Inspection of this pattern suggests that prolonged low flow periods of power station outage in spring result in elevated densities of these taxa and hence overall density in both the spring and subsequent autumn samples (Figure 10.8). This pattern was not observed downstream of the Denison, where power station outages do not lead to very low flows.

Marked year to year variation was therefore observed at particular sites, and is believed to be due to both natural causes (inputs/recruitment from tributaries) and due to variation in power station operations (especially upstream of the Denison confluence). There were, however, no substantive or statistically significant trends over the study period in any of the macroinvertebrate variables (all $p > 0.2$ by F test).

#### *10.3.2.2 River*

All Gordon sites had significantly lower means of total density, diversity and O/E scores than the reference sites (Figure 10.2 and Figure 10.6, all $p < 0.002$ by ANOVA). The majority of dominant taxa had substantially lower densities in Gordon than in reference sites.

As observed in previous data from 1977-78 and 1995-96, all Gordon sites were depauperate compared to reference river sites. For sites upstream of the Denison in 2001-02 to 2004-05 these differences amounted to an average of 26.9 and 59.5 % of overall reference site benthic macroinvertebrate total density and diversity, respectively. For the Gordon downstream of the Denison, they amount to 61.3 and 81.2 % of reference site values.

Gordon river macroinvertebrate assemblage similarity to reference sites was low relative to the mean inter-site similarity for reference sites alone (Figure 10.3). Community composition of all Gordon sites was significantly different from that of reference sites, by Analysis of Similarity (ANOSIM, $p < 0.005$). These differences were due to loss of taxa, as well as changes in relative composition of the remaining taxa.

#### *10.3.2.3 Location within the middle Gordon (zone and site)*

Overall trends were observed of declining macroinvertebrate diversity, density, O/E scores and community compositional similarity to reference sites, with proximity to the power station. Sites in the zone upstream of the Denison confluence (zone 1) were significantly lower in total density and diversity than sites downstream of the confluence in zone 2 (both $p < 0.01$ by ANOVA).

Spatial variation was also observed between sites. Sites in the immediate vicinity of the Denison confluence (63, 60, and 57) had distinctively elevated densities of the hydropsychid caddis *Asmicridea* sp AV1. Sites 69 and 57 experienced occasional anomalous variation in overall macroinvertebrate density and diversity. Sites in the upper reaches close to the power station experienced increases in abundance and diversity associated with prolonged low flows, while other sites did not,.

#### *10.3.2.4 Season*

A significant seasonal effect for all sites was observed for O/Epa, O/Erk, total density (in the absence of simuliids and oligochaetes) and the number of EPTCC species (Figure 10.2, Figure 10.3 and Figure 10.6). Values were higher in spring than autumn, with the exception of O/Erk for which this was reversed.

A zone by season interaction was observed for density of Ephemeroptera and macroinvertebrate community Bray Curtis similarity to reference sites (all $p < 0.02$ by F test). Both variables were higher in spring than in autumn at sites downstream of the Denison (Figure 10.4 and Figure 10.6).

Sites upstream of the Denison confluence had substantially higher benthic macroinvertebrate density and diversity in spring than autumn, particularly at sites 42 and 48.

#### *10.3.2.5 Spatial patterns*

Overall, there is marked spatial variation in macroinvertebrate variables at four spatial scales - river (Gordon vs. reference), zone (upstream vs. downstream Denison), reach (e.g. vicinity to Denison), and site. A combination of effects was observed on benthic macroinvertebrates in the Gordon from the overall whole-river effect of power station operations, the influence of tributary inputs, and local (e.g. hydraulic) 'site' effects.

Benthic macroinvertebrate density and diversity are shown plotted as seasonal means by site in Figure 10.2 for the period spring 2001 to autumn 2005. The overall pattern is one of low diversity and abundance downstream in the middle Gordon upstream of the Denison, increasing downstream, but still falling below values for reference sites. Particularly high total density values are noted for sites 60, 48 and 42, especially in spring 2001, as discussed previously.

Similar trends are observed from species data for the EPTCC group (Figure 10.3), which show a trend of increasing diversity, density and similarity to reference sites with distance from the power station, with all values still falling below means for reference sites even at site 42 (just upstream of the Franklin confluence).

The proportion of macroinvertebrates as EPTCC species is similar to or below reference site values upstream of the Denison confluence (Figure 10.3). However, it rises to very high values, especially in spring, in the immediate vicinity of the Denison confluence (sites 57-63), falling to near-reference values downstream at sites 48 and 42. Inspection of individual species data reveals that this is due to a peak in the density of the hydropsychid caddis *Asmicridea* sp AV1 (snowflake caddis) at sites immediately downstream of the Denison, including site 63 which is often a backwater of the Denison confluence (Figure 10.4). A similar small spring peak at site 60 is observed in Ephemeropteran density, but overall densities fall substantially lower than at reference sites throughout the Gordon (Figure 10.4).

Multivariate (MDS) ordination reveals the distinctive character of benthic macroinvertebrate assemblages at sites 75 and 74 (Figure 10.5), along with a downstream trend in increasing similarity in composition. This pattern is primarily due to the downstream trend in increasing density and diversity. Sites 69 and 60 (Figure 10.5) are occasionally 'anomalous', and this is due to the former being occasionally depauperate, and the latter having high densities of simuliids or *Asmicridea* (see above and next section). Site 69 is located immediately upstream of the major high-flow hydraulic control of the second split, which is likely to substantially alter the local hydraulic environment and may make habitat conditions less suitable during prolonged periods of high flow.

O/E values derived from presence/absence (pa) and rank abundance (rk) data are plotted by site in Figure 10.6 for both Gordon River and reference river sites. The spatial trends in O/E are broadly the same as for number of taxa, with O/E being generally lower downstream of the power station and increasing in a downstream direction. Within this trend, O/E values for site 69 are generally slightly depressed (see above). O/Epa values downstream of the Denison confluence generally fall within the "equivalent to reference", or 'A' band defined for the relevant Hydro Tasmania AUSRIVAS models. O/Erk values for these sites generally fall slightly lower, but still within or close to the reference bands. However, all O/E values within the middle Gordon are consistently lower than the O/E values for the reference sites (both $p < 0.01$ by ANOVA). Reference sites consistently fall within the A or X (more diverse than reference) bands. These sites are therefore highly diverse, consistent with their pristine nature.

#### *10.3.2.6 Temporal patterns*

No overall trends were observed in any macroinvertebrate variable over the period of study. Seasonal effects were, however, marked.

Seasonal differences in benthic macroinvertebrate assemblages are observed in the middle Gordon River, with mean benthic macroinvertebrate density being generally higher in spring than autumn, especially upstream of the Denison ($p = 0.03$ by F test, Figure 10.8, Figure 10.2). This is the inverse of the typical seasonal pattern for reference sites, for which mean densities are only marginally statistically higher in autumn than spring ($p = 0.07$ by F test, Figure 10.2).

This difference in seasonal pattern between the Gordon and reference river benthic macroinvertebrates is most likely caused by the influence of the inverted seasonal pattern of Gordon flows (Figure 10.8 and see discussion). Current power station operations lead to a higher incidence of low flows in winter-spring upstream of the Denison confluence, with prolonged periods of high flow leading to reduced density in autumn. The pattern of densities in spring was consistent with the pattern of low flow events preceding sampling. Densities in spring were lowest in 2000, when the number of flow releases from the power station preceding sampling was highest. The longest periods of spring power station outage occurred in 2002 and 2003, coincident with the highest spring density at sites 75, 74 and 69. For sites upstream of the Denison confluence, spring samples contained higher densities of hydropsychid caddis, leptophlebiid mayflies, orthoclad chironomids and janiirid isopods than autumn samples.

A different temporal pattern in benthic macroinvertebrate density was observed downstream of the Denison confluence. Substantial peaks in simuliid (blackfly) and blephariceridae (torrent midge) density were observed at sites 60, 48 and 42 in spring 2001, causing the total benthic macroinvertebrate density to be significantly higher than in any other season (Figure 10.9, $p < 0.01$, by one way ANOVA). This 'event' was also observed in the main-stem reference Denison and Franklin river sites: De7, Fr11 and Fr21. The two taxa involved are known to be early colonisers of clean or disturbed river substrates, and can be symptomatic of a large preceding flood-induced disturbance. This pattern was not observed in the higher catchment reference sites (De35, Ja7 and Ma7), suggesting that any major recruitment event only affected lower main-stem reaches of the reference rivers. A spring > autumn seasonal pattern in total density was observed for these sites after autumn 2002, similar to sites upstream of the Denison, but with lower amplitude (Figure 10.2).

As noted above, sites 63, 60 and 57 also supported anomalously high densities of the snowflake caddisfly, *Asmicridea*, with densities being significantly more abundant in spring than autumn (Figure 10.4, Figure 10.10). This was the opposite in reference sites, where *Asmicridea* densities were higher in autumn.

The temporal pattern in total benthic macroinvertebrate density at site 63 was intermediate between those for sites upstream and downstream of the Denison confluence (Figure 10.10), indicating a degree of influence from the Denison River on the benthic macroinvertebrate assemblage at this site, especially for *Asmicridea*.

Two sites were not consistent with the general patterns described above. Site 72 did not exhibit the seasonal pattern in benthic macroinvertebrate density observed in the other sites upstream of the Denison (Figure 10.10). The assemblage at this site appears to be affected by inputs from and/or events in the Albert River, the first major unregulated tributary entering the Gordon downstream of the power station, which enters the Gordon immediately upstream of site 72 (also see algae below).

Site 57 (Figure 10.10) did not conform with the temporal pattern observed in sites 60, 48 and 42 (Figure 10.9). There is no obvious reason for this anomaly, other than the possible influence of Ewarts Gorge as a major river level control resulting in seasonal backwater effects during high flow events (Koehnken pers. comm.). A similar backwater effect is likely at site 69, where occasional depressions in overall density are observed.

Variation in duration of low flows is believed to control variation in macroinvertebrate density in spring. Relatively high diversity was observed for sites upstream of the Denison in spring 2003, along with higher O/Epa values (Table 10.7). This is believed to be related to the long duration of power station shut-down prior to sampling (see algae), resulting in greater benthic macroinvertebrate colonisation of middle Gordon sites from in-flowing tributaries in the zone upstream of the Denison confluence. This was confirmed by sampling conducted in the reach downstream of site 74 following a prolonged period of low flows, which revealed a local increase in diversity with distance toward the confluence with the Piguenit River (Davies and Cook unpub. data).

O/Epa values were significantly higher in autumn than spring for all sites, while O/Erk as higher in spring than autumn for Gordon sites and showed no seasonal pattern at reference sites (Figure 10.6). Mean

O/Epa values for Gordon sites below the Denison confluence (60 to 42) were significantly positively correlated with those from reference sites ($n = 8$, $r = 0.882$, $p < 0.002$). A similar, though weaker, correlation was also observed for sites upstream of the Denison ($r = 0.795$, $p < 0.02$).

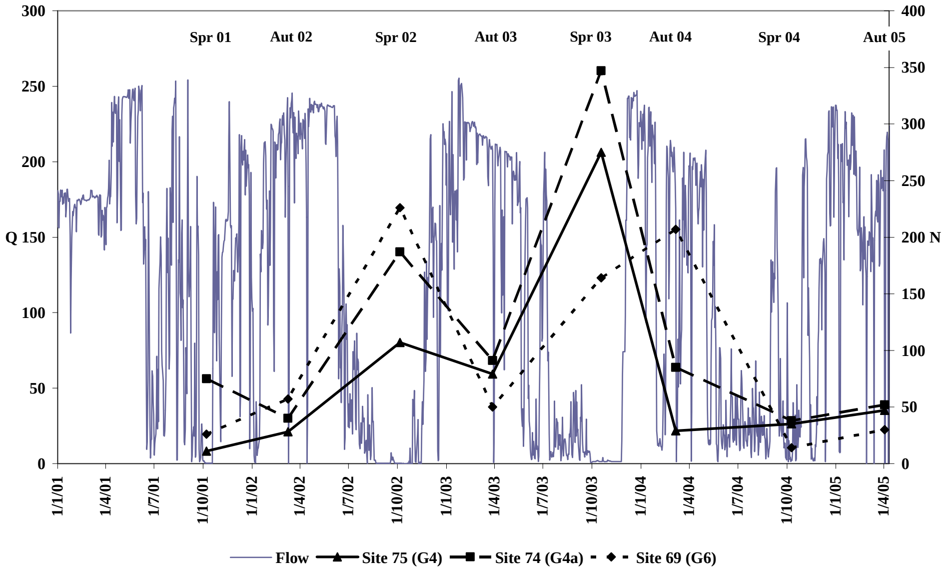


Figure 10.8. Time series of total benthic macroinvertebrate density at sites 75, 74 and 69 (upstream of Denison River), with sampling season indicated. Power station discharge in light blue. Note overall seasonal pattern in density. Note codes in parentheses refer to the number system used in Coleman (1978).

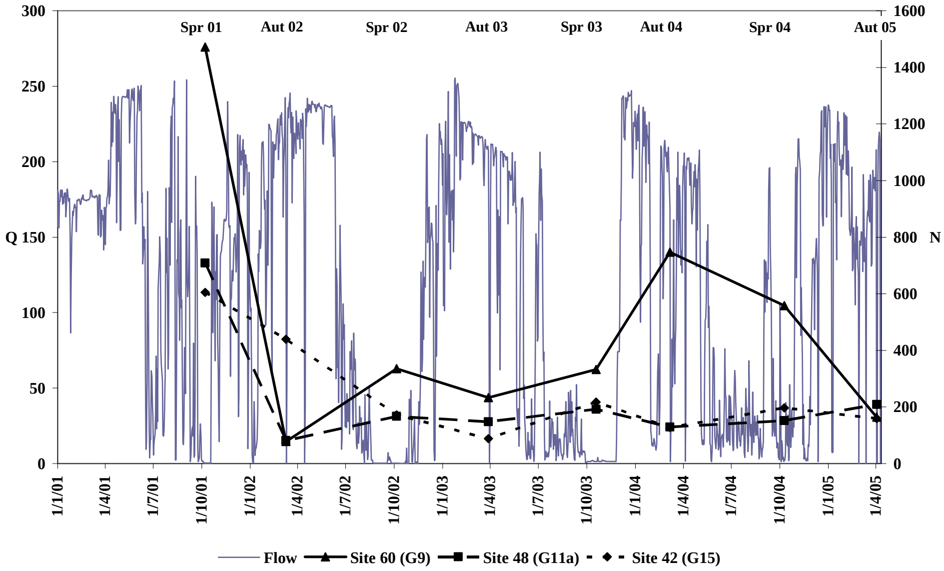


Figure 10.9. Time series of total benthic macroinvertebrate density at sites 60, 48 and 42 (downstream of Denison River), with sampling season indicated. Power station discharge in light blue. Note major peak in spring 2001, followed by weak seasonal pattern in density. Note codes in parentheses refer to the number system used in Coleman (1978).

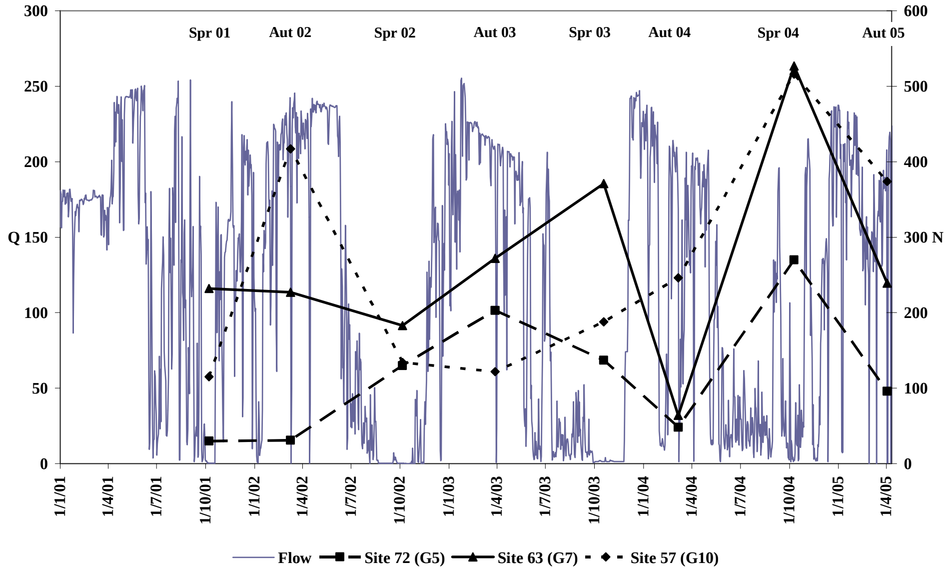


Figure 10.10. Time series of total benthic macroinvertebrate density at sites 72, 63 and 57, with sampling season indicated. Power station discharge in light blue. Note codes in parentheses refer to the number system used in Coleman (1978).

## 10.3.3 2001-05: Benthic algae and moss

Mean % cover of filamentous algae and moss are summarised in Table 10.6 and Table 10.7 on an annual and seasonal basis, respectively and site in Figure 10.11. Mean filamentous algal and moss cover was relatively high (15-30 % of the total stream bed) downstream of the power station. These levels frequently equated to 100 % cover of the wetted stream bed during periods of low flow and power station shut-downs.

Algal and moss cover decreased to very low levels (typically < 2 %) for sites downstream of the Denison confluence. Assessment of algal cover for reference sites only commenced in spring 2004, revealing an average of 1.3 % cover across all sites. Thus, filamentous algal levels in the middle Gordon are unusually high upstream of the Denison River.

Sources of variation are both spatial and temporal, with location across the channel and distance along the Gordon River being key spatial aspects, while variation between seasons and years along with timing and duration of power station shut-downs being important temporally.

### *10.3.3.1 Spatial patterns*

A broad gradient of decreasing algal and moss cover (and hence biomass) with distance from the power station has been consistently observed in all years of sampling between 2001-02 and 2004-05 (Figure 10.11). Sites upstream of the Denison had significantly higher mean algal cover than sites downstream ($p = 0.014$, by F test).

Peaks in filamentous algal cover occurred across the channel centre as well as on stable substrates at the channel margins. This is shown for site 74 in Figure 10.12, where both spring and autumn algal growth occurred across the channel centre, but also close to the margins on boulders and bedrock in spring. Moss cover was generally greater along channel margins on stable substrate elements (e.g. Figure 10.12).

Site 72 experienced consistently low algal cover. Sites 62 and downstream also sustained consistently low algal cover.

#### *10.3.3.2 Temporal patterns*

Filamentous algal growth shows a strong seasonal pattern (Figure 10.13), especially upstream of the Denison confluence. A significant zone by season interaction was observed for filamentous algal cover ($p = 0.00077$ by F test).

Filamentous algal cover was generally higher in spring, due to the occurrence of regulated flow-induced low flows and resulting higher light availability at the stream bed. The highest values for filamentous algal cover were recorded in spring 2002 and 2003, during periods of extended power station shut-down (Figure 10.13). This pattern was most evident at sites 75, 74, 69 and 63.

Site 72 did not exhibit such a marked seasonal pattern, and had generally lower algal levels than the other sites upstream of the Denison confluence. This is believed to be due to the presence of smaller, less stable substrate elements and the potential for localised sand-scouring due to sand inputs from the Albert River.

Downstream of the Denison confluence, algal growth was very limited, and the seasonal pattern was much less marked. This is likely due to the inability to detect significant changes in algal cover at such low levels. Low algal levels in this reach are probably a result of reduced light availability throughout the year with natural winter in-flows from major tributaries, followed by high baseflows during summer-autumn from power station releases. Limited algal growth was observed in this reach on stable substrates (logs, boulders) at channel margins.

Moss cover also varied seasonally but peaking in autumn (Figure 10.14). This observation may be a product of high filamentous algal cover in spring competing for growing space with moss, and/or it may indicate greater tolerance to low light conditions for moss allowing significant growth to occur during the higher-flow summer-autumn period.

Table 10.6 Annual mean values for % cover of moss and filamentous algae at middle Gordon River sites.

| | 01/02 mean | | 02/03 mean | | 03/04 mean | | 04/05 mean | |
|---|---|---|---|---|---|---|---|---|
| **Site** | **Moss** | **Filamentous** | **Moss** | **Filamentous** | **Moss** | **Filamentous** | **Moss** | **Filamentous** |
| **75** | 6.09 | 7.79 | 2.07 | 9.88 | 2.09 | 10.10 | 4.91 | 13.99 |
| **74** | 10.63 | 17.00 | 8.16 | 20.73 | 6.18 | 9.08 | 12.62 | 17.43 |
| **72** | 0.14 | 1.86 | 1.06 | 2.18 | 0.07 | 1.18 | 0.54 | 4.87 |
| **69** | 8.50 | 3.35 | 3.42 | 5.28 | 1.64 | 1.56 | 0.76 | 4.95 |
| **63** | 1.05 | 2.19 | 2.46 | 6.59 | 2.15 | 6.31 | 2.14 | 1.55 |
| **60** | 0.33 | 1.51 | 0.13 | 0.03 | 0.98 | 0.18 | 1.98 | 0.00 |
| **57** | 0.80 | 0.01 | 0.25 | 0.09 | 0.75 | 0.00 | 0.25 | 1.20 |
| **48** | 2.84 | 1.72 | 0.54 | 0.26 | 0.87 | 0.32 | 1.59 | 1.84 |
| **42** | 3.10 | 3.72 | 0.06 | 0.44 | 0.62 | 0.67 | 0.41 | 2.50 |
| **Grand mean** | **3.72** | **4.35** | **2.01** | **5.05** | **1.71** | **3.27** | **2.80** | **5.37** |
| **Mean upstream Denison** | **5.28** | **6.44** | **3.43** | **8.93** | **2.43** | **5.65** | **4.19** | **8.56** |
| **Mean downstream Denison** | **1.77** | **1.74** | **0.24** | **0.21** | **0.81** | **0.29** | **1.06** | **1.38** |

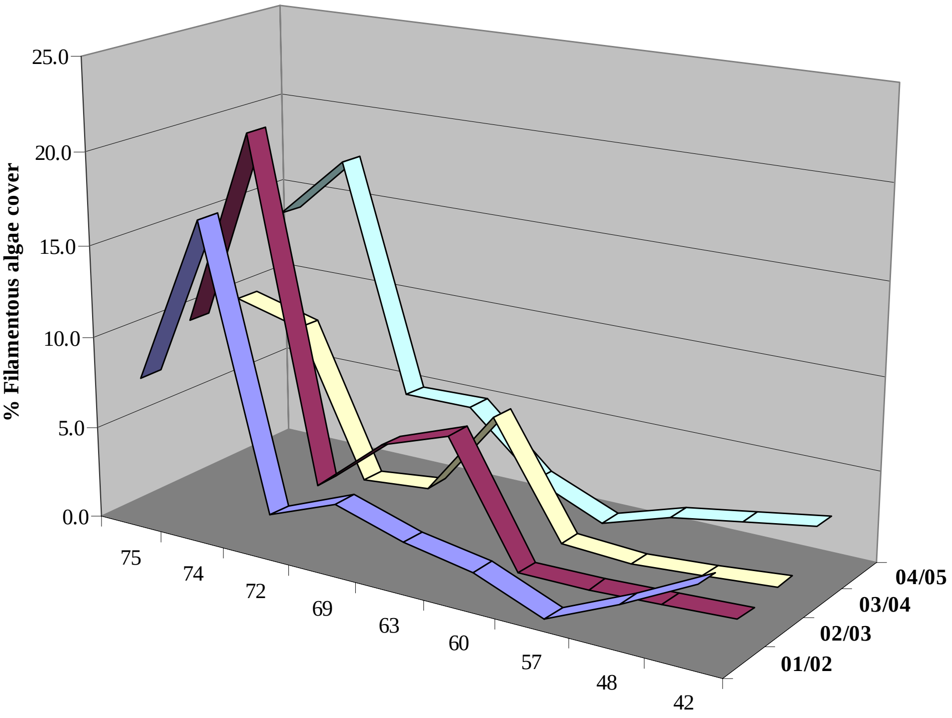
Table 10.7. Seasonal mean values for % cover of moss and filamentous algae at middle Gordon River sites.

**Moss**

| **Site** | Spr 01 | Aut 02 | Spr 02 | Aut 03 | Spr 03 | Aut 04 | Spr 04 | Aut 05 |
|---|---|---|---|---|---|---|---|---|
| 75 | 7.78 | 4.40 | 1.33 | 2.81 | 0.98 | 3.19 | 1.69 | 8.13 |
| 74 | 4.70 | 16.55 | 4.61 | 11.70 | 2.13 | 10.23 | 13.79 | 11.45 |
| 72 | 0.01 | 0.27 | 0.04 | 2.09 | 0.02 | 0.13 | 1.01 | 0.07 |
| 69 | 15.97 | 1.02 | 3.73 | 3.10 | 1.31 | 1.98 | 0.42 | 1.09 |
| 63 | 0.83 | 1.27 | 3.15 | 1.77 | 3.83 | 0.47 | 2.63 | 1.66 |
| 60 | 0.24 | 0.41 | 0.19 | 0.07 | 1.83 | 0.14 | 2.27 | 1.69 |
| 57 | 1.08 | 0.52 | 0.00 | 0.49 | 0.89 | 0.62 | 0.23 | 0.27 |
| 48 | 1.06 | 4.63 | 0.16 | 0.91 | 0.47 | 1.27 | 2.72 | 0.46 |
| 42 | 0.45 | 5.75 | 0.06 | 0.06 | 0.67 | 0.57 | 0.34 | 0.47 |

**Filamentous green algae**

| **Site** | Spr 01 | Aut 02 | Spr 02 | Aut 03 | Spr 03 | Aut 04 | Spr 04 | Aut 05 |
|---|---|---|---|---|---|---|---|---|
| 75 | 7.45 | 8.13 | 17.35 | 2.41 | 18.70 | 1.50 | 13.81 | 14.16 |
| 74 | 21.70 | 12.30 | 35.81 | 5.66 | 16.46 | 1.70 | 19.68 | 15.19 |
| 72 | 1.21 | 2.52 | 2.23 | 2.13 | 2.31 | 0.04 | 4.70 | 5.04 |
| 69 | 5.57 | 1.13 | 3.40 | 7.16 | 3.13 | 0.00 | 9.60 | 0.29 |
| 63 | 4.15 | 0.24 | 9.41 | 3.77 | 12.62 | 0.00 | 2.79 | 0.31 |
| 60 | 0.58 | 2.44 | 0.07 | 0.00 | 0.36 | 0.01 | 0.00 | 0.00 |
| 57 | 0.00 | 0.01 | 0.17 | 0.02 | 0.00 | 0.00 | 0.99 | 1.40 |
| 48 | 0.00 | 3.44 | 0.25 | 0.27 | 0.64 | 0.00 | 2.28 | 1.39 |
| 42 | 1.87 | 5.57 | 0.48 | 0.40 | 1.07 | 0.27 | 3.33 | 1.67 |



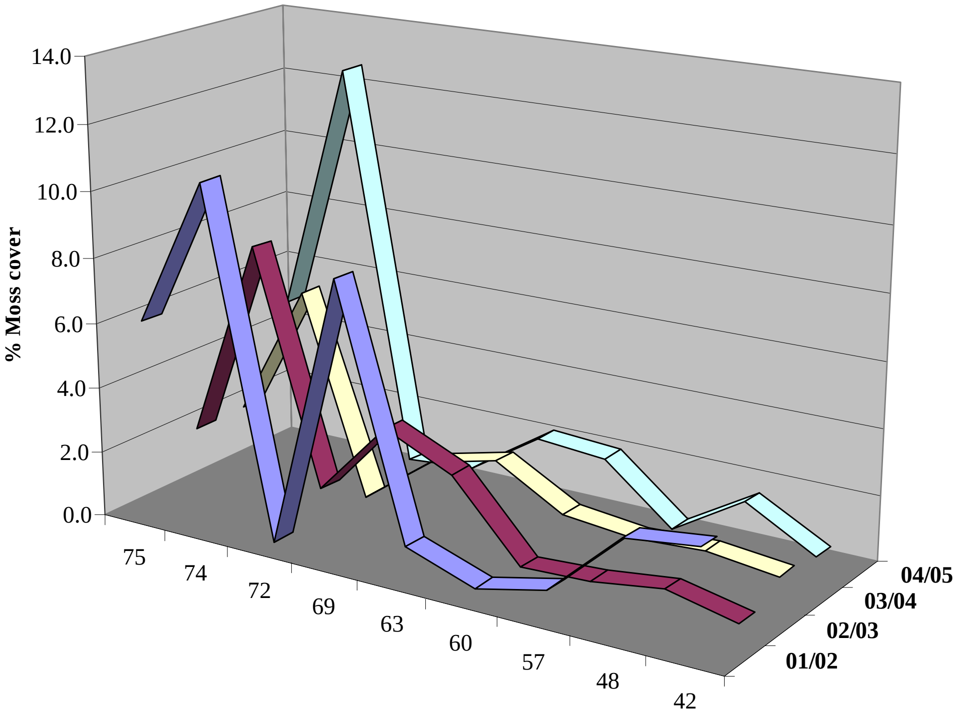
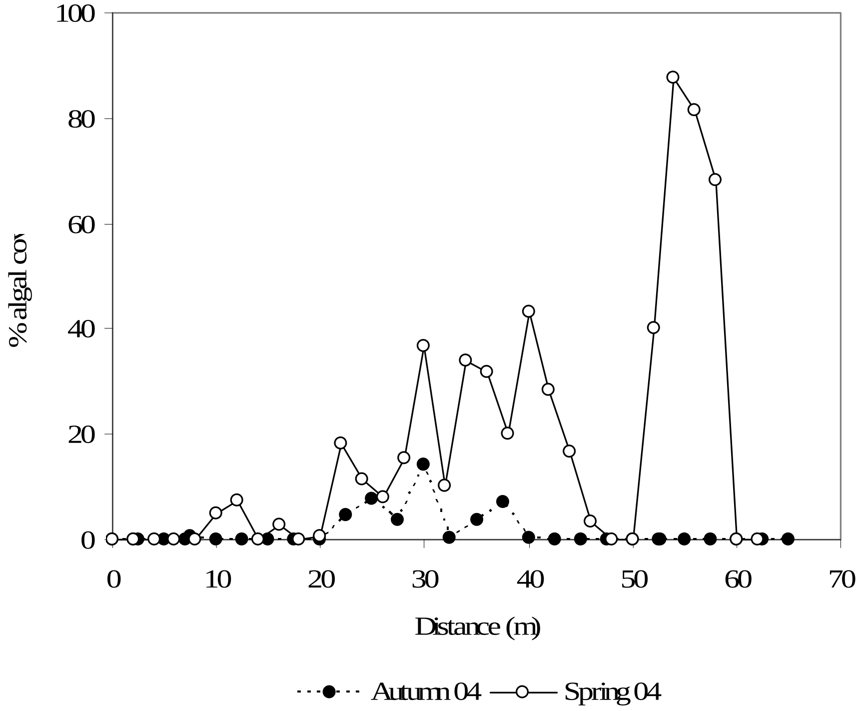


Figure 10.11. Downstream trend in mean % moss cover and mean % filamentous algal cover in the Gordon in 2001-02, 2002-03, 2003-04 and 2004-05.



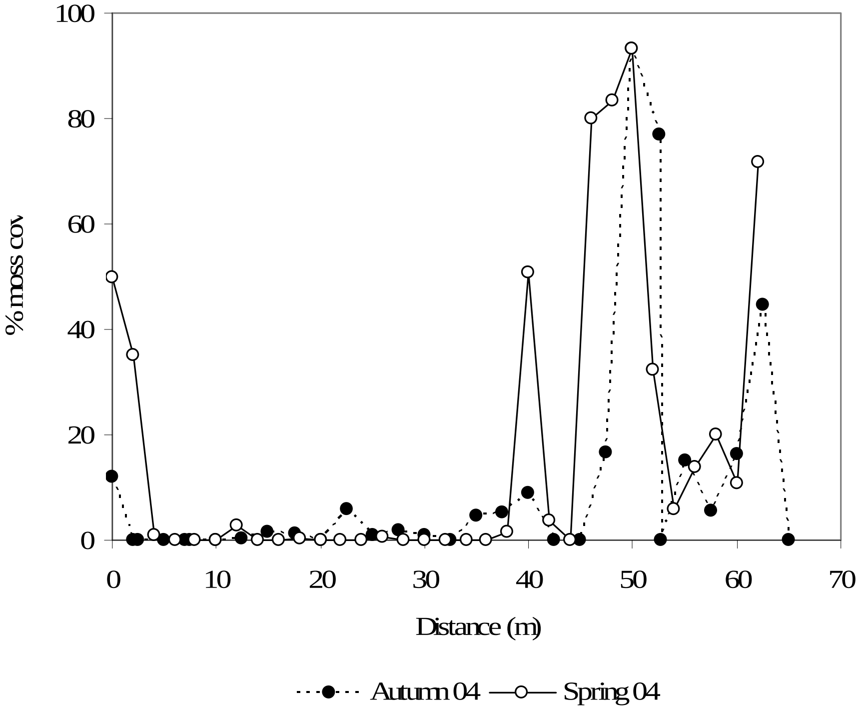


Figure 10.12. Channel profile at site 74 showing typical % filamentous algal and moss cover for autumn and spring 2004. Note differences in % cover and distribution between plant types and season.

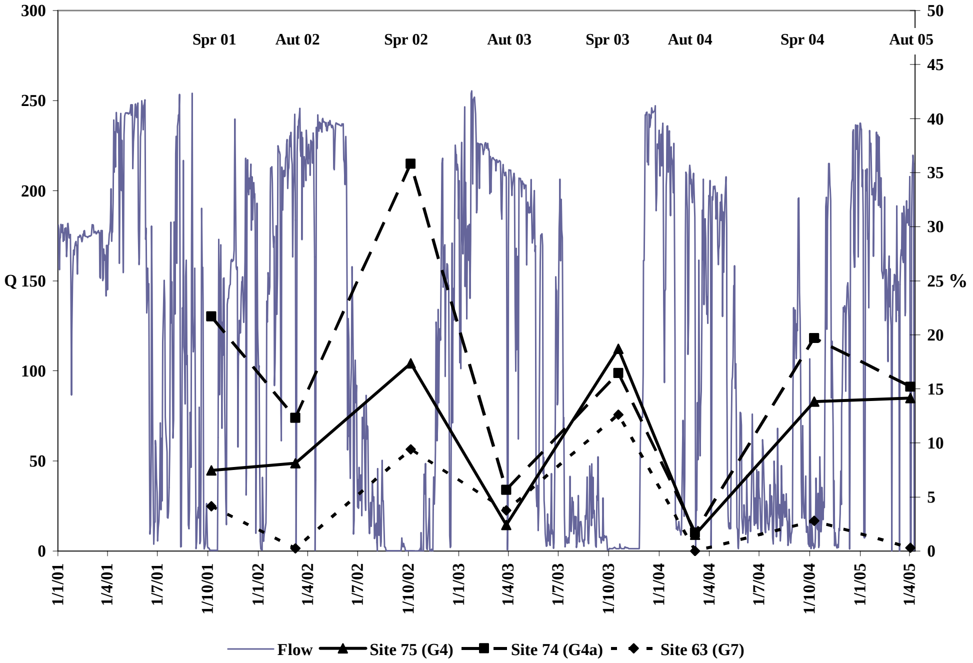


Figure 10.13. Time series of mean filamentous algal density for transects at sites 75, 74 and 72 (upstream of the Denison confluence), with sampling season indicated. Power station discharge in light blue. Note marked seasonal pattern in % algal cover. Note codes in parentheses refer to the number system used in Coleman (1978).

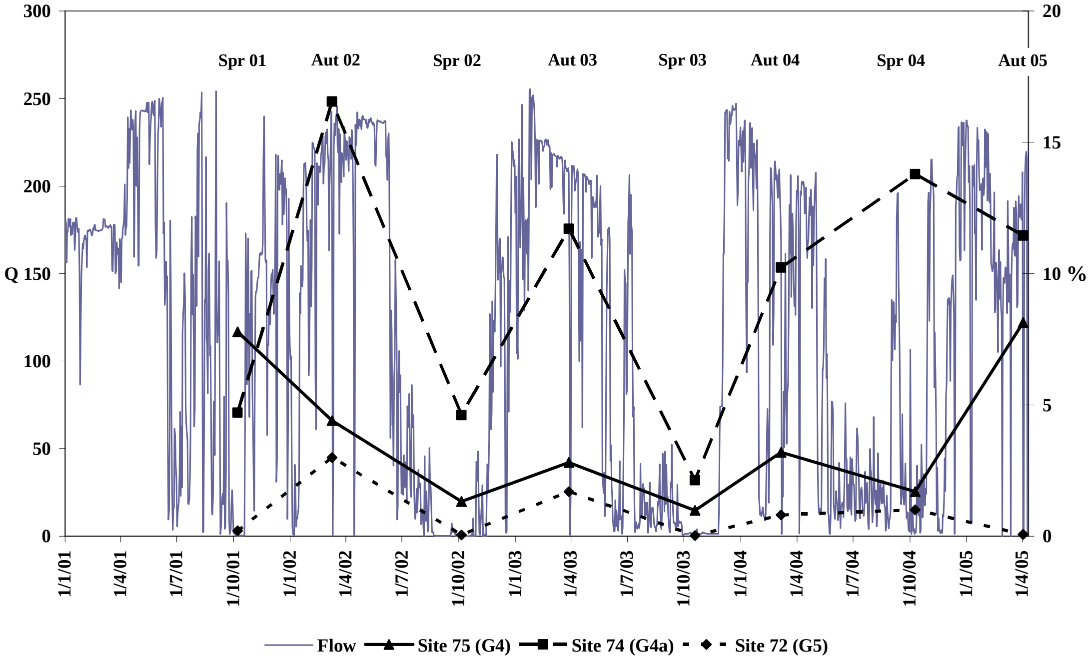


Figure 10.14. Time series of mean moss cover for transects at sites 75, 74 and 72 (upstream of the Denison confluence), with sampling season indicated. Power station discharge in light blue. Note marked seasonal pattern in moss cover that is the inverse of that for algae. Note codes in parentheses refer to the number system used in Coleman (1978).

## 10.4 Analysis and interpretation

### 10.4.1 Benthic macroinvertebrates

There is little doubt that the presence of the Gordon Dam and the regulated flow regime has led to reduced diversity and abundance of benthic macroinvertebrates throughout the full extent of the middle Gordon. This has been observed on all sampling occasions since dam construction (Coleman 1978, Davies *et al.* 1999, Davies and Cook 2001). A combination of the direct effects of rapidly and substantially varying velocities and stranding and changes in substrate composition (bed armouring), with the indirect effects of changes in food resource availability (filamentous algal growth, flux of fine organic particulate matter - FPOM) are thought to be the primary drivers of the condition of benthic macroinvertebrate assemblages in the middle Gordon (see chapter 3 Conceptual model).

The gradient of increasing diversity and abundance downstream of the power station is likely to be a product of:

- reduced severity of velocity changes;
- reduced area of channel dewatering and probability of stranding mortality;
- increased availability of favoured food resources (FPOM, diatomaceous algae, and coarse particulate organic matter, CPOM, in substrate interstices), especially downstream of the Denison River;
- increased input of colonists from tributary rivers and adult insect reproduction; and
- increased availability of substrate interstices as both feeding and refugial habitat.

The character of the Gordon changes upstream of the Denison confluence, in part due to increased channel gradient and changes in geomorphology. This interacts with the modified flow regime and the upstream presence of the dam, to produce a channel which has a less mobile bed substrate which more frequently experiences shallow water-high light conditions and/or exposure and drying. In addition this section has much reduced suspended organic and fine sediment load, and experiences more local and active bank erosion.

The effects of the current power station operations are therefore most severe upstream of the Denison River. Low flows greatly increase light availability to the wetted streambed, enhancing the potential for algal growth, particularly filamentous algae, especially in late-winter-spring. However, power station outages also expose portions of the bed to drying, causing some loss of algal production and macroinvertebrate stranding. When combined with a rapid expansion of filamentous algae within the remnant wetted channel (with up to 100 % cover at low flows), the potential for competitive exclusion of other algal food resources, especially diatoms, is high. Examination of gut contents of the dominant benthic macroinvertebrates from several sites in the middle Gordon (Davies and Cook unpub. data) has revealed that filamentous algae are almost absent from gut contents, even when they dominate the wetted substrate, and that the only significant algal food resource in the diet of grazing species is diatoms. This implies a significant food resource shortage, and may well be responsible for the significantly smaller range of instar sizes (i.e. reduced growth) of aquatic insects upstream of the Denison confluence. In addition, gut content examination of filter feeding invertebrates (e.g. Simuliidae, Hydropsychidae) indicates that fine organic particulates are a primary food source, and that Lake Gordon zooplankton do not provide a significant food resource to benthic macroinvertebrates downstream of the power station.

Sites 63, 60 and 57 consistently experience an anomalously large 'spike' in density of the snowflake caddis, a filter feeder, with densities much higher than in other Gordon and reference river sites. Inspection of gut contents (Davies and Sloane, unpub. data) indicates that *Asmicridea* at these sites feeds primarily on fine organic particulate matter (FPOM), whereas in reference sites and sites further downstream in the Gordon (sites 42 and 48), the diet is dominated by animal material. This indicates that a significant injection of FPOM is occurring from the Denison which, coupled with reduced stranding risk and reduced flood-induced bed disturbance in this regulated flow environment, provides ideal habitat conditions for and enhanced productivity of *Asmicridea*. It appears that these conditions do not occur further downstream.

Benthic macroinvertebrate density and community composition has a seasonal pattern in the middle Gordon, particularly upstream of the Denison confluence, with spring density being higher than in autumn. This pattern is opposite to, and more substantial than, that observed in reference river sites. We believe that this pattern is induced by aseasonal low flows in winter-spring causing:

- concentration of fauna in the residual wetted channel;
- increased representation of colonists sourced from tributaries during prolonged periods of low flows;
- favouring of low flow tolerant and algal tolerant taxa (Janiiridae, Amphipoda etc); and
- removal of natural seasonal life-history cues.

Benthic macroinvertebrate assemblages at sites downstream of the Denison confluence are more similar to those in reference sites (accompanied by anomalously high *Asmicridea* densities), though they still exhibit reduced diversity and density and a reversed seasonal pattern of reduced amplitude. Some changes in assemblage composition in this zone are correlated with or dictated by changes in the main-stem reference rivers, as evidenced by the large peak in simuliid density in spring 2001, and by the high degree of correlation between mean O/Epa values in this zone and in reference river sites.

The greater strength of that correlation for the zone downstream of the Denison confluence supports the hypothesis that yearly recruitment of several benthic macroinvertebrate families (including Simuliidae, Blephariceridae, Chironomidae) in Gordon catchment rivers may not be independent of that in the Denison and Franklin Rivers. This hypothesis will be explored fully after several years' more data collection.

Some local effects on density or diversity are suggested for sites immediately upstream of major hydraulic controls such as the Splits or Ewarts Gorge (e.g. sites 69 and 57) or downstream of in-flowing tributaries (e.g. sites 74, 60 and 57).

### 10.4.2 Benthic algae and moss

Benthic algal and moss levels on reference river beds in the Gordon catchment are generally low, with the local exception of mosses on boulder/bedrock features. This is in large part due to the presence of low nutrient levels and low light availability, coupled with bed instability during large floods.

Light availability is strongly controlled by the dark 'humic' water colour. Work by Bowling *et al.* (1986) and Bowling and Tyler (1986) indicated that the euphotic depth, and hence algal production, was limited in strongly dystrophic ('humic') Tasmanian waters. They showed that photosynthetically active radiation (PAR) is reduced to very low levels within 1-2 m depth in waters with dissolved organic carbon levels similar to those of the middle Gordon River. Thus, one of the main effects of current power station operations on attached algal production is the control of water level in relation to the stream bed. Sustained high flows result in a distinctive 'bathtub ring' of filamentous algal growth, typically of the order of 1-2 m vertical height along the channel margins on stable substrates (e.g. bedrock, snags). However, it is when periods of power station outage and low flows dominate that river levels decline in the Gordon River upstream of the Denison confluence to the point where light availability is increased across the entire river bed. Filamentous algal and moss cover are significantly enhanced and persist under these conditions, which occur predominantly in spring. This results in significant seasonal variation in filamentous algal cover upstream of the Denison confluence.

Filamentous algal and moss densities in the middle Gordon River upstream of the Denison confluence are much higher than in the reference sites. It is anticipated that they will be reduced post-Basslink after the introduction of minimum environmental flows. The introduction of a predominantly 55 $m^3 s^{-1}$ power station release baseflow is likely to lead to decreased light availability for much of the stream bed upstream of the Denison River, especially in areas which previously formed riffles under low flows between power station release peaks. This is likely to reduce filamentous algal production, biomass and cover at sites 75, 74, 69 and 63 on the main stream bed. Filamentous algal cover is likely to become restricted to zones within 1-2 m elevation of the 55 $m^3 s^{-1}$ water level in late winter and spring. Some reduction in moss vigour and cover might also be anticipated.

Observations made by Coleman (1978) of benthic algal cover indicated substantial filamentous algal cover during the post-dam low flow period at Gordon River sites upstream of the Denison confluence in summer, which was associated with high densities of grazing benthic macroinvertebrates (e.g. hydrobiid snails). Algal cover further downstream and elsewhere in the Gordon catchment was low. These observations are consistent with the observations made here for the pre-Basslink monitoring period. The primary difference is that algal levels are now highest during spring, and in response to periods of low flows and power station shut-downs, and that hydrobiid snails densities are very low.

Enhanced filamentous algal abundance is likely to be both a response to changes in the flow regime in the middle Gordon River, as well as a secondary driver of macroinvertebrate abundance assemblage composition, especially upstream of the Denison confluence. Recent work by Chester and Norris (in press) on the Cotter River in the ACT, suggests that filamentous algae compete for habitat space with both macroinvertebrates and diatoms, the favoured food resource of grazing macroinvertebrates. This is supported by the observation that diatoms and filamentous algae comprise 91 % and 9 %, respectively of algal material in gut contents of grazing macroinvertebrate species (e.g. *Nousia* sp AV5/6 and AV sp7) in the middle Gordon River, even in the presence of very high filamentous algal cover (Davies and Cook unpub. data).

## 10.5 Evaluation of the Basslink monitoring program

The design of the Basslink Monitoring Program (BMP) currently allows for the monitoring of:

- benthic macroinvertebrate abundance, diversity and assemblage composition, and mean channel filamentous algal and moss cover at site, reach and whole river level;
- the spatial pattern of benthic macroinvertebrate abundance, diversity and assemblage composition, and of filamentous algal and moss cover, through the middle Gordon River; and
- the seasonal pattern of benthic macroinvertebrate abundance, diversity and assemblage composition, and of filamentous algal and moss cover, at sites, reaches and across the whole middle Gordon River.

The detection of change in the baseline indicator variables can be made relative to the pre-Basslink period, by assessing changes in variance pre- and post-Basslink of specific variables. No substantial temporal trends were detected during the pre-Basslink period, facilitating the estimation of means and variances. A simple model is used that fits the data with no requirement for a trend term and a consistent temporal pattern across zones. Formal analysis of the data collected in this component of the Basslink program in relation to setting limits of acceptable changes (LOAC) and the ability to detect them are provided in chapter 13. The power to detect acceptable levels of change for the macroinvertebrate and algal/moss components was generally high.

The degree of change that can be detected for each of the baseline indicator variables listed in section 10.2.3, given an alpha of 0.05, a power of 0.8, and four years pre- and three years post-Basslink sampling is shown in Table 10.8. The size of the detectable change is highly acceptable for all O/E variables (changes of the order of 0.1-0.13 units), BC similarity (absolute changes of *ca* 6 %, equating to a mean change of *ca*

20 % in pre-Basslink BC values), Proportion EPTCC (0.13 units), N families (27 % change) and N EPTCC Species (35 % change) are all acceptably small.

The ability to detect changes in the remaining variables is more limited, with only *ca* a 70 % increase or decrease being detectable for total density and % moss cover, and around 100 % change being detectable for total mayfly density, and % algal cover.

It should be noted that significant natural events which occur either in the pre- or post-Basslink period, may make the statistical detection of some changes problematic. An example for the benthic macroinvertebrates is the occurrence of a single large 'spike' in density in spring 2001 at sites downstream of the Denison River. This spike is largely due to one taxon, and this taxon was removed from some aspects of the analysis. The occurrence of a single extremely large flood event, or perhaps a fire, may also pose a risk to the detection of changes in benthic macroinvertebrate communities and/or algae. In the absence of such large unforeseeable events, the monitoring program should be able to detect changes of an order of magnitude of concern to managers.

Table 10.8. Measures of change detectable for each macroinvertebrate, algal and moss variable given n alpha of 0.05, a power of 0.8, and four years pre- and three years post-Basslink sampling. Change shown as either ratios or mean differences (see chapter 13 for details).

| Feature | Variable | Post/Pre ratio | Difference |
|---|---|---|---|
| **Macroinvertebrates** | | | |
| | Total density | 1.69 | |
| | Total density* | 2.32 | |
| | N taxa (family) | 1.27 | |
| | O/Epa (single season) | | 0.10 |
| | O/Erk (single season) | | 0.11 |
| | O/Epa (combined season) | | 0.12 |
| | O/Erk (combined season) | | 0.11 |
| | N EPTCC Sp | 1.35 | |
| | Density Ephemeroptera | 2.25 | |
| | Propn EPTCC | | 0.13 |
| | Bray Curtis Similarity | | 6.4 |
| **Algae & Moss** | | | |
| | % Algal cover | 2.18 | |
| | % Moss cover | 1.68 | |

No major changes to the monitoring program for benthic macroinvertebrates or algae are proposed at present. A minor change adopted from 2004-05 was the collection of algal cover data from reference sites (commenced in spring 2004).

Further investigations are continuing to develop the conceptual understanding of the ecology of the Gordon River system (some not part of the BMP itself). These include gut analyses of macroinvertebrates and fish, stable isotope analysis of the aquatic food web and sampling of snag habitats for benthic macroinvertebrates.

## 10.6 Macroinvertebrates and algae indicator variables

### 10.6.1 Benthic macroinvertebrates

A range of indicator variables have been selected for benthic macroinvertebrates, which provide data on the status of abundance, diversity and community composition. Changes are possible in all three areas following commencement of Basslink operations. The indicators are as follows:

**Abundance**

- Total density (number per unit area) of all macroinvertebrates
- Density of taxa from the EPT (Ephemeroptera, Plecoptera, Trichoptera) group
- Density of Ephemeroptera

These values may also be converted to abundance data (numbers per unit river length) by adjustment using wetted area data derived from fixed transects. The method for this will be reviewed following the initial post-Basslink results.

**Diversity**

- Number of all benthic macroinvertebrate taxa (family level)
- Number of EPT species

**Community composition**

Community composition will be formally assessed in two ways:

- by use of a an index of comparative family level taxonomic composition relative to an expected composition predicted from a reference data set – the AUSRIVAS/RIVPACS O/E score; and
- by direct comparison of a site's composition with that of the 6 reference sites sampled at the same time – the Bray Curtis Similarity index.

In addition, exploration of community compositional changes will be conducted by multivariate comparison using multidimensional scaling ordination and multivariate analysis of variance (ANOSIM) derived from a matrix of Bray Curtis similarities.

O/E (observed to expected ratio) values will be derived using AUSRIVAS/RIVPACS models derived for Hydro Tasmania's catchments, in two forms:

- O/Epa (O/E based on presence/absence family level data); and
- O/Erk (O/E based on rank abundance family level data).

O/Epa and O/Erk will be derived for riffle habitat only, both as single-season values (spring and autumn within each year) and as combined-season values (a single combined value per year).

A single Bray Curtis Similarity index value will be derived for each Gordon River site by:

- Calculating the BC value for the site's sample data in each season relative to that of each reference site sampled on the same sampling occasion, using square root transformed BM abundance data;
- Averaging the resulting six values to derive a single value for that sampling occasion.

### 10.6.2 Algae and moss

Any changes in benthic algae and moss post-Basslink are expected to manifest primarily in overall cover and position within the channel. Accordingly, total in-channel percentage cover of algae and moss are the two core indicators to be reported and analysed during Basslink monitoring and assessment.

In addition, changes in position of peak cover within the channel will be assessed. Composition of algal assemblages has not been monitored, though samples of dominant species are being collected. These samples will be inspected for qualitative assessment of any shifts in the identity of dominant taxa.

### 10.6.3 Data aggregation

All benthic macroinvertebrate, algal and moss data will be analysed at site level initially, due to the recognition of a number of site-specific effects on temporal variation in key indicators. Spatial trends in the status of benthic macroinvertebrate, algae and moss, and the nature of temporal variation in key indicators, do not conform to the 'zone' structure described for other disciplines (e.g. geomorphology, fish). This is partially due to marked trends in several indicators with distance from the lake, but also due to local site-scale factors (hydraulic, proximity to tributary junctions, etc.).

The potential and need for data aggregation (to reach or zone levels) has been explored, and will be evaluated in detail during the major post-Basslink data analysis stages (years 3 and 6). Exploration of patterns in the pre-Basslink data, as well as initial evaluation of variance in the data indicates that two major zones may form a reasonable basis for data aggregation during analysis - upstream and downstream of the Denison junction.

In addition to analysis of indicator changes based on site-scale and zone-scale aggregation, formal analysis may also include assessment of changes in the whole of river downstream spatial trends in selected indicators with distance from the dam. The form of such analyses has yet to be evaluated.

# 11 Fish

## 11.1 Chapter summary

This chapter examines four years of baseline data from the Gordon River Basslink Fish Monitoring Program, collected between December 2001 and April 2005. It describes the monitoring and analytical methods used and the key findings of the data, including species distributions, population structure, relative abundance, and discusses data variability and associated implications for temporal comparisons. The chapter also discusses the suitability and capability of the experimental design in meeting the objectives of the monitoring program and the concept of 'limits of acceptable change' and how this may be applied in the context of fish distribution and abundance.

The major findings of the fish chapter are:

- Eight sampling surveys were conducted between December 2001 and April 2005. Surveys were conducted twice yearly in spring/summer and autumn;
- A total of 12 fish species were collected from the reference sites and 10 from the Gordon sites. Only one introduced species, brown trout, was recorded from the reference sites while three introduced species consisting of brown trout, Atlantic salmon and redfin perch were collected from the Gordon River sites;
- Reproductive strategies of introduced and native fish recorded during the study are significantly different, with all but one of the natives exhibiting diadromy, and so migration success has direct implications for the distribution of native fish throughout the middle Gordon River. Significant juvenile galaxiids migration runs were detected in the lower Gordon monitoring reaches during the surveys;
- Native fish were well represented in catches from the downstream zones, but their diversity generally declined with distance upstream in the Gordon River, while the diversity of introduced fish species was greatest in the upper river sites. Brown trout, short-finned eels and lampreys were the most widely distributed species, and were present in all of the Gordon River and Reference zones;
- Trout generally dominated the catches in the Gordon River, particularly the tributaries situated in the middle zones of the monitoring area, while redfin perch were the most abundant species in the most upstream monitoring reach of the Gordon River;
- Galaxiid distribution was characterised by a distinct reduction in catch rates above Ewarts Gorge in the middle reaches of the study area, however an isolated population of climbing galaxias persists in a small tributary immediately below Lake Gordon;

- Fish catches exhibited high variability, with many upstream sites returning low numbers of fish or nil catches. This necessitated the pooling of data to zone level and species groups to permit statistical analysis, which the side effect of reduced replication within the dataset. Power analysis of the data has indicated that statistical testing will be able to detect a doubling or halving of total fish numbers and a 3+ change in native fish catch; and
- Trigger values will be based on catch per unit effort (CPUE) values for all species, for native fish only, and the ratio of CPUE of trout to native fish. Confidence intervals of 95 % were calculated for these parameters using four years of pre-Basslink data. Post Basslink values that fall outside the trigger levels will be targeted for further analysis to investigate the likely cause and ecological significance of the departure.

## 11.2 Monitoring

The aims of the Fish Monitoring Program are to quantify the variability in fish populations to facilitate temporal (pre- and post-Basslink) statistical comparisons of the fish distribution and community structure in the river. The focal points of the study were the 'test' zones, which are located in the Gordon River and tributaries between the Gordon Power Station and the Franklin confluence. The test zones encompass the major area of power station influence, and cover approximately 40 km of the river's length. They included a number of tributaries, such as the Serpentine, Albert, Orange, Denison, Smith, Olga, and Sprent Rivers.

Future temporal comparisons will focus on determining whether hydrological changes caused by Basslink operations result in detectable effects in fish distribution, abundance and population structure. Data from out-of-catchment 'reference' sites have been collected to facilitate the separation of seasonal and inter-annual effects from those of the post-Basslink discharge regime. Reference sites were established at multiple locations along the Franklin, Henty, Sorell and Pocacker Rivers. The reference sites are fundamentally different from the Gordon River test sites as their flows are not regulated, and so comparisons between test and reference sites will be limited to qualitative interpretations.

Monitoring sites were selected during the original Basslink environmental impact assessment, which was carried out during 1999 and 2000. For the Basslink Fish Monitoring Program, sites were chosen based on whether they were located in the main river or a tributary, in a test or reference catchment, their accessibility, the presence of representative habitat, and the presence of fish. Where possible, sites were aligned with those used for macroinvertebrate monitoring to facilitate the exploration of potential processes linking fish and macroinvertebrates. Map 11.1 shows the arrangement of both 'test' and 'reference' zones in the region, as well as the location of the individual sites. The broad locations of the zones are described in Table 11.1.

Map 11.1. Fish monitoring zones in the Gordon and reference rivers, and the location of individual monitoring sites.

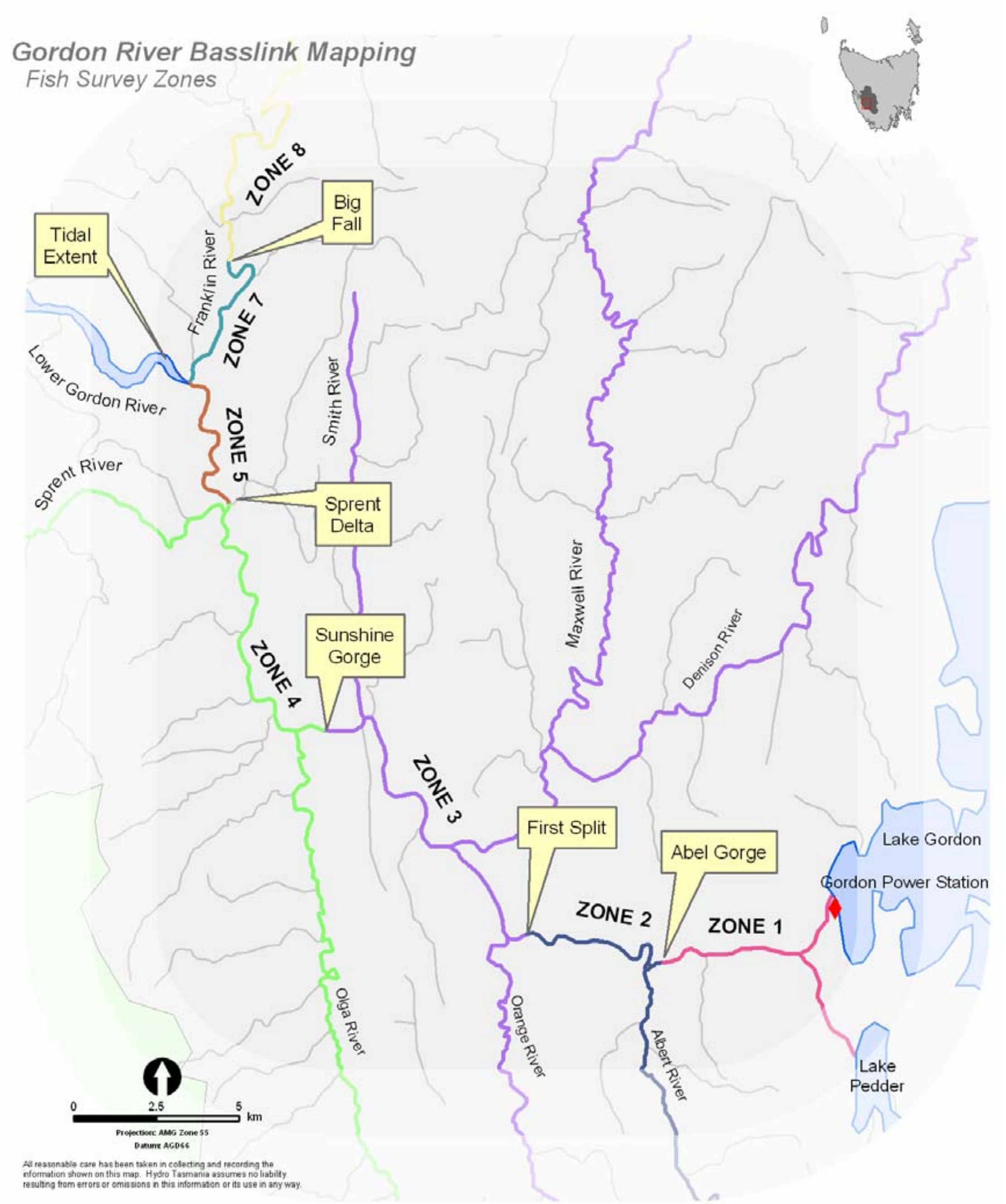
Table 11.1. Test and reference fish monitoring zones.

| | Test zones |
|---|---|
| **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 |
| | **Reference zones** |
| **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 (Sorell and Pocacker Rivers) |
| **Zone 13** | Henty River at or downstream of the Yolande River |
| **Zone 14:** | Henty River upstream of the Yolande River |

Thirty-one test sites were spread through five test zones (zones 1-5). The sites are listed in Table 11.2 and are shown in Map 11.1. The test zones are outlined in Table 11.1 and are shown in Map 11.2. It should be noted that some of the fish zones differ in extent from those used for fluvial geomorphology and riparian vegetation.

Table 11.2. Gordon catchment (test) monitoring sites. Alternative site names are shown in parenthesis. * denotes the 'Orange River' site has replaced the 'Denison u/s Maxwell' site due to ongoing difficulties with access.

| Zone | River Sites | Tributary Sites |
|---|---|---|
| 1 | 75 (G4), 74 (G4a), 73 (G3 u/s and d/s) | Serpentine River, Indigo Creek, Piguenit Rivulet |
| 2 | 72 (G5 upper and lower), 71 (G5a pipe and water meter) and 69 (G6) | Albert River, Splits Creek and Mudback Creek |
| 3 | 68 (G6a), 63 (G7) and 57 (G16) | Smith River, Harrison Creek, Denison River u/s gorge, Denison River @ Maxwell, Orange River* |
| 4 | 54 (Howards Creek), 51 (Platypus Creek), 46 (Gordon u/s Sprent) | Howards Creek, Olga River, Platypus Creek and Sprent River |
| 5 | 45 (Gordon d/s Sprent), 44 (G14), 42 (G15) | Franklin @ Pyramid Island |



Map 11.2. The distribution of the ‘test’ zones (zones 1-5) in the Gordon River and tributaries upstream of the Franklin. The Franklin zones (zones 7 and 8) are ‘reference’ zones. Significant hydraulic barriers to fish passage are also indicated.

Seven river and four tributary reference sites were selected for monitoring in conjunction with the test sites, and these are listed in Table 11.3. These sites were located in five ‘reference’ zones (zones 7-9, 13 and 14), as shown in Map 11.1. The rationale behind the zone selection was discussed in Howland *et al.* (2001).

Table 11.3. Reference monitoring sites.

| Zone (catchment) | River sites | Tributary sites |
|---|---|---|
| 7 (Franklin) | Franklin d/s Big Fall | none |
| 8 (Franklin) | Franklin u/s Big Fall, Franklin @ Canoe Bar | Forester Creek, Ari Creek, Wattle Camp Creek |
| 9 (Birches Inlet) | Sorell River | Pocacker River |
| 13 (Henty) | Henty u/s Bottle Creek, Henty @ Yolande R. | None |
| 14 (Henty) | Henty @ Sisters | None |

‘Optional’ sites, listed in Table 11.4, were included in the monitoring regime and consisted of 11 test and three reference sites, located in both tributaries and rivers. These sites were included to provide additional data for the monitoring program on an opportunistic basis when time permitted. The ‘Orange River’ test site (formerly classified as optional) was reclassified as essential following ongoing access problems with the ‘Denison u/s Maxwell’ site.

Table 11.4. Optional sites surveyed during the monitoring program. The Orange River site has been reclassified as essential due to ongoing access difficulties at the Denison u/s Maxwell site. Alternative site names are shown in parenthesis.

| Zone | River Sites | Tributary Sites |
|---|---|---|
| 1 | 76 (G2) | Left bank Creek @ site 75 |
| 2 | Gordon @ Grotto Creek | Grotto Creek |
| 3 | site 60 (G9), Gordon @ G8, Gordon @ Fluffies | Denison @ Denison Camp |
| 4 | none | Howards Ck inundation, Olga @ riffles |
| 5 | Gordon @ Angel Cliffs | None |
| 8 (Franklin) | Franklin @ Forester Creek, Franklin @ Wattle Camp Ck | None |
| 14 (Henty) | Henty @ West Sister | None |

Table 11.5 summarises the sites sampled during each of the eight surveys carried out between December 2001 and April 2005, and lists the site classification information and the sampling frequency for each site.

Smith Root backpack electrofishing equipment was used to survey fish populations, following the methods described in Howland *et al.* (2001). Fish teams sampled a range of representative habitats at each site. Captured fish were identified, counted, and their fork length recorded to the nearest millimetre. Fish that could not be identified in the field were retained for later identification. General aquatic habitat descriptors were also recorded for each site. Shocking time, as measured by the electrofisher’s chronometer, was recorded and teams fished each site for a minimum of 1200 seconds whenever possible.

Four days were required to complete a monitoring round. Two full days were required to monitor the test sites, one day was required to monitor the major tributary sites, and one day was required to monitor the out-of-catchment reference sites.

Table 11.5. Site information and sampling frequency for surveys undertaken between December 2001 and April 2005.

| Zone | Type | class | priority | Site name | site no | Dec 2001 | Apr 2002 | Dec 2002 | Mar 2003 | Nov 2003 | Apr 2004 | Dec 2005 | Apr 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | River | test | essential | Gordon @ G3 (d/s) | 73 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 1 | River | test | essential | Gordon @ G3 (u/s) | 73 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 1 | River | test | essential | Gordon @ G4 | 75 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 1 | River | test | essential | Gordon @ G4a | 74 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 1 | River | test | optional | Gordon @ G2 | 76 |  | 🟦 |  | ⬛ | 🟥 |  | ▩ |  |
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| 1 | Tributary | test | essential | Indigo Creek |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 1 | Tributary | test | essential | Piguenit Rivulet |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 1 | Tributary | test | essential | Serpentine River |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 1 | Tributary | test | optional | Left bank creek at G4 |  | 🟥 |  |  |  |  |  |  |  |
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| 2 | River | test | essential | Gordon @ G5 (lower) | 72 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 2 | River | test | essential | Gordon @ G5 (upper) | 72 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 2 | River | test | essential | Gordon @ G5a (pipe) | 71 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 2 | River | test | essential | Gordon @ G5a (water) | 71 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 2 | River | test | essential | Gordon @ G6 | 69 | 🟥 | ! | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 2 | River | test | optional | Gordon @ Grotto Creek | 64 |  | 🟦 |  | ⬛ |  |  | ▩ | 🟦 |
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| 2 | Tributary | test | essential | Albert River |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 2 | Tributary | test | essential | Mudback Creek |  | 🟥 | ! | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 2 | Tributary | test | essential | Splits Creek |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 2 | Tributary | test | optional | Grotto Creek |  |  |  |  | ⬛ | 🟥 |  | ▩ | 🟦 |
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| 3 | River | test | essential | Gordon @ G7 | 63 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 3 | River | test | essential | Gordon @ Harrison Creek (G16) | 57 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 3 | River | test | essential | Gordon @ Orange River (G6a) | 68 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 3 | River | test | optional | Gordon @ G9 | 60 | 🟥 |  |  | ⬛ |  |  |  | 🟦 |
| 3 | River | test | optional | Gordon @ G8 |  | 🟥 |  |  |  | 🟥 | 🟨 | ▩ |  |
| 3 | River | test | optional | Gordon @ Fluffies |  |  |  |  | ⬛ | 🟥 |  | ▩ | 🟦 |
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| 3 | Tributary | test | essential | Denison u/s Gorge |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 3 | Tributary | test | removed | Denison u/s Maxwell |  | ! | ! | removed | removed | removed | removed | removed | removed |
| 3 | Tributary | test | essential | Denison @ Maxwell River |  | ! | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 3 | Tributary | test | essential | Harrison Creek |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 3 | Tributary | test | essential | Smith River |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 3 | Tributary | test | opt/essent | Orange River |  | optional | optional | essential | essential | essential | essential | essential | essential |
| 3 | Tributary | test | optional | Denison @ Denison Camp |  |  | 🟦 |  |  |  |  |  |  |
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| 4 | River | test | essential | Gordon @ Howards Creek | 54 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 4 | River | test | essential | Gordon @ Platypus Creek | 51 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 4 | River | test | essential | Gordon u/s Sprent River | 46 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
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| 4 | Tributary | test | essential | Howards Creek |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 4 | Tributary | test | essential | Olga @ Gordon |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 4 | Tributary | test | essential | Platypus Creek |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 4 | Tributary | test | essential | Sprent River |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 4 | Tributary | test | optional | Howards Creek inundation |  | 🟥 |  |  |  |  |  |  |  |
| 4 | Tributary | test | optional | Olga @ Riffles |  |  | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
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| 5 | River | test | essential | Gordon @ G14 | 44 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 5 | River | test | essential | Gordon @ G15 | 42 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 5 | River | test | essential | Gordon d/s Sprent River | 45 | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 5 | River | test | optional | Gordon @ Angel Cliffs | 45a | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 5 | River | test | essential | Franklin @ Pyramid Island |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
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| 7 | River | reference | essential | Franklin d/s Big Fall |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | high flows |
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| 8 | River | reference | essential | Franklin @ Canoe Bar |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 8 | River | reference | essential | Franklin u/s Big Fall |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 8 | River | reference | optional | Franklin @ Forester Creek |  | 🟥 | 🟦 | 🟩 | ⬛ |  | 🟨 | ▩ |  |
| 8 | River | reference | optional | Franklin @ Wattle Camp Creek |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
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| 8 | Tributary | reference | essential | Ari Creek |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 8 | Tributary | reference | essential | Forester Creek |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 8 | Tributary | reference | essential | Wattle Camp Creek |  | 🟥 | 🟦 | high flows | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
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| 9 | River | reference | essential | Sorell River |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
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| 9 | Tributary | reference | essential | Pocacker River |  | ! | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
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| 13 | River | reference | essential | Henty @ Yolande |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 13 | River | reference | essential | Henty u/s Bottle Creek |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
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|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 14 | River | reference | essential | Henty @ Sisters |  | 🟥 | 🟦 | 🟩 | ⬛ | 🟥 | 🟨 | ▩ | 🟦 |
| 14 | River | reference | optional | Henty @ West Sister |  | 🟥 |  |  |  |  |  |  |  |

The test sites could only be accessed when the power station was shut-down, as exposed cobble bars were used as helicopter landing sites, and high flows also limit the effectiveness of the electrofishing gear and the operator's ability to observe and collect stunned fish. High flows also posed significant safety issues associated.

Several of the reference sites were flow sensitive, and these could only be accessed by helicopter under low to moderate flow conditions.

## 11.3 Findings

### 11.3.1 Results overview

Surveys were completed on eight occasions, four during the spring-summer monitoring period and four during autumn. The monitoring months were December 2001, April 2002, December 2002, March 2003, November 2003, April 2004, December 2004 and April 2005. All reasonable attempts were made to ensure consistency of sample dates. The minor modification to the timing of the November 2003 monitoring was not considered a significant departure from the original monitoring design and did not pose any significant implications for the program.

As discussed in the methods, the program has 45 essential sites and 14 optional sites. Table 11.5 shows that four essential sites, situated in zones 2, 3 and 9, could not be sampled on a single occasion due to high flows or logistical constraints. The essential sites were monitored on 353 occasions during the monitoring program, which equates to a sampling success of 98 %.

Optional sites were monitored on 56 occasions between December 2001 and April 2005, which equates to a sampling success rate of 50 %.

A total of 4,321 fish were captured during 517,854 seconds of electrofishing time. Table 11.6 shows a summary of the species caught, their origin, migration requirements and total catch. Table 11.7 shows catch per unit effort (CPUE) summaries for the period of December 2001 to April 2005. The total catch comprised 12 species, three of which were introduced while the remaining eight were native species. With the exception of *Pseudaphritis urvillii*, the native species captured during the surveys were diadromous and require unimpeded access to marine waters to complete their lifecycle. Three of the migratory galaxiids are capable of forming self-sustaining, landlocked populations, but expression of this life history strategy is usually restricted to 'lake-linked' populations (Table 11.6).

Table 11.6. Total numbers of each fish species captured during the monitoring program. [1] denotes species that may form landlocked populations, [2] denotes species that may exhibit a migratory (sea run) population component and [3] denotes species that are vagrant aquaculture escapees.

| Common name | Species | Family | Origin | Life history | # captured |
|---|---|---|---|---|---|
| Climbing galaxias | *Galaxias brevipinnis* | *Galaxiidae* | Native | diadromous[1] | 351 |
| Spotted galaxias | *Galaxias truttaceus* | *Galaxiidae* | Native | diadromous[1] | 790 |
| Jollytail | *Galaxias maculatus* | *Galaxiidae* | Native | diadromous[1] | 248 |
| Tasmanian mudfish | *Neochanna cleaverii* | *Galaxiidae* | Native | diadromous | 7 |
| Sandy | *Pseudaphritis urvillii* | *Bovichthyidae* | Native | non migratory | 342 |
| Australian grayling | *Prototroctes maraena* | *Prototroctidae* | Native | diadromous | 1 |
| Short-finned eel | *Anguilla australis* | *Anguillidae* | Native | diadromous | 540 |
| Short-headed lamprey | *Mordacia mordax* | *Mordaciidae* | Native | diadromous | 31 |
| Pouched lamprey | *Geotria australis* | *Geotriidae* | Native | diadromous | 311 |
| Brown trout | *Salmo trutta* | *Salmonidae* | Introduced | non migratory[2] | 1622 |
| Atlantic salmon | *Salmo salar* | *Salmonidae* | Introduced | diadromous[3] | 1 |
| Redfin perch | *Perca fluviatilis* | *Percidae* | Introduced | non migratory | 77 |

One threatened species of native fish was captured during the fish monitoring surveys. Australian grayling is listed as rare under Tasmania's *Threatened Species Protection Act* (1995) and Commonwealth *Environmental Protection and Biodiversity Conservation Act* (1999). A single specimen was collected from the Henty River in December 2004, but the species has not been collected from the Gordon River or tributaries during the monitoring program.

Of the three introduced species collected during the monitoring program, brown trout (*S. trutta*) were recorded in significant numbers in all surveys whilst only a single Atlantic salmon (*S. salar*) was captured, in March 2003. The December 2001 survey also reported the first confirmed record of redfin perch (*P. fluviatilis*) downstream of Lake Gordon and redfin were collected in all subsequent surveys.

Table 11.7. Catch per unit effort (CPUE) sumary table for all zones fished between December 2001 and April 2005. CPUE units are fish per 1,200 seconds of shock time.

| River | Zone | Type | Zone effort (s) | *A. australis* | *G. australis* | *G. brevipinnis* | *G. maculatus* | *G. truttaceus* | *M. mordax* | *P. fluviatilis* | *P. urvillii* | *S. trutta* | *S. salar* | *N. cleaveri* | *P. maraena* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gordon | 1 | River | 46625 | **0.44** | *0.00* | **0.08** | *0.00* | *0.00* | *0.00* | **0.69** | *0.00* | **0.31** | *0.00* | *0.00* | *0.00* |
| Gordon | 1 | Tributary | 29171 | *0.00* | *0.00* | **2.67** | *0.00* | *0.00* | *0.00* | *0.00* | *0.00* | **1.11** | *0.00* | *0.00* | *0.00* |
| Gordon | 2 | River | 55157 | **0.07** | **0.15** | *0.00* | *0.00* | *0.00* | **0.02** | **0.96** | *0.00* | **2.61** | *0.00* | *0.00* | *0.00* |
| Gordon | 2 | Tributary | 30135 | **0.20** | **0.12** | *0.00* | *0.00* | *0.00* | **0.20** | *0.00* | *0.00* | **3.90** | *0.00* | *0.00* | *0.00* |
| Gordon | 3 | River | 42863 | **1.40** | **1.90** | **0.03** | *0.00* | *0.00* | **0.08** | *0.00* | **0.03** | **4.79** | *0.00* | *0.00* | *0.00* |
| Gordon | 3 | Tributary | 49732 | **0.58** | **0.29** | *0.00* | *0.00* | **0.02** | **0.02** | *0.00* | **0.02** | **10.93** | *0.00* | *0.00* | *0.00* |
| Gordon | 4 | River | 28223 | **2.30** | **1.40** | **0.17** | **0.09** | **1.87** | **0.09** | *0.00* | **0.26** | **2.30** | *0.00* | *0.00* | *0.00* |
| Gordon | 4 | Tributary | 51882 | **1.04** | **0.42** | **0.09** | **0.02** | **1.78** | **0.07** | *0.00* | **0.23** | **5.78** | **0.02** | *0.00* | *0.00* |
| Gordon | 5 | River | 52747 | **3.84** | **1.11** | **3.00** | **3.94** | **5.76** | **0.07** | *0.00* | **2.05** | **1.27** | *0.00* | *0.00* | *0.00* |
| Franklin | 7 | River | 8641 | **3.89** | **0.69** | **4.44** | **0.56** | **3.75** | *0.00* | *0.00* | **2.92** | **1.39** | *0.00* | *0.00* | *0.00* |
| Franklin | 8 | River | 38143 | **1.73** | **0.72** | **0.91** | **0.03** | **0.44** | **0.13** | *0.00* | **0.35** | **4.37** | *0.00* | *0.00* | *0.00* |
| Franklin | 8 | Tributary | 28491 | **0.25** | **0.13** | **1.73** | *0.00* | **2.99** | **0.04** | *0.00* | *0.00* | **3.75** | *0.00* | *0.00* | *0.00* |
| Birches | 9 | River | 22660 | **3.23** | **0.95** | **0.21** | **1.69** | **4.50** | **0.21** | *0.00* | **8.90** | **0.11** | *0.00* | *0.00* | *0.00* |
| Henty | 13 | River | 22356 | **0.70** | **2.52** | **1.93** | **1.88** | **11.27** | **0.05** | *0.00* | **1.40** | **1.45** | *0.00* | **0.38** | **0.05** |
| Henty | 14 | River | 12506 | **0.86** | **2.21** | *0.00* | *0.00* | **0.77** | **0.29** | *0.00* | **0.77** | **10.84** | *0.00* | *0.00* | *0.00* |

### 11.3.2 Distribution and species composition in test sites

Summaries of fish distribution in the Gordon River and its tributaries (no tributaries were monitored in zone 5) are shown in Figure 11.1 and Figure 11.2, respectively. Distance was measured from the mouth of the river at Macquarie Harbour. Note that the distribution of 'tributary' species distribution (Figure 11.2) is shown relative to upstream distance to aid interpretation of the data. Figure 11.3 and Figure 11.4 shows the species composition in the Gordon River and tributary sites in zones 1-5, respectively.

Brown trout (*S. trutta*) exhibited the widest distribution of the introduced species in the test zones, and were collected from all river and tributary sites. In addition to showing a wide distribution, trout were dominant in catches from zones 2-4, particularly the tributaries. Redfin perch (*P. fluviatilis*) were captured only in zones 1 and 2, and were not collected from any tributaries. They comprised the largest proportion of the catch at the zone 1 river sites, and were strongly represented in zone 2. A single Atlantic salmon (*S. salar*) was captured in the Olga River, which is a major zone 3 tributary.

Short-finned eels (*A. australis*), pouched lampreys (*G. australis*) and to a lesser extent short-headed lampreys (*M. mordax*) were the most widely distributed of the native species. Eels comprised a significant proportion of the catch in all river zones and pouched lampreys were strongly represented in catches from zones 3 and 4.

Climbing galaxias (*G. brevipinnis*) were restricted to the downstream and upstream reaches of the middle Gordon River, with an isolated occurrence in a lower zone 3 tributary. Climbing galaxias were present in zone 1, no galaxiids were collected from zone 2, while a single spotted galaxias (*G. truttaceus*) and climbing galaxias was collected in zone 3. Spotted galaxias, climbing galaxias and sandys (*P. urvillii*) were present in zone 4, and all three galaxiids as well as sandys were present in zone 5.

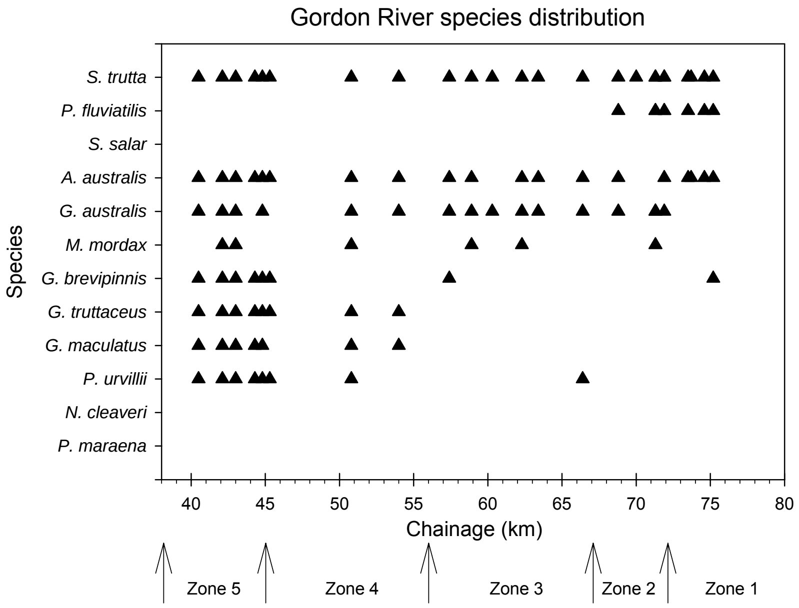

Figure 11.1 Fish species distribution in the Gordon River zones. Chainage indicates distance from Macquarie Harbour.

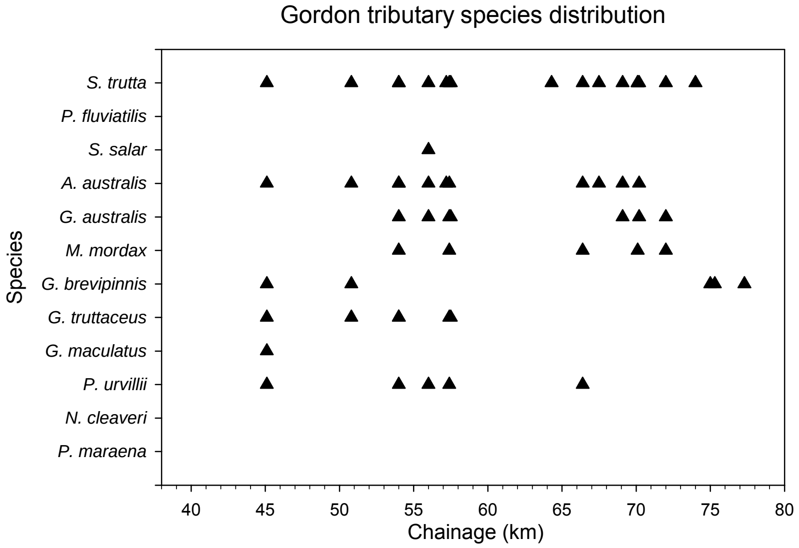

Figure 11.2. Fish species distribution in the Gordon test zone tributaries. Note that zones have not been displayed as the total distance from Macquarie Harbour does not necessarily reflect zone position in all cases. Note that zone 5 does not contain any tributary sites.

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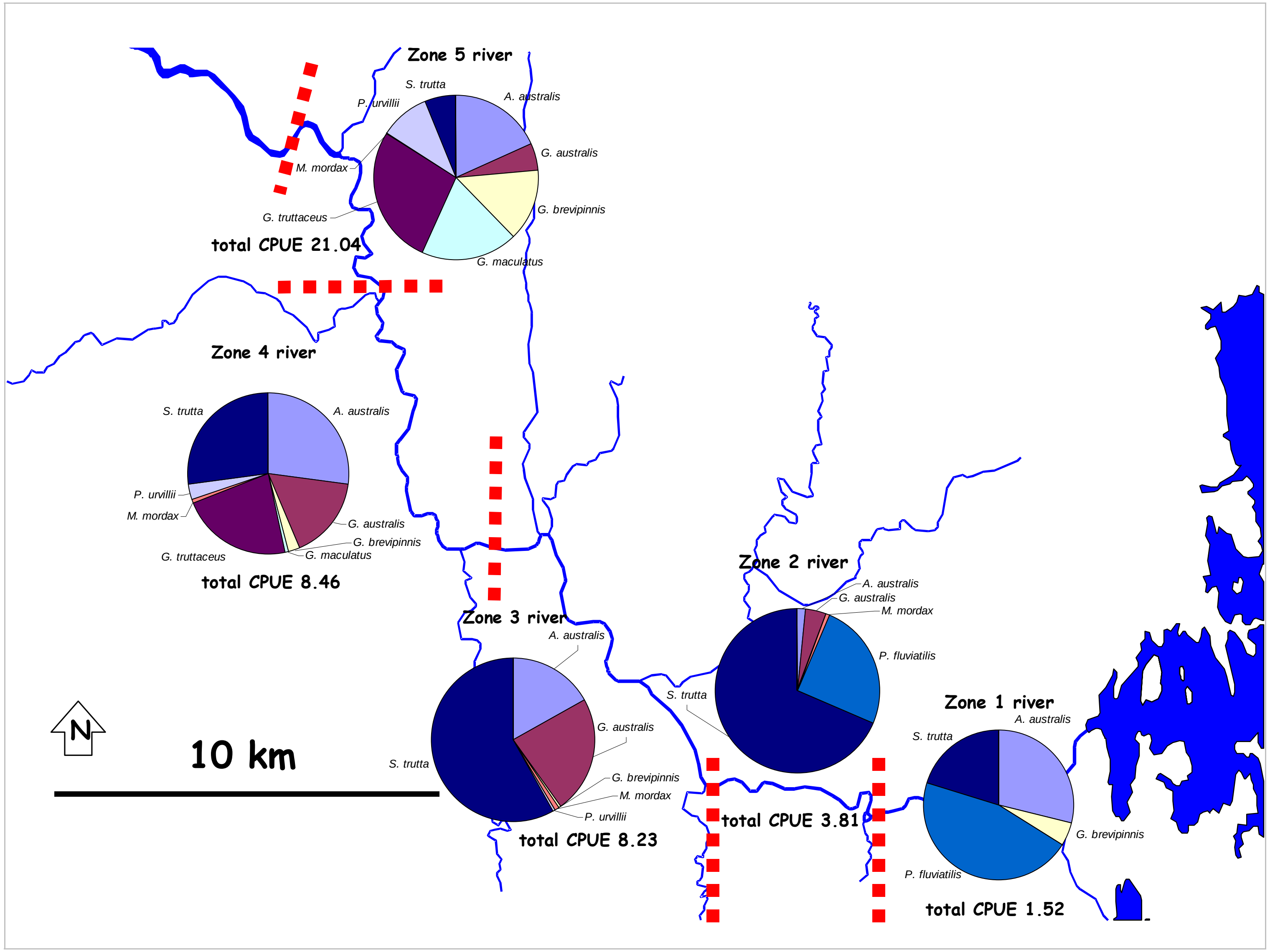

Figure 11.3. Relative species composition in the Gordon River.

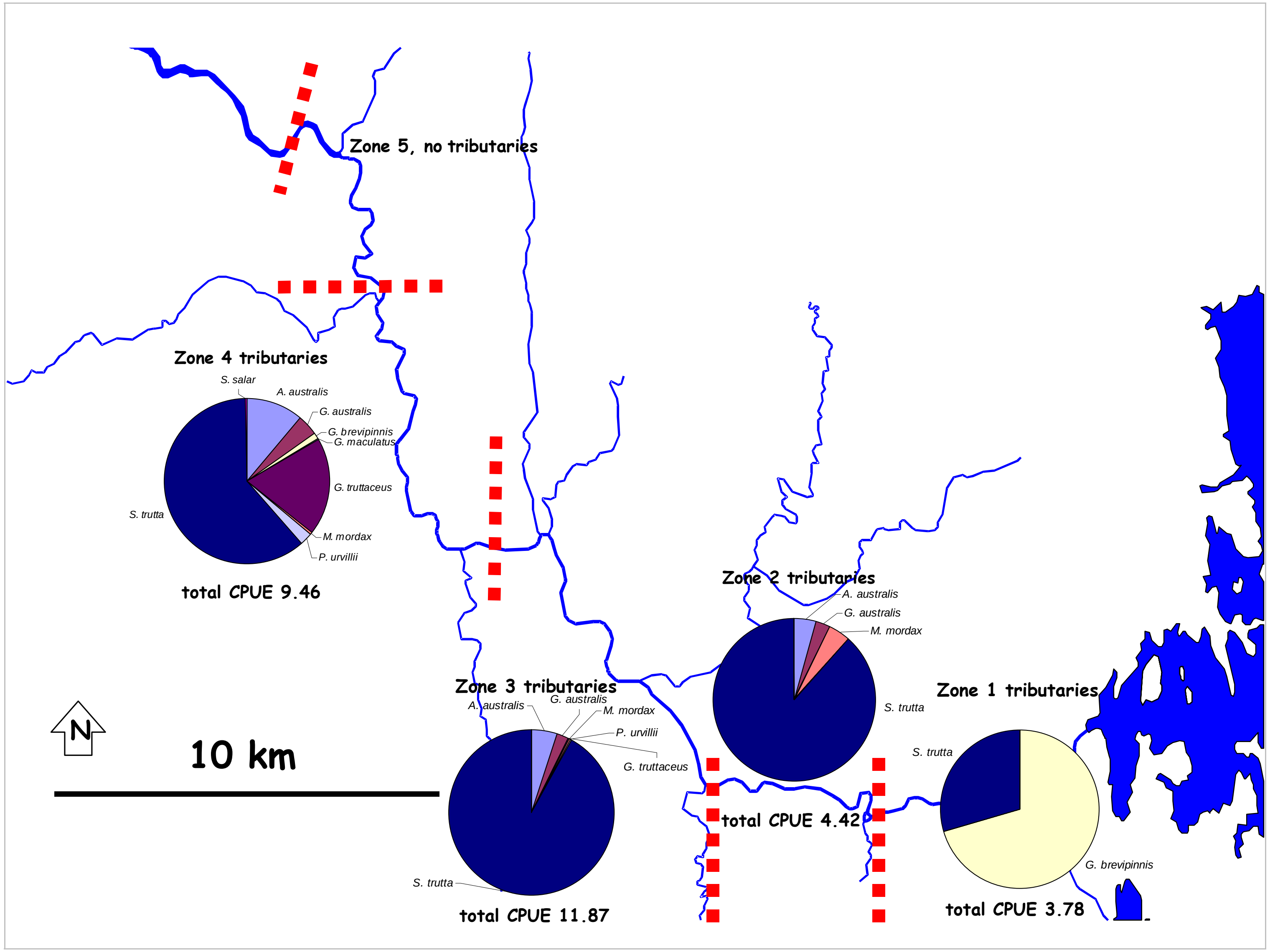

Figure 11.4. Relative species composition in the Gordon tributaries.

### 11.3.3 Distribution and species composition in reference sites

Fish distribution and composition in the reference zones are shown in Figure 11.5 and Figure 11.6, respectively. The community composition graphs are based on catch per unit effort values in preference to count data. Brown trout were present in each zone and were the only introduced species captured in the reference rivers. Trout dominated catches in the upstream zones of the reference rivers; zone 8 river and tributary sites (Franklin River u/s Big Fall) and zone 14 (Henty River u/s Yolande River). Only two trout were collected from Birches Inlet over the monitoring period.

Most of the native fish species showed a similar distribution throughout the reference river zones. However, Jollytails (*G. maculatus*) were consistently absent from zone 8 tributary sites. Tasmanian mudfish (*N. cleaveri*) and a single Australian grayling (*P. maraena*) were only captured in the lower Henty River (zone 13).

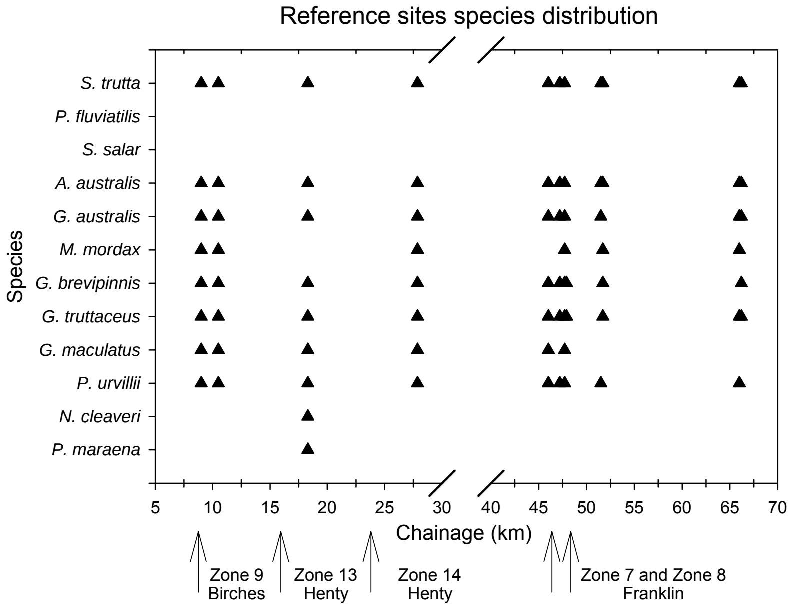

Figure 11.5. Fish species distribution in the Franklin, Henty and Birches Inlet reference zones. Note that the species distribution of the three reference river groups has been plotted on a single chainage graph to aid interpretation. Distance has been measured from Macquarie Harbour (zones 7-9) or the Henty River mouth (zones 13-14).

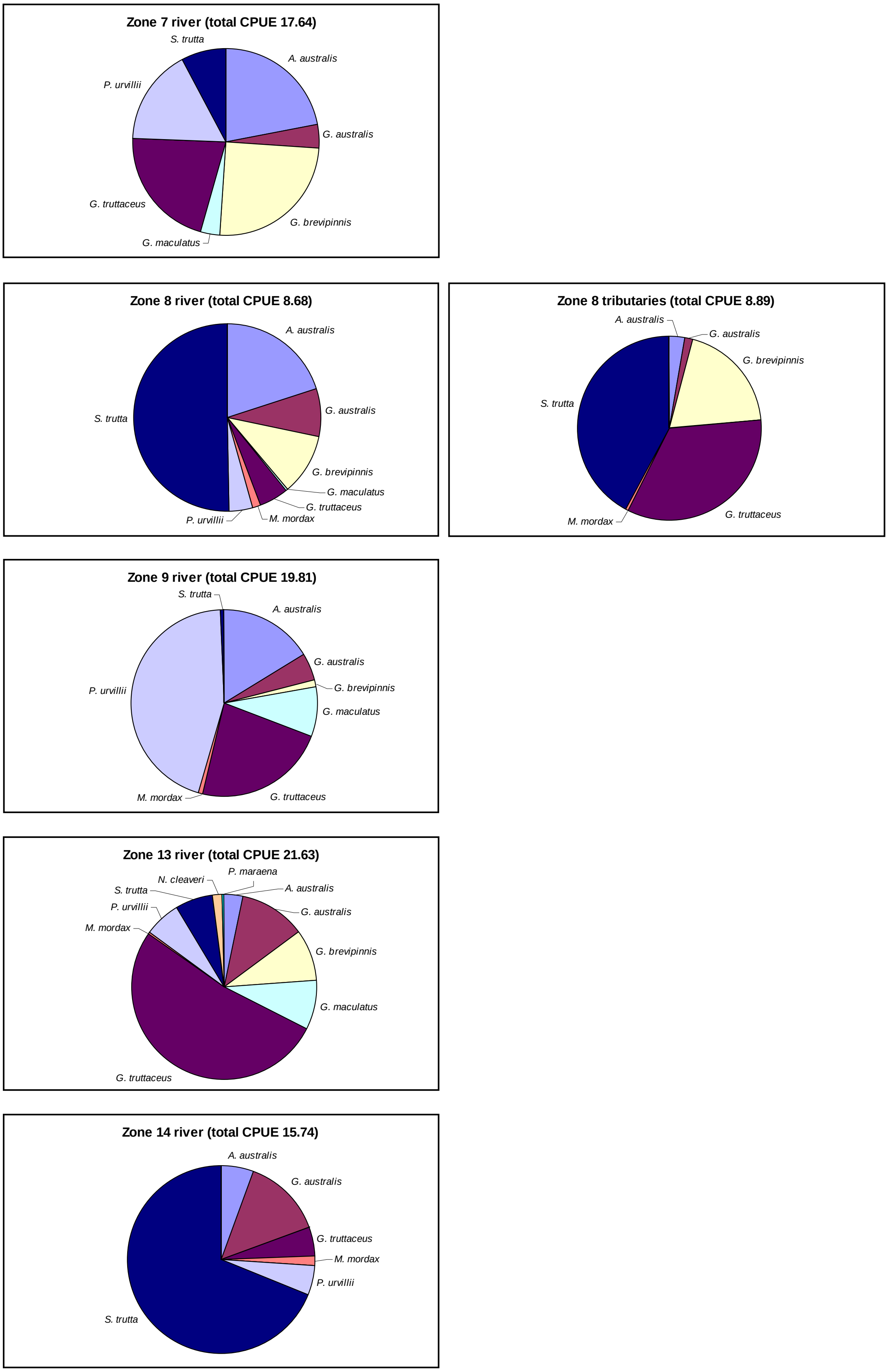

Figure 11.6. Species composition in the reference sites. Zones 7 and 8 are located in the Franklin River, zone 9 represents the Birches Inlet rivers and zones 13 and 14 are located in the Henty River.

### 11.3.4 Species diversity, catch and population structure

Figure 11.7 shows a histogram of species count for the test and reference zones. Data for river and tributary sites were pooled for this analysis. Figure 11.7 indicates that reference zones generally show a greater species diversity in comparison to the test zones 1-3, whilst zones 4 and 5 have a similar range of diversity to the reference zones 8-14. Autumn and summer catches showed similar variability in species diversity. Data for zone 7 were collected from a single site and consequently there is a low degree of spatial replication.

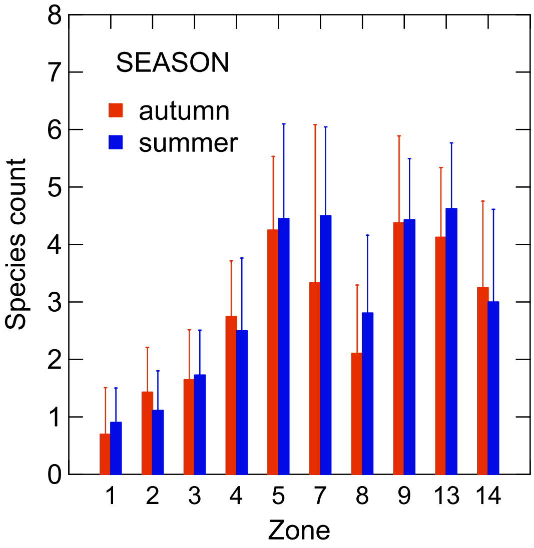

Figure 11.7. Species count for test and reference zones, split by season. Error bars indicate one standard deviation.

The majority of native species collected during the monitoring program exhibited diadromous behaviour. Juvenile galaxiids recruit to the lower reaches of rivers in spring and early summer, whilst juvenile eels tend to migrate upstream from late spring though to midsummer. Adult lampreys migrate from the sea to breed in freshwater, while juvenile lampreys (ammocoetes) remain in freshwater habitats before metamorphosing to young adult life stages and migrating back to the sea. Sandys were the exception to the rule as they do not have a diadromous life history strategy, but may show smaller scale migration patterns within the catchment (McDowall 1996).

#### *11.3.4.1 Introduced species*

Figure 11.8 shows pooled zone catch per unit effort data for introduced species of redfin, trout and salmon., There is a high degree of within- and between-zone variability in both test and reference sites. However, analysis of the log-transformed data (pooled to zone level) did not indicate any seasonal trends in catch abundance, or consistent differences in catch between test and reference sites (two-way ANOVA, F=0.075, P=0.785 and F=1.216, P= 0.273).

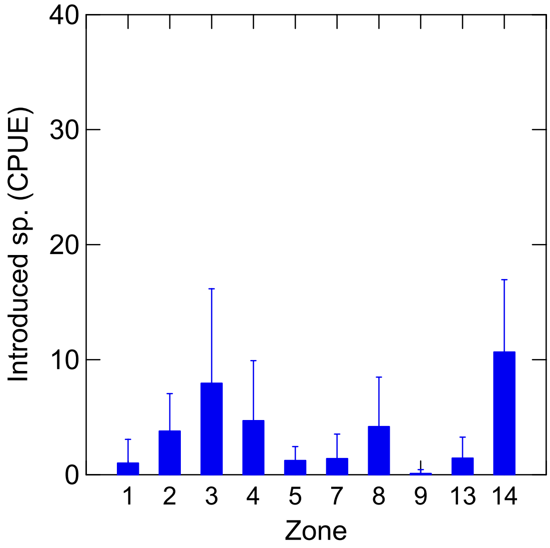

Figure 11.8. CPUE for introduced fish species captured from the test and reference zones between December 2001 and April 2005. Error bars represent standard deviation.

### *11.3.4.2 Brown trout (S. trutta)*

Brown trout were the dominant introduced species in terms of abundance and distribution in most zones. Their population structure was similar in test and reference sites, and Gordon River and tributary populations were also similar in structure.

Figure 11.9 shows brown trout length frequency histograms for each of the eight sampling events conducted between December 2001 and April 2005. Multiple year classes are evident in the histograms, with a seasonal pattern showing the effect of juvenile recruitment in summer and evidence of cohort growth between summer and autumn samples. Juvenile recruitment was particularly strong in November 2003.

The catch statistics shown in Figure 11.8, included trout, redfin perch and salmon. However, trout were the dominant introduced species in both the test and reference sites. Removal of redfin perch (restricted to zones 1 and 2) and salmon (1 fish from the Olga River) records made little difference to the overall catch statistics. Trout were particularly abundant in zone 3, reaching a maximum CPUE of 40 fish per 1200 seconds. They were less abundant in zone 4. When the data are divided into river and tributary subsets, as shown in Figure 11.10, tributary trout catches contributed significantly to catch rates in the test zones (one-way ANOVA on log transformed data, F=17.296, P=0.000).

Trout abundance in the majority of the reference zones was relatively low, particularly in Birches Inlet. Relative abundances in the upstream Henty River site (Henty @ Sisters) were high reaching a CPUE of 23 fish per 1200 seconds and also displayed a high degree of temporal variability.

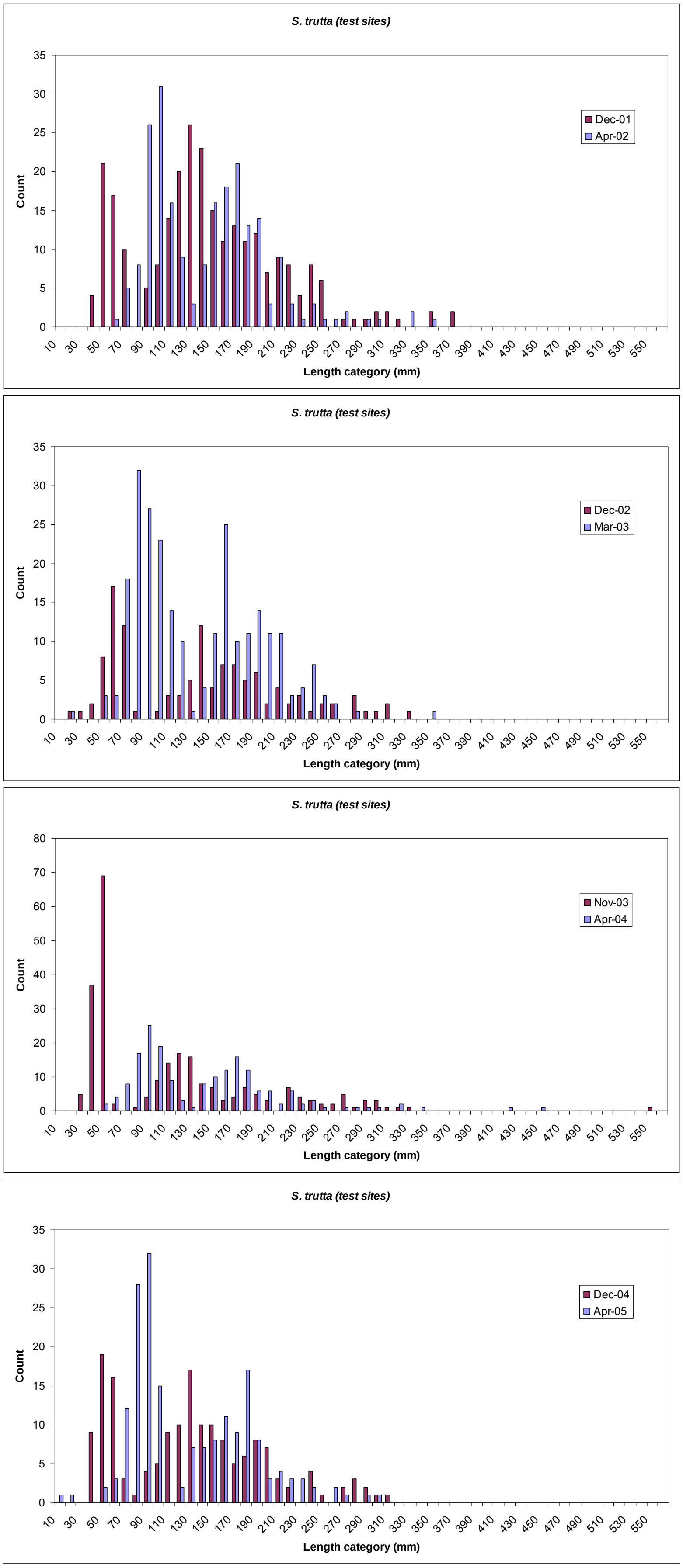

Figure 11.9. Brown trout population structure in the Gordon River test zones between December 2001 and April 2005.

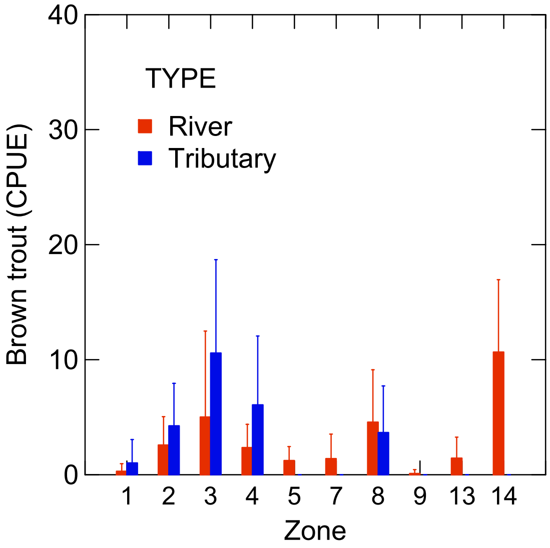

Figure 11.10. Catch per unit effort, split by site type, for brown trout captured from the test and reference zones between December 2001 and April 2005. Error bars represent standard deviation.

### *11.3.4.3 Redfin perch (P. fluviatilis)*

Redfin perch were captured only in zones 1 and 2 (Figure 11.11). Seasonal variability in CPUE is evident between catches in each zone, with catches tending to be higher in zone 1 during summer, and higher in zone 2 during autumn. There were insufficient data to conduct a two way analysis of variance on the data, but there appears to be interaction between season and zone suggesting seasonal movement between zones. More data is required to clarify whether there is a true relationship between seasons and catch rates in zones 1 and 2.

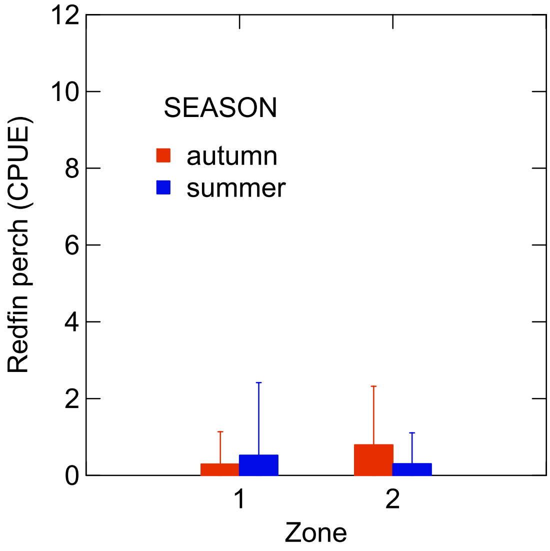

Figure 11.11. Redfin perch CPUE, split by season, collected from zones 1 and 2.

Redfin perch population structure is shown in Figure 11.12. Length frequency distributions from each of the eight sampling events were similar, with no obvious seasonal trends and no evidence of juvenile recruitment or distinct cohorts between samples. The data were pooled to show the length frequency distribution of fish collected during the pre-Basslink study period. Fish ranged from 74-202 mm in length, with modes in the 145 mm and 175 mm length classes. Note that all captured redfin perch were euthanased and retained for later examination of otoliths. This is a different methodology from that used for the other species, where all captured fish were returned at the point of capture. Consequently, the CPUE values for redfin perch may not be directly comparable with those from other species due to the possibility of a "fishdown" effect.

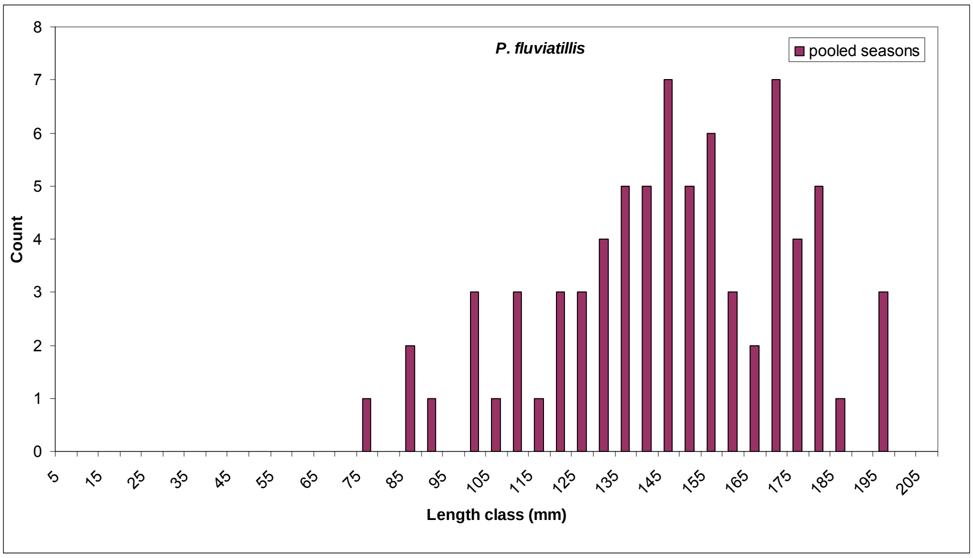

Figure 11.12. Population structure of redfin perch collected from the Gordon River.

#### *11.3.4.4 Native species*

Figure 11.13 shows a CPUE summary for all native fish species captured during the monitoring program. Species comprised of *Galaxias truttaceus*, *Galaxias brevipinnis*, *Galaxias maculatus*, *Neochanna cleaveri*, *Pseudaphritis urvillii*, *Anguilla australis*, *Mordacia mordax* and *Geotria australis.* Native fish abundance, as indicated by CPUE showed a high degree of variability, with low abundances in test zones 1-4 and reference zones 8 and 14, while zones 5, 7, 9 and 13 had high abundances of native species. It is noteworthy that there appeared to be an inverse relationship between zones with high native fish abundance and those with low trout abundance (zones 1, 5, 9 and 13).

Figure 11.14 shows a seasonal breakdown of native fish CPUE in all zones. There was no consistent seasonal trend within pooled downstream zones (one-way ANOVA on log transformed data, F=2.119, P=0.150 - excludes zones 1-3 due to low catches). Migration behaviours shown by the native species pooled in the analysis were not necessarily synchronous, with both anadromous and catadromous species showing differences in migration timing. Juvenile galaxiids tend to migrate upstream into the lower reaches of rivers during spring and early summer, while the timing of the elver migration run may extend from spring into autumn. Adult lampreys migrate upstream to spawn, however the timing of their run may also vary from year to year. In summary, sampling during the migration season should be considered as a 'snapshot' of the run, and may not necessarily coincide with migration peaks for all species.

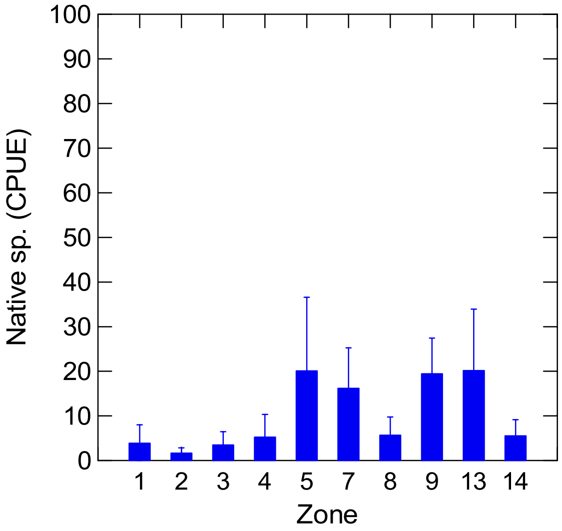

Figure 11.13. Catch per unit effort for all native fish captured from the test and reference zones between December 2001 and April 2005.

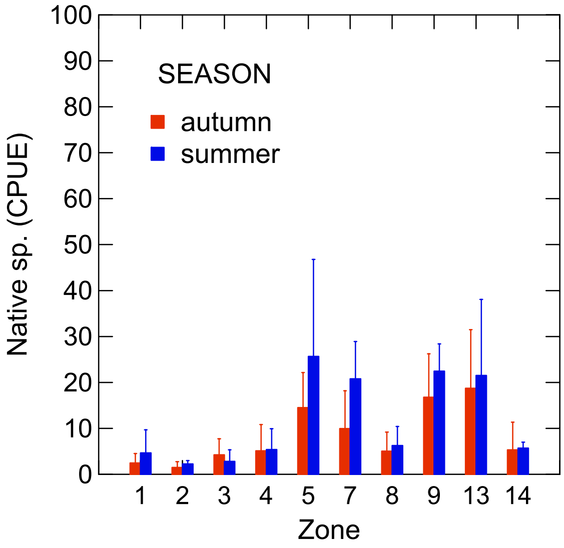

Figure 11.14. Catch per unit effort (CPUE), split by season, for all native fish captured from the test and reference zones between December 2001 and April 2005.

### *11.3.4.5 Galaxiids*

Figure 11.15 shows a summary of galaxiid abundance in the test and reference zones. Catches in the upstream test zones were low, making the relatively abundant zone 1 tributary populations clearly evident. Catches in the downstream test and reference zones were moderate to high with a strong seasonal increase in catch rates and catch variability at these sites. Two-way analysis of variance on log transformed data from zones 4 to zone 14 inclusive, showed that summer catch rates were significantly higher than those collected in autumn (F=5.038, P=0.028).

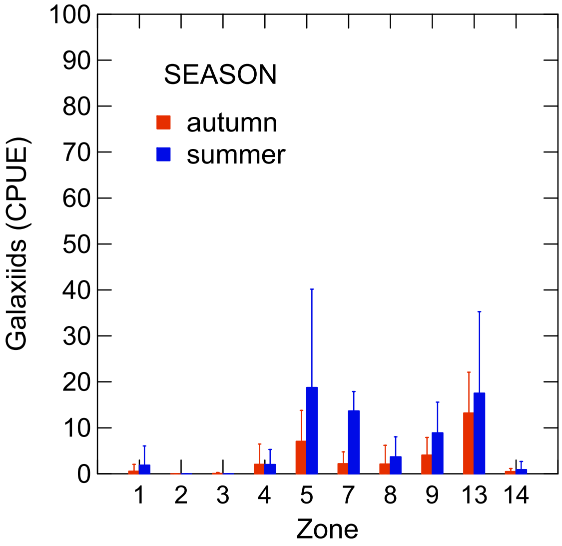

Figure 11.15. Catch per unit effort, split by season, for galaxiids captured from the test and reference zones between December 2001 and April 2005.

Galaxiid populations structure in the Gordon and Franklin Rivers are shown in Figure 11.16 and Figure 11.17, respectively. For the majority of the sampling trips, strong juvenile galaxiid recruitment was clearly evident in the summer data, particularly in the November 2003 and December 2004 data. It is noteworthy that galaxiids recruitment was not apparent in the December 2001 Gordon River data. However, a juvenile cohort was evident in the April 2002 samples indicating unusually late juvenile recruitment into the middle Gordon River. It is also interesting to note that this seasonal anomaly was not apparent in the Franklin River data.

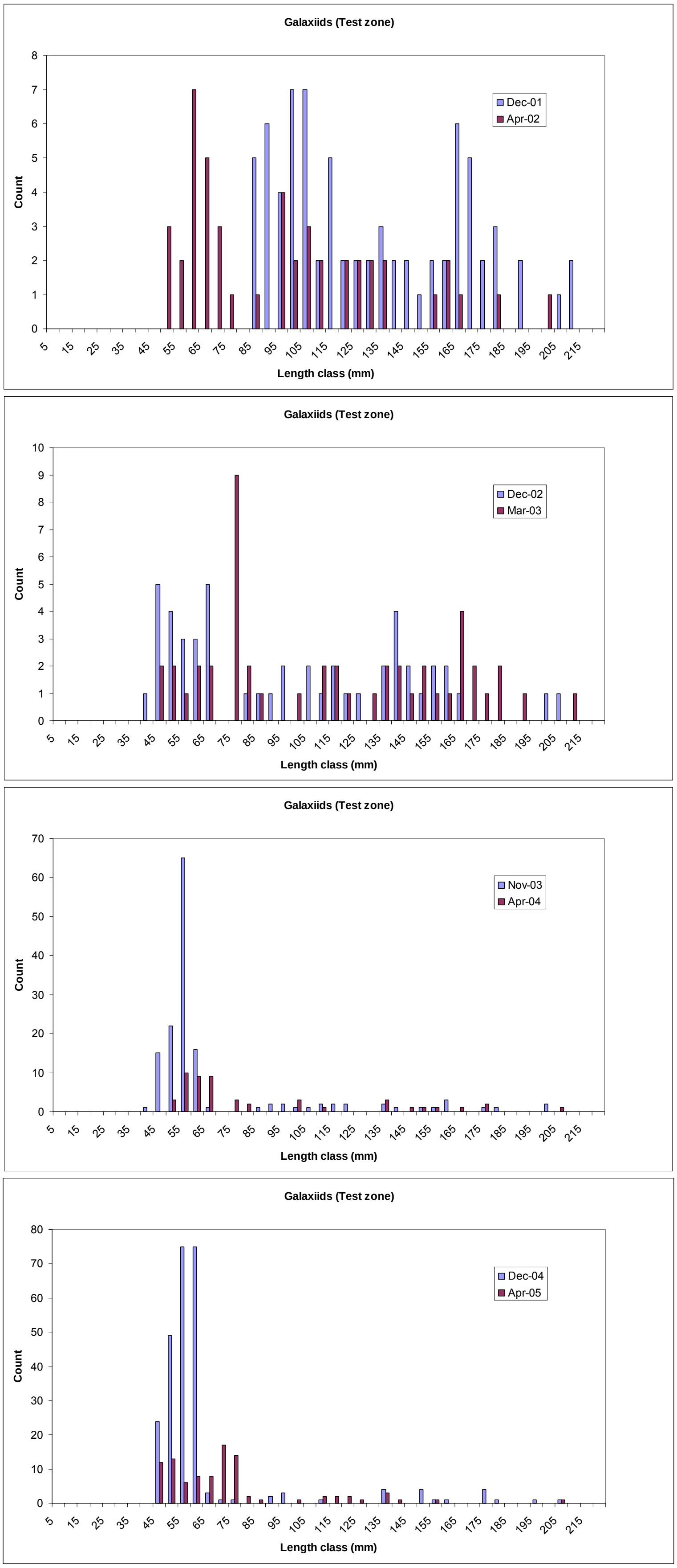

Figure 11.16. Seasonal population structure of galaxiids in the Gordon River collected between December 2001 and April 2005.

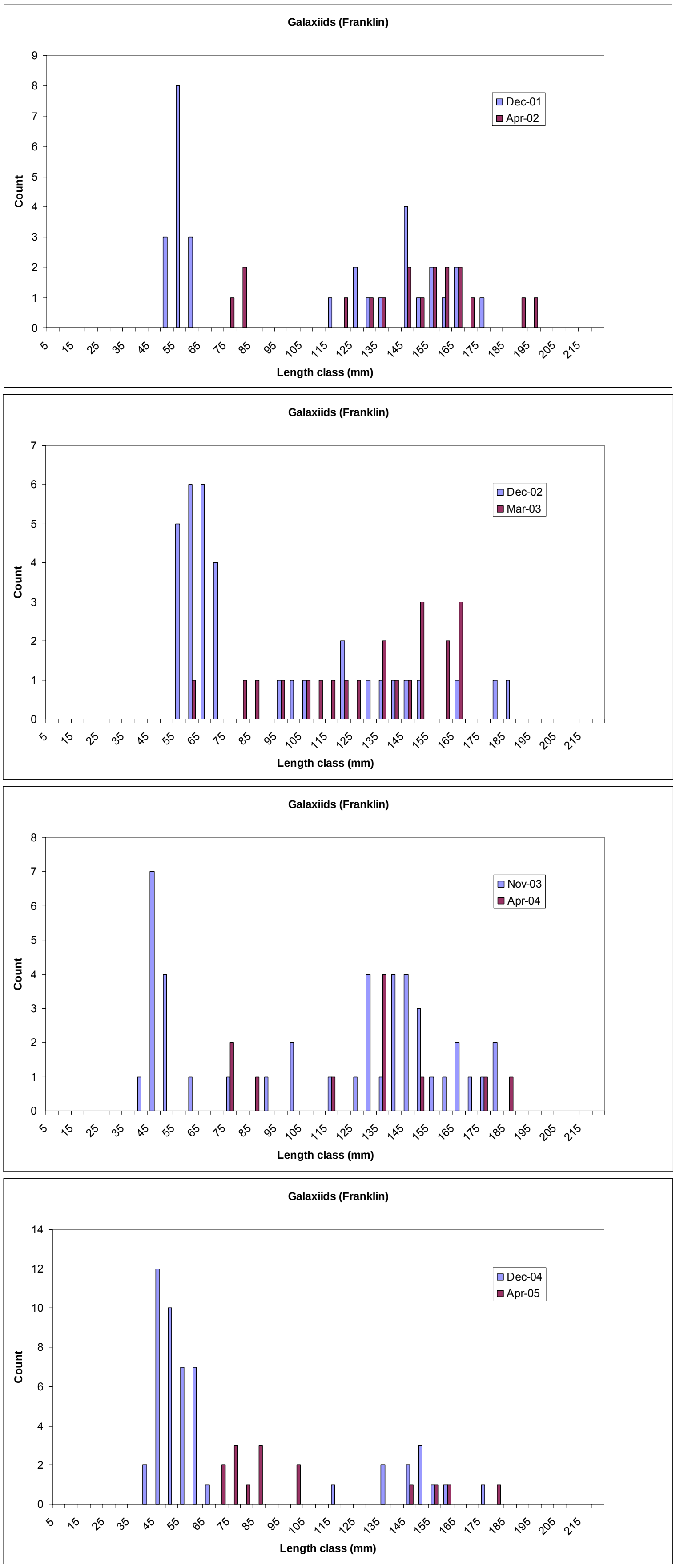

Figure 11.17. Population structure of galaxiids in the Franlin River sites, collected between December 2001 and April 2005.

Hydrographic data from the Gordon Power Station tailrace showed that following a 16 day shut-down in early October 2001, the power station consistently ran 2- to 3-turbines from mid October through to late December, with a natural flow event occurring approximately five weeks prior to sampling. Power station discharge for the same months in 2002-04 generally showed a higher degree of variability. It is also noteworthy that monitoring conducted in November 2003 and December 2004 coincided with significant galaxiids runs that were sampled within two to three weeks of significant natural flow events in the Gordon and Franklin catchments. These flow events also occurred during either low power station discharge or when the station was shut-down. In both of these cases, sampling was conducted when the hydrograph approached baseflow in the Franklin River. Power station discharge varied significantly between these samples.

Figure 11.18 shows a comparison of the population structure of galaxiids collected from the 'test' river and tributary sites over the monitoring period. Recruitment of juvenile galaxiids primarily occurred in the main river, with larger galaxiids being recorded in the tributaries. Length-frequency data for the reference sites displayed similar trends, with larger galaxiids dominant in the tributaries.

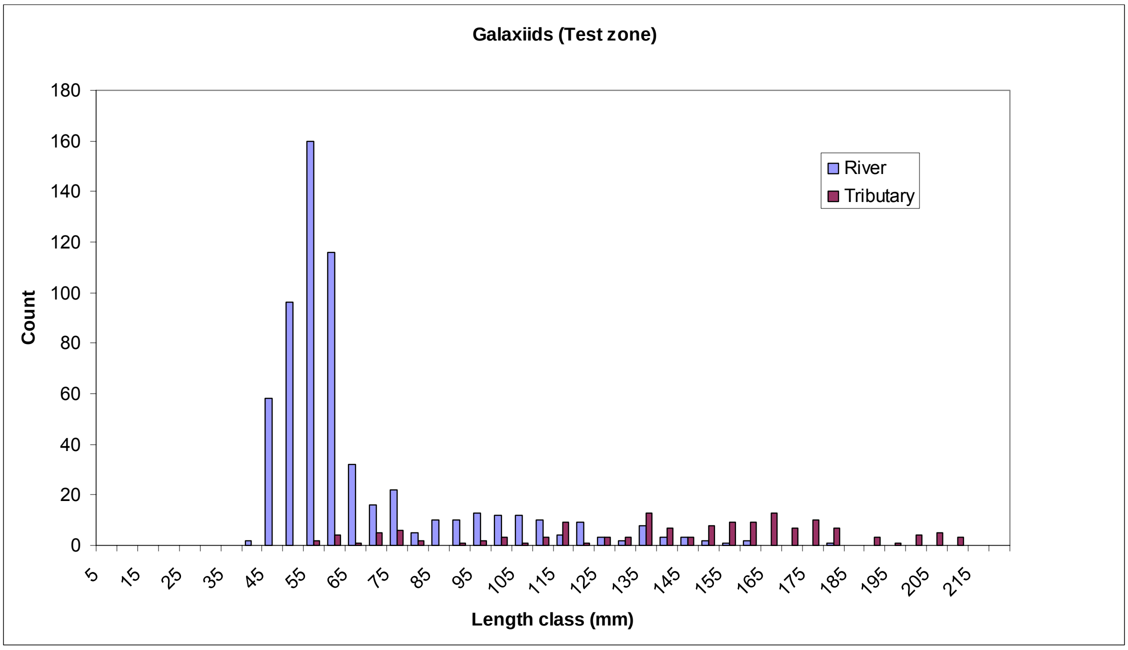

Figure 11.18. Population structure of galaxiids collected from the test zone river and tributary sites over the sampling period.

Figure 11.19 and Figure 11.20 show data for climbing galaxias (*G. brevipinnis*) in the Gordon and Franklin Rivers. The length frequency histograms exemplify the trends shown between tributary and river sites, with strong juvenile recruitment evident at the river sites and larger galaxiids dominating tributary catches.

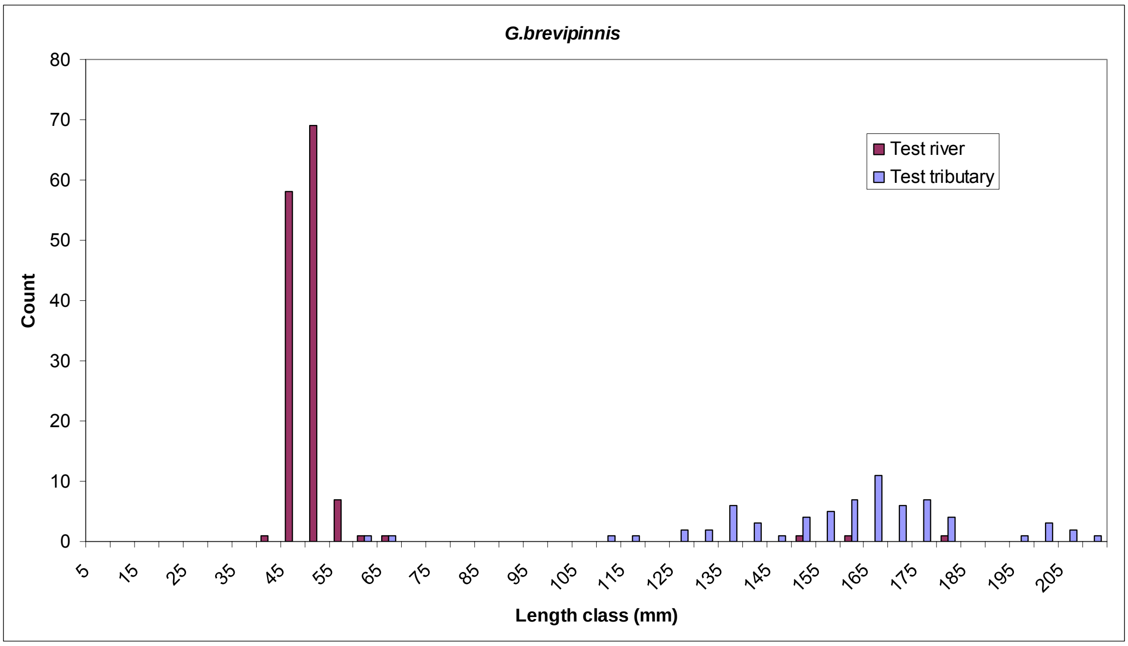

Figure 11.19. Climbing galaxas population structure in the Gordon River and tributary sites.

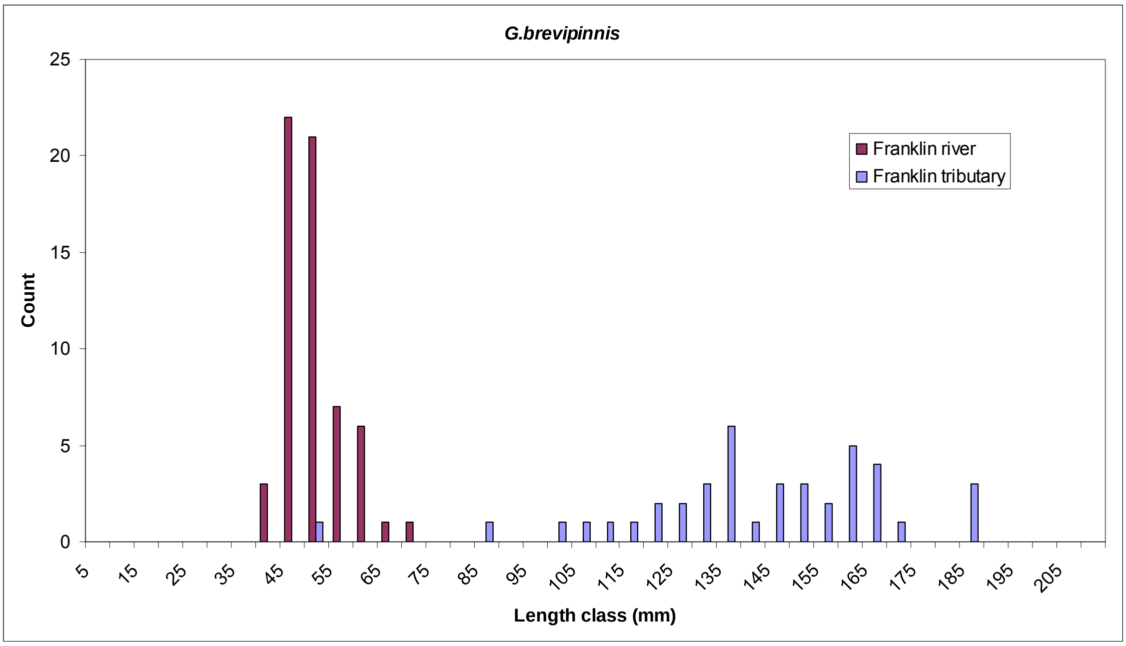

Figure 11.20. Climbing galaxias population structure in the Franklin River and tributary sites.

### 11.3.4.6 Sandys

Sandys were present in test zones 3, 4 and 5, as far upstream as the Olga at riffles site, and throughout the reference zones. CPUE declined with distance upstream in the Franklin and Gordon Rivers. Seasonal trends in catch and population structure were not evident in the data, but upstream sites tended to have larger fish than downstream sites. T-test comparisons between zones 4 and 5, 7 and 8, and 13 and 14 showed significant differences in mean fish size between these site pairs, with larger fish occurring in the upstream zones (two-tailed T-test assuming unequal variances, p=0.020, p=0.004 and p= 0.001, respectively).

### *11.3.4.7 Eels and lampreys*

Figure 11.21 shows that eels were present in all zones and showed a general trend of decreasing abundance with distance upstream. Surprisingly, catches did not show any distinct seasonal trends, as it was expected that the upstream migration of elvers may have been apparent in catches. Abundances were marginally higher during summer in most zones but population structure remained relatively consistent between seasons. The majority of eels collected during the study were 100 to 300 mm in length, but lengths up to 1,070 mm were recorded.

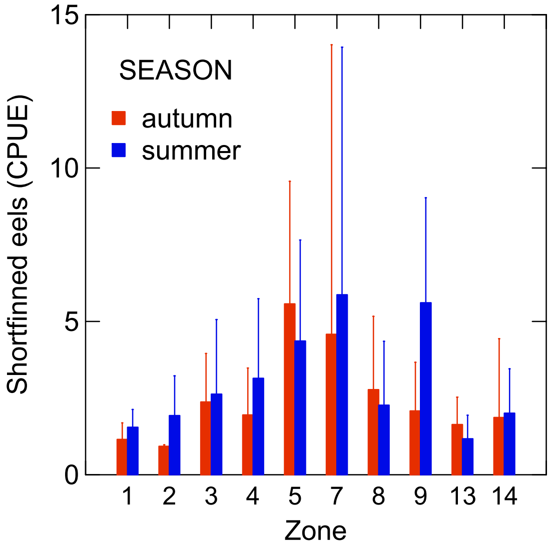

Figure 11.21. Catch per unit effort, split by season, for shortfinned eels captured from the test and reference zones between December 2001 and April 2005.

The vast majority of lampreys were in the ammocoete stage. An occasional macrothalmia was encountered in catches, and only 10 adult lampreys were collected during the monitoring program, most of which were captured in November 2003. Pouched lampreys (*G. australis*) were the dominant lamprey species in the Gordon and reference rivers.

## 11.4 Analysis and interpretation

The fish monitoring program is probably the most resource intensive discipline of the Basslink Monitoring Program. Up to 59 sites are sampled twice yearly by three monitoring teams. With one exception, monitoring sites specified in Hydro Tasmania's Water Licence have been monitored successfully. The 'Denison u/s Maxwell' site, as stated previously, was abandoned due to ongoing access issues, and was replaced with a site on the Orange River. The replacement site has served maintain the structure of the monitoring design, so that five tributary sites were monitored in zone 3. The replacement of the 'Denison u/s Maxwell' site does not have significant implications for the monitoring program.

While all attempts were made to maximise seasonal sampling consistency, the summer 2003 sample had to be brought forward a week into late spring. Fish sampling is conducted in early summer to increase the probability of sampling the galaxiid migration run. The timing of the run peak is highly variable and it is unlikely that moving the monitoring forward by one week would have significantly affected the results for this period.

### 11.4.1 Brown trout

Trout were the most abundant introduced species collected during the program. Trout dominated catches in the Gordon River, particularly in zones 3 and 4. The tributaries in the middle zones are significant in terms of catchment area and habitat quality. They have reasonably high flows and also exhibit a range of in-stream habitat types and substrates. Trout are capable of forming self-sustaining populations without the need to migrate to the sea to spawn, and so populations resident in the tributaries can exist in isolation from the flow regulation influences in the main river. The tributaries are probably an important source of trout recruitment to the Gordon River, via juvenile dispersal.

There is no doubt that low trout catches in the upper zones, particularly in zone 1, are related to flow regulation. The results of the monitoring program support the observations of the IIAS investigative studies of low zone 1 catches. High flows, hydro-peaking, paucity of velocity refuges, lack of suitable spawning habitat, low invertebrate abundance and lack of seasonal water temperature variability all contribute to low abundances in this zone. While there are tributaries in the upper zones the majority drain small catchments and have a limited range of habitats.

Low trout catches in zone 5 may be partially due to a lack of tributary sites, as catch rates in zones 3 and 4 were relatively high in the tributaries in comparison to the river. It should also be recognised that electrofishing efficiency may be higher at some tributary sites in comparison to river sites along the main channel of the river. The electrofishing field is limited, and field strength rapidly decreases with distance from the anode, and so habitat structure and operator technique play an important role in fishing efficiency. The confined, shallow nature and habitat complexity of smaller tributaries enables the operator to effectively ambush, or herd, fish so that they can be shocked using the efficient area of the field. Brown trout are particularly shy and usually flee at the earliest opportunity when approached, or seek refuge in snags or other hiding habitat where possible. The deeper open sections of the river generally have less habitat complexity and present greater scope for fish to detect approaching personnel and flee the electrical field into deeper water.

Given the relative stability of macroinvertebrate and fish communities during the pre-Basslink monitoring period, it is assumed that trout and their impacts have reached a dynamic equilibrium with the regulated hydrologic regime and its resultant aquatic biota.

### 11.4.2 Redfin perch

Prior to the Basslink Monitoring Program, redfin perch (*Perca fluviatilis*) had not been recorded from the Gordon River downstream of Lake Gordon. The species was first collected during the December 2001 surveys. While it is present in low numbers, it is now the most abundant species in zone 1 and second only to brown trout in zone 2.

The likely source of redfin perch is Lake Gordon, where they have been present since 1978 (French 2002). It is thought that adult redfin have survived passage through the Gordon Power Station and were discharged into the river. It is not clear why this has occurred over the last four years nor whether redfin perch will be able to develop self-sustaining populations in the Gordon River, but it is suspected that their appearance may be linked to the relatively low water levels in Lake Gordon. The intake has been closer to the surface of the lake than it has been since 1990, increasing the likelihood of fish entrainment, and analysis of lake levels and stratification behaviour (see chapter 6) have shown that the power station intake has been above the oxycline for the monitoring period.

Predictive passage mortality equations developed by Larinier and Dartiguelongue (1989) for salmonids and eels show that passage through the Francis turbines of the Gordon Power Station is theoretically possible. Maintenance operations such as partial dewatering of the penstocks may also have provided ‘windows of opportunity’ for the recent downstream transfer of live redfin past the power station. For example, a single Shannon paragalaxias, endemic to the Great Lake region of the central highlands, was collected from the tailrace following pipeline maintenance operations at Poatina in 2004 (David Ikedife, pers. obs.). The Poatina Power Station houses six Pelton turbines driven by extremely high pressure water delivered by nozzles, and it is virtually impossible for fish to survive passage through this type of turbine (Travade and Larinier, 1992) under normal operating conditions. The fish was apparently translocated downstream during dewatering of the penstock.

It is likely that fish have been passed downstream under suitable conditions in past years but have failed to establish in the river. The lack of any fish sampling in the middle Gordon River prior to 1999 means that any previous transient introductions to the upper zones would have gone undetected.

It is anticipated that under Basslink, water levels in Lake Gordon will be managed to maximise head and therefore generating efficiency of the power station. Under high lake levels it is reasonable to expect that the likelihood of redfin passage will decrease due to the increased depth of the intake.

It is also likely that a hydro-peaking regime will further decrease the likelihood of redfin establishment in the upper reaches of the river. Redfin captured during the monitoring program were usually collected from marginal habitats such as the shallow, cobbled outflows of dewatering pools in zone 2. Redfin were more prone to post shut-down stranding than brown trout, and so appear to be less able to adapt to a highly variable flow regime.

It is difficult to predict whether the post Basslink environmental flow release will be beneficial to redfin populations. The potential effect of the environmental flow release on redfin abundance and distribution will be extremely difficult to detect during this time, as the pre Basslink data on redfin distribution and abundance is not representative of a stable pre-Basslink condition. A review of the scientific literature did not find any specific studies documenting the effect of environmental flows on redfin perch populations, however, given their widely accepted preference for still or slow flowing water (Fulton 1990, McDowall 1996, McDowall 2000, Morgan *et al.* 2002, Weatherley 1963, Weatherley 1977) it is inferred that the introduction of an environmental flow will not benefit this species in the middle reaches of the Gordon River. The lack of aquatic macrophytes in the Gordon River may also affect recruitment success.

The redfin catch data show some evidence of seasonal changes in abundance between zones. Although this trend is not statistically significant, the small size of the data set limits the sensitivity of the analysis. There may be upstream summer migration or downstream autumn migration, but more data are required to investigate this possibility.

As redfin perch are piscivorus, should they become established in the lower reaches of the river they are likely to have significant and detrimental impact on the native fish communities. If the species becomes more widespread, native fish within the tributaries and possibly elsewhere in the Macquarie Harbour catchment may be detrimentally affected. As an apparently recent introduction, redfin populations and consequent impacts on aquatic biota may not yet have reached equilibrium and further effects, such as population growth and range expansion, may occur independent of Basslink operations. Even if the species does not form self-sustaining populations, but is simply maintained by emigration from the lake, there will be negative implications for fish and invertebrate communities in the zones where redfin are abundant, due to the species' predatory behaviour. The fish monitoring program will monitor the status of redfin stocks in the middle Gordon River and consult with the Gordon River SRC if significant range extensions occur.

### 11.4.3 Atlantic salmon

A single Atlantic salmon was captured from the 'Olga at Gordon' site during the March 2003 survey. The 645 mm long female was captured from a snag adjacent to a riffle in this reach of the river. While it is sometimes difficult to differentiate between Atlantic salmon and sea run trout, abrasions on the fins and shape of caudal peduncle and the position of the eye in relation to the mouth are diagnosing features of Atlantic salmon.

Atlantic salmon are farmed in cages in the seaward region of Macquarie Harbour, occasionally escaping from damaged pens. This fish would have swum at least 75 km upstream from the western region of Macquarie Harbour to reach the Olga River. The fish had well developed gonads but virtually no stomach, which is consistent with the observation that escapees are not well adapted for feeding away from captivity (Edgar 1997).

The presence of this vagrant specimen in the middle Gordon River was noteworthy but did not present significant implications for the river's fish community structure or the monitoring program. Attempts to establish self-sustaining Atlantic salmon populations at various locations around Tasmania have been unsuccessful. Marine farm escapees have not developed wild populations in Tasmanian rivers, and are therefore unlikely to establish in the Gordon River or its tributaries.

### 11.4.4 Galaxiids

Galaxiids were predominantly encountered in the downstream zones of the Gordon River, and throughout the reference zones. Species diversity generally decreases with distance upstream in Tasmanian rivers (Davies 1989) and a similar pattern was observed in the Gordon River. A combination of hydro-peaking, inversion of seasonal flow patterns and hydrological barriers hamper the upstream migration of diadromous fish, particularly species that are not powerful swimmers, strong jumpers or do not possess the ability to climb using wetted channel margins.

The three galaxiid species collected during the monitoring program showed habitat preferences that can generally be categorised by upstream distance. Jollytails (*G. maculatus*) were predominantly found in the lower reaches, spotted galaxias (*G. truttaceus*) in the lower and middle reaches whilst climbing galaxias (*G. brevipinnis*) are recognised as a headwater species. The hydrological conditions in the Gordon River appear to accentuate natural differences in species distribution, particularly in relation to channel features that may act as inhibitors to fish passage under extremes in flow conditions. The occurrence of isolated populations of climbing galaxias in three zone 1 tributaries indicates the climbing galaxias' propensity for inhabiting headwater streams and their ability to negotiate significant migration barriers such as the Splits. Spotted galaxias (*G. truttaceus*) were mainly found downstream of zone 3 (below Sunshine Gorge), with only a single specimen collected from zone 3 (Harrison Creek). The majority of Jollytails (*G. maculatus*) were caught in zone 5 which lies downstream of all potential migration barriers, although two individuals were collected from zone 4 (Platypus Creek and Gordon @ Howards Creek). All three species are diadromous, and juveniles recruit to freshwater during the spring 'whitebait' run. Catch data showed clear summer peaks that were due to this seasonal migratory behaviour. In the Gordon and Franklin Rivers, juvenile climbing galaxias and spotted galaxias appeared to use the main channel of the river as a conduit for upstream migration, while adults predominated in tributaries. This trait was particularly distinct for climbing galaxias, as shown in Figure 11.19 and Figure 11.20. It should be noted, however, that there are two possible origins of the zone 1 tributary populations of climbing galaxias: upstream migration of juveniles, or downstream dispersal of fish from Serpentine Dam releases. Releases from the Serpentine Dam are rare. Area staff indicated that the gates have not been used since 1988 (Brett Brady pers. comm.) and it is therefore unlikely that Lake Pedder is the source of these fish. The origins of these fish will be investigated using otolith chemistry, as this information will be valuable in helping to interpret the effectiveness of the proposed Basslink mitigation measures on migration success.

The migratory behaviour shown by the galaxiids adds to the spatial and temporal variability of the data set. This reduces, to some extent, the monitoring program's capacity to detect a Basslink effect for these species.

### 11.4.5 Sandys

Sandys were restricted to the test zones downstream of Sunshine Gorge, but were found throughout the reference zones. Larger fish were generally found in the upper reaches of their distribution at both test and reference sites. These results are supported by McDowall (1996), who reported that juveniles are most abundant in the lower reaches of rivers during spring and summer, while larger specimens are generally more common further upstream.

### 11.4.6 Eels and lampreys

Eels and lampreys were widely distributed throughout both test and reference sites, and this is no doubt due, in part, to each species' ability to negotiate barriers. They have been collected from all zones and have only been consistently absent from tributaries in zone 1. Eels, particularly juveniles, are accomplished climbers while elvers are able to negotiate wetted vertical surfaces. Lampreys are equipped with an oral disc which is used for parasitically adhering to host fish. This can also be used to help negotiate barriers during upstream migration.

Juvenile lampreys (ammocoetes) predominantly live in habitats with soft substrates until they metamorphose into macrothalmia and start their downstream journey to the sea. Ammocoetes were primarily collected from sand or silt bars in the Gordon River and reference sites, and downstream of zone 1. Ammocoetes of both lamprey species were collected as far upstream as the Albert River in zone 2. They appear to be capable of inhabiting most of the Gordon River under the present flow regime.

Eels are diadromous and are thought to spawn in the vicinity of the Coral Sea. After an extended larval phase, juveniles enter estuaries as glass eels and recruit into rivers as elvers. The data showed little evidence of seasonal elver migration, however eels less than 120 mm in length were only found in zones 4, 5, 7 and 8. Eels larger than 120 mm were present in all zones.

### 11.4.7 Species interactions

Howland *et al.* (2001) reported that the distribution of climbing galaxias appeared to be strongly influenced by the presence of brown trout. The monitoring program supported these observations and found that, with the exception of whitebait runs, climbing galaxias were seldom found coexisting with brown trout, and the majority of adult climbing galaxias observed during the monitoring program were collected from small tributaries where trout were not abundant, (Ari Creek, Forester Creek, Indigo Creek, Platypus Creek and Wattle Camp Creek).

Trout were observed predating on juvenile galaxiids during the early summer migration runs. Juvenile galaxiids were often present in small schools in the downstream zones, particularly zone 5, during the December surveys. On several occasions, trout were observed ambushing schools of juvenile galaxiids in the shallows and around snags.

Measuring trout predation rates on galaxiids is outside the scope of this study, but it is likely that the dominance of trout in the middle test zones has had an adverse impact on galaxiid populations. While migration barriers, habitat availability, food abundance and predation play a varying role in shaping fish community structure in the Gordon River, the unregulated test zone tributaries may play a role as potential habitat refuges for native species. The dominance of trout in the middle zone tributaries has no doubt resulted in increased predation and competition for native species, particularly galaxiids, and may have implications for the effectiveness of the proposed Basslink mitigation measures for fish.

The December 2001 appearance of redfin perch has added another variable to the fish community structure of zones 1 and 2, and it is difficult to predict with any certainty whether redfin will disperse downstream in significant numbers. It is not clear whether this species has become self-sustaining in the river, but in any case it is the dominant fish species in zone 1. Redfin perch are an aggressive piscivore and their presence in the river has implications for its fish community structure, particularly smaller native species that may opportunistically use the river as a conduit to access tributaries in zones 1 and 2.

### 11.4.8 Fish stranding

Fish stranding was uncommon in the middle Gordon and appeared to be restricted to zones 1 and 2. Two dead, partially buried redfin perch were collected from the Serpentine confluence in December 2001, and this was the first reported observation of this species in the middle Gordon River. The fish were in an advanced state of decay and so it was not possible to determine the cause of their death. It is likely that they were killed passing through the turbines of the power station.

A single 1,070 mm long short-finned eel was found stranded at site 72 in March 2003. The eel appeared to have suffered moderate physical trauma which was consistent with a turbine injury and was probably the cause of death and stranding.

Site 72 is characterized by a series of shallow pools, which form when water levels decrease following shut-down. Brown trout were regularly collected from these shallow pools, and redfin perch were collected infrequently. Although relatively shallow and small (the smallest would be approximately 300 mm deep and 50 $m^2$ in area), the pools are capable of sustaining fish for several days during the height of summer and are unlikely to be a cause of significant fish mortality.

In summary, fish stranding following power station shut-down is infrequent in the middle Gordon River. Turbine injury or mortality may be a contributing factor in some stranding events. Post-shut-down entrapment in shallow pools is common at site 72 but is unlikely to result in significant fish mortality.

## 11.5 Evaluation of the Basslink monitoring program

The experimental design of the fish monitoring program is based on a minimum of three years of pre-Basslink data and six years of post-Basslink data. Data were collected from test and reference sites. Test sites are affected by flow regulation from power station operations, which will alter under Basslink. River test sites will be directly affected, while native fish migration to the test tributaries may be affected by flow regulation in the middle Gordon River. Reference sites are subjected to a largely unregulated, natural flow regime.

Hydro Tasmania's Water Licence indicates that the fish monitoring program has been designed to:

- quantify pre- and post-Basslink variability in fish populations and allow statistical comparison between these times and appropriate reference sites;
- assess changes in the longitudinal community structure of the Gordon River with the aim of identifying changes in the zone of influence;
- assess potential changes in catch per unit effort (CPUE) that may be related to habitat availability or other hydrological parameters; and
- determine changes to the fish populations of affected tributaries and in particular, whether recruitment success for juvenile galaxiids is improved under Basslink.

Examination of the existing dataset has highlighted the importance of clarifying the following conditions on statistical analysis of the post-Basslink dataset. The reference zones will be used for qualitative comparison with test zone data, but they are not suitable as 'control' sites in a BACI analysis as they differ significantly from the test zones, particularly in key aspects such as chainage, slope, vegetation, catchment area and hydrological regime. True control sites would be subjected to a pre-Basslink level of flow regulation similar to that found in the Gordon River and have similar catchment characteristics, however there are no other rivers in the region that meet these criterion.

While the data are not suitable for BACI analysis, repeated measures analysis of the data is an appropriate method for detecting Basslink related effects in the test zones (G. McPherson pers. comm.). The reference sites will be valuable in providing a basis for qualitative comparisons of temporal and spatial trends in fish distribution, population structure and abundance in conjunction with repeated measures analysis in the test zones. It is important that changes in fish abundance and distribution in the reference sites should be assessed in context, and that reference site data are used within their limitations. The key limitation are that reference data will not necessarily be a reliable or accurate indicator of natural or baseline changes that may occur in the Gordon River due to the fact that the hydrology in the upper Gordon River is dominated by power station discharge, which bears little similarity to the hydrology in the reference rivers which are unaffected by flow regulation.

To summarise, the monitoring program will be able to detect quantitative temporal changes in the Gordon River fish fauna from the present, regulated condition, and data from the reference sites will be used qualitatively to assist in the detection of potential changes.

The monitoring program design divides the Gordon River into zones based on potential migration barriers along the length of the river, and the use of zones has facilitated the characterisation of longitudinal community structure during the pre-Basslink monitoring phase. However, the migratory behaviour shown by the majority of native species in the Gordon River potentially poses additional complications when attempting to detect post-Basslink related effects. Pulses of recruitment in the lower zones in a particular year may lead to large changes in adult abundance in upper zones in subsequent years, significantly increasing spatial and temporal variability in the data set. If the pre-Basslink monitoring phase has been coincident with a pulse in recruitment success, post-Basslink may reflect an abundance of adult fish. Conversely, factors that may have reduced migration success during pre-Basslink monitoring may result in declines in post-Basslink adult abundance. For example, natural flood events may reduce fish passage success at hydraulic barriers in the river, affecting fish abundance and distribution in the upstream zones. As there is no quantitative data on critical upper or lower flows that allow migration at potential barrier sites in the Gordon River, the effect of flood flow events on passage success cannot be accurately predicted. These potential scenarios highlight the importance of monitoring changes in species population structure to assist in the detection of post-Basslink related changes in community structure, and the importance of using reference sites as qualitative indicators of recruitment trends. Comparisons between pre and post-Basslink population structure in key test tributaries will clearly indicate whether galaxiid recruitment success has altered post-Basslink.

The data have limitations that make statistical assessment of longitudinal changes difficult. Unfortunately the limitations of the site CPUE data cannot be overcome by pooling site data into presence/absence categories in each zone, as reduced replication decreases the power of the analysis to such an extent that there is no way of separating sample variation from real changes. However, in the absence of quantitative analysis of longitudinal changes, descriptive analysis of the data will be used to comment on potential changes due to Basslink related effects.

The ability of statistical tests to detect a Basslink-related effect has been assessed by power analysis, which is detailed in appendix 9, 'Establishing capability of fish monitoring to detect Basslink change'.

While every attempt has been made to maximise sampling effort and consistency at each site, many sites exhibit low numbers of fish due in part to variability of flow regimes and weather conditions prior to and during sampling, species behaviour and habitat changes. Catch per unit effort data has been recorded for each species at each site, and as a result, many records have zero values, particularly galaxiid records at upstream Gordon River sites. This has implications for the structure of the data set, particularly normality and equality of variances, which in turn limits the application of statistical analysis techniques.

Operator efficiency is also a factor that may have increased catch variability. Howland *et al.* (2001) stated that the biases of electrofishing are well known, and that while no gear type is ideal for all situations, this method has the most potential for obtaining a representative sample for the sites surveyed. The fish sampling program is intensive and requires 12 person days to monitor the sites. Teams generally consisted of two people, an operator and an assistant. Operator variability was minimised by selecting field teams from a limited pool of personnel. Teams were structured such that personnel with the least amount of experience were paired with experienced operators in an effort to reduce electrofishing variability via mentoring.

In summary, the power analysis report (appendix 9), based on data collected between December 2001 and April 2004, found that the low density of fish at some sites necessitated the pooling of data at the zone level for each monitoring event. While this reduced the number of zero catches in the dataset, it also eliminated within-sampling event replication for each zone. Individual species were also pooled into four groups to further consolidate CPUE data for each zone. The groups were 'all fish', 'native fish', 'galaxiids' and 'trout'. These groups were selected on the basis of environmental value and migratory behaviour.

Assessment of the data indicated that there is evidence of a temporal trend and zone trend for 'trout' and 'galaxiid' data groups, and these groups are not suitable for detecting a Basslink CPUE effect due to inherent sampling variation. The temporal trend in galaxiid catch rates is not surprising as the migration behaviour of the species in this group is characterised by a seasonal (spring) migration run of juvenile fish, as discussed in the results section of this report.

There was no evidence of a temporal trend for the 'native' and 'all fish' data groups, and so there is a high probability (0.8) that testing can detect a change as small as a doubling or halving of fish numbers for 'all fish', and a 3+ fold change in 'native fish' catch. It is interesting to note that while 'galaxiids' showed seasonal catch trends, the pooled 'native' group did not. Despite the fact that the majority of the members of the 'native' group are migratory, they have differing life history strategies and migration times, and so it is likely that potential seasonal trends in individual species CPUE have been masked in this group.

In light of the limited sensitivity of the monitoring program to detect changes in native fish abundance, alternative avenues to increase the power of the fish monitoring program will be explored within the fish monitoring program. However, it should be recognised that increasing the number of sampling sites has significant logistical limitations given the limited number of suitable landing sites in the Gordon River and its tributaries. Logistical considerations aside, analysis of the fish data has also shown that doubling spatial or temporal replication in an attempt to increase effect detection sensitivity would result in minimal increase in power. With these considerations in mind, preliminary investigations of alternative analysis techniques will primarily focus on further analysis of the native fish data from the downstream test zones, particularly zones 4 and 5.

## 11.6 Fish indicator variables

The capability and limitations of the fish monitoring data have been discussed previously, and this information is directly relevant to the development of appropriate indicator variables for the fish monitoring program. High data variability limited the number of suitable indicators to three catch per unit effort derived variables:

- CPUE for all species;
- CPUE for native fish; and
- ratio of trout CPUE to native fish CPUE.

These variables were derived from data collected from the test sites, which was pooled to the zone level. Pooling to zone level was necessary as a significant number of sites recorded zero catches for one or more monitoring trips, particularly in the upper zones. The development of indicator variables was based on test site data, as data from the reference sites is not representative of the pre Basslink status of fish stocks in the Gordon River due to fundamental differences in biological and physical characteristics.

As its name suggests, CPUE for all species was developed from pooled pre-Basslink catch data for all fish species in the test zones, both native and introduced. While there are significant differences in the environmental value of native versus introduced fish, the all species indicator is valuable in that it is the most sensitive variable capable of detecting a significant, non-species-specific post-Basslink effect. For example, post-Basslink environmental releases may benefit all species to the extent that the all species' CPUE consistently exceeds the baseline parameter.

Native fish represent a significant environmental value of the middle Gordon River. Species-specific CPUE indicator variables could not be developed for individual native species due to the limitations of the catch data, and so the native fish CPUE indicator variable was developed using pooled native species data from the test zones. While it is important to note that there are different migration strategies between the species included in this group, the indicator will serve to highlight departures from baseline catch rates for further analysis at the species level.

The ratio of CPUE for trout to CPUE for natives was derived to test the hypothesis that the post Basslink hydrological regime may have a differential effect on native and introduced fish populations. For example, environmental releases may improve trout recruitment within the main river, but convey little advantage to migratory native species, potentially leading to in increased competition with, and predation on, native species in the middle Gordon River. Triggering of this variable will require further assessment of the data to investigate the change in trout to native catch ratio.

Upper and lower trigger values were developed for the three indicator variables, for post-Basslink year 1 to year 3, for each season (spring and autumn), and annual values were developed for each post-Basslink year. Table 13.6 presents these triggers values.

# 12 Appropriateness of mitigation measures

As stated in chapter 1 (section 1.4.1), the BBR must, amongst other requirements, evaluate the appropriateness of the proposed mitigation measures based on the further data obtained through the Basslink Monitoring Program.

This chapter provides a detailed review of the mitigation measures to address potential Basslink impacts in the Gordon River. It commences with a review of the predicted post-Basslink impacts as understood at the time of writing of the Integrated Impact Assessment Statement in 2001 (section 12.1), the mitigation measures that were identified and considered at the time (section 12.2), and the rationale for selection of a minimum environmental flow and ramp-down rule (section 12.3). Section 2.4 provides an updated presentation of the Gordon River hydrology post-Basslink, incorporating all of the refinements to the TEMSIM model that have occurred over the past four years, and details of how the environmental flow will be delivered operationally through the power station. Section 2.5 provides a detailed evaluation of the mitigation measures, and the chapter concludes that these measures remain the most appropriate mitigation measures to accompany Basslink operation of the Gordon Power Station.

## 12.1 Predicted post-Basslink impacts

As part of the IIAS process, significant effort was directed towards modelling Hydro Tasmania's generation system and the likely changes in hydropower operation resulting from the inter-connection to the National Electricity Market. Without any mitigation measures, the TEMSIM model predicted that the variability of flow discharges from the Gordon Power Station would increase, with a greater number of high flow events, and a greater number of low flow events compared to the 'no-Basslink' scenario.

To understand the implications of this changed hydrology, a suite of studies were undertaken to investigate the changes to river condition since construction of the Gordon Dam and operation of the Gordon Power Station. During these studies, the focus was to interpret the existing condition of the Gordon River in the context of the impacts of the dam, and more importantly, the influence of power station operations on the ecological and geomorphological processes occurring within the river.

Prediction of the impacts of Basslink on the Gordon River environment were made by comparing the TEMSIM modelled hydrology post-Basslink, with the existing pre-Basslink hydrology and extrapolating the observed condition of the river to a predicted future state using the knowledge of the linkages between hydrology and the observed environmental processes. Individual studies were conducted on Gordon River in terms of hydrology, water quality, fluvial geomorphology, karst geomorphology, riparian vegetation, macroinvertebrates, fish, platypus, native water rats, terrestrial fauna, cave flora and fauna and meromictic lakes.

Given the hydrological changes anticipated with Basslink, the aspects of the Gordon River environment that were predicted, in the absence of any mitigation, to be most susceptible to significant change were geomorphology, riparian vegetation, macroinvertebrates and fish. The impact on platypus and native water rats was predicted to be linked primarily to the changes in their primary food source, macroinvertebrates, and to a lesser extent, potential changes in foraging behaviour.

No significant Basslink-related changes were anticipated for water quality, with the over-riding factor in water quality being the long-term management of Lake Gordon, rather than the short-term changes in operation predicted with Basslink. With karst environments, only minor effects on the sediment deposits near the Bill Neilson Cave entrance were anticipated. These sediment deposits are believed to have formed post-dam construction and hence are not considered to be of conservation significance. Investigation of the meromictic lakes of the Gordon River estuary floodplain were also undertaken, however, no potential for Basslink related impacts on these lakes was identified. There were no anticipated impacts on terrestrial fauna resulting from Basslink related hydrological changes in the Gordon River.

Without any mitigation, it was predicted in the IIAS that the following changes would occur post-Basslink:

- *fluvial geomorphology* - Changes to the geomorphic processes controlling stability of the Gordon River banks, notably with an increase in the probability of scour, and an alteration to conditions leading to bank saturation, thus modifying seepage erosion processes. Basslink changes are anticipated to be limited to adjustments of alluvial bank profiles, but no change to river planform compared to the existing effects of flow regulation;
- *riparian vegetation* - Accelerated rates of present trends, but result in the same end-point as the existing regime for the river banks upstream of the Splits, between the Low Water Mark (LWM) and 1.5 m. The existing zone of predominantly mineral substrate from LWM to 1.5 m will increase in extent to reach 2.5 m on the bank. The existing 1.5-2.5 m zone, characterised by reduced cover and diversity of riparian species when compared to unregulated reference tributaries, is predicted to migrate up to occupy 2.5-4 m zone, with a consequent loss of the existing 2.5-4 m zone. No changes are predicted above 4 m due to Basslink. With the predicted increased frequency of inundation and waterlogging expected to result in a lack of regeneration and recruitment, the majority of vegetation to a height of approximately 2.5 m above LWM,

particularly upstream of the Splits, will die and not be replaced in the long-term. As with the similar river bank erosional processes, an accelerated decline of island vegetation is predicted;

- *macroinvertebrates* - Shifts from a 3-zone to a 2-zone within-channel system are predicted. 'Thalweg zone' communities will adjust to a new quasi-equilibrium with a significantly lower abundance and diversity than at present. The 'mid-tidal' zone will disappear, and the 'upper tidal' zone with no macroinvertebrates will become broader downslope to meet the 'thalweg zone'. Further loss of snag habitat availability is predicted, as shorter periods of inundation are not long enough for colonisation. Losses are predicted in the 'thalweg zone' upstream of the Denison River of up to 50 % of extant taxa (i.e a drop of 0.2-0.3 O/E relative to the present mean of 0.9), and both sections will experience further decreases in abundance; and
- *fish* - Reduced habitat availability and increased stranding opportunities within the Gordon River are predicted and, along with reduced (macroinvertebrate) food sources, may lead to further reduced species abundance, particularly for native species. Fish migration is also an important component in determining the makeup of the Gordon River fish community, but the effect of Basslink on upstream passage has not been quantified.

## 12.2 Consideration of mitigation options

The predicted impacts of Basslink operations on the condition of the Gordon River were considered significant enough to warrant the investigation of mitigation strategies. In order to be considered viable, the measures at a minimum would be required to maintain the condition or existing rate of change in the Gordon River at pre-Basslink levels. A suite of potential mitigation options were identified in the IIAS by researchers to address changes expected to geomorphology, riparian vegetation, macroinvertebrates and fish. These were:

*Mitigation options for fluvial geomorphology:*

- A re-regulation dam;
- Physical buttressing of the banks;
- Reduction of the maximum power station discharge (to reduce zone of bank saturation);
- Partial power station ramp-downs or step-downs or similar measures (to reduce phreatic surface gradients in banks);
- Minimising the duration of 3-turbine discharge (to reduce the extent of bank saturation);

- Maintenance of a minimum environmental flow (to lessen scour of bank toe and reduce phreatic surface gradient); or
- A combination of these.

*Mitigation options for riparian vegetation:*

- Minimising the duration and/or magnitude of maximum discharges; and
- Implementing options to minimise bank erosion.

*Mitigation options for macroinvertebrates:*

- A re-regulation dam;
- Minimum environmental flows (to ensure water in the 'mid-tidal' zone and inundation of marginal snag habitats and increase habitat availability); and
- Ramp-downs (would have to be very slow for macroinvertebrates).

It should be noted that a minimum environmental flow to maintain habitat for macroinvertebrates also partially maintains food supply for fish and platypus.

*Mitigation options for fish:*

- Provision of a small (<10 $m^3 s^{-1}$) minimum environmental flow for fish habitat availability;
- Partial ramp-downs of power station discharges (to reduce stranding);
- Options that improve macroinvertebrate populations as food supply for the fish; and
- Manually restocking with natives.

Preliminary investigations into the utility of a re-regulating dam indicated that this mitigation measure had the potential to mitigate Basslink environmental impacts as well as to improve present environmental conditions, but was discounted as it would require a significant storage volume to be effective. In order to create this storage volume, the dam would need to be located some distance downstream of the power station tailrace and would result in the inundation of a significant additional portion of the Gordon River including Abel Gorge. These impacts, combined with the impacts of construction and access to the site far outweighed the potential benefits of such a mitigation measure and it was therefore not pursued any further.

Physical buttressing of the river banks is a measure that has been successfully adopted for other rivers, however the application of this technique in the Gordon River would be problematic due to access and logistical constraints, cost, and requirements for power station shut-down time.

Such a measure was also considered to be counter to World Heritage Area management guidelines for the Gordon River, which dictate that natural processes should govern management actions where possible. For similar reasons, the use of artificial fish stocking in the Gordon River and tributaries was also rejected.

The remaining options were all focussed on modifying the operation of the Gordon Power Station in order to mitigate the predicted Basslink impacts. These measures were favoured as they did not entail any significant additional impact to the downstream environment, and directly addressed the underlying issue associated with Basslink - changes in power station discharge patterns. These measures were also considered to be more in keeping with WHA management guidelines, involved less environmental risk and would be easier to manage adaptively as future monitoring information became available.

Early analysis of the modelling results suggested that Basslink was likely to significantly increase the percentage of time (from 9 % pre-Basslink to 29 % post-Basslink) that power station discharges would exceed 210 $m^3 s^{-1}$. This magnitude of increase would have had the effect of increasing bank saturation and predisposing the banks to higher levels of seepage erosion during power station shut-down. Mitigation of this effect could be achieved be limiting either the maximum discharge from the power station or limiting the duration of high-flow events. Further analysis of the situation revealed that during the period of time (1978-98) that was used to represent the pre-Basslink hydrology the Gordon Power Station was significantly restricted in terms of maximum output due to transmission capacity. When a more representative dataset was used in the comparison, it was clear that Basslink would not significantly increase the occurrence and/or duration of high flow events, and the need for a Basslink mitigation measure to address this issue was negated.

## 12.3 Selected mitigation strategies

Of all the mitigation options considered, the provision of a minimum environmental flow and the implementation of a power station ramp-down rule for high discharges were considered to be the measures that would be most effective in offsetting the anticipated impacts of Basslink on the Gordon River environment. These measures are discussed in more detail in the following sections.

### 12.3.1 Minimum environmental flow

The objective of a minimum environmental flow is to provide a mitigating measure for the impact on in-stream biota by increasing the permanently wetted area of the river channel, thus maintaining more permanently wetted habitat than occurs pre-Basslink. This area could therefore act as a more effective refuge for aquatic biota during hydro-peaking cycles and would counteract the negative influences of Basslink related flow variability. The minimum flow also has the potential to provide minor geomorphic advantages, in that it would increase channel inundation and reduce scour associated with higher water velocities during power station start-up.

Determination of the minimum flow targets was undertaken by considering the hydraulic and habitat characteristics of a suite of representative channel cross-sections in the Gordon River in comparison to the habitat preferences for specific aquatic biota. Modelling the co-occurrence of suitable substrate, water velocities and water depth for a wide range of species, including a selection of macroinvertebrates, fish and platypus, allowed an analysis of available habitat area for these species at different flow rates within the river. These modelled 'Weighted Useable Areas' (WUA) were then expressed as percentages of the WUA available at a reference flow, and classified into habitat risk bands. Flows of any particular magnitude could therefore be expressed in terms of the % WUA available for a species and a judgement on the level of habitat risk for each group of taxa could be made for those different flows.

The amount of useable habitat available for a species rarely follows a linear relationship to the discharge of the river. Some species have more habitat available at low flows, due to a preference for shallow, slow moving water, whilst others may be best advantaged at high flows where, for instance, particular substrates become inundated. Hence the determination of the minimum flow rate will always be a compromise between species. To address this, the IIAS studies identified the minimum flow rates on those taxa that were considered most at risk in terms of % WUA and then used the interaction of the habitat area curves for these species and accepted risk boundaries to derive the recommended minimum flow. This process was undertaken for the hydrological summer (Dec-May), and hydrological winter (Jun-Nov) using different reference flows to reflect the natural seasonality of stream flow in the catchment, thereby leading to a different minimum flow recommendation for each season.

For the minimum environmental flow regime for the Gordon River, it was determined that a minimum of 19 $m^3 s^{-1}$ would be maintained from December-May each year and a minimum of 38 $m^3 s^{-1}$ at all other times, with the exception of periods where a full outage of the Gordon Power Station was required for either maintenance or environmental monitoring in the Gordon River. This is known as the 19/38 minimum flow regime. The location for measuring compliance with these criteria was agreed to be a point just upstream of the junction of the Gordon and Denison Rivers, known as Site 65, some 12 downstream of the Gordon Power Station discharge point. These criteria are set out in Hydro Tasmania's Water Licence under the Water Management Act 1999.

As there is a certain amount of catchment runoff entering the river between the power station and the compliance site, the amount required to be released by Hydro Tasmania to meet its licence commitments is variable and equates to the difference between the stipulated flow at site 65 and the catchment pickup to that point. It is estimated that natural inflows will fully meet the required minimum flows for 7 % of the time on average. At all other times, excepting maintenance and monitoring outages, Hydro Tasmania will need to release water to meet the environmental demand downstream.

A number of strategies were examined by Hydro Tasmania in order to identify the most cost effective method to deliver the required minimum flows. These strategies fell into two main options:

- releases from the Serpentine Dam; or
- discharges from the Gordon Power Station.

The Serpentine Dam options involved either the installation of siphons at the dam or the modification of the dewatering gate. Both options would involve significant capital works, with both options likely to cost greater that $1 million. In addition to this, water released from the Serpentine Dam could not be used to generate electricity as the infrastructure to allow this would be prohibitively expensive. The value of foregone electricity generation associated with releases from Serpentine Dam is estimated to be greater than \$83 per $m^3 s^{-1}$ (i.e. ~\$40,000 per day at 20 $m^3 s^{-1}$). The combination of high capital costs and large loss of revenue associated with releases make provision from the Serpentine Dam uneconomic.

Utilising the Gordon Power Station to release the minimum flow requirement allows electricity generation to occur whilst making these releases and as a result, the value of foregone generation revenue is significantly reduced. Three options were investigated:

- Exact generation using the existing turbines;
- Installation of a dedicated 4th turbine; and
- Operation of the existing turbines either at 17-20 $m^3 s^{-1}$ or above 55 $m^3 s^{-1}$.

Early TEMSIM modelling indicated that the most cost-efficient minimum flow delivery strategy would be to match the environmental demand of downstream with exact generation at the power station. Hence if a flow target of 38 $m^3 s^{-1}$ was to be achieved (i.e. the winter target), and the catchment pickup at that point in time at site 65 was 12 $m^3 s^{-1}$, one of the power station turbines would be operated to discharge the balance of 26 $m^3 s^{-1}$, therefore achieving the minimum flow, without generating excess power when it was not required. By avoiding excessive 'out of merit order' generation in this way, water in the Gordon-Pedder storage could be retained for more profitable electricity market periods and significant savings made.

Further examination of this delivery strategy identified that extended operation of the Gordon Power Station in the range between 20 and 55 $m^3 s^{-1}$ did not comply with the turbine manufacturer's specifications, and there were significant issues with machine vibration and cavitation in this range. Extended operation below 17 $m^3 s^{-1}$ is similarly not recommended, therefore an 'exact generation' strategy could only be employed for a limited amount of time and an alternative was required.

Recognising the advantages in terms of water efficiency of an exact generation strategy, the option of installing an appropriately sized turbine into the 4th or 5th empty machine bays of the Gordon Power Station was investigated. Such a turbine would be optimised for the flow rates required to meet the environmental demand and would provide power at the full hydraulic head of the Gordon Power Station, hence resulting in maximum efficiency of water use, combined with the ability to accurately meet the minimum environmental flow recommendations. Cost estimates for the incorporation of a 35 MW 4-jet pelton wheel turbine came to approximately $25 million to procure with a further $10 million for installation. This $35 million price tag is far greater than the estimated present value of such a machine. In addition to this, the extra costs of generating out of merit order still needed to be factored in, leading to the conclusion that this minimum flow delivery strategy also was not economically viable.

The remaining option is to operate the Gordon Power Station within the manufacturer's specifications to deliver flows at either 17-20 $m^3 s^{-1}$, or above 55 $m^3 s^{-1}$ depending on the environmental demand downstream. The Gordon turbines have very low power generation efficiency (~30 % of optimum) in the 17-20 $m^3 s^{-1}$ range and therefore significantly less power is generated for a given volume of water passing through the power station. Releases of 55 $m^3 s^{-1}$, are more efficient (~98 % of optimum), but the release volumes are in excess of the minimum flow compliance requirement. This results in either inefficient electricity generation at low flows or excess power generation at other times that may not be favourable in terms of electricity market pricing.

In both cases, the revenue gained from power generation to meet the minimum flow requirement is relatively low and there is an overall cost to Hydro Tasmania. The costs are estimated to total an average of $4.1 million per annum. Despite this cost, analysis has shown that this delivery strategy is still the most cost efficient option and provides the best combination of energy efficiency, reduced out of merit order water loss, low capital cost and relatively simple operating rules. Hydro Tasmania therefore currently intends to meet its minimum flow obligations using this '17/55' delivery strategy.

As a commercial business, Hydro Tasmania will continue to explore cost-efficient methods to achieve the objectives of this minimum environmental flow whilst maintaining its commitment to sustainability. A particular proposal under consideration is maintenance of a 10/20 rather than 19/38 $m^3 s^{-1}$ minimum flow at the compliance site. The 10/20 minimum flow would represent a considerable cost saving by making more water available for generation at energy-efficient discharge levels and optimal market periods. Any such proposal will need to verify that it can adequately mitigate Basslink impacts and not cause unacceptable environmental risk.

### 12.3.2 Ramp-down rule

One of the major concerns highlighted during the IIAS process was the potential for increased seepage induced erosion of the Gordon River banks. Seepage erosion was identified as a major process leading to bank instability and collapse in the 2-3 -turbine bank level, and to a loss of overlying vegetation. Loss of vegetation in turn was found to be an important factor in further decreasing bank stability. The highest risk of seepage-induced erosion was found to occur under conditions were the banks were fully saturated, such as after prolonged full-gate power station operation, followed by a complete shut-down of the power station. Under these conditions, a very steep phreatic surface gradient is present in the river banks. Field investigations during the Basslink investigations consistently showed that under these conditions the banks were most unstable and sand was being actively moved through voids in the bank profile downslope and deposited at the bank toe. These unconsolidated sediments were then susceptible to scour during the next high flow event, thereby continuing bank instability and riparian vegetation loss.

The TEMSIM modelling during the IIAS process predicted that post-Basslink, there would be greater number of high flow, 'full-gate' discharge events, followed by rapid drops in water level as the power station shut-down (Locher 2001). Each of these hydro-peaking cycles would increase the potential for seepage erosion to occur and a measure was sought to reduce the rapid draining of the banks during river drawdown, thereby reducing seepage erosion and one of the main mechanisms of bank loss in the Gordon River. The IIAS investigations concluded that the groundwater recharge of the river banks was very rapid (a matter of hours) during high river flows and the need to control bank drainage during drawdown was apparent for all power station discharges above 210 $m^3 s^{-1}$ exceeding 1 hour in duration. Subsequent monitoring, evaluation of the bank piezometer data and modelling using SEEP-W software has determined that it was appropriate to reduced this threshold and control the drawdown of any flows that exceed 180 $m^3 s^{-1}$ for over 1 hour.

In order to control bank dewatering a power station ramp-down rule was formulated which states that if the Gordon Power Station has been discharging water at greater than 180 $m^3 s^{-1}$ for more than 60 minutes, and water discharges are to be reduced to less than 150 $m^3 s^{-1}$ for any period, then Hydro Tasmania must ensure that water discharges from the Gordon Power Station are reduced from discharges above 180 $m^3 s^{-1}$ down to 150 $m^3 s^{-1}$ by not more than 30 $m^3 s^{-1}$ in any 60 minute period. The ramp-down rule decreases in-bank water surface slopes following high flows by requiring the power station to shut-down at a slower rate as compared to present. The lower recession rate of the river allows water to drain from the bank at a lower slope such that water exiting the bank has insufficient energy to transport sediment through the bank profile.

The ramp-down rule was successfully field-tested prior to its acceptance as a mitigation measure with approval of Basslink. It is anticipated that this 180/150 ramp-down rule will mitigate the anticipated increases in seepage erosion associated with Basslink hydro-peaking, and will therefore maintain current trends in river geomorphology. Hydro Tasmania will be implementing this strategy with the commencement of Basslink operations.

## 12.4 Gordon River hydrology incorporating the minimum flow and ramp-down mitigation measures

Since the IIAS, the TEMSIM model that has been used to predict Basslink operation of the Gordon Power Station has been refined significantly and can now take into account likely system conditions such as lake levels that were not possible to accurately predict in 2001. Analysis of the new Basslink modelling indicates that the post-Basslink hydrology for the Gordon River will be less extreme than initially predicted during the IIAS. This is consistent with analyses at the time, which suggested that the TEMSIM model was not a perfect representation of the Hydro Tasmania generation system and did not incorporate all of the real-world constraints that affect the operation of the Gordon Power Station. Incorporation of many of these constraints into the model and the addition of hydrological data as it has become available since 2001 has significantly improved the utility of TEMSIM in predicting future operations. The minimum flow and the ramp-down strategies, that have now been included in the model, have been shown to have a significant influence on the operation of the Gordon Power Station and have modified the hydrological predictions for the river substantially.

These new hydrological predictions can now be compared with real, rather than modelled, hydrological data for the period leading up to Basslink, and a more meaningful analysis can also be made based on increased data from the Basslink Monitoring Program. These hydrological data are considered in the following sections of this report when discussing the effects and adequacy of the adopted mitigation measures. Figure 12.1 compares the predicted post-Basslink flow exceedence curves with the last 5 and 15 years of historical data. Figure 12.2 provides a breakdown between the hydrological summer and winter for the predicted flow exceedence patterns. It should be noted that the modelled TEMSIM data does not incorporate total power station shut-downs for the purposes of environmental monitoring or station maintenance, whilst the historical data does. This is estimated to affect the statistics for low flows for less than 10 % of the time.

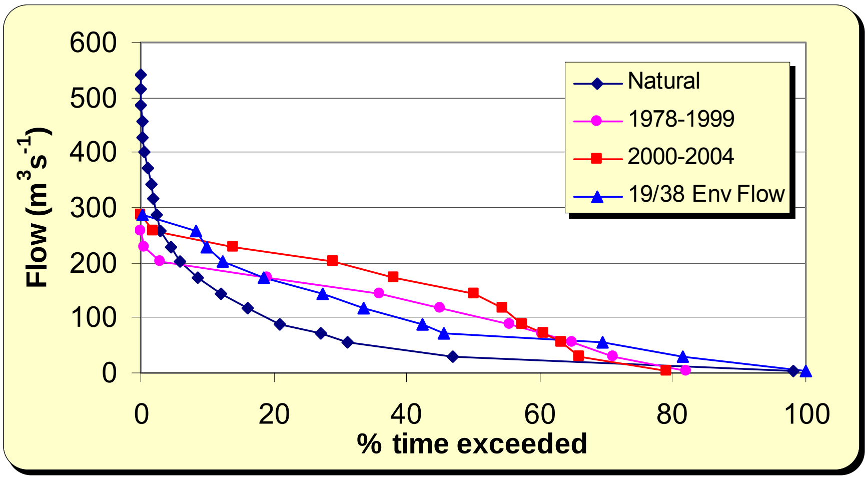

Figure 12.1. Comparison of the post-Basslink 19/38 predictions with natural and historical power station discharges at the power station. All curves based on hourly flow data at the Gordon Power Station with the exception of the 1978-99 curve which is based on daily flow records (no hourly records are available for this time period). Natural flows are based on actual and modelled flows between 1958-73.

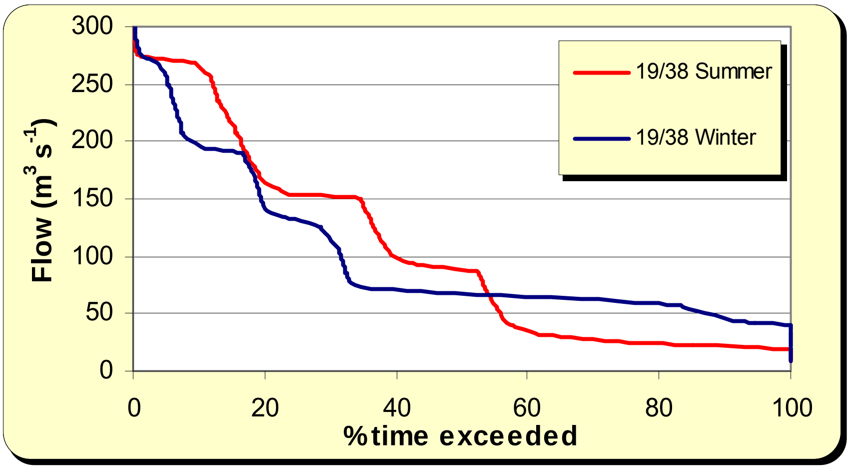

Figure 12.2. Seasonal breakdown of the post-Basslink flow exceedence curves at the environmental flow compliance site (site 65).

The key features of new predictions for post-Basslink hydrology are:

- a trend to increased flow variability (hydro-peaking) post-Basslink is still predicted and remains as one of the primary ecological and geomorphic drivers in the Gordon River;
- the overall amount of 3-turbine, full-gate operation that was previously predicted will be reduced and will be comparable to present (pre-Basslink) operations;
- the amount of operation in the 100-200 m3 s-1 range (2-3 turbines) will be significantly reduced with respect to historical operation;

- the dominance of flows in the 55-85 m3 s-1 range (1-turbine) is significantly increased, particularly during the hydrological winter, in order to meet the minimum environmental flow requirement;
- the minimum flow will not be maintained whilst the Gordon Power Station is fully shut-down for maintenance or environmental purposes. Long shut-downs for critical maintenance are typically scheduled for the wettest period of the year (Sept-Oct);
- the predicted percentage exceedence statistics for flow patterns in the Gordon River post-Basslink are closer to what would be expected in the natural system than have been observed over the last 5 or 15 years of historical operation; and
- the significant difference in Gordon Power Station operation between winter and summer will continue post-Basslink. This seasonal variability is often greater than the variability in river flow patterns between years.

In summary, the hydrological predictions for the Gordon River are less extreme in terms of variability and high flows than the modelling presented during the IIAS in 2001, but still features a significant degree of hydro-peaking that is offset by the implementation of a minimum environmental flow and ramp-down rule. The anticipated effectiveness of these measures in maintaining the condition or trends observed during four years of the pre-Basslink monitoring period is discussed below.

## 12.5 Anticipated environmental response to the mitigation measures

The following sections review the mitigation measures from the perspective of each scientific discipline, based on the greater knowledge of the predicted Basslink hydrology, the delivery strategy for the minimum flow, and riverine function through the BMP. The fluvial geomorphology analysis is undertaken in considerable detail, to evaluate the risk that the minimum environmental flow may cause an increased risk of scour of the Gordon riverbanks.

### 12.5.1 Fluvial geomorphology

#### *12.5.1.1 Sediment transport modelling background*

As part of the IIAS, the potential sediment transport capacity of the middle Gordon River was modelled under the natural, pre-Basslink, and modelled Basslink flow regime by researchers at Melbourne University (Wilkinson and Rutherfurd in Koehnken, *et al.* 2001). The modelling calculated the potential transport capacity of the river at three sites in the river in geomorphic zones 1, 2 and 4, respectively. The model estimates the theoretical sediment load a river could transport if an infinite supply of sediment was available. It does not take into account stabilising influences such as vegetation, or large woody debris, and should be considered as a tool for comparing the *relative* rather than *actual* potential of the Gordon River to scour the bank toe under varying flow regimes.

Initial hydraulic analysis associated with the modelling indicated that even at low flow, with the power station off, the shear stress was above that required to entrain the sediment sizes present on the bank toes. Total potential sediment transport is therefore related to the time-weighted sediment transport rate for each flow level, as there is no threshold flow value required for sediment entrainment (if sediment is available). The model examined the three flow regimes (natural, the flow regime in 2000, and the projected Basslink flow) and compared the results as a relative indication of potential changes to bank toe scour. The full modelling report is available in Koehnken *et al.* (2001).

Using updated flow duration curves, the model has been re-run for site 75 (zone 1). Site 75 is being used because it is the only site of the original three investigated for which there are modelled updated post-Basslink flows. This site is of relevance because virtually all of the flow is controlled by power station usage, so any changes in the model results are the direct result of power station operations, rather than changes to unregulated in-flows.

The other change to the model has been the lowering of the relative 'zero' water level height on the bank toe. In the initial modelling, the 50 $m^3 s^{-1}$ bank level was assumed to be the bank toe, with all other flow levels referenced back to this height. This resulted in a relative sediment transport rate of '0 $kg s^{-1}$' for 50 $m^3 s^{-1}$, with values increasing with water depth. Because the low end of the hydrograph is of interest with respect to the proposed environmental flow, the reference level on the bank was reduced to the 2.5 $m^3 s^{-1}$ flow level. For this reason, the potential sediment transport results are higher, and not directly comparable to the original modelling.

#### *12.5.1.2 Updated sediment transport model*

The following steps were completed as per the original modelling, and replicated for this BBR review of the post-Basslink 19/38 environmental flow regime:

- Flow levels at site 75 were converted to water heights relative to the 2.5 $m^3 s^{-1}$ bank height;
- Shear stress for flow levels between 2.5 and 550 $m^3 s^{-1}$ was calculated using the same equation as in the initial modelling;
- Relative sediment transport for each flow level was calculated using the shear stress results and the updated Ackers-White function as previously applied;
- The sediment transport results were time-weighted using flow duration curves to provide a relative sediment transport capacity for each flow regime; and

- ➢ The total potential sediment transport capacity for each flow regime was calculated by summing the sediment transport associated with each flow interval.

The flow duration curves, and sediment transport curves are shown in Figure 12.1 and Figure 12.3, respectively.

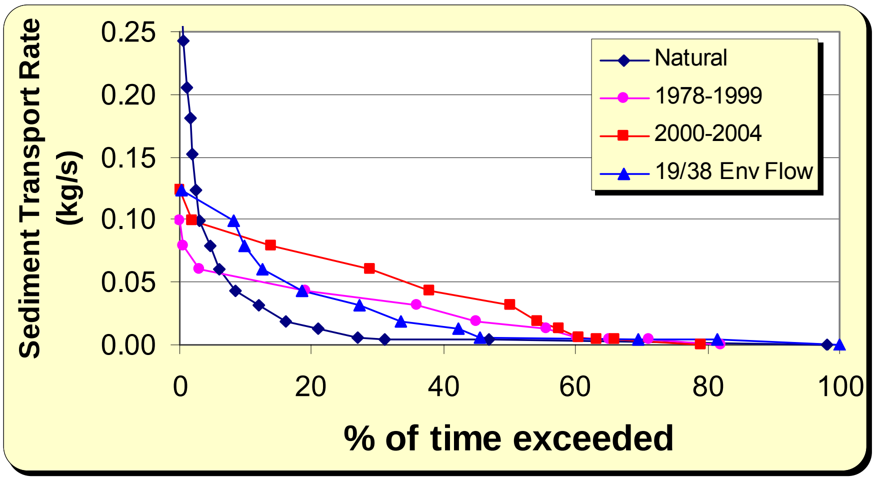

Figure 12.3. Relative sediment transport rate for each flow duration curve based on shear stress and potential sediment transport. Sediment transport rates are relative to a baseline of 2.5 $m^3 s^{-1}$ (i.e., sediment transport at 2.5 $m^3 s^{-1}$ is considered to be '0').

Figure 12.4 shows the sediment transport associated with each flow regime, based on time-weighting of the sediment transport rate curves (i.e. duration of flow interval x sediment transport rate for interval). The sediment transport curves show a reduction in sediment transport at flows >280 $m^3 s^{-1}$ for all regulated flow regimes. It is also evident that the pre-Basslink period (2000-04) has had the highest relative sediment transport of all of the periods, associated with the long duration of 3-turbine power station operation. The post-Basslink curve shows a reduction in relative sediment transport compared to the pre-Basslink period, with a shift in sediment transport towards higher flow rates as compared to the 1978-99 regulated flow time period.

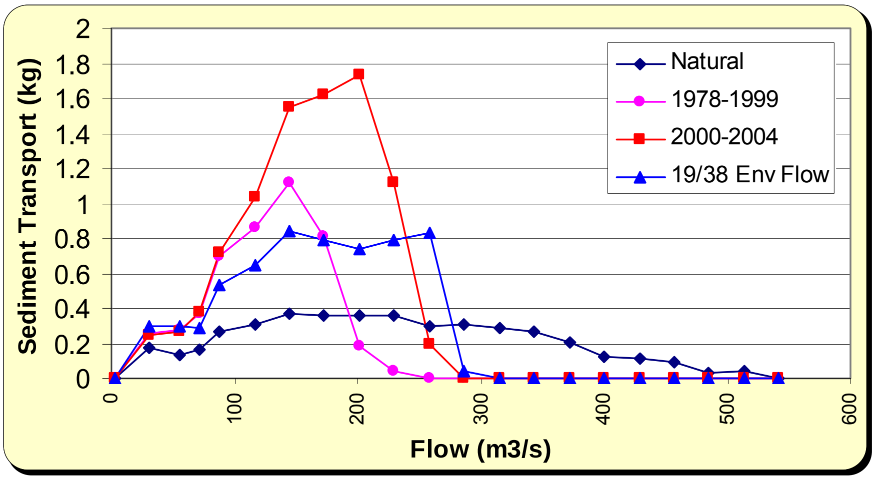

Figure 12.4. Sediment transport curves for each flow regime. These curves should be considered relative only.

The overall trends are summarised Figure 12.5, with all regulated flow regimes showing a relative increase in sediment transport capacity as compared to the pre-dam natural conditions. The pre-Basslink period has had the highest transport capacity, with the post-Basslink 19/38 environmental flow regime predicted to decrease potential sediment transport capacity relative to the present, but increased by about 25 % compared to the 1978-99 time period.

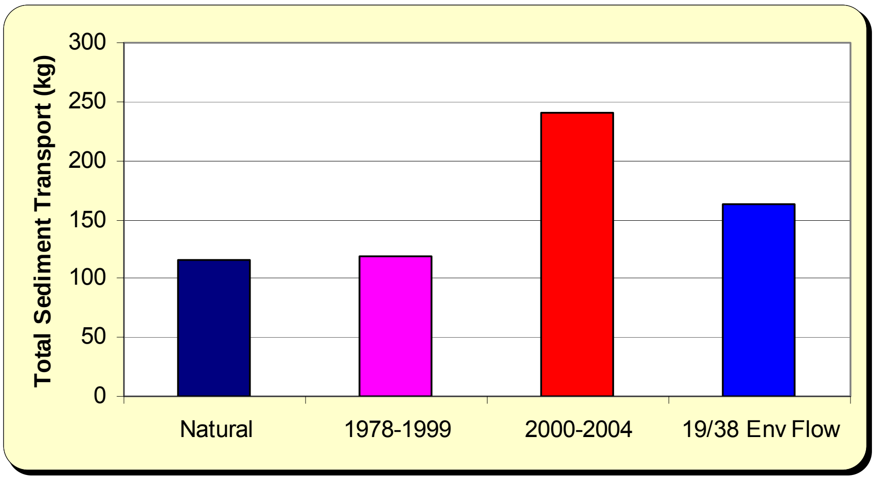

Figure 12.5. Total sediment transport for each flow regime, based on integrating the area under the curves in the previous figure.

The modelling results show that the extended 55 m$^3$ s$^{-1}$ flow associated with the 19/38 flow regime marginally increases the sediment transport associated with the ~50-60 m$^3$ s$^{-1}$ flow range (Figure 12.4), but the majority of sediment transport potential continues to be associated with the higher flow rates. The modelling also shows that relative to the 2000-04 pre-Basslink flow regime, potential sediment transport capacity is projected to decrease under the 19/38 environmental flow regime due to a reduction in the duration of flows between ~60 and ~225 m$^3$ s$^{-1}$. Relative to pre-Basslink conditions, the sediment transport capacity is predicted to increase at very high flow rates (>250 $m^3 s^{-1}$) reflecting a 6 % increase in power station operation in this flow range (Figure 12.1) compared to present.

#### *12.5.1.3 Summary of modelling*

The model results show that under the proposed 19/38 environmental flow regime to be implemented post-Basslink, sediment carrying capacity of the river in the 50-60 $m^3 s^{-1}$ flow range will increase marginally compared to present conditions, but this flow range accounts for a very small percentage of the total potential sediment transport capacity of the river (~3 %), with high flows continuing to dominate sediment transport capacity. Under the 19/38 environmental flow regime, the potential sediment transport capacity of the river will reduce relative to present conditions. This does not translate to reduced erosion rates in the river under the environmental flow regime, as erosion is dependent on the availability of material for transport, such as from bank slumping. What the model results indicate is that the total shear stress on the toe under the 19/38 flow regime will reduce relative to present conditions.

These results are not transferable to downstream areas, as the timing of unregulated in-flows relative to power station usage is a major factor in sediment transport. High power station discharge which coincides with a large storm events (which rarely occurs under the present flow regime), will substantially increase the sediment transport capacity of the river relative to 3-turbine flow in the absence of downstream in-flows. A discussion of how the timing of the 19/38 flow regime will affect bank erosion is presented in the next section.

#### *12.5.1.4 Impact of the minimum flow measure on bank erosion*

The sediment transport capacity analysis shows that the river can transport sediment at all flow levels, with the greatest transport capacities associated with high flow. This indicates that bank erosion in the middle Gordon River is more dependent on the availability of sediment for transport, rather than flow rates. Sediment availability in the middle Gordon River has increased markedly since flow regulation due to the large-scale loss of vegetation from alluvial banks, and the occurrence of seepage induced bank slumping on alluvial banks, primarily upstream of the Denison River. This section examines the potential impact of the increased number of 55 $m^3 s^{-1}$ flow releases associated with the environmental flow on present erosion trends in the middle Gordon. This analysis is based on the erosion trends presented in chapter 7 Fluvial geomorphology and the projected timing of environmental flow releases post-Basslink.

The 55 $m^3 s^{-1}$ environmental flow is equivalent to the minimum efficient discharge of 1-turbine. To assess the present impact of 1-turbine discharge on the middle Gordon, the same erosion trends for zones 2-3 and 4-5 as presented in chapter 7 are shown in Figure 12.6 and Figure 12.7. The figures have been modified, and the below 1-turbine erosion trend has been labelled with the percentage of time that flow from the power station was limited to one turbine during each monitoring period (% time) and number of 1-turbine on-off events occurring during the monitoring period.

The figures show that during the Basslink baseline monitoring, there have been two time periods when 1-turbine power station operation has been high: autumn-spring 2003, and autumn-spring 2004. Both of these periods occurred over winter, when in-flows are high, and water is available in other hydro schemes, resulting in reduced operation of Gordon Power Station.

In zones 2 and 3, prolonged-duration 1-turbine operation coincides with periods of net deposition in the below 1-turbine bank level, but with erosion in the 1-2-turbine bank level. In these zones sediment delivery from upstream is minor, and the winter deposition is believed to be associated with the downslope transport of material from exposed bank faces during rain events (Photo 12.1, Photo 12.2), and in zone 3, also from the deposition of sediment in the backwater created by floods in the Denison during power station-off conditions.

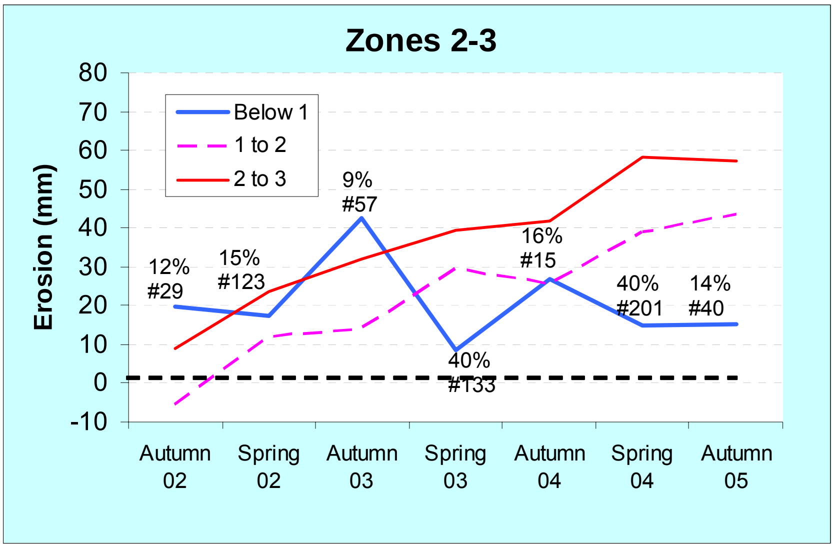

Figure 12.6. Erosion trends in zones 2 and 3 showing the flow duration (% time) of 1-turbine power station operation and the number of 1-turbine power station events during each sampling interval.

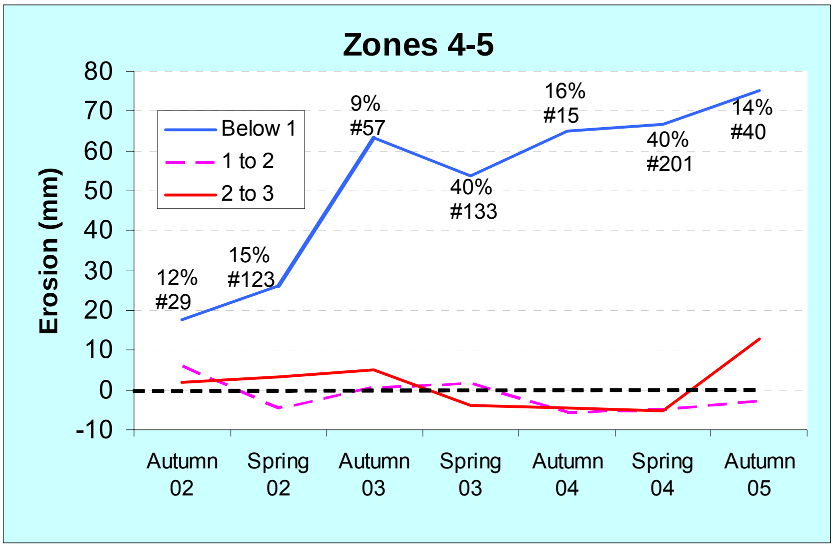

Figure 12.7. Erosion trends in zones 4 and 5 showing the flow duration (% time) of 1-turbine and the number of 1-turbine power station events during each sampling interval.

Photo 12.1. Erosion of exposed bank in zone 1 by rainfall during power station shut-down. Sediment is being transport by sheetwash and through rills. Deposition occurs at water level, as shown in next photo.

Photo 12.2. Deposition of sediment in 0-1-turbine zone through erosion of upslope bank.

In zones 4 and 5, the two periods of extended 1-turbine operation show deposition (autumn 2003-spring 2004) or relatively low rates of erosion (autumn 2004-spring 2005) in the <1-turbine level, with no clear trend in the other bank levels. The reduced erosion and deposition during winter is associated with the deposition of sediment from the unregulated in-flows during natural storm events.

In summary, recent prolonged operation of 1-turbine has only occurred during periods of high in-flows, and has been associated with deposition in the 0-1-turbine bank level in zones 2-5, and erosion in the 1-2-turbine level in zones 2 and 3. These trends, however, are not the direct result of the 1-turbine flow *per se*, but rather the greater influence of natural rainfall events occurring during low discharge from the power station.

The increased discharge at the 55 $m^3 s^{-1}$ level associated with the environmental flow will differ from present conditions, in that the flow will occur predominantly during dry periods, rather than wet periods when natural in-flows do not achieve the environmental flow target at site 65. During these periods, deposition from the downslope movement of material, or fluvial deposition from natural high flow events will not occur, so the net impact will be no change or erosion. The sediment modelling shows the 55 $m^3 s^{-1}$ flow increasing sediment carrying capacity a small amount relative to present conditions, with the duration of the high flows continuing to dominate potential sediment carrying capacity in the river. In zones 1-3, where bank toes are relatively stable, the environmental flow is unlikely to affect bank profiles or stability. In zones 4 and 5, where toes are eroding, there may be an increase in toe erosion associated with the environmental flow level, however, this will be offset by a reduction in high flow events (which presently correlates with toe erosion) as compared to present conditions.

#### *12.5.1.5 Impact of the ramp-down rule*

Prolonged 3-turbine power station usage results in elevated in-bank water surfaces, with water levels equivalent to river levels recorded >25 m inland from the river bank. Following power station shut-down, the river water level drops rapidly, creating high in-bank water surface slopes draining towards the river. Seepage erosion occurs when these in-bank water surface slopes are sufficient to entrain and transport sediment down the bank face. This process is most common in zones 2 and 3, where water fluctuations of up to 4.5 m occur over short periods of time.

Although summer seepage was identified in the field as a major process, the erosion pin results from zones 2 and 3 indicate that the 2-3 -turbine level is also eroding at a relatively constant rate through scour (erosion pin results exclude cavity pins), suggesting that scour and seepage are operating in the 2-3 -turbine zone. The 1-2 -turbine level pins results from the same zones do show seasonality, with reduced erosion recorded in autumn, following prolonged periods of extended power station operation. This seasonal reduction in erosion is interpreted as reflecting deposition due to seepage erosion, with the material derived from upslope (2-3 -turbine level). This newly deposited material and additional underlying bank material is scoured from the banks following re-initiation of power station operation, resulting in net erosion of the 1-2 bank levels.

Reducing seepage events in the 2-3 -turbine zone are likely to reduce deposition in the 1-2 -turbine bank level, potentially eliminating the seasonal trend shown in the erosion pin results. However, the 1-2 -turbine erosion pin results do not show a bank which is in equilibrium once the seepage related deposition is removed, rather, the long-term trend is erosion, with a seasonal reduction due to the increased deposition from seepage. Therefore, it is possible that if the seepage deposition is reduced, net erosion of the 1-2 erosion pin level will increase due to scour. This may lead to bank steepening and destabilization.

Overall, the implementation of the ramp-down rule is likely to reduce seepage induced erosion but is may alter the relative contribution of scour and seepage erosion processes to bank erosion in zones 2 and 3. This may alter the net rate of erosion, but based on the long-term erosion pin results, it is unlikely to halt the long-term erosion trend. Continued monitoring of the effectiveness of the ramp-down rule in maintaining the pre-Basslink trends will be required.

### 12.5.2 Water quality

Water quality, particularly water temperature, is influenced by releases from the Gordon Power Station. Under present operations, there is short-term variability in the temperature of the river.

When the power station is operating, the thermal regime of the river is dominated by these releases and reflects the temperature of Lake Gordon at the depth of the power station intake. During power station shut-down, the tributaries of the Gordon River are providing water at ambient temperatures, which are warmer than the power station discharges in summer and cooler in winter.

Presently, the thermal regime of the Gordon River is dominated by commercial operation of the Gordon Power Station throughout the year, totally approximately 75 % of the time. Providing a minimum flow for the river via the power station will have the effect of extending this influence, resulting in a thermal regime that is dominated by the Lake Gordon temperatures for approximately 85 % of the time. For the other 15 % of the time, the minimum flow is either met by natural inflows (7 %) or does not apply during maintenance or monitoring outages. Most of these periods will be of short duration, as they are under present operations, and any periods of thermal recovery are unlikely to be of any ecological significance. Longer shut-downs associated with major refurbishment works at the power station are typically undertaken during the wetter, cooler and biologically less active months where the difference between power station discharge and ambient tributary temperatures are low. It is anticipated that the benefits of the minimum flow in terms of refuge and habitat area will far outweigh the small increases in thermal regulation.

The ramp-down rule will have little effect on downstream water quality. This mitigation measure operates when the discharge volumes are high and thermal regulation effects are at their maximum. It is unlikely that this measure will have any effect on dissolved oxygen levels, unless air injection is used to smooth vibration during turbine ramp-down. This will be monitored through the BMP.

### 12.5.3 Karst geomorphology

The minimum environmental flow for the river will be of little consequence to the caves because, at such low levels, the river does not inundate any of the features of interest. The ramp-down rule should benefit the caves by reducing the speed at which water recedes from the caves after high discharges and thereby limit the potential for erosion of sediments in these areas. There are no anticipated risks associated with either measure for karst geomorphology.

### 12.5.4 Riparian vegetation

The minimum environmental flow is not likely to have a major impact on the riparian vegetation of the middle Gordon River due to the lack of vegetation in the river channel below the 1-turbine level on the bank. There will be a reduced time that these sites are exposed, and subsequently suitable for seedling establishment however this impact is considered minor for two reasons: the existing recruitment is very limited and sporadic in these areas; and there is little persistence of this recruitment. Potential impacts may be greater on some of the cobble bars where there has been some successful recruitment. The increased waterlogging and reduced opportunities for gaseous exchange in the sediments may lead to increased oxygen stress in these areas. Given the low abundance of extant vegetation in these areas, this impact is unlikely to be of significance.

Potential positive effects of a minimum environmental flow may include greater propagule transport along the river in times of traditionally low flows following shut-downs that may coincide with propagule dispersal times. Whilst propagule availability is not likely to be the main limitation on recruitment, more continual baseflows may reduce impacts of the riparian corridor fragmentation.

The ramp-down rule will lead to lower in-bank water surface slopes and subsequently slower drainage of banks following shut-downs. This slower water recession has the potential to lead to a lack of drainage or water exchange in slower-draining sediments such as silts, which may increase waterlogging effects on plant roots for substantial distances from the bank. Given this area is currently dominated by rainforest species, the ability of the vegetation to adapt may be limited and stress indicators may become apparent. The current monitoring program includes monitoring of bank drainage, and assessment of tree species further up the bank to detect such impacts.

Positive impacts on geomorphology from this mitigation option have potential benefits for riparian vegetation. If the ramp-down rule results in a decrease in sediment erosion, this will reduce the instability of banks and subsequent loss of overlying riparian vegetation, especially in zones two and three.

### 12.5.5 Macroinvertebrates and algae

The provision of a minimum environmental flow is the main measure targeted towards mitigating the adverse impacts of hydro-peaking on macroinvertebrates and algae. An evaluation of the anticipated post-Basslink hydrology and its effects on habitat availability in the compliance reach near site 65 (Figure 12.8) was undertaken as part of another study to investigate the viability of an alternative minimum flow scenario (Davies 2005; Howland 2005).

For each transect, the available habitat for a range of species that are known to exist in that location was calculated using the hydraulic and habitat characteristics of the river, and the habitat preferences for those species. The habitat preferences were derived from samples taken in a comparable reach of the Franklin River and data from experts and other research outside of this study. This methodology mirrors the technique used to derive the original environmental flow recommendations during the IIAS (Davies 2001).

It was concluded that the minimum environmental flow as provided by the preferred delivery strategy has a high probability of maintaining the current levels of diversity and abundance of aquatic biota post-Basslink. The effectiveness of the minimum environmental flow in providing these benefits will increase with distance from the power station as attenuation of hydro-peaking increases and tributaries contribute more to the baseflow of the river. Downstream of the compliance point at site 65, and the Denison River, the minimum flow will become less important, as natural tributary inputs begin to have a significant influence on the baseflow of the river and the minimum flow releases contribute proportionally less to the river's hydrology.

The minimum flow is expected to substantially reduce the area of river bed exposed between power station discharge peaks, especially in low-flow riffle/run habitats upstream of the Denison confluence and thereby provide low-flow refuge habitat for benthic macroinvertebrates in the zone between the Albert and Denison Rivers,

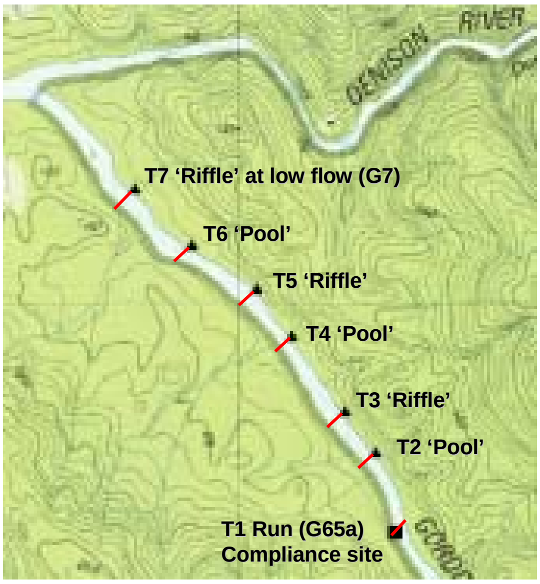

Figure 12.8. Transect sites in the compliance reach used in evaluating habitat area with the predicted post-Basslink hydrology. From Davies 2005.

The influence of the minimum flow on algae growth is important in controlling the quality of in-stream habitats. The minimum flow will act to increase the mean water depth in the river particularly over riffles (Figure 12.9), thereby reducing light availability to the river bed and the spread of filamentous algae in these areas. Figure 12.10 shows the high abundance of filamentous algae present in the upper reaches of the Gordon River during the pre-Basslink period. It is expected that filamentous algae growth in these reaches will decline with the implementation of the minimum flow post-Basslink, leading to an improvement is substrate availability for macroinvertebrates.

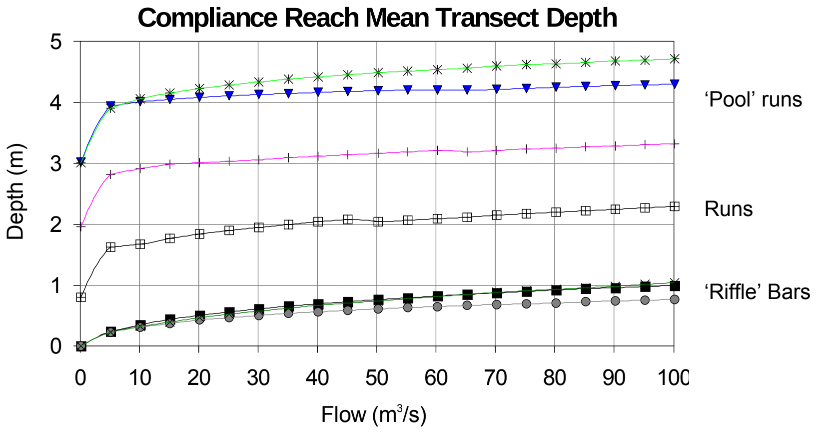

Figure 12.9. Water depth in comparison to flow for various habitats in the Gordon River. From Davies 2005.

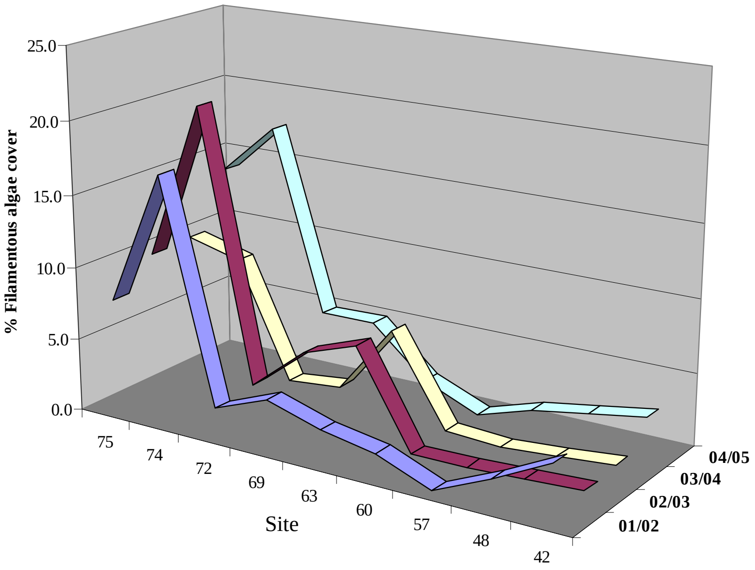

Figure 12.10. Percentage of filamentous algae cover in the Gordon River. The peak cover amounts in the upper zones of the river are up to 100 % of the remnant river channel during power station outages. From Davies 2005.

It is not expected that the proposed ramp-down rule will have any significant effects on the benthic biota. Its influence will primarily affect a small zone of bank associated habitat, with which most in-stream biota has little association due to the history of level change and erosion. The 30 $m^3 s^{-1}$ per hour rate of change far exceeds any rate at which most macroinvertebrates would be able to respond to falling water levels and therefore offers little advantage in this respect.

### 12.5.6 Fish

The minimum environmental flow will reduce the area of dewatered river channel created during power station shut-downs. This will effectively maintain a permanently wetted area that could serve as a refuge for aquatic fauna as well as maintaining some degree of habitat connectivity. This benefit to fish populations will particularly apply in the Gordon River upstream of the Denison confluence.

It is difficult to predict whether the post-Basslink environmental flow release will be beneficial to redfin populations. The potential effect of the environmental flow release on redfin abundance and distribution will be extremely difficult to detect during this time, as the pre-Basslink data on redfin distribution and abundance is not representative of a stable pre-Basslink condition. A review of the scientific literature did not locate any specific studies documenting the effect of environmental flows on redfin perch populations, however, given their widely accepted preference for still or slow flowing water (Fulton 1990, McDowall 1996, McDowall 2000, Morgan et al. 2002, Weatherley 1963, Weatherley 1977) it is inferred that the introduction of an environmental flow will not benefit this species in the middle reaches of the Gordon River. The lack of aquatic macrophytes in the Gordon River may also affect recruitment success.

The ramp-down rule will provide fish communities in the Gordon River with a cue or warning of impending flow reduction. This may minimise the incidence of fish stranding, particularly at upstream sites where wide, flat bars experience largely unattenuated discharge variations.

Short-finned eels are the most common native fish in the main river channel in zones 1 and 2. The species has the ability to travel short distances over land under suitable conditions and is unlikely to benefit significantly from flow ramp-downs. If the proposed minimum environmental flows resulted in improved galaxiid recruitment to the upper reaches of the river, the ramp-down rule may reduce stranding risk for galaxiids migrating into the upper zones.

## 12.6 Conclusion

It is anticipated that the effects of Basslink on the Gordon River environment will not be as pronounced as predicted during the IIAS process in 2001, however, the two mitigation measures that were proposed at that time are still highly relevant in the management of the Gordon River post-Basslink. Utilising water management options through regulation of the Gordon Power Station to achieve mitigation is highly appropriate as these measures

- are anticipated to maintain the current condition or trends in the Gordon River at pre-Basslink levels;
- directly address some of the hydrological drivers leading to the predicted Basslink impacts;

- do not require a high level of access or construction work in this World Heritage Area;
- are cheaper to implement than some of the other alternatives;
- are relatively risk free; and
- are reversible and adaptable should additional monitoring data indicate that this is required.

This last point is a key consideration as knowledge of the Gordon River environment is continuing to increase due to the Basslink Monitoring Program, and the response to changing hydrology associated with Basslink can only be partial predicted. Recognising this, Hydro Tasmania has committed to an adaptive management policy that will dictate changes in management actions should the nominated mitigation measures not prove effective. Having the flexibility and ease of change associated with the selected mitigation measures enhances Hydro Tasmania's ability to adaptively manage its impacts on the Gordon River into the future.

The minimum environmental flow is expected to have significant benefits for the aquatic biota of the Gordon River through provision of aquatic habitat and a high level of longitudinal connectivity. This minimum flow will incorporate a seasonal component to reflect the natural hydrology and has been set at a level that provides a sustainable balance between the needs of the various aquatic biota and the costs of flow delivery. The minimum flow will help to offset Basslink impacts on all aquatic biota and will minimise filamentous algae build up in the river channel whilst presenting little risk to other aspects of the Gordon River environment.

The ramp-down rule has been designed to limit seepage induced erosion in the Gordon River banks, and directly addresses one of the key impact mechanisms associated with Basslink. This rule has been formulated through detailed investigation and modelling, is predicted to limit erosion associated with bank saturation and drainage, and is relatively inexpensive and simple to implement. The only risk for other aspects of the Gordon River environment would be if bank drainage was too inhibited and waterlogging of mature vegetation at the back of the banks occurs. Waterlogging will be monitored through the piezometer array, and the rule modified if required. The ramp-down rule may benefit riparian vegetation by increasing bank stability and reduce fish stranding by providing a cue to impending drawdowns.

In conclusion, whilst there are numerous influences on the operation of the Gordon Power Station and the response of the downstream environment, it is believed that the proposed mitigation measures adequately protect the Gordon River from the predicted Basslink impacts. Coupled with the comprehensive Basslink Monitoring Program, these measures will allow Hydro Tasmania to adaptive manage its impacts on the Gordon River environment whilst still allowing for the commercial operation of the Gordon Power Station. Investigation of more effective and cost-efficient methods to achieve the mitigation aims will continue to be undertaken during the course of the Basslink Monitoring Program, and in particular Hydro Tasmania will investigate the environmental and economic implications of a 10/20 environmental flow regime to mitigate Basslink impacts.

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# 13 Indicator variables

This chapter discusses the approach taken to detect post-Basslink changes and differentiate those attributable to Basslink from those caused by other factors. It details the three-stage 'indicator variables' approach to detecting post-Basslink changes and lists the indicator variables from the individual disciplines along with their associated trigger values. It also discusses the capability of the various indicator variables to detect change.

## 13.1 Indicator variables and limits of acceptable change

Changes to the Gordon River environmental condition following the commencement of Basslink operations are required to be 'no net Basslink impact', that is 'impact that remains within the present boundaries, recognising inherent variability in the environmental indicators as well as long-term presently occurring trends'. A primary task of the Basslink monitoring program is to determine if there is evidence of change in the biological or physical characteristics of the Gordon River following the introduction of Basslink. Where there is evidence of change an additional task is to determine if the change is likely to be Basslink-related.

Hydro Tasmania's Water Licence requires the BBR to consider, and if appropriate and practicable, propose "limits of acceptable change" for each of the key scientific disciplines which:

- are consistent with the aims of adaptive management;
- recognise the regulated nature of the Gordon River; and
- recognise the potential for conflicts between the management objectives of different disciplines.

Evaluation of post-Basslink environmental change in the middle Gordon River will utilise a three-stage process based on indicator variables derived from the various monitoring disciplines. The three-stage process is analogous to the use of 'trigger values' as used in the ANZECC/ARMCANZ (2000) water quality guidelines, in that values are set for 'indicator variables' which, if exceeded, invoke management actions. The three-stages involve answering the following questions:

- Were the trigger values exceeded?
- Can the exceedence be attributed to a Basslink effect?
- Does the exceedence require management intervention?

The detection of change in the post-Basslink period will be through indicator variables exhibiting values or patterns that are judged unusual by reference to pre-Basslink values and patterns.

## 13.2 Establishing percentiles for trigger values

It is suggested that the trigger values of a scaled indicator variable be set at the estimated 2.5th and 97.5th percentiles for that variable, where the estimated values are determined from a suitable statistical model applied to pre-Basslink data. An implication of this definition is that there is a probability of 0.05 of incorrectly declaring there is evidence that the system is outside acceptable limits for a single indicator variable.

Given that there are 26 indicator variables recommended for use, with the potential to add further variables, the probability of exceeding at least one trigger value, i.e. of erroneously declaring there is a post-Basslink change, is substantially greater than 5 %. An exact value cannot be determined because it is dependent on the extent of correlation among the indicator variables. However, given the diversity of variables being used, it could be in the vicinity of a 20 % error.

It is noted that ANZECC/ARMCANZZ (2000) guidelines suggest a means for constructing trigger values and setting appropriate limits for the monitoring of rivers. This is in a different context to the present situation. The presumption is that there is lengthy period of monitoring ("two years of contiguous monthly data at the reference site is required before a valid trigger value can be established") from a reference river and a trigger value that is defined as the 80th percentile "based on the *most recent* 24 monthly observations". The guidelines are not indicated for application where there is a stratification such as the zonal groupings in the Gordon River, plus seasonal variation all to be accounted for with only two monitoring periods per year for a four year period and does not allow for substantial short-term trends of the type observed in the geomorphic data.

Further, it is noted that the use of the 80th percentile as a trigger value is intended for situations where there is a single observation at each monitoring time, as revealed in the following quote: "a minimum resource allocation would set $n=1$ for the number of samples to be collected each month from the test site. It is clear that the chance of a *single* observation from the test site exceeding the 80th percentile of a reference distribution which is *identical* to the test distribution is precisely 20 %. Thus the Type I error in this case is 20 %. This figure can be reduced by increasing $n$. For example, when $n=5$ the Type I error rate is approximately 0.05." In the current construction of trigger values, they are based on the distribution of means formed under circumstances where the probability of exceeding trigger values when there is no post-Basslink change can be precisely determined from knowledge of the distribution. The choice of a 5 % Type I error is consistent with the above statement.

There is also the question of which statistic is more appropriate as the basis for combining individual observations and setting trigger values - mean or median. Given the small amount of available data, the complex spatial and temporal components of variation and the possibility of serial correlation, the mean is judged to be the only viable choice. Furthermore, the fact that the means employed in construction of trigger values are generally based on a minimum of eight sampling occasions by at least three sites per zone and up to five zones, there are strong grounds, through the Central Limit Theorem, for assuming the distribution of the means is well approximated by a Normal distribution, although for some variables this may relate to data on a transformed scale.

## 13.3 Attributing exceedence to Basslink

Three questions must be addressed in consideration of whether exceedence of the indicator variables' trigger values can be attributed to Basslink-related causes:

- "How can allowance be made for post-Basslink change that is merely the natural temporal variation that would arise without any change in process?"
- "With what level of confidence is the monitoring program capable of detecting post-Basslink changes?"
- "Is it possible to establish if change identified as occurring in the post-Basslink period is caused by Basslink rather than by non-Basslink events?"

The first two questions can be answered through the definition and application of objective criteria and the role of this chapter is to develop and apply those definitions. Consideration of the third question will require information that cannot be obtained until the post-Basslink period.

### 13.3.1 Making allowance for non-Basslink variation

The pre-Basslink data provide an indication of the variability, trends and patterns that characterise aspects of the physical and biological structure of the middle Gordon River under the current operating conditions. These data form the baseline from the pre-Basslink period and allow the derivation of indicator variables against which post-Basslink conditions can be measured.

Change from the pre-Basslink period to the post-Basslink period may be attributed to one or more of the following sources:

- **Ongoing systematic change** that is a reflection of a lack of equilibrium in the pre-Basslink period, as illustrated by an ongoing trend in bank erosion;
- **Basslink-related change** that is a consequence of the implementation of Basslink;
- **Post-Basslink, non-Basslink-related systematic change** that is observed beyond the Gordon River. For example, the widespread introduction of a disease or exotic species; and
- **Chance variation** which is a name for change that is the combined effect of natural and human inputs that occur as part of normal activity.

While an expectation of systematic changes originating in the post-Basslink period is reasonable there is no objective way in which an "acceptable limit" can be placed on all of the above components of change. The recommended strategy developed in this chapter, is that indicator variables (as surrogates for the "limits of acceptable change" concept) can currently be determined only from ongoing systematic change and chance variation that can be estimated from pre-Basslink data.

Where the indicator variable's trigger values are found to be exceeded the next stage would be to determine if the cause is entirely or partly attributable to a non-Basslink origin. At this point more detailed modelling is required. This is likely to involve the introduction of variables based on reference river data and possibly interrelations among variables from different disciplines. At this stage it would also be anticipated that results from related variables would be taken into account and expert interpretation would be employed to assess the likely reason for trigger values being exceeded.

Where there is judged to be a contribution from a non-Basslink cause, the indicator variable trigger value would, if possible, be modified to reflect that non-Basslink contribution. Such an adjustment can only be made after an event has occurred in the post-Basslink period.

### 13.3.2 Practical issues

Basing the indicator variables and their trigger values on the past four years of pre-Basslink data raises the following issues:

- Variability in environmental conditions over such a short period may not reflect the longer term variability and may lead to an underestimation of chance variability.
- Correlation between successive responses for a variable is likely. With only four years of data it is not possible to reliably determine if there is a serial correlation structure. An important implication is that it is not possible to say whether an observed trend over the four years is a consequence of a systematic effect, serial correlation, or chance.
- The operational characteristics of the power station have varied over the four pre-Basslink years, particularly in respect of the frequency and length of operation of the third turbine.

Consequently, the trigger values given in this chapter, as well as the indicator variables themselves, may be expected to change as further information and initial application indicates their value and effectiveness.

## 13.4 'Trigger values' for indicator variables

The trigger values for the variables judged to be useful indicators of post-Basslink change, in the various disciplines, are presented below together with discussion of relevant practical issues. An explanation of the statistical results underlying the values presented in this chapter can be found in chapter 4 (Design and inference).

### 13.4.1 Fluvial geomorphology

As noted in section 7.7, the key aspects of the post-Basslink changes with implications for hydrological stability in the middle Gordon River are the increase in the percentage of time of full capacity discharge, and the increased on-off fluctuations of the power station more fully utilising the range of flows. Examination of hydrological and erosional processes in the five fluvial zones of the Gordon River led to the selection of erosion or deposition averages from sites within the five zones as the indicator variables for detecting post-Basslink change.

Trigger values are provided for selected indicator variables as either erosion or deposition (see Table 13.1). The limits are based on a limited amount of monitoring data and unverifiable assumptions as explained below. If the initial post-Basslink values fall outside the specified limits, consideration should be given to reviewing the assumptions underlying the model on which they are based.

As explained in chapter 4, the diversity of processes occurring in the river and longitudinal heterogeneity coupled with the limited length of the pre-Basslink monitoring period has led to the need to pool data across sites within zones. Further pooling has been necessary either across turbine levels to allow zonal comparisons, or across zones to allow comparisons of turbine levels. This pooling restricts the capability to build verifiable stochastic models that are necessary to construct reliable limits on the range of values expected as a result of chance variation.

A further complication is the evidence of possible ongoing systematic change in many erosion indicators. Given that there are only four years of data, there is limited information on which to base a mathematical formula for a trend line. Yet another concern is the possibility that part of the trend may be a consequence of the changing pattern of use of the third turbine over the pre-Basslink monitoring period, a changing pattern that would continue even if Basslink were not implemented.

Table 13.1 Predicted lower and upper limits for erosion and deposition over the period from spring 2001 to spring 2006 assuming pre-Basslink conditions apply into the post-Basslink period. Note that a positive number implies erosion and a negative number implies deposition.

| Total amount (mm) from spring 01 to spring 06 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Erosion per pin in pins that show erosion | | | Deposition per pin in pins that show deposition | | | Overall level of erosion | | |
| Zone | Mean | Lower limit | Upper limit | Mean | Lower limit | Upper limit | Mean | Lower limit | Upper limit |
| 1 | 23 | 14 | 31 | -20 | -31 | -10 | -4 | -11 | 2 |
| 2 | 106 | 70 | 143 | -24 | -37 | -11 | 44 | 30 | 58 |
| 3 | 146 | 106 | 186 | -52 | -75 | -29 | 72 | 52 | 91 |
| 4 | 100 | 89 | 112 | -50 | -75 | -26 | 60 | 42 | 79 |
| 5 | 78 | 51 | 106 | -71 | -101 | -40 | -9 | -30 | 12 |

| Average amount (mm per year) between spring 01 and spring 06 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Erosion per pin in pins that show erosion | | | Deposition per pin in pins that show deposition | | | Overall level of erosion | | |
| Zone | Mean | Lower limit | Upper limit | Mean | Lower limit | Upper limit | Mean | Lower limit | Upper limit |
| 1 | 4.5 | 2.8 | 6.3 | -4.0 | -6.1 | -2.0 | -0.9 | -2.3 | 0.5 |
| 2 | 21 | 14 | 29 | -4.8 | -7.4 | -2.1 | 8.9 | 6.0 | 11.7 |
| 3 | 29 | 21 | 37 | -10.4 | -15.0 | -5.7 | 14 | 10 | 18 |
| 4 | 20 | 18 | 22 | -10.1 | -15.0 | -5.2 | 12 | 8 | 16 |
| 5 | 16 | 10 | 21 | -14.1 | -20.2 | -8.0 | -1.9 | -6.1 | 2.3 |

Note that 'erosion per pin in pins that show erosion' is determined separately at each monitoring time. The same applies to deposition. Therefore, the set of pins from which mean erosion per pin, or mean deposition per pin, is computed varies among monitoring times.

Another fact to be taken into account is that Basslink does not commence until 2006 and the first post-Basslink geomorphology measurements may not be available until October 2006. Thus prediction based on the present dataset is not for the next sampling period, i.e. October 2005, but for the third sampling period beyond the current time (September 2005). If the trend is in error then the effect will be substantially magnified if the prediction is 18 months into the future. It is therefore strongly recommended that the results presented in Table 13.1 be considered as no more than a sample of what is possible, and that it is understood more reliable estimates will await the collection of additional data in October 2005 and March 2006. Adding data from two additional sampling periods will allow much greater confidence in trend determinations.

### 13.4.2 Karst geomorphology

In the other disciplines, indicator variables values used in the construction of trigger values are based on averages across sites and sometimes across zones. The fact that averages are used is part of the justification for the formal method of constructing trigger values. No averaging is considered reasonable in respect of Karst erosional pins and no formal alternative can be suggested. Hence it is not considered appropriate to construct trigger values as defined above. Nevertheless, it is accepted that consideration of possible changes in pattern at one or more of the pins should take place and an informal basis for alerting to possible change is described below.

Three principal indicator variables will be used: the current maximum range of change, the current average rate of change, and the long-term trend since the pins were first installed (Table 13.2). Future changes outside the current range of change, or which cause the average rate of change to be varied by ±100 %, or to reverse, or which significantly change the long-term trends as shown on the graphs of pin changes, will indicate a need for further investigation.

To assess changes to the dry sediment bank in Bill Neilson Cave, additional limits based on the percentage of the time that the pins in the bank are inundated, both on a long-term basis and on an average seasonal basis, will be added. The present maximum height of inundation in the cave will also be considered.

In the dolines, the limit will be an increase in the sum of the distances between the erosion pins of more than 20 mm, with consideration given to whether the pins could have been disturbed by wildlife.

Table 13.2. Indicator variables and their nominated rigger values for sediment transfer changes in the caves

| Location | | Pin no. | Change between sampling periods | | |
|---|---|---|---|---|---|
| | | | Current max erosion | Current max deposition | Average change |
| Channel Cam | | 1 | -9 | 8 | 0 |
| | | 28 | -13 | 5 | -2 |
| GA-X1 cave | | 2 | -6 | 11 | 0 |
| | | 3 | -4 | 2 | -1 |
| | | 4 | -7 | 4 | -2 |
| Kayak Kavern | | 16 | -40 | 1 | -17 |
| | | 17 | -51 | 35 | -4 |
| | | 18 | -15 | 11 | -1 |
| | | 19 | -26 | 42 | 2 |
| | | 29 | n/a | n/a | n/a |
| | | 30 | n/a | n/a | n/a |
| Bill Neilson Cave | 6A Wet sed bank at entrance | 20 | -19 | 8 | -2 |
| | | 21 | -3 | 4 | 0 |
| | | 22 | -3 | 3 | 0 |
| | 6B Wet sed bank II | 25 | -7 | 0 | -1 |
| | | 26 | -2 | 1 | 0 |
| | | 27 | -2 | 4 | 1 |
| | 6C Dry sed bank | 23 | -3 | 2 | 0 |
| | | 24 | -1 | 24 | 3 |

### 13.4.3 Riparian vegetation

A number of variables were considered as comprising a possible basis for comparison between pre- and post-Basslink periods, most of which are measures of abundance or density of flora species, seedlings or ground cover conditions. Selection criteria for indicator variables and the sites as which they will be monitored is discussed in detail in section 9.9.

Riparian vegetation is monitored as abundance of species, size classes, and percentage ground cover. Indicator variables are based on four years of monitoring abundance and ground cover variables, such that:

- **Abundance variables:** Number of seedlings less than 5 cm, and total number of seedlings. These data have been collected twice yearly. Trigger values are provided in Table 13.3; and
- **Ground cover variables:** Percentage cover for bare ground, bryophytes, ferns, shrubs and total vegetation for which data have been collected once per year. Trigger values are provided in Table 13.4.

The use of the third turbine may influence both river geomorphology, as described above, and riparian vegetation regardless of post-Basslink changes. Consequently, the indicator variables have been defined to consider the use of the third turbine. Abundance and ground cover variables are presented as ratios of values from above the 3-turbine level ("above") to (a) corresponding values between the 2- and 3-turbine levels ("high") and (b) corresponding values between the 1- and 2-turbine levels ("low").

To meet statistical requirements, the ratios were log-transformed and 1 was added to each value before transformation. The transformation used was:

$$\log\left[\frac{x+1}{y+1}\right]$$

Where *x* is the "above" count and *y* is either the "high" or "low" count.

The limits presented in Table 13.3 are for the ratio $(x+1)/(y+1)$. Since there are seasonal differences in riparian vegetation abundance and cover, limits are presented for both individual seasons and for the full year (i.e. spring and autumn monitoring data).

No indicator variable was defined for the ration 'above'/'high' percent total vegetation because of non-linear trends (Table 13.4). Furthermore, trends were not consistent across monitoring zones (Figure 13.1).

Table 13.3. The range within which 95 % of values are likely to lie for means of ratios for selected abundance variables based on monitoring for one year, two years and three years in the post-Basslink period.

| Number of seedlings less than 5 cm: Ratio (number above 3-turbines+1) to (number between 2- and 3-turbines+1) | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| **Full year** | 0.7 | 2.2 | 0.8 | 2.0 | 0.9 | 1.9 |
| **Autumn** | 0.5 | 2.0 | 0.6 | 1.8 | 0.7 | 1.7 |
| **Spring** | 0.7 | 2.4 | 0.8 | 2.2 | 0.8 | 2.1 |

| Number of seedlings less than 5 cm: Ratio (number above 3-turbines+1) to (number between 1- and 2-turbines+1) | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| **Full year** | 0.9 | 3.8 | 1.1 | 3.3 | 1.2 | 3.1 |
| **Autumn** | 0.7 | 3.9 | 0.9 | 3.3 | 1.0 | 3.2 |
| **Spring** | 0.7 | 3.8 | 0.9 | 3.3 | 0.9 | 3.1 |

| Total number of seedlings: Ratio (number above 3-turbines+1) to (number between 2- and 3-turbines+1) | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| **Full year** | 0.7 | 2.5 | 0.8 | 2.2 | 0.8 | 2.1 |
| **Autumn** | 0.5 | 2.3 | 0.6 | 2.0 | 0.6 | 1.9 |
| **Spring** | 0.6 | 2.7 | 0.7 | 2.3 | 0.7 | 2.2 |

| Total number of seedlings: Ratio (number above 3-turbines+1) to (number between 1- and 2-turbines+1) | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| **Full year** | 0.8 | 4.6 | 1.0 | 3.8 | 1.0 | 3.5 |
| **Autumn** | 0.5 | 4.4 | 0.7 | 3.7 | 0.8 | 3.4 |
| **Spring** | 0.6 | 4.7 | 0.8 | 4.0 | 0.8 | 3.7 |

Table 13.4. The range within which 95 % of values are likely to lie for means of ratios for selected ground cover variables based on monitoring for one year, two years and three years in the post-Basslink period. Note that seasonal figures are not provided because monitoring occurs only once per year.

| | Ratio (% above 3-turbines+1) to (% between 2- and 3-turbines+1) | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| **% bare ground:** | 0.2 | 0.9 | 0.2 | 0.8 | 0.2 | 0.7 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **% bryophyte** | 1.1 | 6.1 | 1.3 | 5.0 | 1.4 | 4.7 |
| **% fern** | 0.5 | 3.1 | 0.6 | 2.5 | 0.6 | 2.3 |
| **% shrub** | 0.6 | 2.0 | 0.7 | 1.8 | 0.7 | 1.7 |
| **% total vegetation** | 1.0 | 3.2 | 1.1 | 2.8 | 1.2 | 2.6 |

| | **Ratio (% above 3-turbines+1) to (% between 1- and 2-turbines+1)** | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| **% bare ground:** | 0.1 | 0.7 | 0.1 | 0.5 | 0.1 | 0.5 |
| **% bryophyte** | 3.3 | 9.9 | 3.7 | 8.8 | 3.9 | 8.3 |
| **% fern** | 1.1 | 7.8 | 1.4 | 6.3 | 1.5 | 5.8 |
| **% shrub** | 0.6 | 4.5 | 0.7 | 3.6 | 0.8 | 3.3 |
| **% total vegetation** | 3.0 | 11.6 | 3.5 | 10.0 | 3.7 | 9.4 |

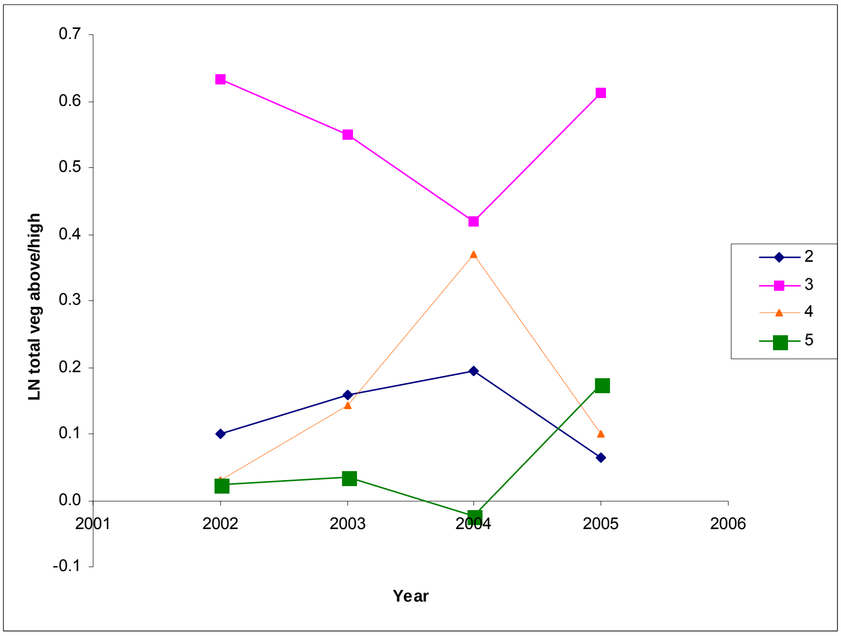


Figure 13.1 Evidence of non-linear trends in the mean 'above'/'high' ratio for percent total vegetation in the pre-Basslink period with the different lines representing different zones (2-5).

### 13.4.4 Macroinvertebrates and algae

There are a number of macroinvertebrates and algal indicator variables which can be used as a basis for comparison between pre- and post-Basslink periods. Section 10.6 outlines in detail the selection of these indicator variables, which provide data on the status of macroinvertebrate and algal abundance, diversity and community composition. Changes are possible in all three areas following commencement of Basslink operations. Table 13.5 and Table 13.6 present trigger values for indicator variables for macroinvertebrates and algae, respectively.

Both the macroinvertebrate and algal communities are in a ‘quasi-stable’ state that should allow for an interpretable assessment of pre- versus post-Basslink conditions. They do not exhibit marked long-term trends or patterns in composition, abundance or distribution within the middle Gordon River. The overall composition and pattern of macroinvertebrates and the trends they exhibit downstream of the power station have been consistent over the study period (2001-05). Both macroinvertebrate and algal data exhibit a degree of seasonal variation due to an interaction between intra-annual variation in power station operations, river flows and seasonal factors such as light and recruitment. These sources of temporal variation are on a smaller scale (<1 year) than the scale of comparison of the pre- versus post-Basslink phase (*ca* 3-5 years) which makes them suitable indicators of any potential post-Basslink affects.

The defined macroinvertebrate indicator variables include density, number of families, O/Epa, O/Erk, and number of EPTC species (Table 13.5), while the benthic algal variables include percentage moss cover and percentage algal cover (Table 13.6). Note that for two of the variables, data are recorded only yearly, so there are no seasonal limits for these variables. For 'density' there was evidence of a non-linear trend in zone group 1, so limits for this variable are only provided for zone group 2.

Table 13.5. The range within which 95 % of values are likely to lie for means for selected macroinvertebrate and algal variables based on monitoring for one year, two years and three years in the post-Basslink period.

| Density based on zone group 2 data only | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 118 | 459 | 137 | 394 | 146 | 370 |
| Autumn | 110 | 566 | 136 | 486 | 149 | 456 |
| Spring | 72 | 373 | 90 | 320 | 98 | 301 |

| Number of families | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 12 | 18 | 12 | 17 | 13 | 17 |
| Autumn | 11 | 19 | 12 | 18 | 13 | 18 |
| Spring | 10 | 17 | 11 | 16 | 11 | 16 |

| O/Epa | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 0.84 | 1.02 | 0.86 | 1.00 | 0.87 | 0.99 |
| Autumn | 0.72 | 0.94 | 0.75 | 0.92 | 0.76 | 0.91 |
| Spring | 0.88 | 1.10 | 0.91 | 1.08 | 0.92 | 1.07 |

| O/Epa combined | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 0.70 | 0.89 | 0.72 | 0.87 | 0.72 | 0.86 |

| O/Erk | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 0.75 | 0.94 | 0.77 | 0.92 | 0.78 | 0.91 |
| Autumn | 0.77 | 1.00 | 0.80 | 0.98 | 0.81 | 0.97 |
| Spring | 0.65 | 0.88 | 0.68 | 0.86 | 0.69 | 0.85 |

| O/Erk combined | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 0.65 | 0.82 | 0.66 | 0.80 | 0.67 | 0.80 |

| Number EPTC species | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 6.9 | 12.0 | 7.4 | 11.3 | 7.6 | 11.0 |
| Autumn | 6.9 | 13.4 | 7.5 | 12.6 | 7.8 | 12.3 |
| Spring | 5.5 | 10.8 | 6.1 | 10.1 | 6.3 | 9.9 |

| Abundance E | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 4.4 | 15.8 | 5.1 | 13.5 | 5.3 | 12.7 |
| Autumn | 3.8 | 17.0 | 4.5 | 14.6 | 4.8 | 13.7 |
| Spring | 3.4 | 14.6 | 4.0 | 12.6 | 4.3 | 11.8 |

| Proportion abundance EPTC | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 0.1 | 0.4 | 0.2 | 0.3 | 0.2 | 0.3 |
| Autumn | 0.1 | 0.4 | 0.1 | 0.4 | 0.2 | 0.4 |
| Spring | 0.1 | 0.3 | 0.1 | 0.3 | 0.1 | 0.3 |

| Bray Curtis | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 21 | 32 | 22 | 31 | 22 | 30 |
| Autumn | 19 | 33 | 21 | 32 | 22 | 31 |
| Spring | 17 | 31 | 19 | 30 | 20 | 29 |

Table 13.6. The range within which 95 % of values are likely to lie for means for selected benthic algal indicator variables based on monitoring for one year, two years and three years in the post-Basslink period.

| Algal cover | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 2.5 | 7.6 | 2.8 | 6.6 | 2.9 | 6.2 |
| Autumn | 2.3 | 8.9 | 2.7 | 7.7 | 2.9 | 7.2 |
| Spring | 1.9 | 6.5 | 2.2 | 5.7 | 2.3 | 5.4 |

| Moss cover | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 2.6 | 5.1 | 2.8 | 4.7 | 2.9 | 4.5 |
| Autumn | 2.2 | 4.7 | 2.4 | 4.3 | 2.5 | 4.2 |
| Spring | 2.5 | 5.5 | 2.7 | 5.1 | 2.8 | 4.9 |

### 13.4.5 Fish

Species diversity, abundance, distribution and population structure are the primary factors that are being assessed as part of the fish monitoring program. High variability limited the number of suitable indicators, as discussed in section 11.6. Seven native and three introduced species have been recorded from the middle Gordon River during pre-Basslink monitoring. As discussed in chapter 4, the sparsity of many species in sections of the river has limited the number of variables for which quantitative analysis of change is appropriate. Three indicator variables are judged to be suitable. These include the catch per unit effort (CPUE) for all fish, native fish only, and the ratio of trout to native fish. The upper and lower limits for these indicator variables, for spring, autumn and the full year are outlined in Table 13.7.

Table 13.7. The range within which 95 % of values are likely to lie for selected catch per unit effort (CPUE) variables in the fish monitoring program based on monitoring for one year, two years and three years in the post-Basslink period.

| CPUE for all species | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 5.5 | 23.6 | 6.4 | 20.3 | 6.8 | 19.1 |
| Autumn | 4.3 | 25.2 | 5.4 | 21.6 | 5.9 | 20.3 |
| Spring | 3.8 | 22.2 | 4.7 | 19.0 | 5.2 | 17.9 |

| CPUE for native species | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 1.1 | 11.7 | 1.4 | 9.1 | 1.5 | 8.2 |
| Autumn | 0.7 | 12.8 | 1.0 | 10.0 | 1.2 | 9.1 |
| Spring | 0.6 | 10.6 | 0.9 | 8.3 | 1.0 | 7.5 |

| Ratio of CPUE for trout to CPUE for natives | | | | | | |
|---|---|---|---|---|---|---|
| **Post-Basslink** | **1 year** | | **2 year mean** | | **3 year mean** | |
| | **Lower** | **Upper** | **Lower** | **Upper** | **Lower** | **Upper** |
| Full year | 0.5 | 3.4 | 0.6 | 2.8 | 0.7 | 2.6 |
| Autumn | 0.3 | 3.2 | 0.4 | 2.7 | 0.5 | 2.5 |
| Spring | 0.4 | 3.6 | 0.5 | 3.0 | 0.5 | 2.7 |

### 13.4.6 Water quality

Unlike the other disciplines, the water quality indicator variables are based on methods presented in the ANZECC/ARMCANZ (2000) guidelines for water quality monitoring and reporting. The trigger values are established at the 20th or 80th percentile of reference site values and a trigger for further investigation occurs when the median value from the test site exceeds the trigger values.

For dissolved oxygen, the ‘reference’ values are those recorded pre-Basslink, while the ‘test’ values will be those recorded post-Basslink. It has been shown that both high and low concentrations of dissolved oxygen are potential issues in the tailrace discharge, so both 20th and 80th percentile values are of interest. These are summarised in Table 13.8.

Table 13.8. Median, 20th and 80th percentile dissolved oxygen (mg $L^{-1}$) values recorded at the power station tailrace site for the years 1999-2000 to 2004-05 and their overall average values from 1999-2005.

| Year | Median | 20th percentile | 80th percentile |
|---|---|---|---|
| 1999-2000 | 8.68 | 6.08 | 11.90 |
| 2000-01 | 7.77 | 5.50 | 10.99 |
| 2001-02 | 7.21 | 6.08 | 8.91 |
| 2002-03 | 8.87 | 7.18 | 10.25 |
| 2003-04 | 8.57 | 7.65 | 9.99 |
| 2004-05 | 7.76 | 6.71 | 10.59 |
| Average | 8.14 | 6.53 | 10.44 |

Additional event-based triggers may be obtained from the incidence of extreme dissolved oxygen events, since these have the potential to directly affect downstream biota. The relevant indicator variable is the percent of time per year that dissolved oxygen concentrations exceed 12 mg $L^{-1}$ (a value indicating approximately 100 % oxygen saturation) or are less than 6 mg $L^{-1}$. Annual trigger values of 8 % for the incidence of high dissolved oxygen values and 5 % for the incidence of low dissolved oxygen values would provide an indication of a change from recent pre-Basslink conditions and, therefore, the need for further investigation.

In terms of water temperature, little post-Basslink change in downstream thermal regulation is anticipated. For this parameter, the percentile exceedence method discussed above and detailed in the ANZECC/ARMCANZ (2000) guidelines for water quality monitoring and reporting will be used to determine trigger values. The 'reference' data will be those taken before Basslink commencement and the 'test' data will be those taken after.

The indicator variables derive from the difference between the power station discharge (using site 75 temperature data as analogues) and the furthest downstream water temperature monitoring site (site 62). The difference values provide an indication of the changes to the thermal pattern with distance downstream and the influence of unregulated tributary flows. The derived indicator variables are 'monthly percentiles of daily mean differences', and 'monthly percentiles of daily standard deviation differences'.

The mean values give an indication of the absolute differences between the power station tailrace (as represented by the surrogate site 75 values) and site 62 (downstream of the Denison confluence) for each month. The standard deviation values give an indication of the variability recorded. Should future monthly median values of either parameter exceed the 20th or 80th percentile values given for that month, further investigation is warranted. Table 13.9 and Table 13.10 give the percentile values for each month for mean and standard deviation values, respectively. These values should be updated with 2005-06 pre-Basslink data prior to their use in assessing any potential changes due to post-Basslink operations.

Table 13.9. Number of days sampled, and monthly median, 20th and 80th percentile values of daily mean differences in water temperature between sites 75 and 62, for the period July 1999 to June 2005.

| Days | Month | median | 20th percentile | 80th percentile |
|---|---|---|---|---|
| 186 | January | -0.36 | -0.51 | -0.18 |
| 170 | February | -0.32 | -0.41 | -0.24 |
| 160 | March | -0.25 | -0.37 | -0.15 |
| 121 | April | -0.13 | -0.26 | 0.00 |
| 124 | May | -0.05 | -0.15 | 0.06 |
| 108 | June | 0.11 | -0.09 | 0.58 |
| 94 | July | 0.09 | -0.05 | 0.46 |
| 115 | August | 0.01 | -0.18 | 0.39 |
| 120 | September | -0.37 | -0.91 | 0.03 |
| 147 | October | -1.02 | -1.34 | -0.55 |
| 134 | November | -0.75 | -1.46 | -0.36 |
| 149 | December | -0.35 | -0.51 | -0.21 |

Table 13.10. Number of days sampled (N), and monthly median, 20th and 80th percentile values of daily standard deviations of differences in water temperature between sites 75 and 62, for the period July 1999 to June 2005.

| N | Month | median | 20th percentile | 80th percentile |
|---|---|---|---|---|
| 186 | Jan | 0.24 | 0.17 | 0.33 |
| 170 | Feb | 0.23 | 0.16 | 0.32 |
| 160 | Mar | 0.20 | 0.14 | 0.28 |
| 121 | April | 0.17 | 0.12 | 0.24 |
| 124 | May | 0.10 | 0.08 | 0.21 |
| 108 | Jun | 0.25 | 0.10 | 0.56 |
| 94 | Jul | 0.23 | 0.12 | 0.36 |
| 114 | Aug | 0.23 | 0.11 | 0.38 |
| 120 | Sep | 0.22 | 0.13 | 0.38 |
| 147 | Oct | 0.24 | 0.15 | 0.45 |
| 134 | Nov | 0.28 | 0.17 | 0.53 |
| 149 | Dec | 0.22 | 0.14 | 0.32 |

For water temperature, the indicator variables are statistical constructs and exceedence of the trigger values will not, of itself, indicate beneficial or detrimental impacts. Rather, it would indicate that thermal regulation had changed from pre-Basslink conditions and that further investigation was needed to determine the cause and possible effect.

## 13.5 Capability of the monitoring program to detect change

The indicator variables present the range of variation expected during the post-Basslink period if there is no change in operating or environmental conditions. The lower and upper limits and their width, or range, provide one indication of how useful these variables may be in detecting change in the post-Basslink period.

A useful alternative way of considering the capability of the monitoring process to determine any changes is to firstly specify a minimum level of change for an indicator variable that is considered to be of practical importance and secondly to determine how likely or probable is the detection of that minimum level of change. As discussed in chapter 4, power analysis is a statistical method which enables the probability (power) of the indicator variables to measure change to be assessed after the commencement of Basslink after one, two or three years. The application of power analysis to the different monitoring disciplines (except for Karst geomorphology as discussed in section 13.3.2) is discussed below.

### 13.5.1 Fluvial geomorphology

Concerns about the uncertainty in the underlying model and the length of the forward projection apply to power analyses in a similar manner as the application of indicator variables to erosion data. These concerns included the diversity of geomorphic process, longitudinal heterogeneity, pooling of data across sites, ongoing systematic changes in erosion indicators and the timing of geomorphology measurements relative to commencement of Basslink. Consequently, the power analysis results presented in Figure 13.2 should be viewed as provisional and illustrate what is possible in detecting change associated with Basslink after one year. The assessment of the reliability of the results will improve with the collection of additional data from the October 2005 and March 2006 monitoring periods.

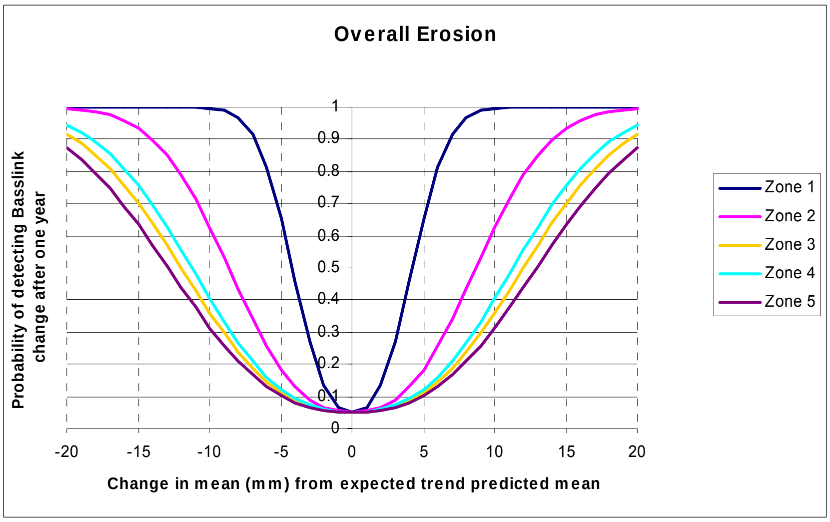


Figure 13.2. Power curves for detection of change in mean erosion levels from predicted levels at the spring 2006 monitoring time based on pre-Basslink trends. Note that negative change implies an excess of deposition over erosion whereas a positive change implies an excess of erosion over deposition. The power is based on the assumption of a 5 % type 1 error and a two-tailed test.

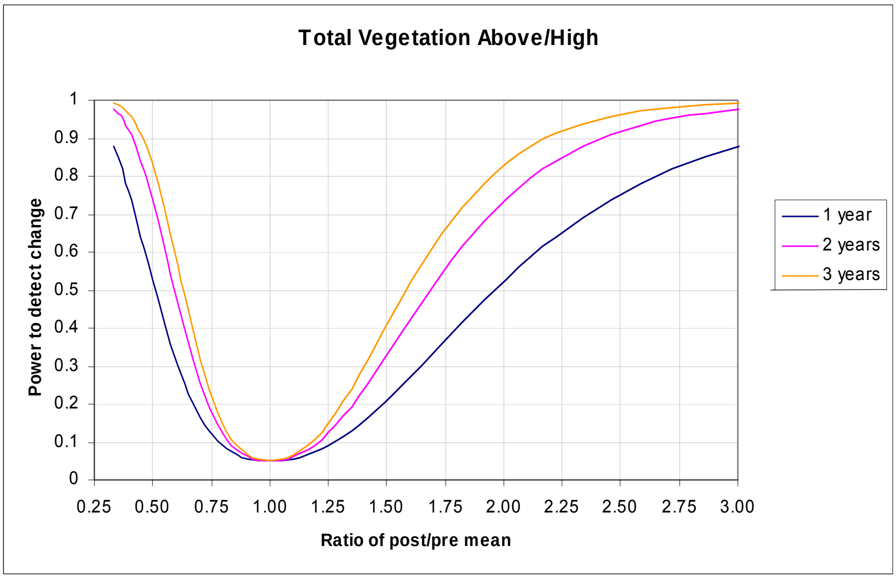
### 13.5.2 Riparian vegetation

Power analysis was applied to the riparian vegetation indicator variables to assess their probability of detecting change. Power analysis was applied to:

- total vegetation;
- seedlings smaller than 5 cm;

- total seedlings;
- percent bare ground;
- percent bryophytes;
- percent ferns; and
- percent shrubs.

The probabilities of detecting change are expressed for one, two and three years post-Basslink as displayed in Figure 13.3 to Figure 13.6. The probabilities are determined for the two flow regimes relative to the third turbine of (1) above/high and (2) above/low.



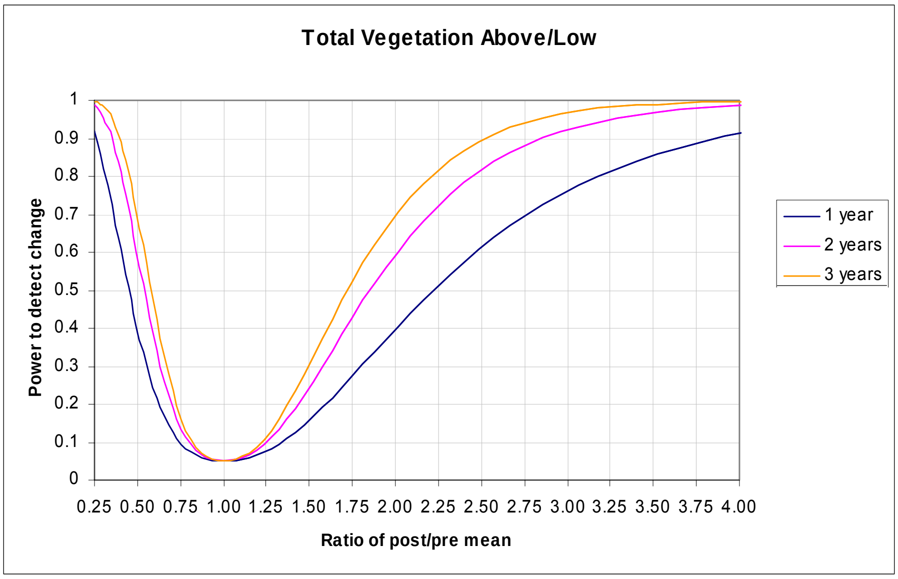


Figure 13.3. Probability of detecting a specified change in ratios of abundances in total vegetation in the post-Basslink compard to the pre-Basslink period, i.e., power, on the assumption that the type 1 error rate is 5 % and the test is two-tailed.

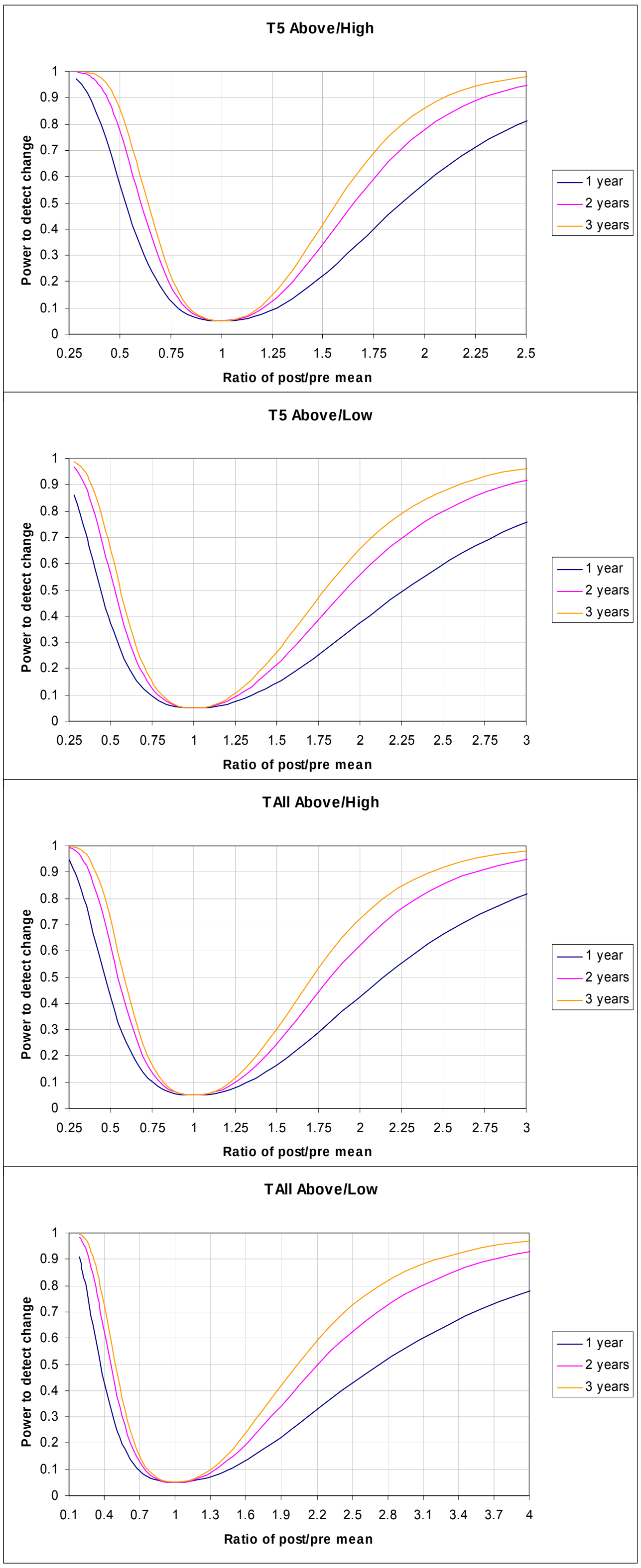


Figure 13.4. Probability of detecting a specified change in ratios of abundances of seedings smaller than 5 cm (T5) and all seedlings (TALL) in the post-Basslink compard to the pre-Basslink period, i.e., power, on the assumption that the type 1 error rate is 5 % and the test is two-tailed.

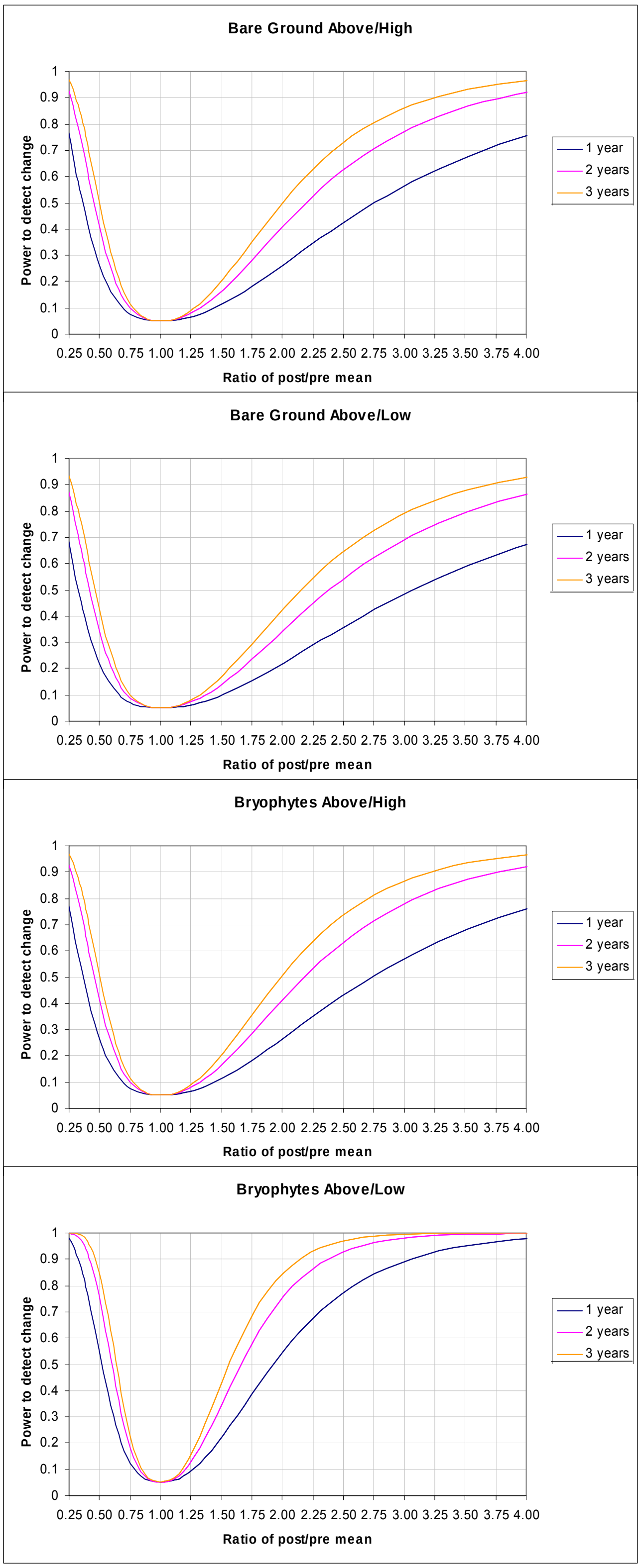


Figure 13.5. Probability of detecting a specified change in ratios of % ground cover for bare ground and bryophytes in the post-Basslink compared to the pre-Basslink period, i.e., power, on the assumption that the type 1 error rate is 5 % and the test is two-tailed.

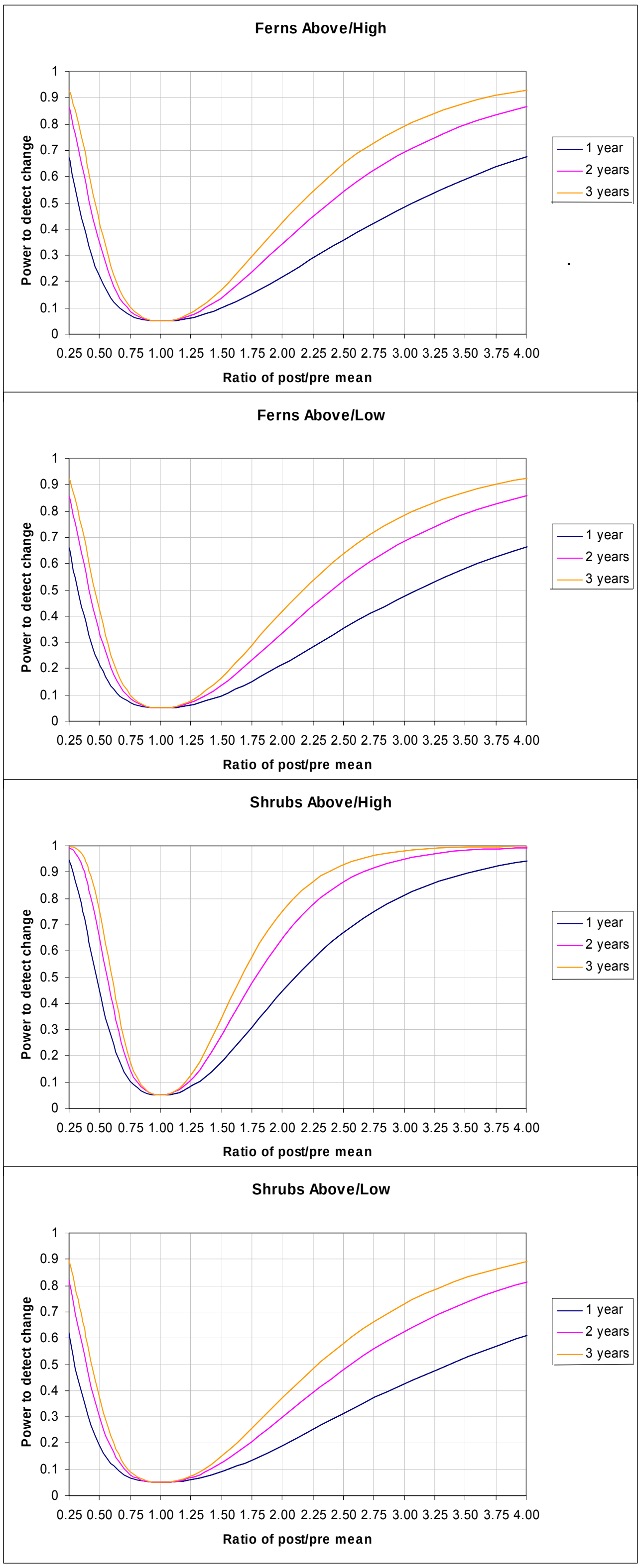


Figure 13.6. Probability of detecting a specified change in ratios of percent ground cover for ferns and shrubs in the post-Basslink compared to the pre-Basslink period, i.e., power, on the assumption that the type 1 error rate is 5 % and the test is two-tailed

### 13.5.3 Macroinvertebrates and benthic algae

Power analysis was applied to the macroinvertebrate and benthic algal variables to assess their probability in detecting change. Power curves are presented in Figure 13.7 to Figure 13.10 for density of macroinvertebrates for zone 2, number of families, O/Epa, O/Erk, algal cover, moss cover, abundance of EPTCC species, abundance of E species and proportional abundance of EPT species. The power curves demonstrate the capability of the macroinvertebrate and algal variables to detect specified levels of post-Basslink change after one, two and three years of monitoring.

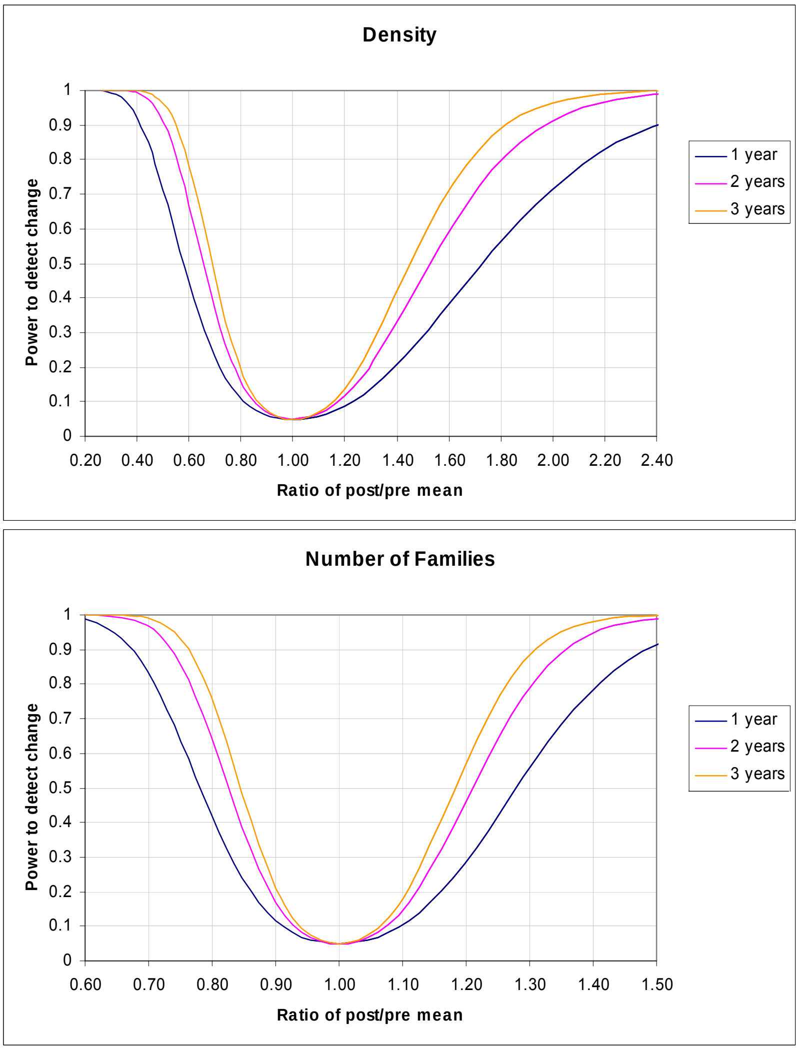


Figure 13.7. Probability of detecting a specified change for macroinvertebrate density and number of families in the post-Basslink compared to the pre-Basslink period, i.e., power, on the assumption that the type 1 error rate is 5 % and the test is two-tailed.

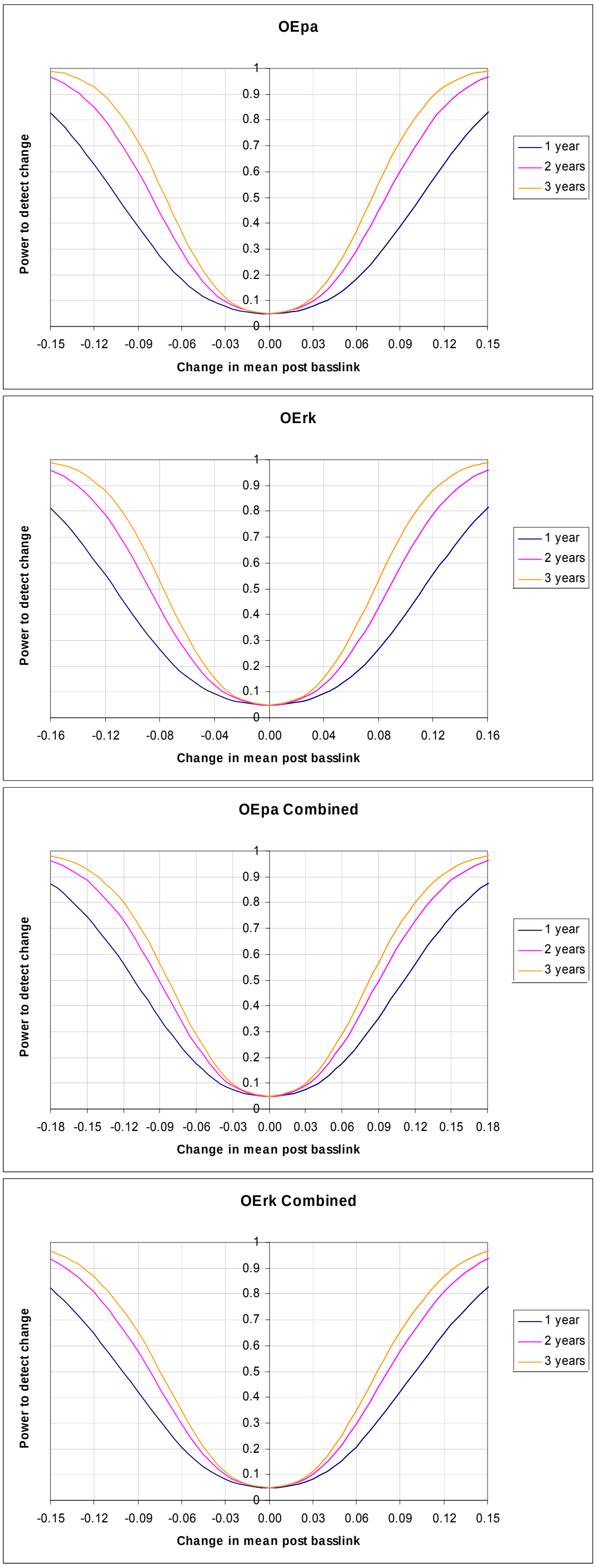


Figure 13.8. Probability of detecting a specified change for O/Epa and O/Erk singuarly and combined in the post-Basslink compared to the pre-Basslink period, i.e., power, on the assumption that the type 1 error rate is 5 % and the test is two-tailed.

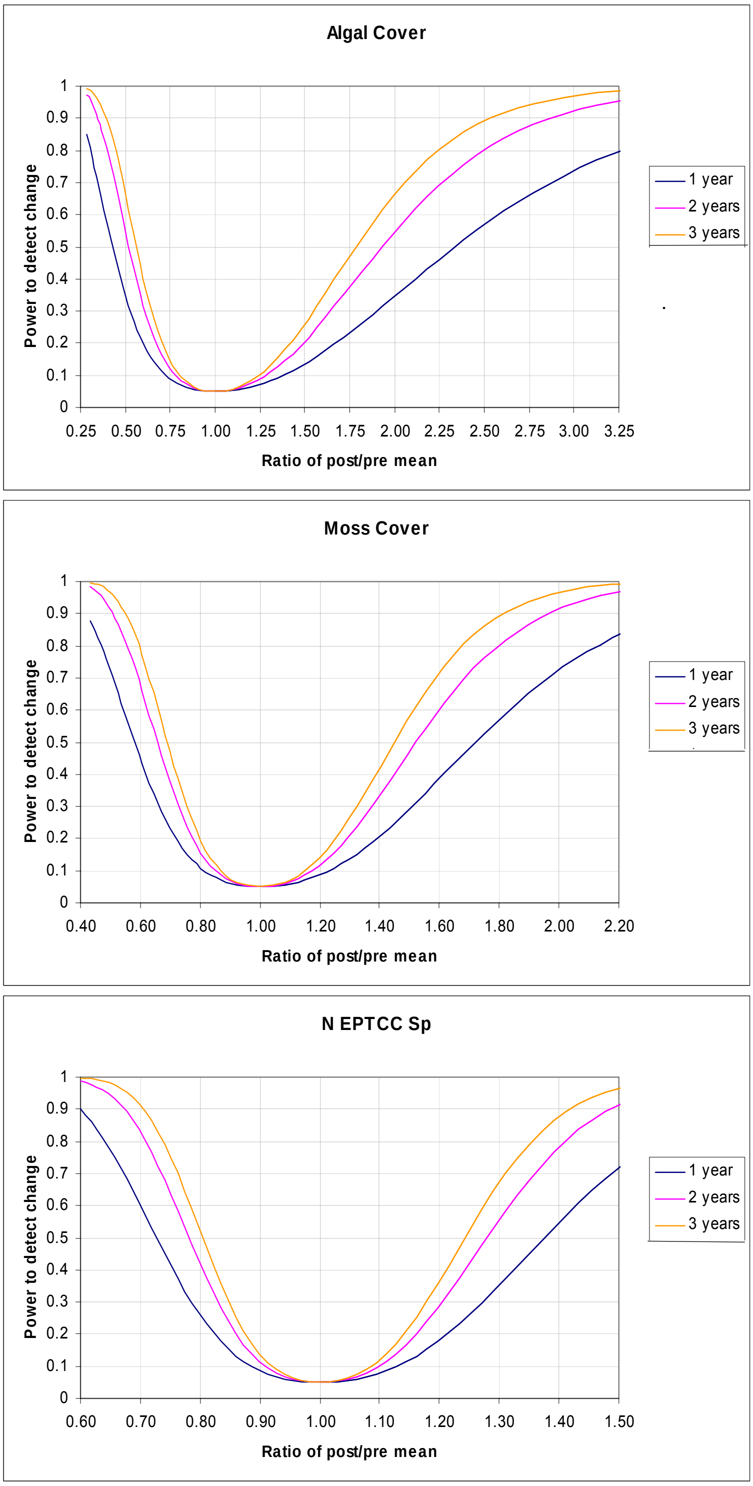


Figure 13.9. Probability of detecting a specified change for algal cover, moss cover and abundance (N) of EPTC macroinvertebrate species in the post-Basslink compared to the pre-Basslink period, i.e., power, on the assumption that the type 1 error rate is 5 % and the test is two-tailed

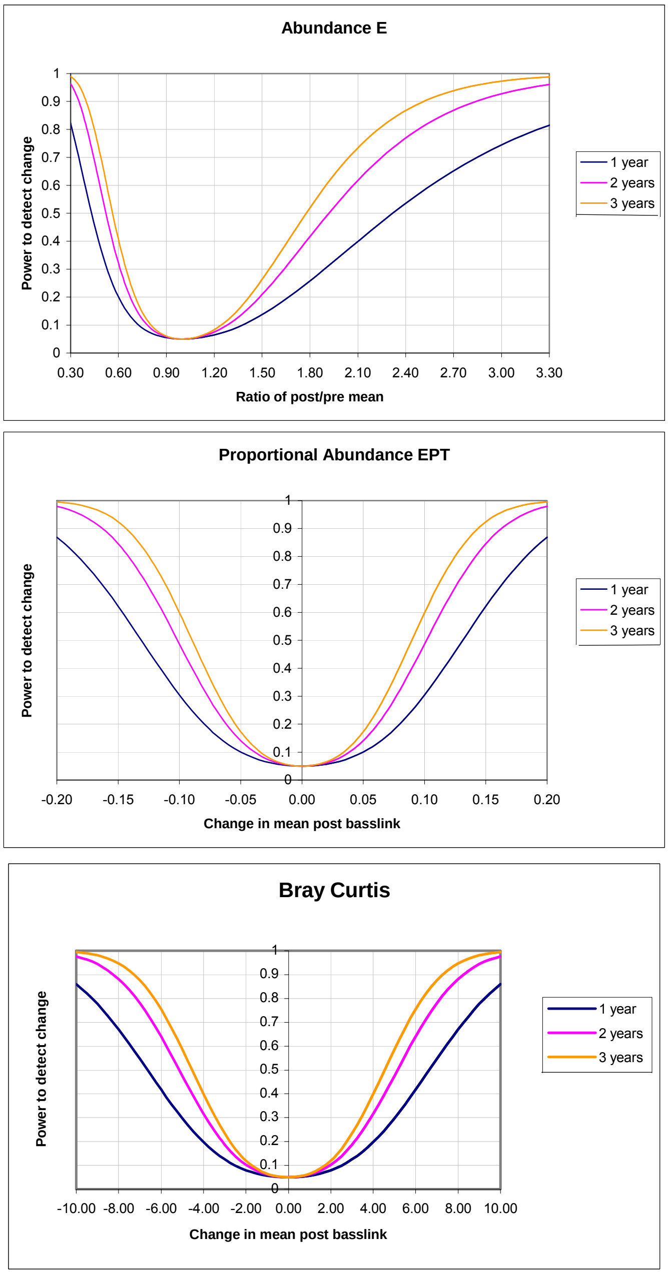


Figure 13.10. Probability of detecting a specified change for abundance of E species, proportional abundance of EPT species and Bray Curtis in the post-Basslink compared to the pre-Basslink period, i.e. power, on the assumption that the type 1 error rate is 5 % and the test is two-tailed.

### 13.5.4 Fish

Power analysis was applied to the catch per unit effort (CPUE) all fish, native fish only and the ratio of trout to native fish data to assess their probability in detecting any changes associated with the commencement of Basslink after one, two and three years of monitoring. The power curves for each of the three fish indicator variables are presented in Figure 13.11.

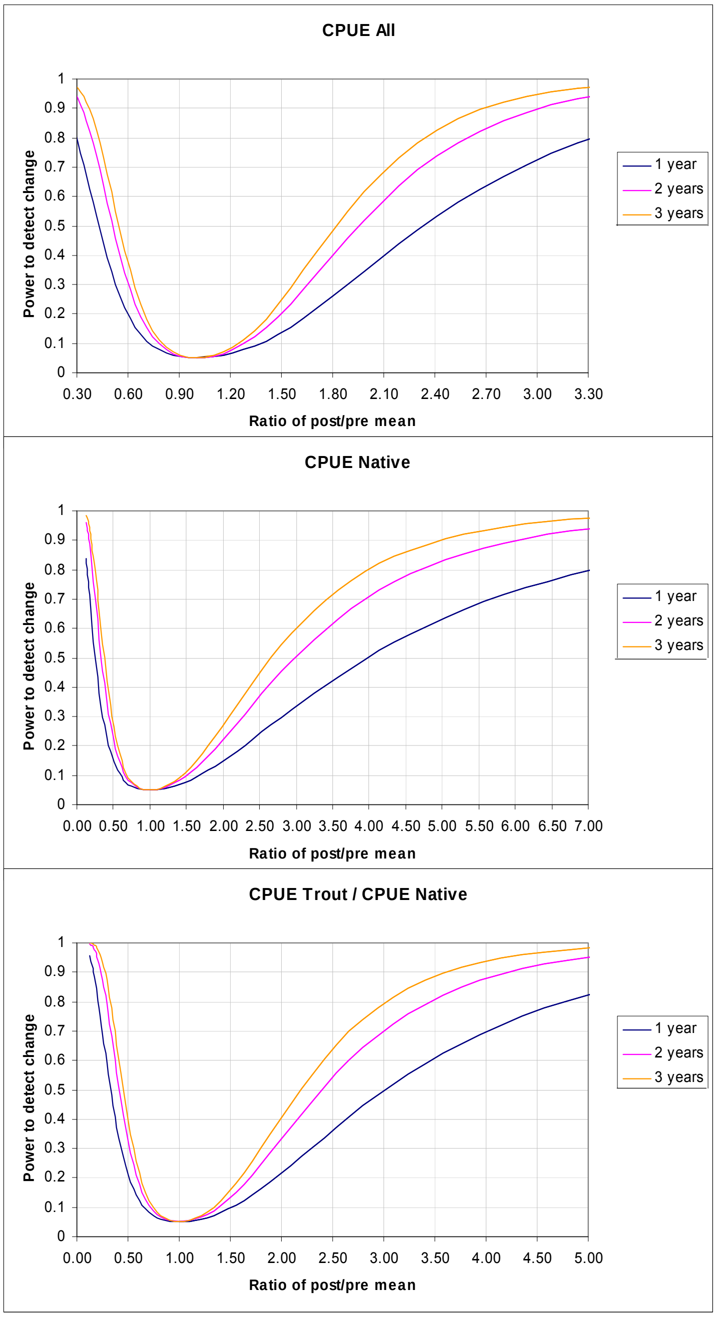


Figure 13.11 Probability of detecting a specified change in the ratio of CPUE means for all fish, native fish only, and the ratio of trout to native fish post-Basslink to pre-Basslink, i.e., power, on the assumption that the type 1 error rate is 5 % and the test is two-tailed.

## 13.6 Status of the trigger values

As explained in section 1.5 of this report, trigger values presented in this document are considered 'interim' trigger values until a final set is produced by April 2006. This is to allow for incorporation of the final pre-Basslink data sets, and further statistical exploration of the data.

During January to March 2006, the lead researchers will work with the consulting statistician to the Gordon Basslink Monitoring Program (BMP) to incorporate the final data into the statistical models, and fully explore a range of statistical approaches to developing trigger values. These will be reviewed by the Scientific Reference Committee in April 2006. The final set of trigger values will be provided to the relevant Tasmanian and Commonwealth Ministers once agreement is reached by the Scientific Reference Committee.

The 2005-06 Annual Report for the BMP will provide the final pre-Basslink data and the final set of trigger values.

## 13.7 The three-stage process

The indicator variables and their trigger values, including the assumptions and probability of their accuracy, have been defined for water quality, fluvial geomorphology, riparian vegetation, macroinvertebrates, benthic algae and fish data. This has produced a list of 26 indicator variables. Following the implementation of Basslink, each discipline will evaluate the results with respect to the identified trigger values. This process represents the first stage in the three-stage approach to evaluating post-Basslink conditions.

Once assessed, values which exceed the nominated trigger values will invoke the second stage of the process, which is to determine if the exceedence can be attributed to a Basslink effect. This will be done by examining the broader patterns and trends of associated monitoring data, with the assistance of the conceptual model and information about related processes to develop hypotheses to indicate the cause of the excessive values. From this, appropriate investigative work would be undertaken.

The third stage is to determine if management intervention is required. This will be done by assessing the effect of the excessive value and its ecological implications.

In April 2006, along with finalising the trigger values, the Scientific Reference Committee will consider appropriate response protocols to data exceedences of any of the indicator variables, in recognition that the response would vary considerably depending on the nature of the exceedence that has occurred.

## 13.8 Responsibilities

The researchers will routinely evaluate their monitoring results against the relevant trigger values and important qualitative conditions. The outcomes of this evaluation will be reported in the relevant field report, along with the researcher's expert opinion on the cause and consequences of any exceedence. Exceedences will be reported in the Gordon River Basslink Monitoring Annual

Reports along with information on the response taken to exceedences and the findings and outcomes.

Hydro Tasmania has the responsibility to co-ordinate and ensure delivery of the monitoring program, to receive and review field reports, and to seek out and act on information on post-Basslink changes in a timely and appropriate manner.

Hydro Tasmania will take advice from the researchers, its internal review and management entities, external experts, and the Gordon River Scientific Reference Committee (SRC), as needed. The SRC will provide ongoing review of the process and its outcomes through its regularly scheduled meetings.

## 13.9 Review of indicator variables

Within six months of the third and sixth anniversaries of the Basslink commencement date, Hydro Tasmania must prepare a Basslink Review Report which will include formal reviews of the indicator variables and trigger values. Trigger values can be reviewed in the intervening periods if a compelling case to do so is made. The SRC will play a key role in any review of indicator variables.

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# 14 Conclusion

The BBR must meet five essential requirements. It must:

- present trends from all consolidated data collected subsequent to the IIAS investigations;
- evaluate the adequacy of the Gordon River Basslink Monitoring Program and, if necessary, propose refinements;
- evaluate the appropriateness of the proposed Mitigation Measures based on this further data;
- consider and, if appropriate and practicable, propose 'limits of acceptable change' for each of the key scientific disciplines which: are consistent with the aims of adaptive management; recognise the regulated nature of the Gordon River; and recognise the potential for conflicts between the management objectives of different disciplines; and
- respond to any written comments on the Draft Basslink Baseline Report received from the World Heritage Area Consultative Committee, following Hydro Tasmania's written invitation to comment.

The individual discipline chapters (chapters 6-11) supported by the foundation chapters (chapters 1-5) have effectively met the first two requirements. Chapter 12 (Appropriateness of mitigation measure) has addressed the third, and chapter 13 (Indicator variables) has addressed the fourth requirement. Comment from the WHACC was sought and received during the preparation of this report, and Hydro Tasmania's response to these comments is presented in appendix 2.

The Basslink Baseline Report has documented, through background material, the conceptual model, and the various discipline chapters, the presently occurring environmental conditions in the middle Gordon River.

Building on the consolidated results of the past four years of the Gordon River Basslink Monitoring Program, the BBR has discussed the various trends, variability and data ranges for the monitored scientific disciplines, as well as the underlying processes contributing to these. These results have permitted the BBR to fulfil its primary purpose, which was to provide an accurate and appropriate statement of pre-Basslink environmental conditions against which the post-Basslink conditions can be compared.

One significant outcome of this work has been the development of quantitative indicator variables for all disciplines, and the determination of trigger values for each variable. The evaluation of these will form the first stage of a three-stage process to detect post-Basslink changes.

In the context of managing the impacts of Basslink on the Gordon River, the aims of adaptive management are:

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

The principal mechanism for adaptive management, post-Basslink, will be the review of the monitoring data in the Annual and Review Reports from the BMP, and the regular and timely assessment of the indicator variables by the Gordon SRC. 26 indicator variables have been derived in order to quantitatively compare post-Basslink conditions with those presently prevailing. These and their trigger values are listed in chapter 13 Indicator variables, as is the process and responsibilities for response to trigger value exceedence.

The Scientific Reference Committee, with its representation of State and Commonwealth scientists, lead BMP researchers, and an independent chair, will provide ongoing scientific advice and review of the process and its outcomes. Responsibility for amending the Water Licence to modify the Gordon River Basslink Monitoring Program or the mitigation measures will rest with the Tasmanian Minister administering Hydro Tasmania Water Licence under the Water Management Act.

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