BASSLINK INTEGRATED IMPACT ASSESSMENT STATEMENT

POTENTIAL EFFECTS OF CHANGES TO HYDRO POWER GENERATION

APPENDIX 6:

GORDON RIVER RIPARIAN VEGETATION ASSESSMENT

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June 2001

Prepared for

Hydro Tasmania

the renewable energy business

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Plate 1 cover photo: *Leptospermum riparium* on an island at the bottom of Abel Gorge in the Gordon River (Site 70), 7.4 km below the Gordon dam, looking across a big pool to Abel Gorge. Note: there is no understorey vegetation, tree roots are exposed and leaves are absent from the trunks of the shrubs to height of approximately 2.5 m.

EXECUTIVE SUMMARY

The effect of current operation of the Gordon Power scheme on riparian vegetation of the Gordon River in comparison with its tributaries

The riparian vegetation of the Gordon River above its junction with the Denison River contrasts starkly with that of neighbouring unregulated rivers, the Denison and Franklin Rivers, which are tributaries to the Gordon. The Denison and Franklin Rivers have a complex riparian vegetation of mixed ages on a wide range of substrates (bedrock, cobble and sand) right to the water's edge at low river flow. In the Gordon River above its junction with the Denison River there is a plimsoll line in the vegetation at approximately 2.5 m on the river bank below which leaves are absent on the branches of trees and shrubs. This height is equivalent to a flow of 140 cumecs during the efficient operation of two turbines. Between 1.5 and 2.5 m on the bank in this section of the Gordon River, there is a decrease in the total cover of riparian plants and ferns and an increase in the cover of grasses in comparison to its tributaries.

At heights between 0 and 1.5 m on the banks of the Gordon River above its junction with the Denison River the bank is mostly comprised of mineral substrate (rock and sand). This coincides with a decreased cover and species richness for most plant groups in this section of the Gordon River in comparison with tributaries.

The above effects decrease with distance down the Gordon River from the Splits and with increased width of channel. At the head of Ewarts Gorge 23.3 km from the dam, below the junction with the Denison River the plimsoll line is at approximately 2.0 m on the bank.

Recruitment in the Gordon is very low in comparison with its unregulated tributaries because the high periodicity of flood prevents establishment and the dam limits down-stream movement of propagules. The principal remaining riparian tall shrub species below the plimsoll line in the Gordon River is *Leptospermum riparium*. In many cases it occurs in mature stands which have thinning crowns and dead lower limbs. There is little or no recruitment.

There has been a large reduction in the contribution of epiphytic and terrestrial mosses but an increase in mosses on rocky substrates in the Gordon River in comparison with its unregulated tributaries. This probably reflects the increase in mineral substrate.

Removal of vegetation cover from the lower slopes of the river bank and erosion of sediment has led to undermining of vegetation and collapse of riparian and rainforest vegetation into the river, particularly on stretches of the river where banks are of alluvial origin.

Islands of vegetation on cobble banks and rock bars in the river, in addition to suffering loss of species cover and diversity, have been undermined and overturned by the force of water focussed at a particular height on the bank.

The main causes for the loss of riparian vegetation cover and diversity are inundation (submergence of foliage), waterlogging (saturation of soils), changes in the seasonality of flow (high summer flows from the dam) and reduction in the available daylight hours for photosynthesis and growth. In addition there are the effects of scouring by water and undermining of vegetation concentrated on a narrow region of the bank rather than being spread over a wide range of flow rates.

Expected changes under Basslink

It is expected that the Basslink Power Scheme would lead to further changes in riparian vegetation on the Gordon River in particular a rise in the height of the plimsoll line on the bank of the Gordon River to approximately 4.0 m in the region from Abel Gorge to Second Split, 7-12 km from the dam. The causes for this are:-

- Direct injury to plant leaves caused by increased inundation of vegetation up to 4.0 m on the river bank
- Direct injury to plant roots arising from waterlogging to 4.0 m on the river bank. However this will be at a reduced intensity in comparison to the current regime for the interval 0-1.5 m on the river bank, because flow will be low for short periods during most days allowing banks to drain
- Reduced light and time available for plants to photosynthesise, grow and reproduce in summer, in comparison with the current regime, because of inundation up to 4.0 m on the river bank during the day. Typically, in the summer months, the power station operates at flow rates greater than 140 cumecs between 9.00 a.m. on one day and 2.00 a.m. on the following day. There is then a short period of low flow (less than 70 cumecs) between 3 a.m. and 8 a.m.
- Reduced light and time available for plants to photosynthesise, grow and reproduce in summer, in comparison with the current regime, because there are fewer days during summer that are free from flood.
- Greater frequency and amplitude of water level fluctuation under Basslink would reduce recruitment of riparian species. New germinants would be exposed to greater disturbance by inundation, waterlogging, erosion of substrate, dumping of sediments and light limitation.
- Higher peak flows under Basslink would increase scouring, undermining and erosion on islands and acceleration of the rate of removal of islands of vegetation in the Gordon River
- Higher peak flows under Basslink would accelerate the rate of loss of the principal tall shrub (*Leptospermum riparium*) stabilising river banks in the Gordon River
- Higher peak flows under Basslink would increase the frequency of landslips on steep river banks (initially as river adjusts to new flow regime)
- The rare moss, *Rabdodontium buftonii* known only from the Gordon River (Albert Gorge to Ewarts Gorge) is expected to thrive under Basslink
- All these effects are expected to be most severe immediately below Abel Gorge 7-12 km below the dam and decrease with distance from the dam.

Mitigation Options

The greatest benefit to riparian plants would be achieved by mitigation options which included long periods of low flow (less than 50 cumecs) during summer each year. Short periods free from inundation, or a long period free from inundation in a single year, would reduce stress, or may allow recruitment to occur but not the survival of those recruits. Therefore most mitigation options only effect the rate of change of vegetation and don't effect the end point. However, reducing the maximum flow under Basslink from 250 to 210 cumecs would mean the adverse effects on riparian vegetation would reach a lower position on the river bank (for example, 3.5 m rather than 4.0 m, in a region 7-12 km below the dam). This would limit reductions in species cover and abundance associated with inundation and waterlogging to heights less than 3.5 m on the river bank in this region of the river.

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1 INTRODUCTION

Riparian vegetation is specialised vegetation that occupies the disturbed zone on river banks between low water mark and peak flood. It is adapted to, and dependent on disturbance by flood, colonising new habitat made available by partial or complete destruction of existing vegetation, erosion and deposition of sediments. The frequency and duration of disturbance determines the probability of the removal of existing vegetation and its replacement with new riparian communities (Kalliola and Puhakka 1988, Tabacchi *et al*. 1998). The frequency of disturbance also determines the species richness of riparian communities. Maximum plant species richness occurs in regions of rivers (usually the middle reaches) where there are intermediate levels of disturbance (Nilsson *et al*. 1989, Tabacchi *et al*. 1990, Pabst and Spies 1998, Tabacchi *et al.* 1998) and provides support for the Intermediate Disturbance Hypothesis of Connell (1978). In the upper reaches of rivers gradients are steep (>4˚), the channel is constrained in a V-shape, there is more kinetic energy, flash floods are common, there is potential for a high sediment load and a high degree of disturbance. In the middle reaches of rivers with gradients of 1-4˚, there is a moderate sediment load, intermediate disturbance, the channel is stable and there is great spatial heterogeneity and a wide range of niches available for plant species to occupy. Near the mouth of a river where gradients are low <1˚, the channel is commonly unstable or braided and subject to high rates of sediment deposition (Tabacchi *et al.* 1998). The intermediate levels of disturbance in riparian zones often lead to riparian plant communities being more species rich than the adjacent forest communities where they experience low levels of disturbance (Gregory *et al.* 1991, Planty-Tabacchi *et al.* 1996). Where comparisons have been made of species richness in the main river channel and tributary streams, the main channel tends to have greater species richness than its tributaries even though tributaries may each have a distinct flora determined by their geology, geomorphology and hydrology (e.g. canyons) (Nilsson *et al.* 1994).

It is well accepted that the species richness in regulated rivers is lower than in free-flowing rivers (Jansson *et al.* 2000). Regulated but unimpounded rivers tend to be most similar to natural, free-flowing rivers. In contrast storage reservoirs, which commonly have changed timing and increased intensity of water level fluctuations, and run-of-river impoundments, which commonly have increased frequency of water level fluctuations, are most dissimilar in species richness from natural, free-flowing rivers. All regulated rivers studied by Jansson *et al.* (2000) had more coarse-grained river margin soils and lower percentage cover of plant species and lower species richness than natural free-flowing rivers. Changes occur rapidly on the margins of rivers following regulation. Nilsson *et al.* (1997) showed that there were few species and sparse vegetation cover on the margin of regulated rivers soon after the onset of regulation. In the following decades many species colonised but species richness remained impoverished in comparison with free-flowing rivers. One might ask why no plant life history benefits from river regulation. The answer is probably that margins of regulated rivers are so different from natural environments that no species are adapted to them, although it is possible species with adaptations have not yet invaded (Jansson *et al.* 2000).

It is generally agreed that riparian corridors provide an important conduit for the dispersal of plant species (Gregory *et al.* 1991, Nilsson *et al.* 1994). Dams cause fragmentation of riparian corridor and affect long-distance seed dispersal (Jansson *et al.* 2000). Species with a dispersal strategy involving wind, or seeds which float for long periods on water (long floaters) are favoured over other strategies (e.g. short floaters) (Jansson *et al.* 2000). Plant attributes have been recognised as potential indicators of the disturbance regime (Grubb 1977, Noble and Slatyer 1980, McIntyre *et al.* 1995). One of the major consequences of the interaction between natural and human induced disturbance regimes in riparian temperate zones is the increase in the number of endogenous and/or exogenous stress tolerant plants (Tabacchi *et al*. 1998). In addition there are species which benefit from human disturbance. These include ruderals (adapted to low stress high disturbance); annual and biennial species (with short life spans) and externals (accidentally colonise riparian zones because of accessibility of habitat and availability of propagules) (Tabacchi *et al*. 1998, Jansson *et al.* 2000). These attributes are favoured over the woody perennial habit.

Although there have been numerous studies of the impacts of river regulation on stream-side biota there is still little known about the relationships between deviations from natural flow and losses of ecological integrity (Jansson *et al.* 2000).

This is a report on research funded by Hydro Tasmania (14 days field work and 8 days writing) to assess the current state of riparian vegetation on the middle Gordon River, and projected changes to riparian vegetation that might occur following implementation of the Basslink Project.

2 METHODOLOGY

2.1 Analysis of hydrology data for the Gordon River as it relates to the riparian vegetation

Data presented in Appendix 2 of this report series – Gordon River Hydrology Assessment (Palmer *et al*, 2001) was analysed by Hydro Tasmania to determine the proportion of daylight hours in each month of years 1997 and 1998 that plants were free from inundation and light was available for photosynthesis and plant growth. Hourly data of flow rates from the dam (current) were compared with modelled data for Basslink (TEMSIM 450) and simulated natural river flows based on rainfall records (Natural). All days were assumed to be 12 hours. The time plants were free from inundation was calculated using a threshold value of 140 cumecs (the flow rate produced by efficient operation of two turbines), which at site 70, 9.1 km down stream of the dam, was equivalent to a water height of 2.5 m on the river bank.

2.2 Mapping of riparian plant communities in the Gordon River

Mapping of riparian plant communities and the adjacent forest communities was confined to a section of the Gordon River between the base of Abel Gorge (7.4 km below the Gordon dam) to the Second Split (12.0 km below the Gordon dam). Mapping was confined to this 4.6 km segment of the river because mapping of riparian communities principally involved mapping the remaining dominant riparian shrub species *Leptospermum riparium* (Plate 1). Maps gave little or no information about understorey shrub, herb, moss and epiphyte species that were most affected by dam operation. The segment of the river chosen was considered to be representative of the communities in the Gordon River between the dam and the junction with the Denison River. The plant communities were mapped from a raft, which was paddled down the river. Boundaries between communities were marked on a large-scale map (1:2500) of the Gordon River (supplied by Hydro Tasmania). Community nomenclature was consistent with Kirkpatrick *et al.* (1995).

Riparian vegetation on islands, cobble bars and sandbanks in the river (as distinct from on river margins) represents an important component of the total riparian vegetation of the river. This is because the banks of the Gordon River are generally steep (consequently have a narrow riparian zone) and overhung by rainforest, reducing light intensity. However, islands and gravel/sand bars generally have a low profile, are fully exposed to disturbance, are well illuminated and therefore have a wide range of niches for riparian species. The degree of erosion on islands, bars and banks, and of the levels of seedling recruitment was visually assessed on the Gordon River from the base of Abel Gorge (7.4 km below the Gordon dam) to the start of Ewarts Gorge (Harrison Creek, 23.3 km below the Gordon dam).

2.3 Cover and abundance of plant species within riparian communities in the Gordon River compared to its tributaries

The cover and abundance of vascular plant species within riparian communities was assessed in four river sections: the Gordon River (in two regions; Abel Gorge to Second Split and First Split to Ewarts Gorge), the Denison River (from 9 km to 2 km upstream of Marriotts Gorge) and the Franklin River (Jane River junction to Shingle Island). Results for the Gordon River were compared with neighbouring control rivers, the Denison River and the Franklin River (see Plates 2). Plant cover and abundance in the riparian zone was assessed using 2 m wide belt transects consisting of contiguous 2 x 2 m quadrats, oriented perpendicular to the river margin. Two replicate transects were conducted in riparian vegetation on each of the 5 common substrates; bedrock bar, cobble bank, sand bank, mud bank and steep riverbank overhung by rainforest. The substrates cobble bank, sand bank and mud bank were invariably well illuminated, occurring either on islands within the river or on a well-illuminated bank (high incident sunlight for at least a proportion of the day). The sampled substrates bedrock bar and steep riverbank were invariably overhung by rainforest and in poorly-illuminated positions (low incident sunlight). Note: steep riverbank included near-vertical cliffs of cross-bedded sedimentary material (cobble and sand). The cobble banks referred to here are of low profile.

In each 2x2 m quadrat within each transect, species abundance and cover estimates for the various strata (trees, tall shrubs, low shrubs, graminoids, grasses, and herbs) were made. Herbarium specimens of unknown species were collected and lodged with the Tasmanian Herbarium. Nomenclature followed Curtis and Morris (1975) and Buchanan (1995) for dicotyledons, and Morris (1979 & 1994) and Buchanan (1995) for monocotyledons. Field studies were conducted in July/August 2000, therefore reproductive material (flowers and fruits) were absent from most species. As reproductive material is essential for classification to species level, some grasses, graminoids and herbs were only classified to genus e.g. *Carex spp.*, *Ehrharta spp*., *Gnaphalium spp.*

The sampling regime resulted in the assessment of riparian vegetation on approximately 40 transects (303 quadrats). A distinct plimsoll-line (a line in the trees and shrubs below which there were no leaves) was present on the banks of the Gordon River at about 2.5 m, corresponding to constant water levels developed during efficient power station operation with two turbines. Little vegetation was present on the riverbank at heights less than 1.5 m as this corresponded to constant water levels developed during efficient power station operation with one turbine. There is a reduction in the height of the plimsoll line with distance down the river and with increased width of the channel (see section 4.1.2). The approximate heights of vegetation change on the river bank (1.5 and 2.5 m) were used as boundaries for the purposes of analysis. The data was divided four ways and five analyses were conducted. The first analysis was conducted on all data (303 quadrats). The second analysis was conducted on quadrats occurring 0–1.5 m above water level at time of sampling (called channel sites for the remainder of this report, n = 192). The third analysis was conducted on quadrats occurring at 1.6–2.5 m above water level at time of sampling (called low bank sites, n = 62). The fourth analysis was conducted on quadrats occurring above 2.5 m above water level at time of sampling (called high bank sites, n = 49). The fifth analysis compared the substrates cobble (islands and banks) with sand (principally riverbank) for channel sites (n = 83) and low bank sites (n = 38) within the Gordon River. The division of data in this way allowed us to test three questions:-

1. Does the riparian vegetation in the Gordon River, in the region exposed to regular inundation (channel sites 0-1.5 m, and low bank sites 1.6-2.5 m), differ from unmanaged tributaries?
2. Does the riparian vegetation in the Gordon River, no longer exposed to natural peak floods (high bank sites >2.5 m), differ from unmanaged tributaries?
3. Does substrate (e.g. cobble and sand) affect the degree of change in the riparian vegetation?

2.3.1 Analysis

The data was analysed using the pattern analysis package PATN (Belbin 1994). Species quantitative data (abundance scores) from each 2 x 2 m quadrat were used allowing analysis of species in site data by classification and ordination. Species data were range-standardised [(D_{ij}-min i. or j.)/range i. or j.] prior to analysis giving equal weighting of species. The ordination used was semi- strong- hybrid multidimensional scaling (SSH) (Belbin 1994) in four dimensions based on a Kulczynski association measure. The analytical technique of vector fitting was used to interpret 19 environmental variables and the significance of the maximum correlation values tested using a Monte-Carlo randomization with 100 permutations. Classifications were carried out by a hierarchical, polythetic, agglomerative-clustering procedure using the default options in PATN.

2.3.2 Vegetation Guilds

Species were grouped into seven vegetation guilds: trees, tall shrubs, low shrubs, herbs, grass, graminoids and ferns. These groups were tested over the three rivers for significant differences in percentage cover. The percentage cover data were natural log transformed before analysis with a student's t-test.

2.3.3 Species Analysis

The mean relative importance value of each species recorded in the floristic survey in each quadrat were calculated as follows; $P_1 = \% C_i / \Sigma \% C_q$, where the relative importance (P_1) of a species (i) is the percent cover of this species ($\%C_i$) divided by the total percentage cover of all species for the quadrat ($\%C_q$). Significance in the relative importance of each species between the Gordon River and the two control rivers was calculated with a student's t-test.

2.4 Root mat density

The depth and density of roots was assessed on two sandbanks differing in slope. The first sand bank (slope of 11 degrees) was site 71 (7.8 km below the dam, on the LHS bank, adjacent to a large gravel island supporting two small islands of vegetation, just below the big pool at the base of Abel Gorge) and was dominated by a mature stand of tea tree (5 266 500 mN, 410 450 mE). The second bank (slope of 20 degrees) was 50 m upstream of site 70 (9.1 km below the dam, on the RHS bank, on an inside bend of the river, 50 m upstream of a vegetated gravel island) (5 266 450 mN, 409 650 mE). This bank was fringed by *Leptospermum riparium* (rooted 0.5 to 1.5 m up the bank) and topped by thamnic rainforest (starting about 2.5 m up the bank).

At the first site, an auger was used to collect soils at depth intervals: 0-10, 10-20 and 20-30 cm, starting near low water level and at 1, 2 and 3 m distant from this point up the bank on two parallel transects perpendicular to the direction of river flow. The total number of samples collected = 3 depths x 4 positions x 2 transects = 24 samples. At the second site the same protocol was used but with only 3 sample positions up the slope. The total number of samples collected = 3 depths x 3 positions x 2 transects = 18 samples. Samples were returned to the lab, dried, and total weight of roots obtained. The aim of this experiment was to answer the question:-

Do roots in steep sand banks on the Gordon River influence stability of these banks? This is based on the assumption that roots in the top 10 cm of the sand bank will play an important role in preventing erosion of the bank.

2.5 Contribution of mosses to stream bank stability

In collaboration with Mr Patrick Dalton (School of Plant Science, University of Tasmania, expert in Bryophytes) a 2-day study (25/9/00 and 15/10/00) was conducted of the distribution of mosses within the riparian zone on the Gordon River in comparison with its tributaries. Complete collections of mosses were made in the riparian zone of the Gordon River (at several sites between Abel Gorge and Ewart's Gorge) and two sites in the Franklin River (1 km upstream of Double Fall, and Flat Island). In addition, the distribution was determined for a rare and endangered moss species that was rediscovered during the study of the vascular flora.

3 CURRENT CONDITIONS

3.1 Hydrology of the Gordon River as it relates to the riparian vegetation

This section is an overview based on hydrological data and reports supplied by Hydro Tasmania, discussions with geomorphologists, and on observations and quantitative assessment by the authors of the vegetation of the Gordon River compared with its tributaries, conducted over 14 field days (June to September 2000). It is an assessment of the current state of the riparian vegetation on the Gordon River compared with adjacent unmanaged rivers, the Denison and the Franklin. This is followed by a detailed assessment of quantitative data.

During the 22 years the Gordon Power Station has been operating, changes have occurred in the geomorphology of the river and in riparian plant communities on the banks of the river. These cannot be determined directly because no survey of the river was conducted before the impoundment and the Gordon Power Station were established. However, these changes can be inferred by comparing the Gordon River with neighbouring rivers traversing similar geology and terrain with comparable flows, naturally determined by rainfall.

3.1.1 Unmanaged rivers: the Franklin and Denison

In unmanaged river systems which are tributaries to the Gordon River (e.g. Franklin and Denison Rivers) the riparian vegetation occupies a zone that extends from low summer river flow where, at its lowest extent it grades into naturally occurring aquatic and semi-aquatic species (Plate 3), to peak flood level where it grades into the adjacent rainforest communities (at its upper extent, Plate 4). These riparian communities occupy the ecotone between aquatic species and rainforest in a region exposed to high light intensities, and disturbance caused by the force of flood waters, large logs smashing into the vegetation and periodic deposits of sediments. With few exceptions all substrates (bedrock, cobble, sand, silt) are well vegetated to the low water mark (Plates 5 and 6)

3.1.2 Hydrology of the Gordon River

The Gordon Power Station has been in operation for the last 22 years (1978 – 2000). During the first 12 years two turbines were operating, but 10 years ago a third turbine was added to the station. The station most commonly operates with two turbines. The third turbine currently operates at its efficient load for approximately 11% of time. The flow rate in the Gordon River produced at efficient load for each turbine is 70 m^3s^{-1}. Therefore for two and three turbines, river flow at efficient load is 140 m^3s^{-1} and 210 m^3s^{-1}. However at full gate (maximum water flow) with three turbines operating, a flow rate in excess of 250 m^3s^{-1} can be produced.

This can be translated into river heights. For example at site 70, 9.1 km from the dam (taken from Fig. 1 showing on-off sequence for the Gordon power station):-

- One turbine at efficient load (70 m^3s^{-1}) raises the river level to 1.5 m

- Two turbines at efficient load (140 m^3s^{-1}) raise the river level to 3.1 m
- Three turbines at full gate (250 m^3s^{-1}) raise the river level to 4.5 m

This assumes that there is no additional flow contributed by rainfall. The height of the water within the river, however, is also strongly affected by width and slope of the channel and constrictions to flow. For example, when the power station is operating at three turbines full gate, the river height on a steep section of the Albert Gorge at site 75 is 3.0 m (3.6 km from the dam), compared with 4.5 m at site 70 (9.1 km from the dam) and nearly 5 m at site 69 (12 km from the dam, near Second Split, Fig 1).

The operation of two turbines in the Gordon River has produced an obvious plimsoll-line in the riparian vegetation at approximately 2.5 m (manifest as a line in the trees and shrubs below which there are no leaves) from Abel Gorge to Second Split (7.4 to 12.0 km below the Gordon dam, Plates 7 and 8). The major constriction at the Second Split causes ponding and a plimsoll-line rises to approximately 3.5 m on the riverbank (Plates 9). Below the First Split the channel becomes broader and the plimsoll-line falls to approximately 2.0 m on the riverbank (Plate 6). The plimsoll-line continues beyond the junction with the Denison River and was obvious at about 2.0 m on the bank at the start of Ewarts Gorge (Harrison Creek, 23.3 km below the Gordon dam). Broadening of the river channel and modification to flow provided by natural tributaries results in a progressively less marked plimsoll line lower on the river bank with distance down the Gordon River (Plate 10).

Generally, between 1.5 and 2.5 m riparian vegetation cover is reduced and it shows signs of scouring by water (Plates 11). Below 1.5 m on the riverbank vegetation is under water whenever the power station is operating, most riparian vegetation has disappeared and mineral substrate predominates (Plates 12).

At heights above 2.5 m on the riverbank riparian vegetation is only underwater during the operation of the third turbine, used at its efficient load for approximately 11% of the time for the last 10 years. Although there are no obvious effects on the health of the vegetation, structural changes have occurred (see below).

An explanation of these changes comes from hourly flow rate records (in cumecs, m^3s^{-1}) in the Gordon River under different management regimes; natural (simulated natural flow based on rainfall records), current (current flow rates from the Gordon Dam) and TEMSIM (simulated flow rates under the proposed Basslink scheme) (Figure 2). All flow rates presented below are for site 70 (9.1 km below the dam) for the period 1/1/97-1/1/99. Under natural flow, big flood peaks (approaching 900 m^3s^{-1}) provide a huge surge of water but usually only last from days to a week and most commonly occur in winter. In the summer months occasional peaks are separated by long periods of flow rates less than 50 m^3s^{-1} (see Fig. 2c). Under the natural regime plants to as low as 1.5 m on the bank have 23-28 days in January, February and March free of flood when they can photosynthesise and reproduce while air temperatures and light intensities are optimal (Fig 3). Under managed flow maximum flows are lower (210 m^3s^{-1} for 3 turbines at efficient load and 250 m^3s^{-1} at full gate) but occur throughout the year (Fig 2a). During the growing season for riparian vegetation in January, February and March under the current regime plants at 1.5 m on the river bank receive only 9, 4 and 1 days respectively free of flood (data not shown). This improves marginally for plants at 2.5 m on the bank, where they receive 21, 8 and 5 days respectively free from flood (Fig 3). It is only during September to October in each year that there are longer periods free from flood (22 days each month at 1.5 m on the bank and approximately 25 days each month at 2.5 m on the bank). However these periods free from flood are of little value to riparian plants as days are short, and often overcast and rainy, severely limiting photosynthesis. Further, this is the wrong time of the year for reproduction, seed-set and recruitment.

The proportion of flow in the Gordon River for the three different management regimes, natural, current and TEMSIM, over a wide range in flow rates is compared in Figure 4. Under natural river flow massive floods of >400 m^3s^{-1} occurred for 2% of the time, while flows of <100 m^3s^{-1} and <50 m^3s^{-1} occur for more than 75% and 50% of the time respectively. Under the current regime there are no floods >250 m^3s^{-1}, but flows of <100 m^3s^{-1} and <50 m^3s^{-1} only occur for less than 35% and 20% of the time respectively. In addition, under the current regime, low flow rates usually only occur for periods of a fraction of a day to days, between peaks of power demand. On many occasions this does not allow time for plants to recover from the stress of inundation (submergence) and waterlogging, and certainly leaves no time for recruitment. Plants require atmospheric air and light at the canopy for photosynthesis, respiration and growth, and require oxygen in the soil for root respiration and growth.

Note: A distinction is made here between inundation and waterlogging. Inundation is the submergence of plant leaf and stem tissue. Leaf tissue has a high oxygen demand (requires atmospheric concentrations and diffusion rates) and is rapidly killed by submergence even in well-oxygenated water. Waterlogging is the complete saturation of soil, which limits oxygen supply to roots.

An alternative way of looking at the hourly flow rates for 1/1/97-1/1/99 is to calculate an inundation integral and a waterlogging integral (Fig 5). Under the current regime in the Gordon River the river banks are submerged for approximately twice as long each year under >70 cumecs (<1.5 m in height up the bank at site 71) and >140 cumecs flows (<2.5 m in height up the bank at site 71) than occurred naturally, but there is little difference at higher flow rates (>210 cumecs flows, <4 m in height up the bank at site 71).

However, even these figures are misleading. If the power station operates during the daytime and is off at night, although plants may not be submerged or waterlogged at night, there is no light to carry out photosynthesis.

3.1.3 The role of waterlogging

In comparison with adjacent rivers the riparian vegetation of the Gordon River has suffered a decline in species cover and richness during the period since regulation of river flow. This has probably been caused by a reversal in the seasonality of flooding, a reduction in the time (daytime free of inundation) available for photosynthesis together with the direct effects of inundation of shoots and waterlogging of roots. This has occurred despite many riparian plant species being highly resilient to flooding.

Waterlogging occurs when all pores in the soil that are normally filled with air are filled with water. See Attachment 1 for detailed description of waterlogging and its effect on plants.

The water of the Gordon River is highly oxygenated, facilitated by its passage over falls, rapids and cobble banks. Therefore it can be assumed that oxygenated water enters the riverbank during a flood. The degree of waterlogging suffered by plants will then depend on the temperature of the water and the soil, the respiratory activity of roots and microbes and the length of residence of water in the riverbank. The length of residence of water in the bank has three components; a) the length of the flood, b) the height of the watertable developed in bank and the reservoir of water in that watertable, and c) the composition of the bank (whether sand, silt, clay or cobble). The reservoir of water in the bank once the flood passes will influence the time taken for the bank to drain. Deoxygenated water may still be flowing out of the bank long after the flood has passed. The composition of the bank will influence the rate of drainage. The cobble banks in the Gordon River are very coarse and might be expected to be highly permeable to oxygenated water but in many places are cemented with iron, which has low permeability to water. Unconsolidated medium to fine sand is highly permeable to water and it is likely that these represent the substrates least likely to be waterlogged. Direct measurements in the Gordon River suggest it takes 4-12 hours (average of 8 hours) to saturate or drain a sand profile 10 m from the river (Fig 6, and Geomorphology Report this volume). In addition to obtaining enough oxygen to avoid waterlogging injury, to grow rapidly trees require a continuous flux of oxygen to their roots for extended periods.

In comparison with a coarse sand (with infiltration rates of approximately 184 cm h^{-1}, Smith and Stoneman 1970), loam and clay soils have low permeability to water (common infiltration rates are 2.7 and 1.5 cm h^{-1} respectively). These soils will require at least 10 times as long to fully drain and recharge with oxygen. Therefore, loam and clay soils are highly susceptible to waterlogging and are probably continuously waterlogged under the current regime. The common position of the finest sediments is on the banks of creeks that flow into the Gordon, where at high water levels, there is a back-flow of water into the creeks.

Appendix 4 of this report series – Gordon River Fluvial Geomorphology Assessment (Koehnken *et al*. 2001) indicates that 73% of the banks of the Gordon River between Abel Gorge and Second Split are alluvial (i.e. comprised of medium to fine sand and silt, see Table 1). If only 5% of this alluvium is silt, 68% of the riverbank should be fully drained in 8 hours. A further 27% (15% bedrock and 12% cobble) will not be penetrated by water or will drain rapidly. Only 5% of the riverbank (silt) is likely to have low permeability to water and consequently slow drainage and great susceptibility to waterlogging.

There is great variation between species in their tolerance to waterlogging. Taller species, whose crowns extend above the flood level (to allow photosynthesis to continue) and whose root systems can conduct oxygen (i.e. contain aerenchyma) are the most resistant to waterlogging. The best example of a tolerant species present in the Gordon River is *Leptospermum riparium* (tea tree) (Plates 1, 13, 14).

3.1.4 The role of inundation

Inundation may act separately or in concert with waterlogging to kill riparian plants in the Gordon River. Inundation is the complete submergence of stem and leaves of plants. Inundation can cause rapid death of photosynthetic tissue (leaves or phyllodes). The gas-exchange of leaves (or phyllodes) is normally carried out in the atmosphere, and the requirements of leaves and stems of terrestrial species far exceeds that of root systems (diffusion of O_2 in air is 10 000 times faster than in water). Inundation, even in oxygenated water, starves the aerial portions of plants of O_2 required for respiration and CO_2 required for photosynthesis. In addition to inundation there is severe light attenuation in the Gordon River in water less than 1 m deep which is tea-coloured and stained with tannins and humic acids. Therefore, even if there were sufficient concentration of CO_2 under water, there would be insufficient light for photosynthesis.

The reduced species richness and cover of riparian vegetation in the Gordon is probably caused by a combination of reversal in the seasonality of flooding, a reduction in the time (daytime free of inundation) available for photosynthesis, together with the direct effects of injury due to inundation of shoots and waterlogging of roots (Plates 15, 16 and 17). In comparison with tributaries, these stresses have greatly reduced the occurrence of most mosses, mat-forming herbs (e.g. *Plantago paradoxa, Oxalis radicosa, Oreomyrrhis sessiflorus, Epilobium spp.*), graminoids (*Carex spp, Diplarrena latifolia, Libertia pulchella*), and colonising shrubs (e.g. *Pomaderris apetala, Coprosma quadrifida, Acacia melanoxylon, A. dealbata, Tasmannia lanceolata*) in the riparian vegetation lower on the banks of the Gordon River. *Leptospermum riparium* is the riparian species most resistant to these constraints and, in most cases, is the only riparian shrub species low on the riverbanks in the Gordon River above the Second Split. Inundation probably plays an important role in the removal of the leaves from the lower crowns of shrubs and trees and the production of the obvious plimsoll line at a height of 2.5 m on the river bank (approximate height of water under efficient operation of 2 turbines).

3.1.5 The role of mosses in stream bank stability

Mosses appear to be a critical component in the stability of stream banks and the riparian environment. They are aggressive colonisers of the harshest habitats. Moss communities in adjacent unmanaged river systems (e.g. Franklin and Denison Rivers) exist a few centimetres above the water level at low flow, on cobble bars, logs, rock bars and sandbanks, exposed to the full force of the floodwaters. On the riverbanks they extend from the water's edge, often as a continuous ground cover over log debris, rock surfaces and on the ground beneath the tree or shrub canopy. A likely scenario is, after each flood event, that the sediment load (mostly sand and silt) settles on all surfaces and also settles on mosses where it is trapped (enveloped) by the continuously growing moss banks or clumps (Plates 18-21). In many cases it is these banks and clumps of moss that form the substrate for seedling establishment for colonising herb, shrub and tree species. Therefore, the mosses trap the sand and silt (there may be tonnes of sediment immobilised within moss communities for every metre of riverbank) and they provide an important substrate for recruitment within riparian communities. Mosses don't form the only substrate. Recruitment of shrub and tree species commonly occurs directly into stable cobble bars and sand banks.

A comparison of the species richness of mosses and liverworts (hepatics) in the Gordon and Franklin Rivers shows that most terrestrial and epiphytic mosses and liverworts present in riparian zone of the Franklin River are absent from the Gordon River (see Table 2). However, the Gordon River has a larger suite of mosses and liverworts that grow on bare rock than occurs in the Franklin, which may indicate a shift in environment of the Gordon River towards mineral substrate (see Table 2).

Removal of the mosses, mat-forming species and seedlings of shrub and tree species from the lower surfaces on islands and riverbanks allows the sediments they trapped to be mobilised (mostly acid-washed white sand). Water erosion has then proceeded into the peat soil and root mats of the remaining shrub and tree species. The stability of the riverbanks is then dependent on retention of the peat and root mats, which prevent further erosion of the banks. In addition the epiphytic mosses that grew on live shrubs and trees have been killed. Invariably these epiphytic mosses have adventitious tree roots growing into them. Removal of the epiphytic plant cover (mostly mosses, but also herbs, ferns and tree seedlings which seeded into the mosses) and erosion of sediments they bound has exposed masses of adventitious roots on stems and branches of *Leptospermum riparium*. In backwater regions there is also a carpet of true roots on the soil surface, probably stimulated by the availability of oxygen in the highly aerated water during power station operation (Plate 14). Although the loss of the sand bound to these epiphytic communities represents a very substantial mobilisation of sediment, it would be easy to mistake the presence of these adventitious roots as indicating large-scale bank erosion, but this is not the case (Plates 13, 22 and 23).

3.1.6 Out-wash and transport of sediments, and landslip

Evidence from the geomorphologists indicates that, in places where banks of the Gordon River are alluvial, (mainly medium to fine sand, which is 73% of bank substrate between Abel Gorge and Second Split), and where the protective veneer of underlying peat has been removed from the soil surface at the rivers edge (following the loss of protective vegetation), there is significant erosion of sediments. Unconsolidated sediments within the banks, no longer protected by the peat mat, are mobilised once saturated and flow out into the river channel as water levels fall rapidly when turbines are switched off. The out-flow is manifest as deltas or rills of sand and silt (see Plate 24) sometimes 10-15 cm deep. The outflow of mobilised sediments undermines peat mats and root systems of trees and causes them to topple into the river channel. This exposes a new surface of unconsolidated sediments to erosion (Plates 25-26). There is potential for significant modification of riverbank morphology and associated plant communities in reaches identified as most prone to erosion by this mechanism (Koehnken *et al.* 2001).

Although landslip is a common occurrence in all the rivers studied, the frequency of occurrence of landslip in the Gordon River, particularly upstream of the Denison River, is greater than its tributaries (see Geomorphologists report, this volume). Landslips carry with them masses of attached riparian vegetation and mature rainforest established above the riparian vegetation on steep banks (Plates 27).

Finer sediments (mostly acid-washed white sand) are found deposited in linear bars at positions in the river where flow rates are reduced (e.g. behind the big rock bars just below First Split and just below Kayak Kavern). These large sand bars are completely unvegetated (Plate 28).

3.1.7 Erosion of islands in the Gordon River

The long-term prognosis for the islands in the river (which represent a significant proportion of the riparian vegetation) is not good. As well as suffering the loss of many riparian species and the stripping of soils back to peat and root mats (in regions up to the plimsoll-line), the constant high flow rates associated with the operation of two turbines have set up eddies around most of the bigger islands supporting trees and around many smaller islands and cobble banks. These eddies are cutting into the sides of the islands and add to the damage caused by continuous attrition at the up-stream and down-stream ends of these islands. The islands at site 72 have been reduced to one third of their original size and are being eroded from up-stream and down-stream ends as well as being undercut from the sides (Plates 29-30). Even 20 km from the dam (approximately 3 km below the junction with the Denison, just below the limestone cliffs containing Kayak Kavern), a large vegetated island in the middle of the river channel shows evidence of major changes in morphology. The sides of the island are being undercut and tall trees in the centre of the island are dying. However, at the tail end of this island there is some evidence of recruitment on recently deposited river sediments on a high terrace.

On vegetated cobble islands and bars, beneath the first layer of cobbles, is a thick mat of shrub and tree roots which extend 2-10 m from the fringe of the riparian vegetation out into the water. These roots provide the plants with water (at low river-flow) and nutrients (in black organic sediments that settle between the cobbles). The undermining of the cobble banks strips back these root mats limiting the catchment of nutrients and water available to the vegetation. Islands are also exposed to erosional processes more commonly seen on the riverbanks. These include out-wash of finer sediments from beneath the roots each time the turbines are turned off, and major land-slips into the river (described above).

In exposed positions, for example on rock bars or islands thrust into the main channel of the river, the roots of shrubs and trees are being (or have been) stripped of soil, undermined and torn from the substrate. In these locations even the inherent resistance to waterlogging has not saved *Leptospermum riparium*. Whole islands of vegetation have been undermined and overturned in this way (Plate 31).

In the long-term (50 years) it is likely that most islands (particularly those upstream of the Denison River) in the Gordon River will be undermined and removed. It is possible that a new stable river geomorphology will be established, with a more linear arrangement of unvegetated cobble banks and sandbanks.

3.1.8 Recruitment

Recruitment of riparian species is almost nonexistent in the Gordon River above the Denison junction (see discussion below). This is probably caused by

- the dam preventing the transport of propagules from higher reaches of the river
- the stressed condition of the remaining riparian vegetation in the river resulting in low levels of reproduction
- disturbance by repeated floods (operation of the power station) which may uproot, inundate, waterlog or bury newly germinated seedlings

The exceptions observed were episodes of regeneration at site 75 (3.6 km below the dam) and on the island at site 70 (9.1 km below the dam) described below. In the Gordon River below the Denison junction, 2.5 m above the low water level, there is evidence of recruitment by natural pioneer species on newly deposited gravel bars and sand banks (see discussion below). Improved recruitment below the Denison River junction probably relates to a greater range of available propagules and natural variation in river level imposed upon the regulated flow.

3.1.9 Riparian vegetation of the Gordon River in comparison with its tributaries

The riparian vegetation of the Gordon River between Albert Gorge and Ewarts Gorge stands as a stark contrast with the unmanaged tributaries. Below the plimsoll line at approximately 2.5 m (equivalent to the operation of two turbines), the principal remaining riparian tall shrub species is *Leptospermum riparium*. In many cases these are mature stands of pure *Leptospermum*, which have thinning crowns and dead lower limbs. In contrast in the Denison and Franklin Rivers there is a healthy, complex, tall shrub storey of mixed ages on a wide range of substrates; bedrock, cobble and sand.

Between 0 and 1.5 m (equivalent to the operation of one turbine) on the same section of the river the riverbank is mostly mineral substrate. There is decreased species richness, decreased total cover and cover of moss ferns herbs and trees and an increased importance of opportunistic semi-aquatic species including *Restio tetraphyllus* (at the end of sandbars), *Isotoma fluviatilis* (on finer gravel banks), *Schoenus spp* and *Myriophyllum pedunculata* (on sand banks).

Between 1.5 and 2.5 m on banks of the Gordon River from Abel Gorge to Second Split and First Split to Ewarts Gorge, there is a decrease in the total cover of riparian plants and ferns but an increase in the cover of grasses. The ferns have low tolerance to inundation and high light intensities (caused by thinning of tree and shrub crowns). Grasses are highly tolerant of disturbance.

At heights on the bank greater than 2.5 m in the region where major natural floods no longer occur there is increased tall shrub cover but a decreased fern and tree cover. The increased tall shrub cover is probably the result of reduced physical damage to tall shrubs caused by natural flood. The Gordon may have fewer trees, as it is a broad river, and may have had fewer sites with overhanging trees. Alternatively, a lower tree cover may reflect reduced tree health as a result of waterlogging of roots or water and nutrient deficit following the absence of flood. Lower tree cover will result in greater light penetration, which may cause reduction in fern cover.

3.2 Mapping of riparian plant communities in the Gordon River

With few exceptions the riparian community up to the plimsoll-line at 2.5 m in the Gordon River between the Abel Gorge and the Second Split was either dominated by *Leptospermum riparium* (tea tree) or was absent from the river (Attachment 2). This is in contrast to the riparian communities in the Franklin and Denison Rivers, which were dominated by a mixture of shrubs. In approximate order with increasing height above water level, common shrubs species in cobble bars were: *Leptospermum riparium, Acacia melanoxylon, Coprosma quadrifida, Pomaderris apetala, Acacia dealbata, Atherosperma moschatum, Tasmannia lanceolata* and *Nothofagus cunninghamii*. In the Gordon River, in the absence of *Leptospermum*, much of the riparian habitat was mineral substrate or bare log debris. However in the zone between 1.5 and 2.5 m on the riverbank some herb, grass and graminoid species were present. Mineral substrates devoid of vegetation were very common and included mud (in back channels where creeks entered the Gordon River), sand (deposited as bars within the river behind major obstacles and on riverbanks usually on the inside of bends in the river), cobbles and rock (in places, with some moss cover).

With few exceptions the forest community adjacent to the riparian community was thamnic rainforest dominated by *Nothofagus cunninghamii* (myrtle), *Lagarostrobos franklinii* (Huon pine), *Atherosperma moschatum* (sassafras) and *Eucryphia lucida* (leatherwood). A Map of riparian plant communities on the Gordon River from Abel Gorge to the Second Split (Attachment 2) shows the fringing tea tree scrub community (*Leptospermum riparium*) percentage of continuous cover along the river bank and the adjacent communities. There were six communities abutting riparian communities, defined by Kirkpatrick *et. al*. (1995), on the section of the Gordon River investigated:

- *Nothofagus cunninghamii* rainforest.
- *Lagarostrobos franklinii* rainforest.
- *Leptospermum-Melaleuca* forest, probably the closest vegetation type to our *Leptospermum riparium* riparian community, although *Melaleuca* spp. are a very small component of the riparian vegetation within the Gordon River.
- *Eucalyptus nitida* wet sclerophyll forest.
- *Eucalyptus obliqua* wet sclerophyll forest.
- Buttongrass moorland. This extends nearly to the riverbank at the bottom of Abel Gorge.

3.3 Cover and abundance of plant species within riparian communities in the Gordon River

Where comparisons have been made of species richness in the main river channel and tributary streams, the main channel tends to have greater species richness than its tributaries (Nilsson *et al.* 1994). However, this study indicates that the Gordon River has lower species diversity (richness) and cover of vascular species in the riparian zone than the smaller adjacent rivers, the Franklin and the Denison.

The Gordon River has a lower relative cover of ferns and herbs than both the Franklin and the Denison Rivers, lower cover of graminoids than the Franklin River and lower cover of low shrubs and trees than the Denison River, but a greater relative cover of grasses than both tributary rivers. There is also a greatly reduced range of mosses in the riparian zone of the Gordon River compared with the Franklin River.

There is invasion of opportunistic semi-aquatic species on bare sand and cobble surfaces in the Gordon River, in places where the original vegetation has been removed by inundation and waterlogging. The increase in grasses and opportunistic semi-aquatic species suggests the new environment in the Gordon River is favouring an ephemeral weedy habit.

3.3.1 Interpreting an ordination

An ordination using all data collected in the Gordon, Franklin and Denison Rivers (303 sites, Fig.7) shows there are differences between the riparian species of the three rivers (for a detailed explanation of ordination techniques see Attachment 3). Although there are parts of the ordination space where sites for all three rivers overlap, there are also parts of this space where sites for one river predominate or are present alone. The environmental vectors most closely correlated with ordination of sites (i.e. R>0.5 in Fig 7) are: site (indicating major difference between rivers, 0.67), height above water (0.79), litter (0.65), cover (0.65), substrate depth (0.56), rock (indicating bare rock or cobble, 0.61), trees (0.71), tall shrubs (0.55), ferns (0.59), herbs (0.51) and richness (0.50). The ordination shows the Gordon differs from other rivers in having riparian vegetation higher up the river bank (caused by managed flow), greater substrate depth (probably caused by erosion and re-deposition of sediments), reduced litter (swept by frequent floods), more tall shrubs or a greater proportion of tall shrubs in the riparian vegetation (principally *Leptospermum riparium* and *Acradenia frankliniae*), but less ferns, trees and herbs, and lower species richness. The reduction in ferns and herbs is probably related to the long periods of inundation. The Gordon may have fewer trees, as it is a broad river, and may have had fewer sites with overhanging trees assessed. Alternatively, a lower tree cover may reflect reduced tree health as a result of waterlogging of roots or water and nutrient deficit following the absence of flood.

In contrast the Denison, the smallest river, differs from the other rivers by having extensive cobble banks (high rock cover Fig 7c), more overhanging trees (Fig 7b) and greater contribution of herbs (Fig 7a) and ferns (Fig 7b,c).

A better picture of the effects of the current managed flow in the Gordon can be gained by dividing the river bank into height intervals which relate to levels of inundation caused by operation of one, two or three turbines at the Gordon Power Station. The three divisions used are; channel sites, 0-1.5 m in height up the river bank (which in the Gordon River are inundated whenever the power station is operating, Fig. 8), low bank sites 1.6-2.5 m in height up the river bank (inundated with efficient operation of 2 or 3 turbines, Fig 9) and high bank sites > 2.5 m in height up the river bank (historically only flooded for 11% of the time over the last 10 years when 3 turbines are operating at efficient load, Fig 10).

3.3.2 Ordinations

- Changes in relative abundance of species and a reduction of species diversity in the Gordon River are readily apparent from all ordinations (Figs 7-10). This conclusion is reinforced by declines in the cover of the vegetation guilds trees, low shrubs, herbs and ferns on channel sites, declines in the cover of trees and ferns on low bank sites and ferns on high bank sites (Fig 11). Both channel and low bank sites displayed increase grass cover, and high bank sites increased tall shrub cover (Fig 11, Tables 3 & 4).

- Fitted vectors showed that *site* (the river in which the transect or quadrat was conducted) was the most significant variable clearly distinguishing the three rivers. Channel sites on the Gordon River were correlated with the variables of decreasing *species richness*, *total cover, herb, tree, moss* and *fern* cover (Fig 8). Low bank sites on the Gordon River were correlated with the variables of decreasing *rock*, *fern* and *total cover* and increasing *grass* and *substrate depth* (Fig 9). High bank sites on the Gordon River were correlated with variables of decreasing *fern* and *tree* cover and increasing *tall shrub* cover (Fig 10)

- Given the nature of these deeply incised, temperate river systems, characterised by a contained river channel, steep banks with overhanging rainforest vegetation and high rainfall, it is interesting that the data show significant changes in both low and high bank vegetation (> 1.6m) (Figs 9 & 10 and Tables 5 & 6). There are the differences mentioned in point 2 above and also the appearance of the dry sclerophyll species *Acacia verticillata* and *Pultenaea juniperina* on banks and islands. This may be a result of:-
    - waterlogging of adjacent rainforest communities has caused thinning of the tree crowns providing enough light for invasion of grass and sclerophyllous species, but too much light for the epiphytic ferns.
    - the absence of high flood peaks (5–9 m above low flow rates) and consequent reduced soil moisture on banks greater than 2.5 metres above water level.

- Channel sites on the Gordon River displayed significant increases in the mean relative importance value of the species *Isotoma fluviatilis*, *Myriophyllum pedunculata* and *Restio tetraphyllus*, which typically occupy semi-aquatic habitats (Tables 3 & 4).

- The significant declines in guilds and species on the Gordon River are probably related to prolonged inundation and waterlogging. *Leptospermum riparium* is the only species that was common in the Gordon River prior to dam construction and is still common. It is likely that this species' adaptation to a waterlogged environment means it is the least affected by waterlogging, hence its dominance in the river today. Although inundation resistant, *Leptospermum riparium* is, in many places, being torn from its substrate by high flow rates. Together with the lack of observed recruitment, even *L. riparium* is expected to disappear from channel sites in the future.

- Herb communities in the Gordon-below-Denison occurred much higher above water level at time of sampling than on the Denison and Franklin Rivers. This is probably related to increased sediment transport and deposition in the Gordon River, and/or that a certain minimum height above the managed flow rate in the Gordon is required before herb recruitment can take place and survive the effects of waterlogging/inundation.

- Analysis of substrate effects on the degree of change in the vegetation of the Gordon River is mixed. Channel sites (0 – 1.5m) displayed a trend towards floristics being controlled by *type* (whether a quadrat was on an island or bank within the river) (Fig. 12, Table 5). Low bank sites (1.6 – 2.5m) were distinctly positioned along a gradient of *substrate depth*, *type* and *rock cover*, with *substrate depth* and *site* being antagonistic to *rock* cover. Associated with increasing *substrate depth* were increasing *tall shrub* and *bare ground* cover, and decreasing *tree* cover (Fig. 13, Table 6). The probable explanation is that:
    - on channel sites (0 – 1.5 m) the prolonged inundation and sheer force of current override any possible substrate effects on species distributions.
    - on low bank sites (1.6 – 2.5 m) where above ground parts of plants have greater respite from inundation, the depth of substrate starts to influence waterlogging effects. The increase in tall shrub cover (principally *Leptospermum riparium*) associated with increasing substrate depth would tend to support this hypothesis.

- Complete species lists are presented for sites visited on the two sections of the Gordon River (Abel Gorge to Second Split, Table 7a; Denison Junction to Ewarts Gorge, Table 7b), the Denison River (from 9 km to 2 km upstream of Marriotts Gorge, Table 8) and the Franklin River (Jane River junction to Shingle Island, Tables 9). The total number of species (species diversity) summed over all sites are similar for each of the rivers before they join (71-75 species). However, at the sites visited (303 quadrats) species diversity was lower in the Gordon River.

3.4 Tea tree root-mat density and stream bank stability

In an undisturbed forest in southwest Tasmania root mat density will be strongly influenced by nutrient status, water status and oxygen concentrations.

3.4.1 Nutrient status

The principal environmental factors determining distribution of plant communities in Southwest Tasmania on nutrient-poor substrates is disturbance (particularly fire) and its effect on nutrient capital. In southwest Tasmania the inherent nutrient status of the parent rock (commonly quartzite or schist) is very low. Accumulation of nutrients (principally N and P) within a vegetation type then has to rely on interception of cyclic salts (nutrient elements present in incoming rainfall). In a forest community on these substrates almost all the nutrients reside in the standing plant biomass of trees and shrubs and the peat soil that has developed from rotted leaf and branch litter. To build the nutrient capital to sustain a rainforest may take more than 500 years. If the forest is burnt nutrient capital is lost and one of the successional stages towards this forest takes the place of the forest. On soils of adequate nutrition, disturbance by fire or flood can deflect a community from reaching the climax, rainforest. This is also the case for riparian communities. They are present in a corridor of disturbance created by the river.

Accumulation of nutrient capital on mineral surfaces in the riparian environment is dependent on establishment of colonising species, which affect flow rate and sediment deposition in their immediate vicinity. This in turn allows a subsequent wave of colonisation, which increases accumulation of sediments and litter build-up. Working against community establishment, are the erosive forces of the river. In this way the process is analogous to the disturbance by fire.

As almost all the nutrient available to roots will be on cation exchange complexes in the surface peat soils, this is where the major density of roots will be concentrated. Deeper roots will penetrate the cobble, sand or silt subsoils to provide access to water supplies during dry periods and for anchorage.

3.4.2 Water status and oxygen concentration

As well as preferentially occupying parts of the soil profile rich in nutrients, roots will explore the soil profile and preferentially occupy zones of high water status in environments where water is scarce. If water is freely available, as is the case in riverine rainforests, water will be extracted principally from surface horizons even though soils may be deep and well aerated.

If soils are waterlogged (for detailed description of waterlogging see Attachment 1), root systems are characteristically shallow and restricted to the surface soil horizons. Long periods of waterlogging and subsoil anoxia adversely affect deeper roots. Root pruning of trees (at the watertable level) commonly occurs in species less tolerant of waterlogging. There is generally reduced vigour of above- and below-ground components of plants arising from oxygen deficiency in roots, and excessive consumption of carbohydrates during periods of anaerobic respiration. Eventually there is root tip death. Waterlogging will therefore reduce the vigour of roots inhabiting subsoils and decrease root density in this part of the profile. Tolerant plants with the genetic capacity to produce aerenchymatous roots can occupy periodically waterlogged soils, but these roots are also often shallow. Only true aquatic plants can survive in permanently waterlogged soils.

3.4.3 The role of mosses in stream bank stability

Observations made in the unmanaged rivers (Franklin and Denison Rivers) would suggest that much of the resistance to scouring and erosion in riparian communities near the waters edge is provided by compact mosses which are extremely resistant to the physical force of the water. However, they appear quite sensitive to inundation. A comparison of species richness of mosses and liverworts (hepatics) in the Gordon and Franklin Rivers shows that most terrestrial and epiphytic mosses present in riparian zone of the Franklin River are absent from the Gordon River (Table 2). However, the Gordon River has a larger suite of mosses and liverworts that grow on bare rock than occurs in the Franklin, which may indicate a change in environment in the Gordon to mineral substrate (Table 2). The loss of mosses and liverworts, and the herbs, graminoids and tree seedlings associated with mosses, exposes peat surfaces and root mats to the full erosive force of the river waters.

3.4.4 Erosion and the role of tea tree in stream bank stability

In exposed positions on the Gordon River between Abel Gorge and Ewarts Gorge, where tea tree (*Leptospermum riparium)* is present on rock surfaces thrust into the current, root mats are being torn from the substrate (Plate 31). In less exposed sites, the shrub *Leptospermum riparium* appears to be the only species with great tolerance to inundation and waterlogging. Currently it is the only species growing in the sand and silt banks that are at greatest risk of erosion (Plates 5, 8, 13, 14).

The key questions are:-

1. Does tea tree (*Leptospermum riparium*) play a key role in the stability of stream banks?
2. Will it continue to do so under the current flow regime?

The answer to the first question has to be yes. Although assessment of root mat density (measured as dry weight of roots per unit volume of sandy soil) on sandy stream banks of 11° and 20° slopes was very low (sites at site 72 and site 70 respectively), root weight generally increased near the soil surface (0-10 cm) and with height up the bank (Fig 14). The distance (in metres) up the sloping bank is not, however, height above the water. The top of an 11° slope, 6 m in length, was approximately 2.5 m in height up the bank. The crest of the slope, a levee bank between a tributary stream and the Gordon River, was colonised by *Leptospermum riparium* (Fig 14a) and the roots sampled were almost exclusively *Leptospermum* roots. The top of the 20° slope also about 6m long was approximately 3.5 m in height up the bank. The upper slopes of the bank (> 3.5.m in height) was colonised by thamnic rainforest but the bank was fringed (at about 1 m) by *Leptospermum riparium* (Fig 14b) so roots higher on the bank probably belong to rainforest species. Therefore, *Leptospermum riparium* roots may play a role in bank stabilisation on levy banks such as occur at site 72, but appear to have little role in bank stabilisation at site 70. Further, it is dubious whether these root densities (up to 5 g dry weight of root in approximately 800 cm^3 of soil) play an important role in stabilising the lower slopes of these sandbanks. However, the presence of *Leptospermum riparium* on the top of sand and silt banks between the Gordon River and tributary streams (on levee banks) may be important to stability of these banks. Elsewhere tree roots from rainforest trees, which extend down the bank surface in the aerated zone, probably play a role in bank stability. It is likely that the top few millimetres of all sandbanks are sufficiently aerated by turbulent river water for most plant roots to survive.

The answer to the second question (Will *Leptospermum riparium* roots continue to play a key role in the stability of stream banks under the current flow regime?) is probably no, in the long-term, for the region of the Gordon River between Abel Gorge and Ewarts Gorge.

No terrestrial plant can survive continuous waterlogging even though it might possess morphological adaptations (e.g. aerenchyma) which allow it to survive periods of waterlogging. It appears that under the current regime there is not a sufficiently long time between floods (periods of power station operation) to establish adequate air-filled porosity in soils occupied by *Leptospermum riparium* rooted low on the river bank. Between Abel Gorge and Ewarts Gorge, tea trees rooted at a position 0-1.0 m on the bank are dead (e.g. on the cobble bar at site 69, see Plates 6 & 7) or are dying (many instances on cobble bars and riverbanks). Mature trees of *L. riparium* in this region of the river, which are higher on the banks (1.0 – 2.0 m), but still lower than the plimsoll line (e.g. 2.0 m on the bank), may well survive for long periods, provided they are not torn from the substrate by high-water-flows. However, with no recruitment (see below) these stands have no chance of long-term survival.

3.5 Recruitment

The maintenance of plant communities on the margins of the river is dependent on recruitment of new individuals into the population. This requires a source of propagules and disturbance events followed by favourable conditions for seedling establishment and early growth. The principal disturbance events in the riparian environment are flood, tree fall and landslip but fire may also reach the margins of rivers. Favourable conditions for early establishment of terrestrial plant species include a period of 2-6 months with:-

- low water levels (i.e. no inundation or further deposition of sediments),
- warm weather (allows more rapid germination and establishment)
- sunlight (or at least sun flecks) (for photosynthesis and growth)
- a stable substrate (allowing time for establishment and growth), and
- a substrate which is well drained with adequate air-filled porosity (so roots receive enough oxygen for respiration and growth).

On sand and mud banks seeds may germinate on the soil surface. On cobble banks seeds will settle between cobbles where there is a moist microenvironment. On rock bars and logs germination will only occur in sand and silt trapped by mosses.

In a natural river system it would be expected that pulses of recruitment would occur during summers when the above conditions are met.

In the Gordon River, under managed flow, many of these conditions are not met and recruitment of terrestrial plants upstream of the Ewarts Gorge becomes an extremely rare event. Large shifting sandbars (e.g. just below First Split and just below the rock bar 100 m downstream of Kayak Kavern) were uncolonised and had no recruitment. The majority of sandy riverbanks upstream of the Ewarts Gorge were uncolonised except for surviving mature tea tree and had no recruitment.

In addition, there is likely to be a greatly reduced supply of propagules in the middle Gordon River caused by the Gordon Dam, which represents a major barrier to down-stream transport of water-borne propagules and by the reduced reproductive vigour of stressed riparian vegetation.

In the Gordon River between the Dam and Ewart's Gorge (Olga Camp) there were only six locations where substantial recruitment was observed to occur:-

- At site 75 (just below the dam), where young eucalypt saplings (*Eucalyptus obliqua*) and riparian shrubs (e.g. *Acacia mucronata* and *Pomaderris apetala*) were present on a cobble bar high on the river bank (at least 10 years old)
- At site 70 (9.1 km below the dam), where an even-aged stand of young *Leptospermum riparium* (5 to 10 years of age) was developed adjacent to an unhealthy mature stand of *L. riparium*
- On land-slips high up the bank, above the plimsoll-line, where rainforest species were seen to be establishing
- On top of the sand and mud banks, which divide the Gordon River from tributary streams, there was occasionally prolific seedling regeneration of Huon pine (*Lagarostrobus franklinii*). The thinning canopies of the tea trees appear to provide excellent light for establishment
- On a large island, near Kayak Kavern, 3 km downstream of the junction with the Denison River, where a range of colonising shrub species were found on a high cobble terrace at the tail end of the island. The range of colonizing species included trees *Acacia melanoxylon* and *A. verticillata,* shrubs *Leptospermum riparium, Pomaderris apetala, Coprosma quadrifida, Clematis aristata*, and *Tasmannia lanceolata*
- On a high sandbank at the head of Ewart's Gorge, amongst recently deposited sand beneath a thinning stand of *L. riparium*, a mixture of colonising herb and shrub species was found. These included the grass *Ehrharta sp.* and the herbs *Myriophyllum pedunculata, Hydrocotyle muscosa, Oxalis radicosa, Oreomyrrhis sessiflorus, Wahlenbergia sp.*, *Epilobium sarmentaceum*, as well as shrubs (e.g. *Coprosma quadrifida* and *Tasmannia lanceolata*)

The first two of these observations appear to relate to single recruitment events during the maintenance of the power station combined with changes in morphology of the channel, which reduced inundation. The last two are well down the river. It was at the head of Ewart's Gorge where the first evidence was found of recruitment by a combination of riparian shrubs and herbs common in the Denison and Franklin Rivers. Interestingly, however, colonisation in the Gordon River below the Denison junction occurred at a greater height above water level (1.5 – 1.7 m) than seen in the Denison and Franklin rivers (typically below 0.5 m).

In the unmanaged rivers of the Franklin and Denison, the sequence of colonisation of cobble bars appeared to be *Leptospermum riparium/Acacia melanoxylon* initially followed by sand-trapping mosses, then herbs such as *Plantago paradoxa, Oreomyrrhis sessiflorus, Oxalis radicosa, Wahlenbergia spp, Epilobium spp,* and then a further wave of colonisation of the shrubs *Pomaderris apetala, Coprosma quadrifida, Epacris spp, Tasmannia lanceolata* along with the herb *Viola hederacea*.

Colonisation of sandbars near low water level was by tiny semi-aquatic herbs; *Ranunculus trichophyllus, Lilaeopsis polyantha, Myriophyllum pedunculata, Hydrocotyle muscosa* and *H. hirta, Gratiola nana* and *Hypericum japonicum*. Higher up on the same sand banks (and also probably in successional sequence were *Leptospermum riparium* and then the herbs and shrubs indicated in the sequence for cobble bars (above).

On all surfaces within the riparian zone a sequence of mosses occurs which trap sand and silt which allow these surfaces to colonised by a rich array of shrub and tree seedlings as well as herbs and graminoids. This is the case for log debris as well as rock bars and steep banks, where in shady locations they are then invaded by seedlings of rainforest species including *Lagarostrobus franklinii* (Huon Pine), *Nothofagus cunninghamii* (myrtle) and *Eucryphia lucida* (leatherwood), *Tasmannia lanceolata* (mountain pepper). On surfaces covered by moss including rock and stems of trees and shrubs a rich array of terrestrial and epiphytic ferns occur (e.g. *Sticherus tener, Blechnum spp., Hymenophyllum spp.,* and *Phymatosorus diversifolium*).

In the Gordon River the main constraints to recruitment are repeated inundation and waterlogging, on a daily basis, instability of the substrate and lack of propagules. Where soils are intact and exposed only to high water rather than constant deposition and/or erosion, semi-aquatic species are establishing in some instances e.g. *Isotoma fluviatilis, Myriophyllum pedunculata, Schoenus sp.* and *Restio tetraphyllus*. *Isotoma fluviatilis* also appears to be capable of establishing on exposed surfaces on cobble and rock bars. These species may assist in bank stability

4 POTENTIAL BASSLINK CHANGES

Basslink will increase the frequency of on-off events for the Gordon Power Station. The power station will be run to meet peak power demand on the Australian grid, and during low demand, Tasmania will buy power from the grid. This will mean the power station will be on for 6-18 hours and off for 6-18 hours most days in summer and winter (Fig 15). While the power station is on it will be operating at close to maximum output for more of the time than is the case currently. The use of three turbines during operation is predicted to increase from 10% to 30% of the time, based on TEMSIM modelling.

The changes to the patterns of riparian vegetation on the Gordon River arising from Basslink may be substantial. Generally, in comparison with the current regime, Basslink will result in an increased frequency of both high-flow and low-flow events (depicted in Figs. 4 and 15). The hourly flow rates presented on an annual basis in Fig 4 might suggest that Basslink would more closely mirror the natural regime, and therefore one might expect it to be beneficial to riparian plant communities. However, this is deceptive. Under Basslink, short periods of low flow (usually 4 to 5 hours) are sandwiched between periods of high flow each day (Fig 16, also see Figs 2, 3a,b and 15).

As indicated in discussion under 'Current condition', there are at least three stresses acting on the riparian vegetation; inundation, waterlogging and light limitation.

- Inundation (submergence of vegetation) prevents gas exchange and prevents plants carrying out photosynthesis and respiration through their leaves.
- Waterlogging is the depletion of oxygen in the soil and prevents respiration by plant roots.
- Light limitation. During submergence beneath water plants tolerant of inundation cannot photosynthesise or respire and therefore cannot grow. To survive and grow plants require adequate daylight hours when they are not inundated or waterlogged to acquire carbon through photosynthesis.

A mean inundation integral (Fig 5a) can be obtained for the period 1/11997-1/1/99 by summing the hours that the Gordon power scheme is operating at different flow rates (1, 2 and 3 turbines =70, 140 and 210 cumecs respectively; equivalent to 1.5, 2.5 and 4.0 m height on the river bank at Site 70, 9.1 km below the dam, Fig 5). It can be seen that under Basslink, plants up to 1.5 m on the bank at Site 72 are inundated for approximately 50 days less per year than is the case currently (Fig. 5). At 2.5 m on the bank Basslink and the current regime provide similar levels of inundation. However, under Basslink there is a longer period (100 days per year) of inundation for plants at 4.0 m on the bank than under the current regime (30 days per year).

In addition to inundation, is the stress of waterlogging. According to the geomorphologists it takes approximately 8 hours to saturate or drain a riverbank of medium to fine sand (the most common bank substrate on the river). The most common period of operation of the power station is approximately 16 h, from 9.00 a.m. one day to 3.00 a.m. the following day (Fig 16). During 1997 and 1998 there was an average of 150 days per year where plants at 2.5 m on the bank were free from inundation for only 1-4 hrs and there were a further 40 days when these plants were inundated all day (a total of 190 days, see Fig 17). Therefore there is sufficient time to saturate the riverbank most days the power station is operating, and particularly in summer (Figs 3 and 18). Once the power station is switched off it will take 8 h for the banks to drain. Adding 8 h of waterlogging to the inundation stress each day gives a combined stress integral called 'Mean annual waterlogging '(Fig 5b). Under Basslink and the current regime riverbanks at Site 70 (9.1 km below the dam, Fig 5b) up to a height of 1.5 m spend a similar time (270-280 days per year) inundated or waterlogged. This integral of inundation and waterlogging is relatively greater for Basslink than for the current regime with increasing height up the bank, with a 3-fold difference at 4.0 m on the bank. Plants at 4.0 m on the bank receive an annual waterlogging integral under Basslink and the current regime for 170 and 55 days per year respectively.

To assess light limitation to riparian plants under Basslink, TEMSIM data for 1997 and 1998 was analysed and days divided into classes based on the number of hours in the day (assuming a 12-hour day) that flow rates exceeded 140 cumecs (equivalent to a height of 2.5 m on the bank at site 70, Fig 17). There was a stark contrast between Natural, Current and Basslink regimes in the time available during the year for plants to photosynthesise. Under current and Basslink regimes riparian plants 2.5 m on the bank received on an average year 49% and 40% of the number of full (12 hour) days for photosynthesis than was the case in the natural regime (Fig 3). Under the Basslink TEMSIM model plants received fewer 12 h days (19% reduction) than was the case under the current conditions but more days (257% increase) with only 1-4 hours free from inundation (Fig 17).

However, this is not the full picture. Most riparian plants in the Gordon River would be expected to be actively growing and photosynthesising in summer when days are long and river levels are low. In winter, under natural river flows, low temperatures, short days, low sun angle, periodically high water levels and seasonal dormancy would be expected to greatly reduce photosynthesis. Therefore a more realistic comparison might be the number of full days available for photosynthesis at 2.5 m on the riverbank during peak growing season (January, February and March). For the three regimes Natural, Current and Basslink, the average numbers of full days for photosynthesis during these growing season months are 84, 19.5 and 10 respectively (out of a total of 90 days, see Fig 3). For the six summer months November to April the average number of days free from inundation was 154, 43.5 and 36.5 respectively for the three regimes Natural, Current and Basslink

This leads to the conclusion that under Basslink there would be a reduction in light available for plant growth in comparison with the current regime. The reduction in the availability of light would be expected to reduce vigour and growth, and reduce reserves of carbohydrate required for recovery from injury that might be caused by inundation, waterlogging, scouring by water or undermining of the root systems.

Although this looks a bleak picture for the riparian plants, there are benefits provided by Basslink. Basslink, unlike the current regime, operates with frequent on-off cycles, and therefore the water has a shorter residence in the bank which reduces the severity of waterlogging by increasing the oxygen concentration in the root zone (see Attachment 1 for a description of waterlogging), particularly in the zone 0-1.5 m on the river bank (Fig 5). With the frequent on-off cycles it is likely that the water within the profile would be replaced with sufficient rapidity for oxygen concentrations in the root zone to be high enough to prevent root tip death. However, because these on-off cycles follow each other in close succession it is unlikely that the soil environment would be well aerated. This will reduce root growth and prevent active root exploration of the soil and encourage production of adventitious aerenchymatous roots in those species with the genetic capacity. The survival of roots may also be assisted by their generally shallow nature, occupying the top 30-50 cm of the soil profile most likely to be permeated by each cycle of Basslink. Therefore it would be expected that the intensity of waterlogging under Basslink would be less than under the current regime.

In summary, under Basslink the following is expected :

- Increase in the use of three turbines and full-gate capacity of the power station under Basslink will increase the degree of inundation suffered by riparian plants and reduce the light availability for photosynthesis, growth and reproduction, manifest and their capacity to recover from stress;

- Inundation (submergence of leaves of plants) to higher levels on the river bank which would raise the plimsoll line on the bank (e.g. to approximately 4.0 m in the region 7-12 km down stream of the dam);
- Waterlogging (saturation of plant root systems) to higher levels on the river bank (e.g. to approximately 4.0 m in the region 7-12 km down stream of the dam) but that the intensity of the waterlogging would be reduced through more frequent drainage of the bank;
- Riparian vegetation zones to shift up the bank by 1-1.5 m (see description of zones 0-1.5, 1.6-2.5 and >2.5 m described for the region 7-12 km down stream of the dam, in Current conditions). New zones in this region will be 0-2.5, 2.5-4.0 and >4.0. This will be manifest as
    - reduction in vegetation cover and diversity to 4.0 m on the river bank
    - reduction in moss, herb, tree and fern cover, an increase in grass cover (particularly *Erharta tasmanica*) and increased cover of the semi aquatic species *Isotoma fluviatilis, Myriophyllum pedunculata* and *Restio tetraphyllus* to a height of 2.5 m on the bank;
- Increased undermining of vegetation by sediment out-wash described by geomorphologists;
- Increased scouring, undermining, erosion and acceleration of the rate of removal of islands of vegetation in the Gordon River;
- Acceleration in the rate of the loss of the principal tall shrub (*Leptospermum riparium*) stabilising river banks in the Gordon River
- Increase in the loss of vegetation through landslips on steep river banks
- Rare moss, *Rabdodontium buftonii* known only from the Gordon River (Albert Gorge to Ewarts Gorge) to thrive under Basslink.
- Reduction in recruitment of riparian species because more frequent flood events will reduce the likelihood of seedling survival. Below the junction with the Denison River negative effects on recruitment should be partially mitigated by the transport of propagules and imposition of natural flow regimes from the Denison River on top of Basslink periodicity.

All these effects would expected to be most severe immediately below Abel Gorge 7-12 km from the dam and decrease with distance from the dam. However, effects would be expected to be detectable at least to the junction with the Franklin River.

5 MITIGATION OPTIONS

Principal additional mitigation options are:-

- Reduce flow rates to <50 cumecs during summer for a period three months (January to March) every year to provide a period free from inundation to allow growth, reproduction and recruitment to occur within the riparian vegetation at a time when these communities are most metabolically active. In addition, there would need to be 24-48 hour shutdowns (flow rates of <50 cumecs) on most weekends for the remainder of the year to reduce negative effects of inundation and waterlogging. Recruitment would have to be assisted by artificially broadcasting seed of local riparian species onto the riverbanks, as the source of recruits in the Gordon above the Denison junction is very limited. This option is likely to be impossible because of expense and impractical because of the logistical problems associated with stabilising banks and applying seed in the steep and hostile terrain.

    Expected effect: Some recovery of riparian vegetation affected by the current regime (e.g. in the height zone 1.0-2.5 m on the river bank, in region 7-12 km downstream of the dam)

- Reduce maximum flow, particularly frequency of full-gate operation (e.g. to maximum flow rate of 210 cumecs), so effects of Basslink don't reach so high on the river bank.

    Expected effect: reduced impact of Basslink. It would be expected that riparian vegetation in region 7-12 km downstream of the dam would be affected to a height of 3.5 m not 4.0 m on the river bank

- Implement options to minimise bank erosion.
  Expected effect: reduction in vegetation loss through undermining and landslip, and greater opportunity to revegetate bare mineral substrates.

Generally mitigation options will not be effective on riparian vegetation unless they involve long shutdowns during summer together with short shutdowns at other times of the year, or reductions to maximum flow. Infrequent short shutdowns or very occasional long shutdowns may slow the process of change in the vegetation but are unlikely to affect the end point. The time of the year these shutdowns occur is also critical.

There are mitigation options (other than shutdowns) that would stabilise substrates and make them more hospitable places for colonisation. There are ways of producing planting stock so chances of survival might be increased. For example, advanced stock of *Leptospermum riparium* could be planted at or near the new mean high water mark on bare cobble and sand banks. The substrate could be stabilised using hessian rope mat (woven like the rigging in sailing ships) or by the use of fallen logs.

Sediment out-wash deltas described by the geomorphologists represent an extremely hostile site for seedling establishment. On highly mobile, waterlogged, acid washed sand or silt, with very low nutrient status it would be very difficult to establish any vegetation cover using potted seedlings, particularly if there is continued erosion of the deltas at high river flows and further deposition of sediment each time water levels fall.

It is unlikely that a program of planting seedling stock without any other complimentary mitigation option would yield any long-term benefit. The new flow rates in the Gordon River imposed under Basslink would probably result in several years of active erosion during which time river morphology would adjust to suit the new regime. Any attempt to establish plants during this period would probably prove futile. Following the geomorphological readjustment, direct seeding of riparian species might be successful in re-establishing the tall shrubby riparian fringe on the Gordon River at or near the mean the new river height provided flows from the dam were modified for a period to allow establishment.

6 MONITORING CONSIDERATIONS

Any further monitoring of Gordon River riparian vegetation should consider the following.

General:

Conduct a study of the riparian vegetation before and after Basslink is implemented. The current study could be considered an adequate 'before' study, although there is much more to be learnt about the processes involved. Studies should be conducted at intervals following implementation of Basslink. This would allow the effect of this management change to be accurately quantified rather than relying on comparison with other rivers, and would allow more accurate prediction of the consequences of any future changes to the management of the Gordon Power Station.

Specific studies would be required to determine:

- Dissolved oxygen concentrations in alluvial river banks during operation of Basslink to ascertain the severity of waterlogging
- Role of mosses in riparian communities. The presence of mosses on the riverbank appears to be a key indicator of disturbance by inundation;
- Relative importance of inundation, waterlogging and light limitation on the survival and growth of riparian plants in the three riparian zones described in the section on 'Current condition' (riparian zones identified were: channel sites at 0-1.5, low bank sites at 1.6-2.5 m and high bank sites at >2.5 m);
- Rates of change in species cover and diversity on islands of vegetation in the river channel;

- Effect of the major tributaries to the Gordon (e.g. the Denison and Franklin Rivers) and distance from the dam on the severity of the stresses outlined;
- Determine levels of natural recruitment of riparian species on river banks between the Gordon Dam and Macquarie Harbour and the interaction between reproductive strategy (e.g wind versus water dispersal; long floating versus short floating seeds) and flow regime (effect of shutdowns).

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FIGURES AND TABLES

Figure 1. Water levels at various positions in the Gordon River down-stream of the dam recorded from 12 - 26/8/00, during an on-off sequence which included full gate discharge at 250 cumecs (water levels at Site 70 are the white trace).

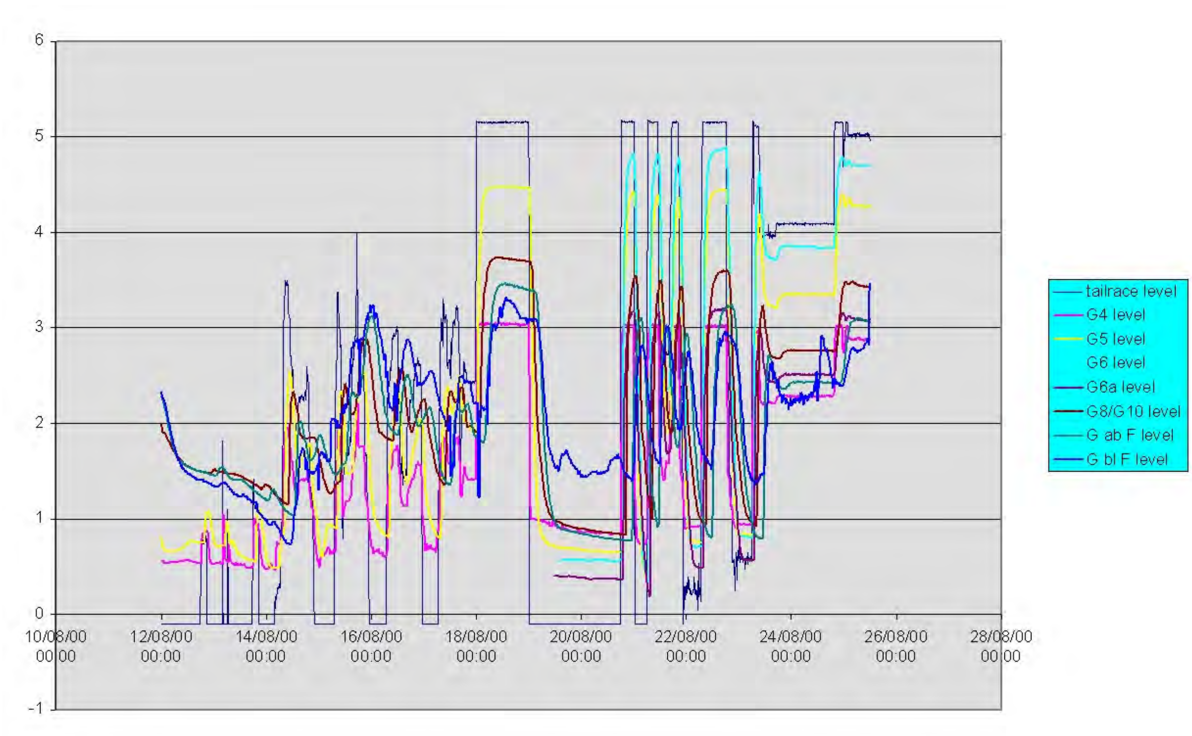


Figure 2. Hourly flow (cumecs) for the period 1/1/97-1/1/99 at Site 72 (9.1 km downstream from the dam) for: current power station operation: power station operation under Basslink simulated using TEMSIM 450 MW: and natural flow simulated from rainfall records.

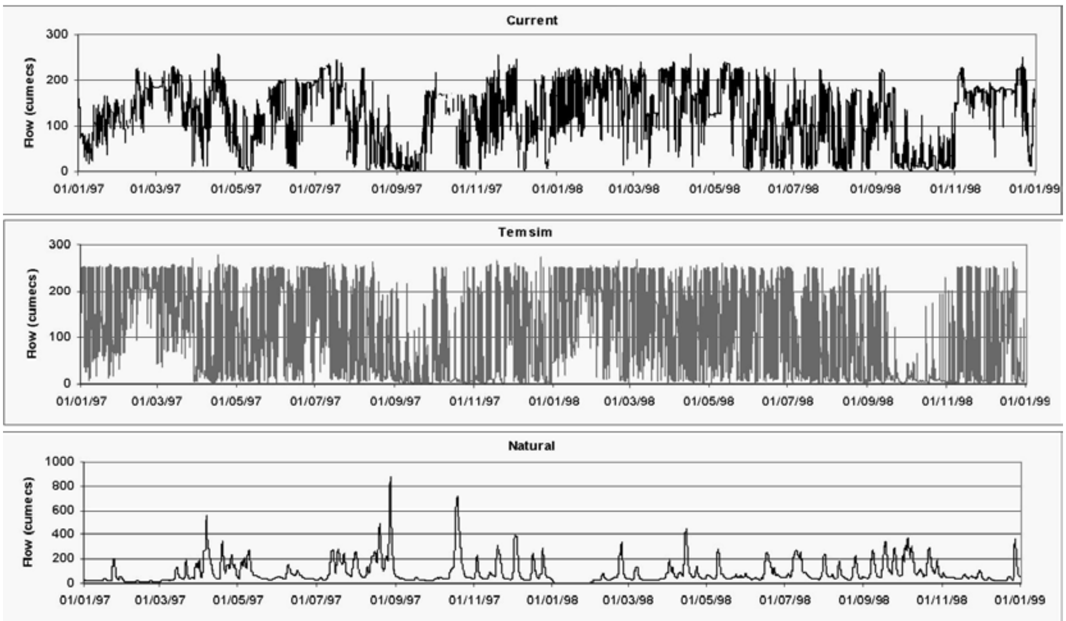


Figure 3. Average number of days per month during 1997 and 1998 when flows from the Gordon Power Scheme did not exceed 140 cumecs during daylight hours for current power station operation (Current), power station operation under Basslink simulated using TEMSIM 450 MW (TEMSIM) and natural flow simulated from rainfall records (Natural).

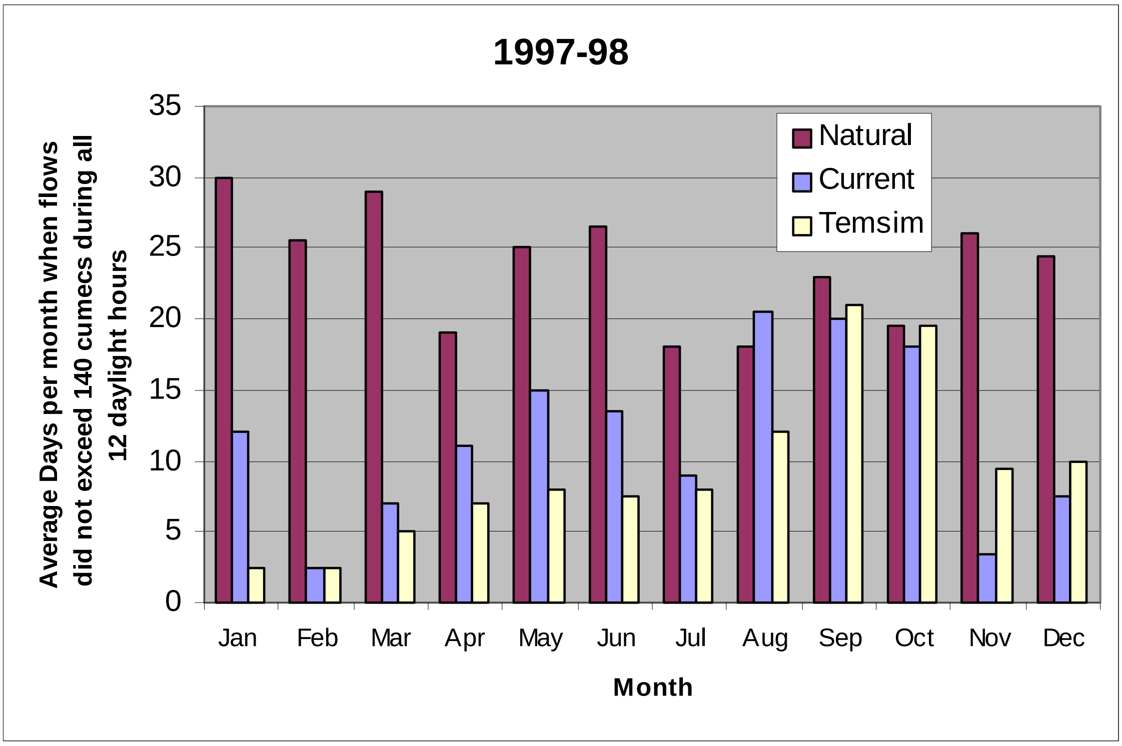


Figure 4. Hourly flow (cumecs) at Site 72, 9.1 km down stream from the dam, for natural, under current operation of the Gordon Power scheme and for power station flow modelled under TEMSIM 450 MW for the period 1/1/97 to 1/1/99 (two years data)

4.

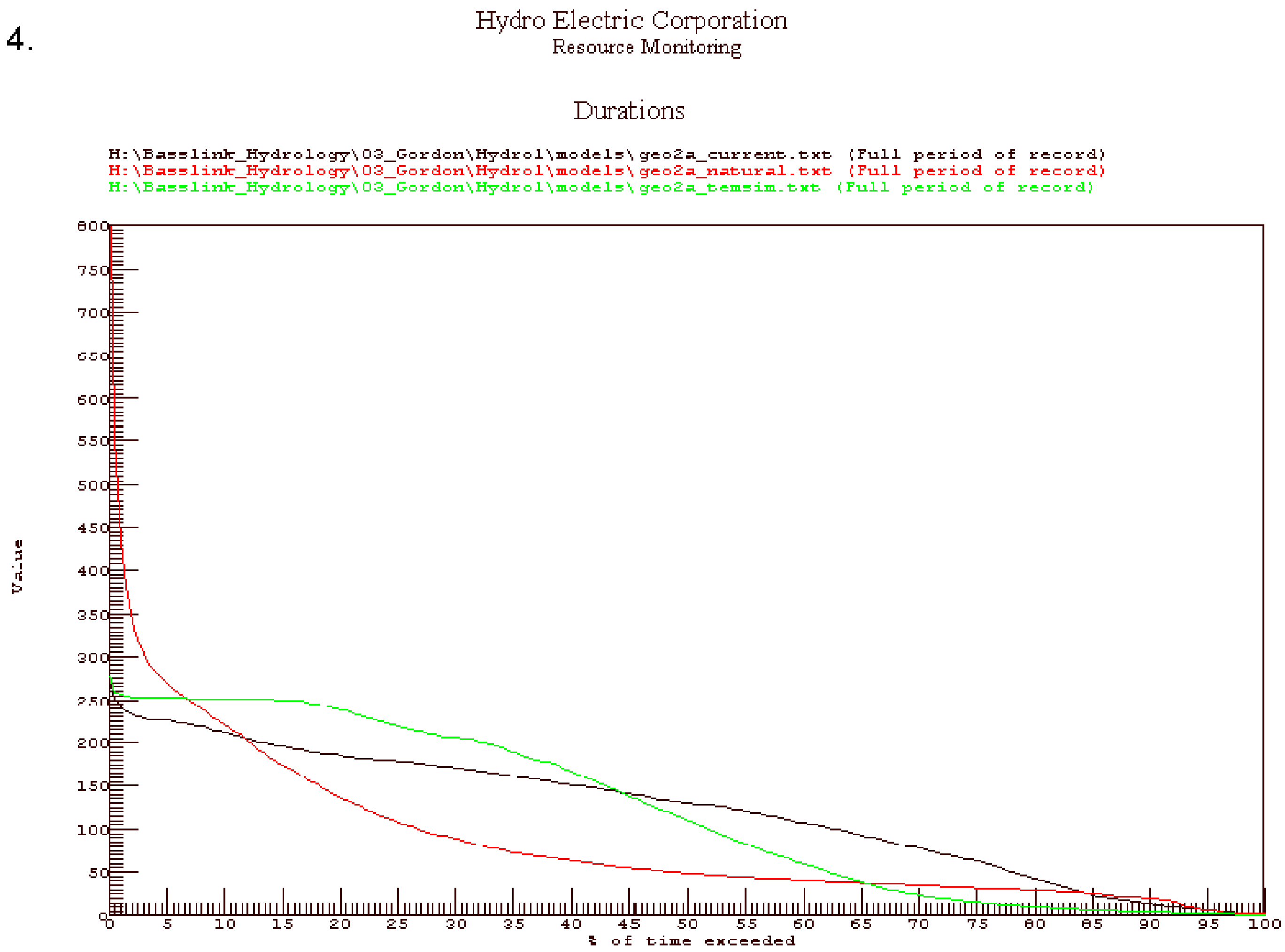


Figure 5. Mean annual inundation and b) mean annual waterlogging calculated from hourly flow (cumecs) for the period 1/1/97-1/1/99 at Site 72 (9.1 km down stream from the dam) for current power station operation, power station operation under Basslink simulated using TEMSIM 450 MW and natural flow simulated from rainfall records by summing total hourly records of flows >70 cumecs (1.5 m), flows >140 cumecs (2.5 m) and >210 cumecs (4.0 m), to give duration of stress at each of the bank heights 1.5, 2,5 and 4.0 m at Site 72.

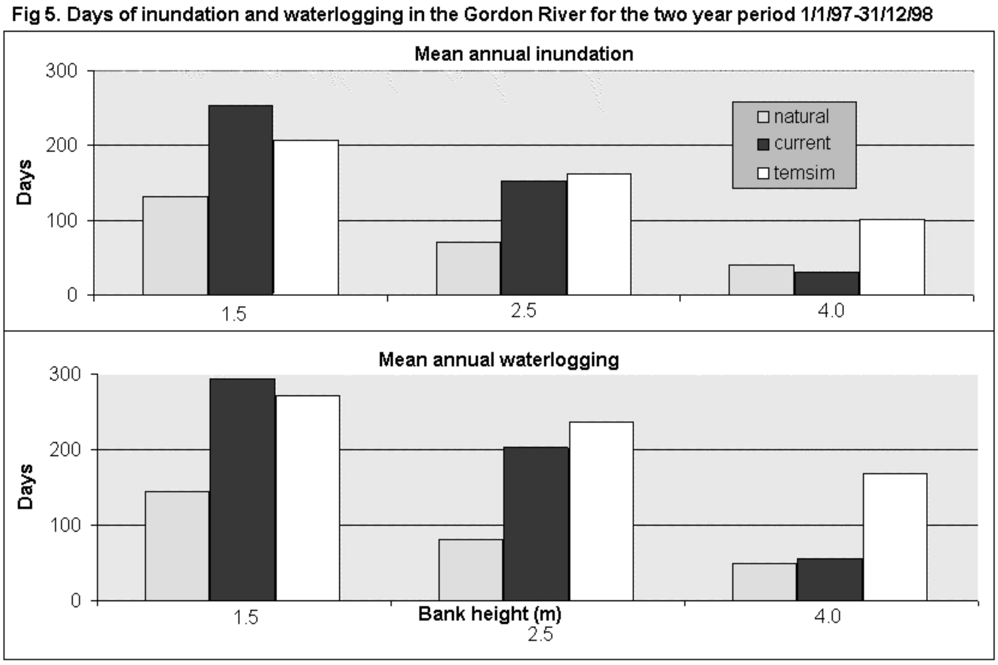


Figure 6. Water levels in a medium to fine sand bank at Site 72 on the Gordon River showing water levels at 1, 2, 4 and 8 h after shutdown following a) 6 h, b) 12 h, c) 24 h and d) 240 hour operation of the power station at full gate (250 cumecs).

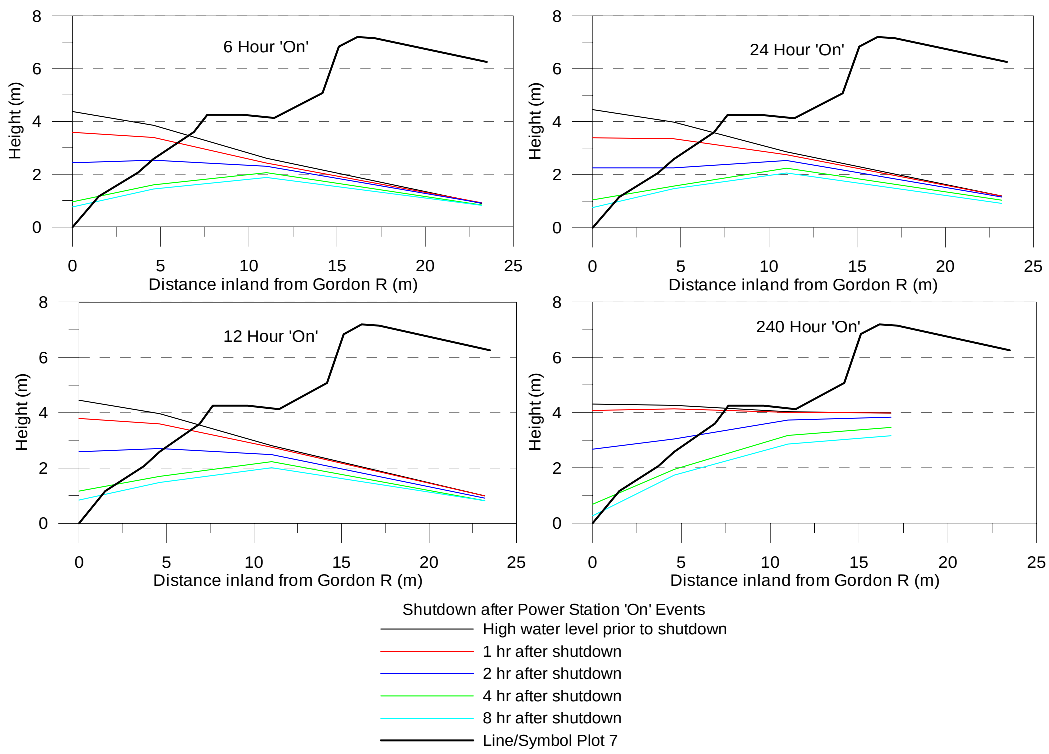


Figure 7:
Ordination in four dimensions showing all sites (n = 303) and significant fitted vectors (R > 0.5) for environmental variables with respect to (a) axes 1 v. 2; (b) axes 1 v. 3; (c) axes 1 v. 4, of the Gordon, Franklin and Denison Rivers.

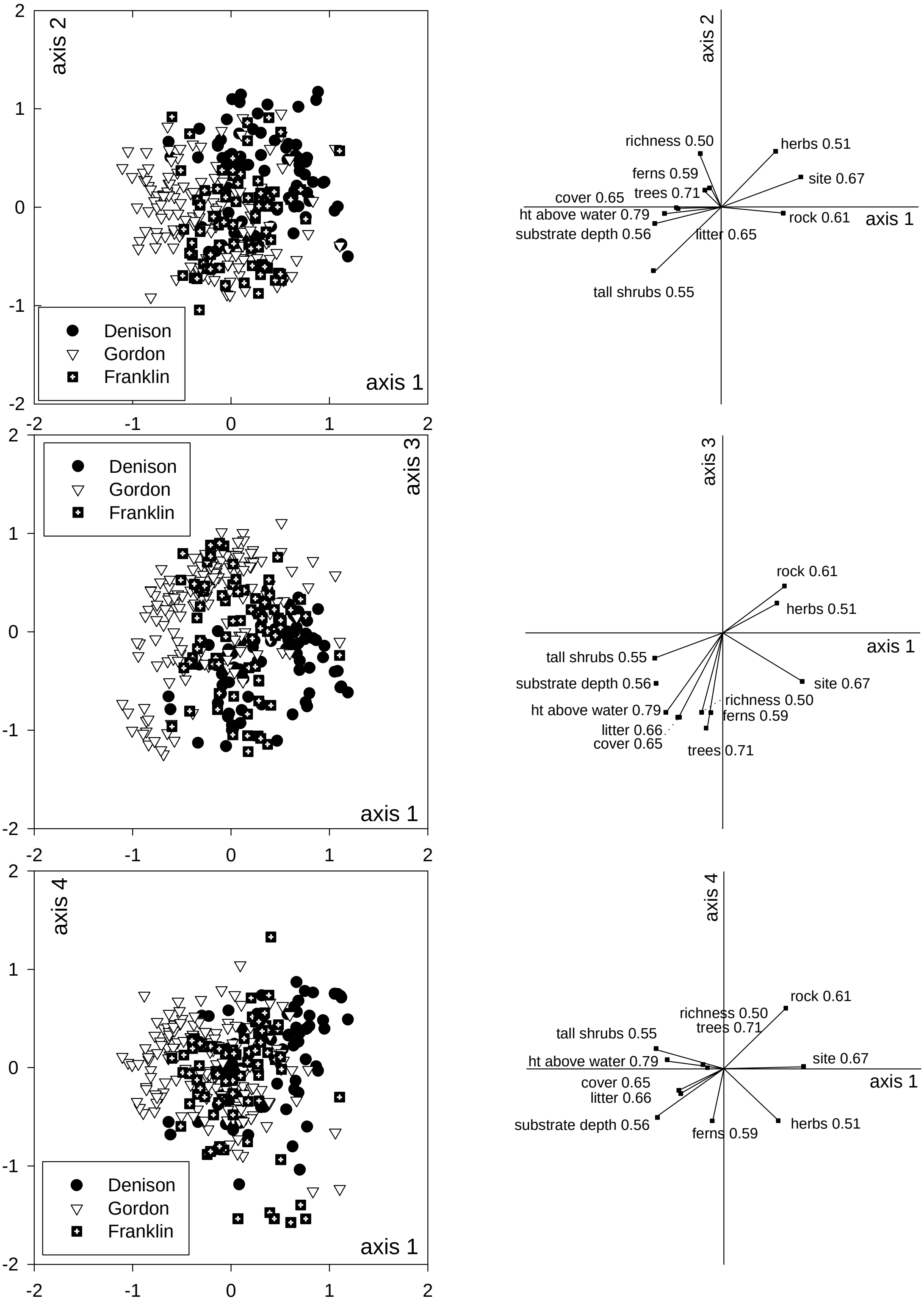


Figure 8:
Ordination in four dimensions showing channel sites (0 - 1.5 m, n = 192) and significant fitted vectors (R > 0.5) for environmental variables with respect to (a) axes 1 v. 2; (b) axes 1 v. 3; (c) axes 1 v. 4, of the Gordon, Franklin and Denison Rivers.

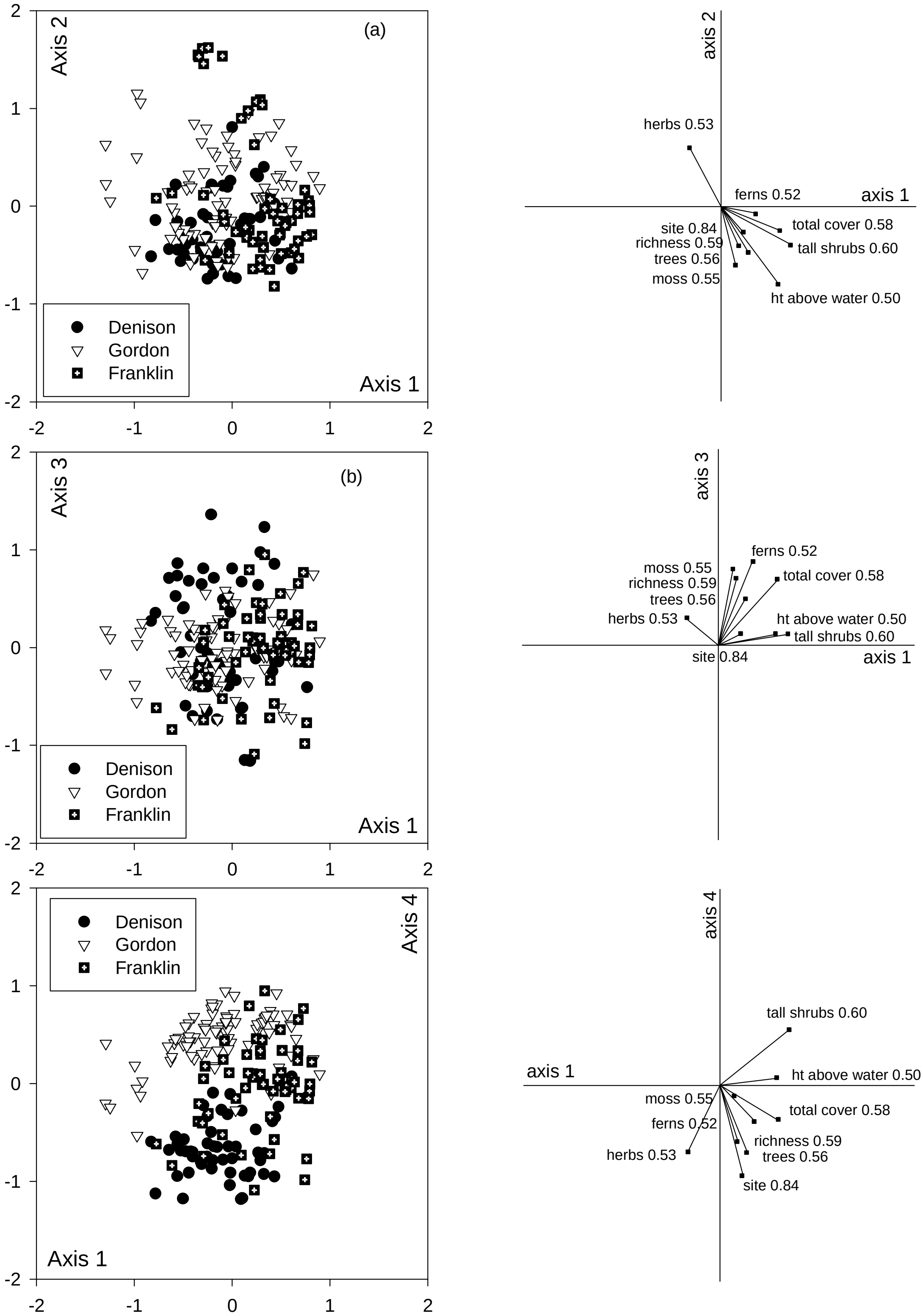


Figure 9:
Ordination in four dimensions showing low bank sites (1.6 - 2.5 m, n = 62) and significant fitted vectors (R > 0.5) for environmental variables with respect to (a) axes 1 v. 2; (b) axes 1 v. 3; (c) axes 1 v. 4, of the Gordon, Franklin and Denison rivers.

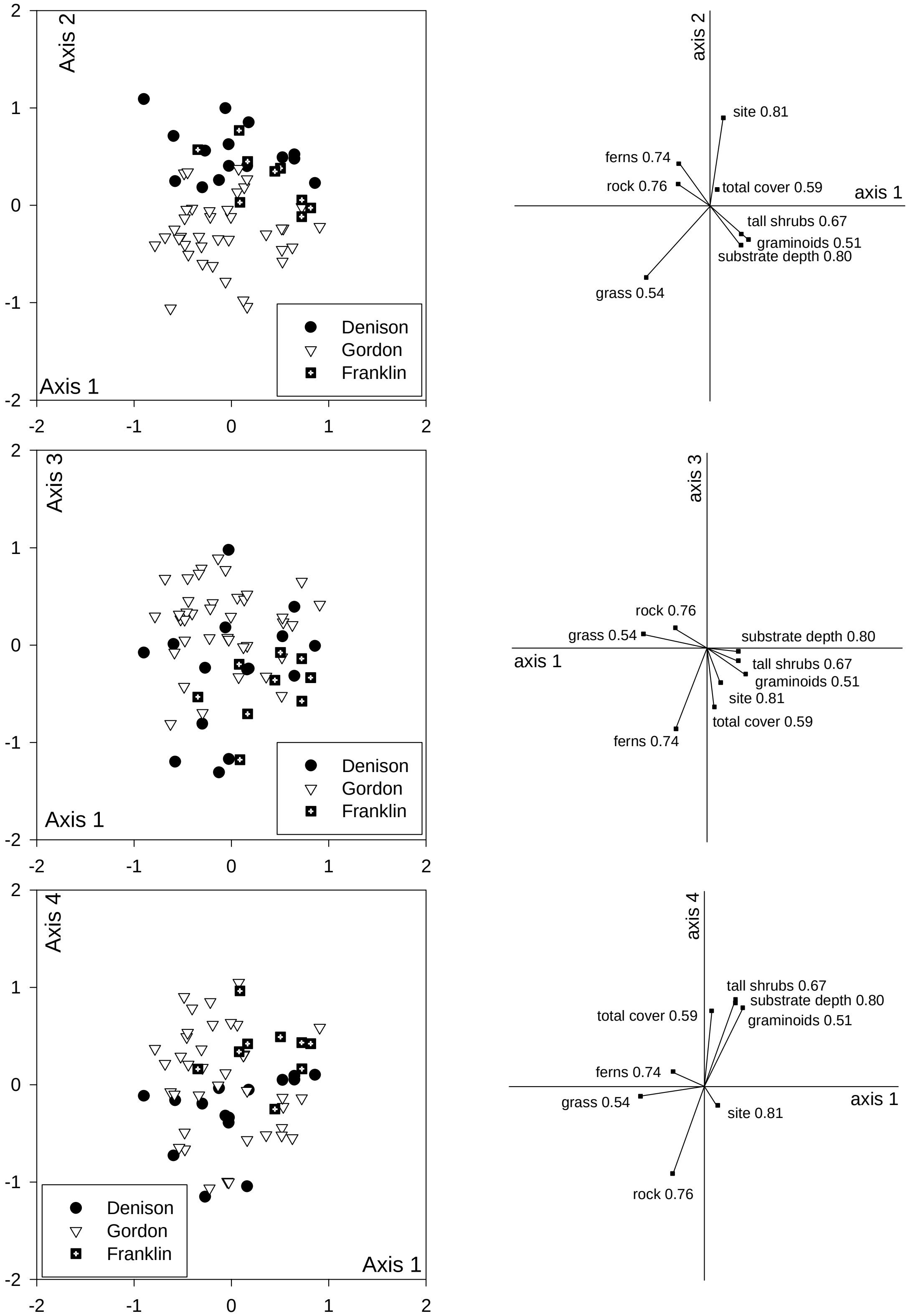


Figure 10:
Ordination in four dimensions showing high bank sites (> 2.5 m, n = 49) and significant fitted vectors (R > 0.5) for environmental variables with respect to (a) axes 1 v. 2; (b) axes 1 v. 3; (c) axes 1 v. 4, of the Gordon, Franklin and Denison Rivers

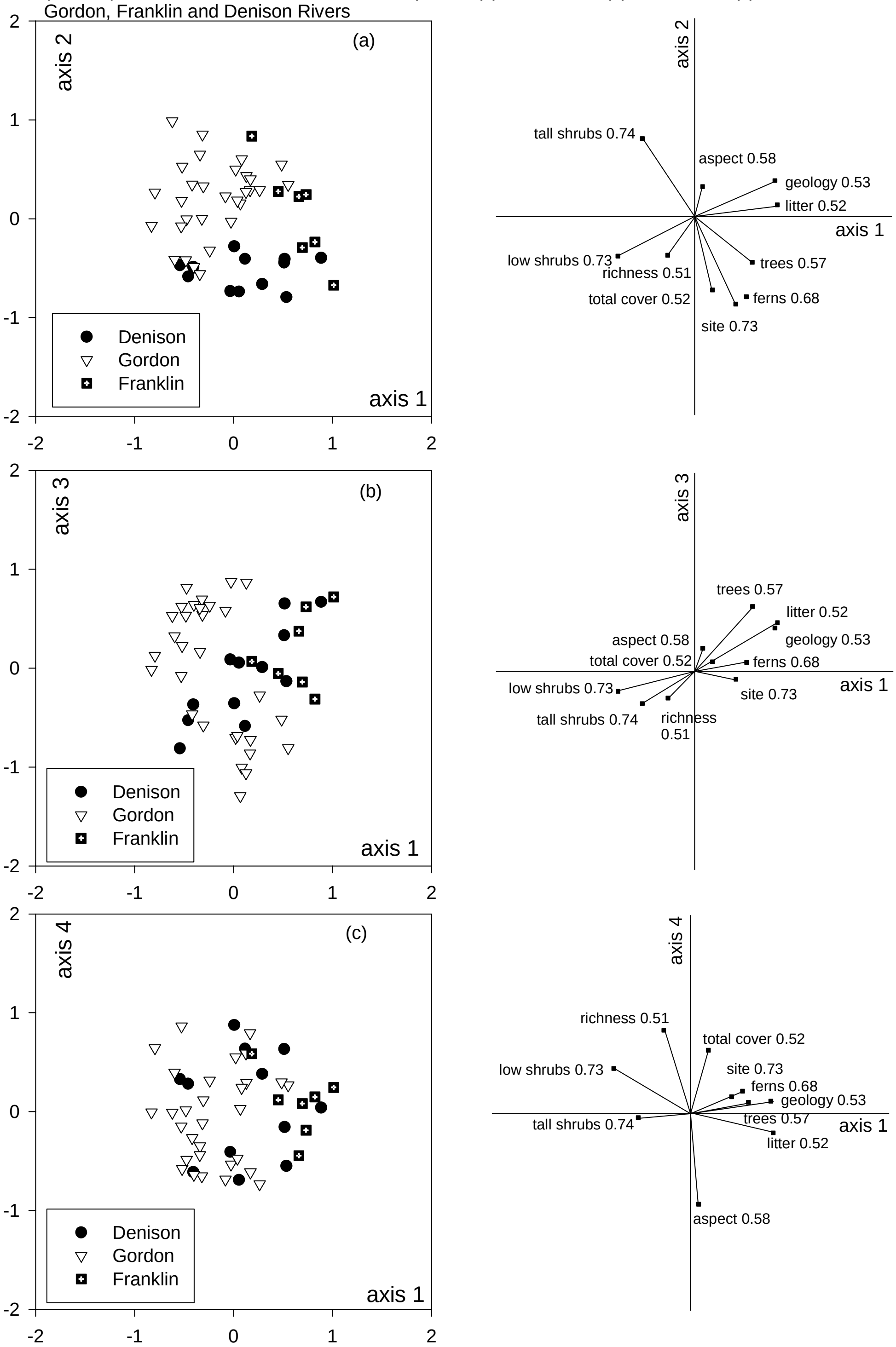


Figure 11: Mean percentage cover of vegetation guilds at all sites and data partitioned into zones: 0-1.5 m, 1.6-2.5 m and > 2.5 m on the river bank for the Denison, Gordon and Franklin rivers. Different letters indicate a significant difference between rivers at the P < 0.05 level, ns = not significant.

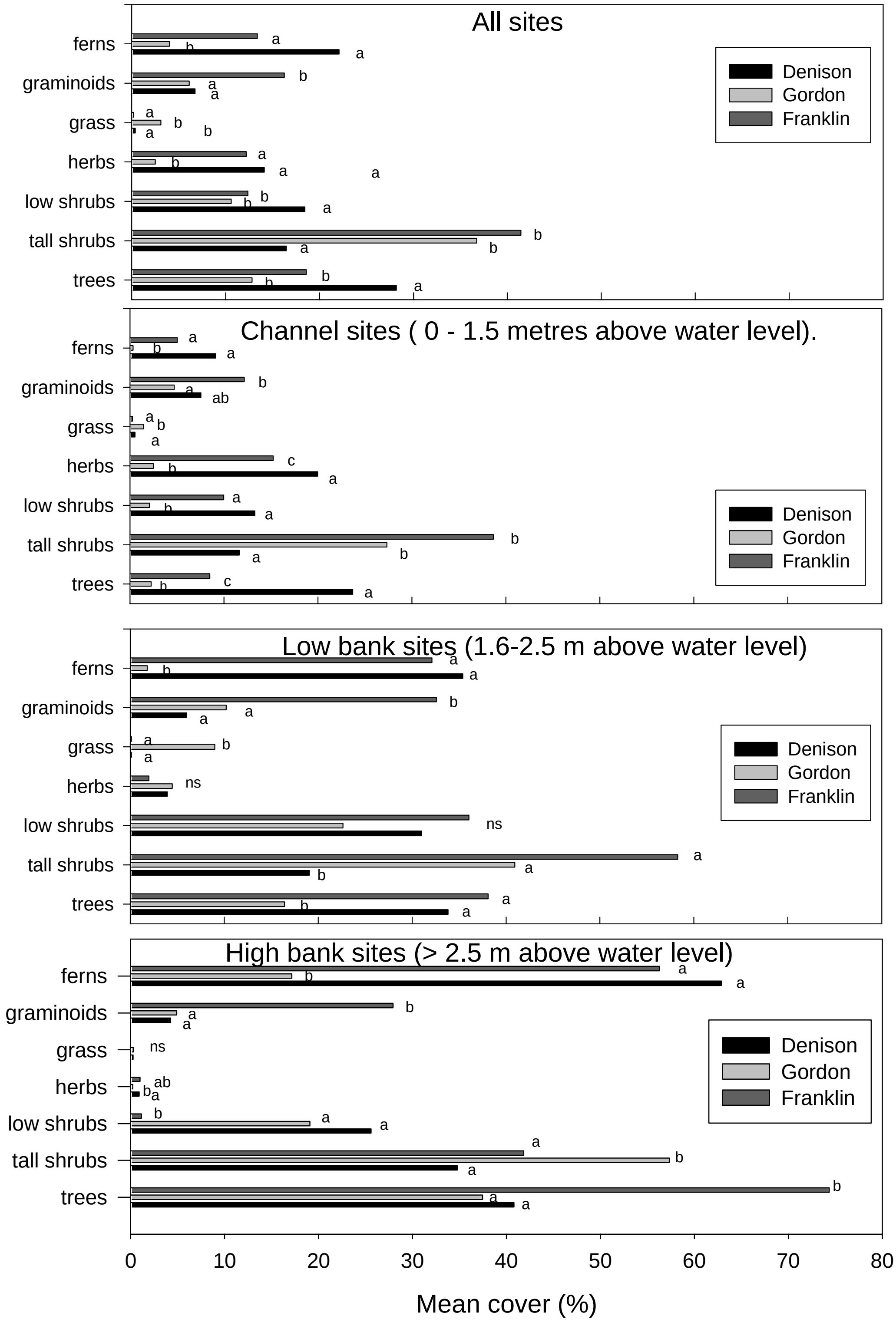


Figure 12:
Ordination of channel site (0 - 1.5 m, n=83) classification groups and significant fitted vectors (R . 0.5) for environmental variables of the Gordon River with respect to (a) axes 1 v. 2; (b) axes 1 v. 3; (c) axes 1 v. 4. A - E refer to groups produced by classification procedure. Group attributes in Table 5.

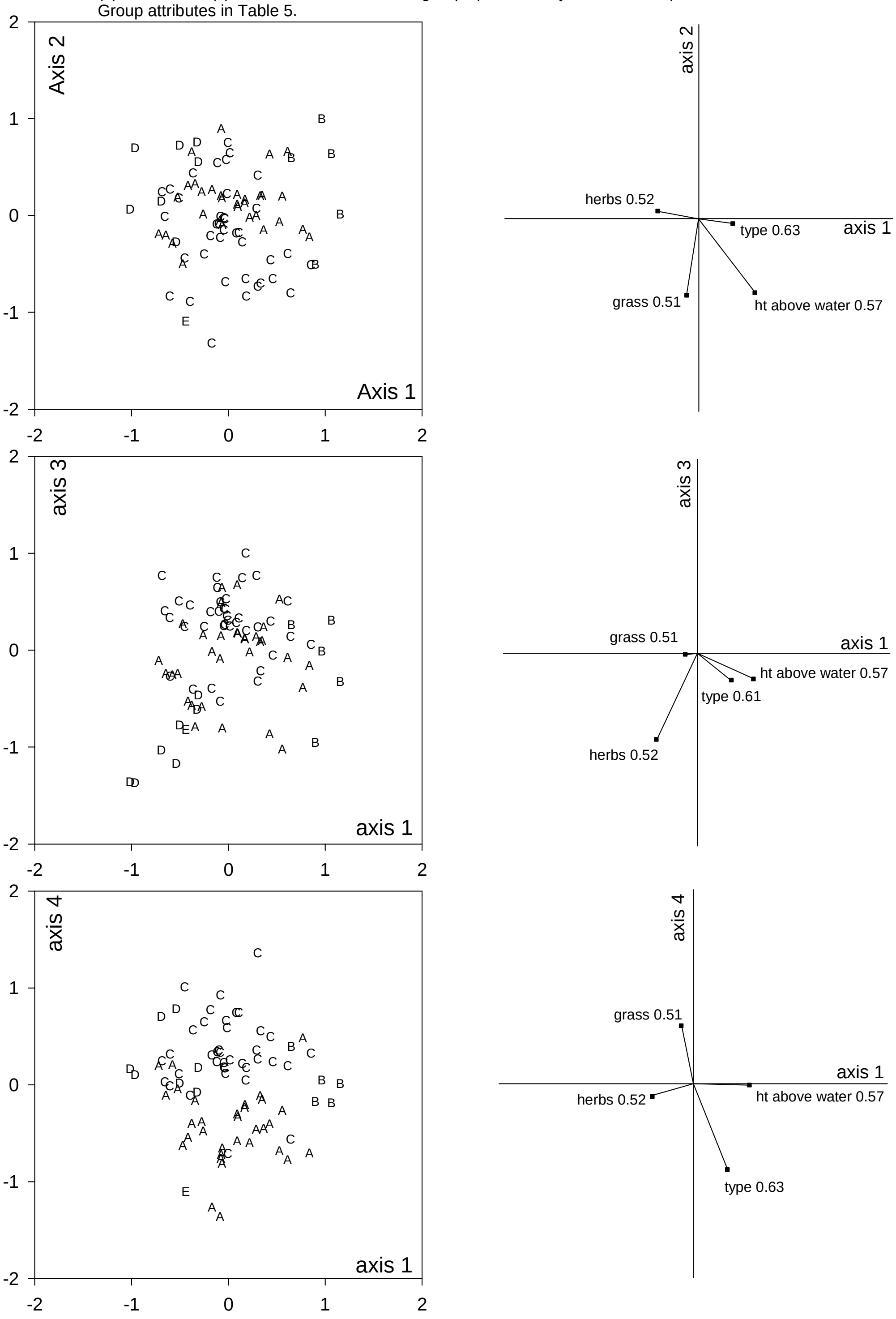


Figure 13:
Ordination of low bank sites (1.6 - 2.5 m, n = 38) classification groups and significant fitted vectors (R > 0.5) for environmental variables of the Gordon River with respect to (a) axes 1 v. 2; (b) axes 1 v. 3. A - E refer to groups produced by classification procedure. Group attributes in Table 6.

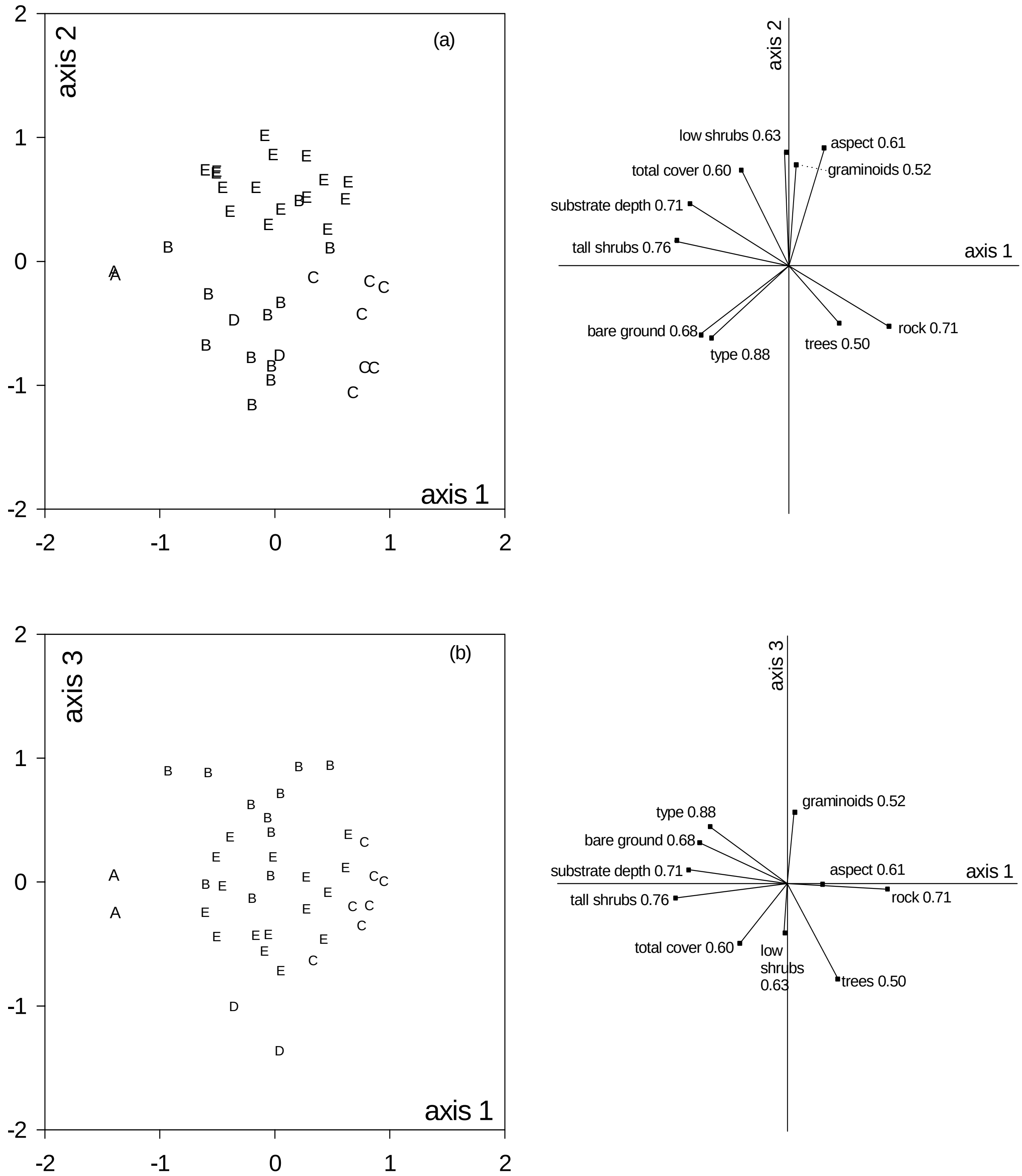


Figure 14. Mean dry weight of root material (+ SE) collected from sandbanks at a) Site 70, 7.8 km below the dam (low slope angle, 11°) and b) Site 72, 9.1 km below the dam (high slope angle 20°). Root material was from three depth intervals; 0-10, 10-20 and 20-30 cm in auger holes spaced at 2 m intervals up the bank from near water level 0 to 6 m.

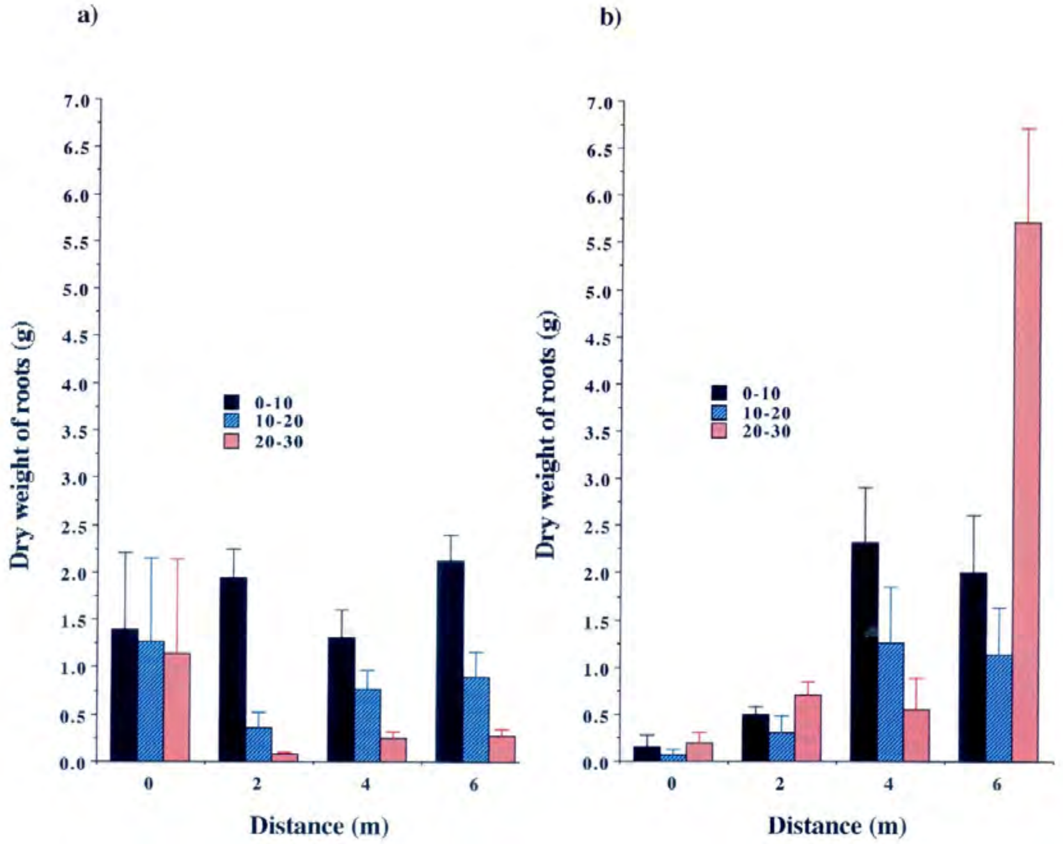


Figure 15. Hourly flow (m^3s^{-1}) at Site 72 (9.1 km down stream from the dam) for current power station operation, for power station operation under Basslink simulated using TEMSIM 450 MW and natural flow simulated from rainfall records, for a) February 1997 and b) July 1997.

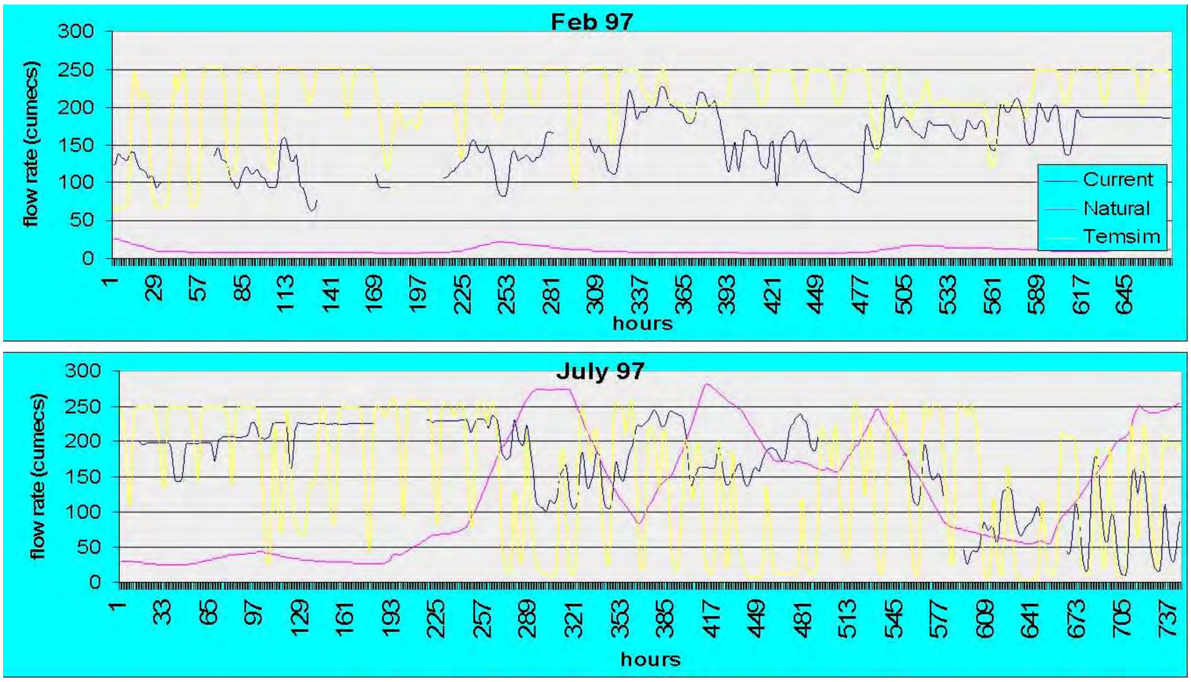
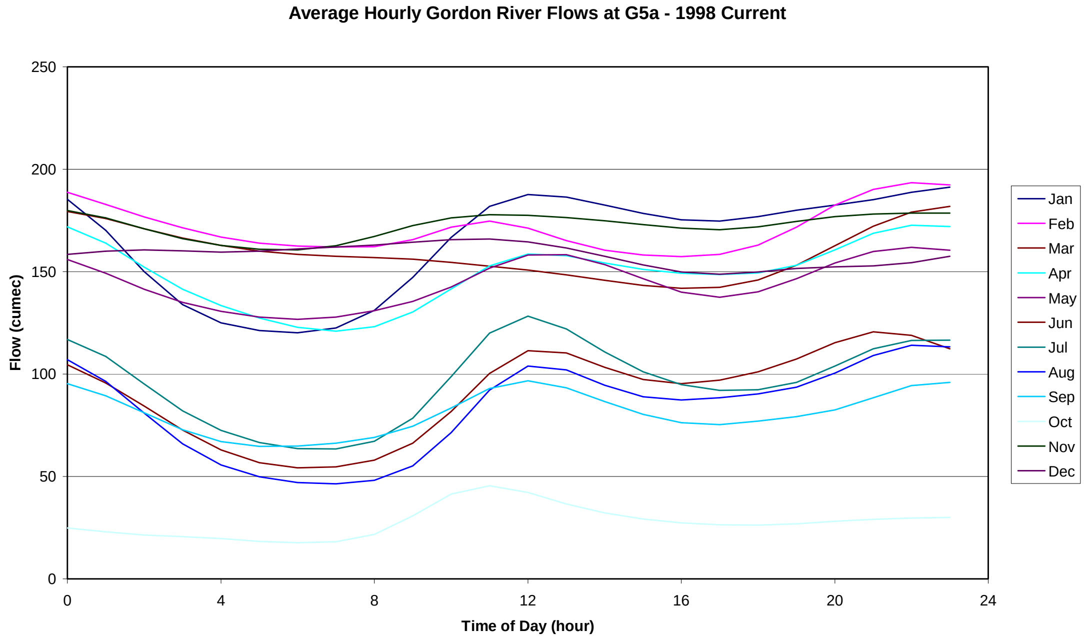


Figure 16. Average hourly Gordon River flows at Site 71for each month during 1998 a) for the current regime and b) and Basslink modelled under TEMSIM 450 MW.



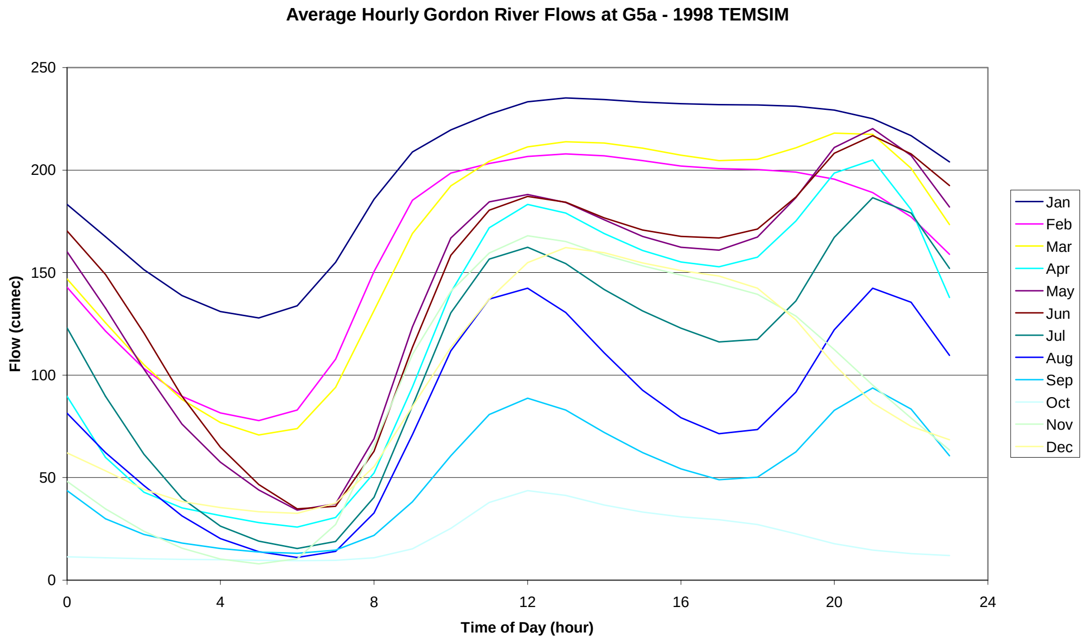


Figure 17. The average number of days per year (during 1997 and 1998) that plants at Site 72 (9.1 km from the dam), at a height of 2.5 m on the river bank (equivalent to flow rates of 140 cumecs), were free from inundation and able to carry out photosynthesis for 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 daylight hours, under the current regime (Current), Basslink modelled using TEMSIM 450 (TEMSIM) and natural flow simulated from rainfall records (Natural). A uniform 12 hours of daylight was assumed to be available each day if plants were not submerged.

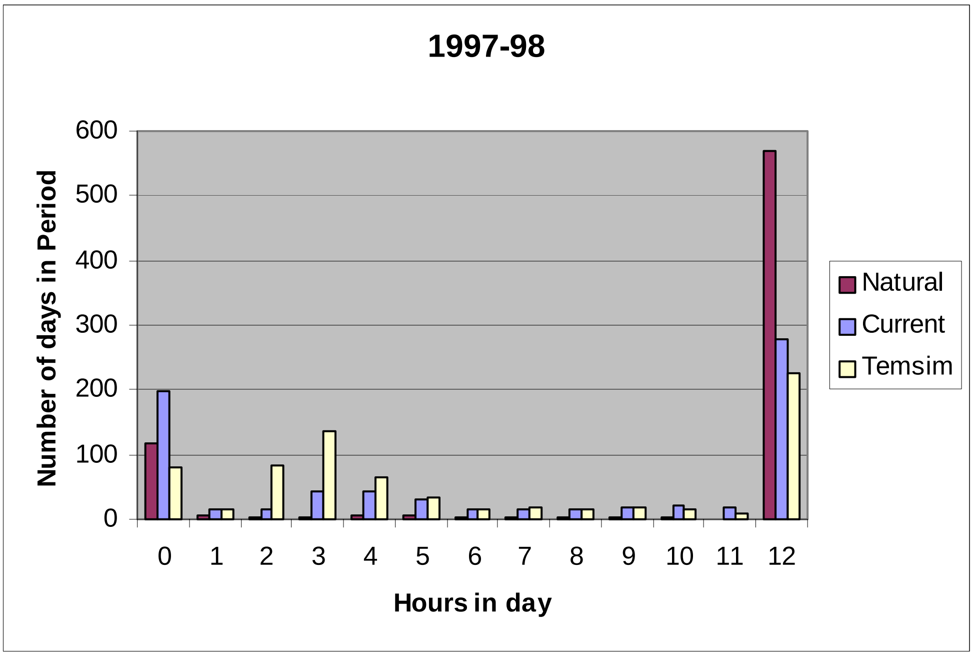


Figure 18. The average number of days per season (summer, November to April and winter, May to October) during 1997 and 1998 when flows from the Gordon Power Scheme did not exceed 140 cumecs during daylight hours for current power station operation (Current), power station operation under Basslink simulated using TEMSIM 450 MW (TEMSIM) and natural flow simulated from rainfall records (Natural).

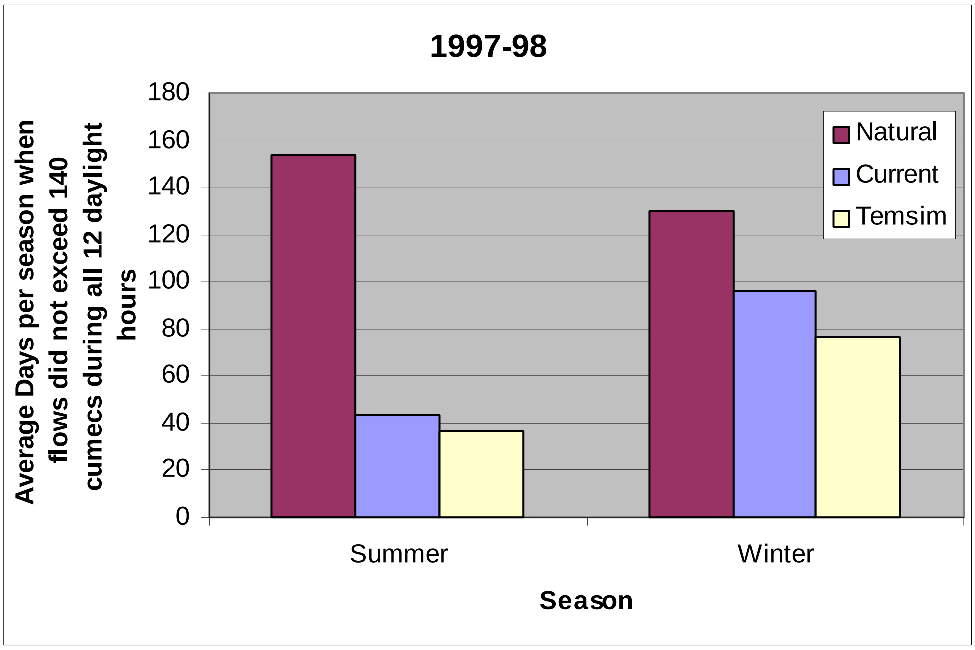


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Table 1. Bank Materials on the Gordon River from Abel Gorge and Second Split

Bank Materials	Proportion of river bank (%)
Cobbles	6
Cobbles and other	6
Alluvial	64
Alluvial and other	9
Bedrock	9
Bedrock and other	6
Total	100

Table 2. Comparison of riparian bryophytes in the Gordon River and Franklin River

	Species	Epiphyte	Rock	Terrestrial
Gordon River				
Mosses:	*Rhabdodontium buftonii**	√	√	
	Racomitrium crispulum		√	
	Fissidens strictus		√	
	Campylopus bicolor		√	
Hepatics:	*Plagiochila retrospectans*			√
	Aneura alterniloba		√	√
	Riccardia aequicellularis		√	
	Marchantia berteroana		√	
	Jungermannia sp.		√	
Franklin River				
Mosses:	*Orthotrichum rupestre*	√		
	Cryphaea tenella	√		
	Lembophyllum divulsum	√		
	Funaria hygrometrica			√
	Ceratodon purpureus			√
	Chrysoblastella chilensis			√
	Campylopus bicolor (hummocks)			√
	Philonotis sp.			√
	Breutelia pendula			√
	Fissidens asplenioides			√
	Bryum billardierei			√
	Bryum sp.			√
	Racomitrium crispulum		√	
	Sematophyllum uncinatum		√	
	Rhacocarpus purpurescens		√	
	Unidentified species			√
Hepatics:	*Isotachis sp.*			√
	Plagiochila sp.			√
	Chiloscyphus semeteres			√
	Riccardia aequicellularis			√
	Siphonolejeunea nudipes	√		
	Lejeunea sp.	√		
	Unidentified species			√

*This is an endemic taxon, previously considered to be rare.

Table 3. Species with significant (< 0.05) mean relative importance value (P_1) in channel (0- 1.5 metres above water level), low bank (1.6 – 2.5 metres above water level), and high bank (> 2.5 metres above water level) sites for the Gordon and Denison Rivers. Increased P_1 is equal to increased cover of that species on the Gordon River; decreased P_1 is equal to decreased cover on the Gordon River. Vegetation guilds defined as (t) = trees, (ts) = tall shrubs, (ls) = low shrubs, (h) = herbs, (g) = grass, (gd) = graminoids and (f) = ferns.

Channel sites	Low bank sites	High bank sites
Species with increasing P_1	**Species with increasing P_1**	**Species with increasing P_1**
Ehrharta spp (g) *Leptospermum riparium* (ts) *Myriophyllum pedunculata* (h)	*Acacia verticillata* (t) *Acradenia frankliniae* (ts) *Bauera rubioides* (ls) *Ehrharta spp* (g) *Leptospermum riparium* (ts) *Pittosporum bicolor* (ts)	*Acacia verticillata* (t) *Acradenia frankliniae* (ts)
Species with decreasing P_1	**Species with decreasing P_1**	**Species with decreasing P_1**
Acacia melanoxylon (t) *Anodopetalum biglandulosum* (ts) *Atherosperma moschatum* (t) *Blechnum nudum* (f) *Blechnum penna-marina* (f) *Blechnum wattsii* (f) *Coprosma quadrifida* (ls) *Epacris impressa* (ls) *Epilobium sarmentaceum* (h) *Epilobium perpusillum* (h) *Eucryphia lucida* (t) *Hymenophyllum flabellatum* (f) *Hymenophyllum peltatum* (f) *Juncus astreptus* (gd) *Juncus pallidus* (gd) *Lagarostrobus franklinii* (t) *Leptospermum scoparium* (ts) *Nymphoides exigua* (h) *Oreomyrrhis sessiflorus* (h) *Oxalis radicosa* (h) *Plantago paradoxa* (h) *Pomaderris apetala* (ts) *Wahlenbergia sp* (h)	*Acacia melanoxylon* (t) *Acacia mucronata* (t) *Anodopetalum biglandulosum* (ts) *Blechnum nudum* (f) *Blechnum wattsii* (f) *Epilobium sarmentaceum* (h) *Eucryphia lucida* (t) *Gleichenia dicarpa* (f) *Gnaphalium spp* (h) *Hymenophyllum flabellatum* (f) *Hymenophyllum peltatum* (f) *Hypericum japonicum* (h) *Nothofagus cunninghamii* (t) *Trochocarpa cunninghamii* (ls) *Wahlenbergia sp* (h)	*Acacia dealbata* (t) *Acacia melanoxylon* (t) *Acacia mucronata* (t) *Anodopetalum biglandulosum* (ts) *Atherosperma moschatum* (t) *Blechnum wattsii* (f) *Clematis aristata* (ls) *Dicksonia antarctica* (f) *Hymenophyllum flabellatum* (f) *Hymenophyllum peltatum* (f) *Leptospermum scoparium* (ts) *Pimelea drupaceae* (ls) *Polystichum proliferum* (f) *Prionotes cerinthioides* (ls) *Viola hederacea* (h)

Table 4. Species with significant (< 0.05) mean relative importance value (P_1) in channel (0- 1.5 metres above water level), low bank (1.6-2.5 metres above water level) and high bank (> 2.5 metres above water level) sites for the Gordon and Franklin Rivers. Increased P_1 is equal to increased cover of that species on the Gordon River; decreased P_1 is equal to decreased cover on the Gordon River. Vegetation guilds defined as (t) = trees, (ts) = tall shrubs, (ls) = low shrubs, (h) = herbs, (g) = grass, (gd) = graminoids and (f) = ferns.

Channel sites	Low bank sites	High bank sites
Species with increasing P_1	**Species with increasing P_1**	**Species with increasing P_1**
Acacia verticillata (t)	*Acacia verticillata* (t)	
Ehrharta spp (g)	*Bauera rubioides* (ls)	
Isotoma fluviatilis (h)	*Ehrharta spp* (g)	
Juncus bassianus (gd)		
Leptospermum riparium (ts)		
Restio tetraphyllus (gd)		
Species with decreasing P_1	**Species with decreasing P_1**	**Species with decreasing P_1**
Atherosperma moschatum (t)	*Aristotelia pedunculata* (ls)	*Acacia melanoxylon* (t)
Australina pusilla (h)	*Atherosperma moschatum* (t)	*Asplenium flaccidum* (f)
Blechnum nudum (f)	*Blechnum chambersii* (f)	*Aristotelia pedunculata* (ls)
Carex appressa (gd)	*Blechnum nudum* (f)	*Atherosperma moschatum* (t)
Carex sp (gd)	*Carex sp* (gd)	*Blechnum chambersii* (f)
Coprosma quadrifida)ls)	*Cennarhennes nitida* (ts)	*Blechnum wattsii* (f)
Diplarrena latifolia (gd)	*Dicksonia antarctica* (f)	*Carex appressa* (gd)
Epacris mucronulata (ls)	*Diplarrena latifolia* (gd)	*Clematis aristata* (ls)
Gratiola nana (h)	*Diplazium australe* (f)	*Dicksonia antarctica* (f)
Hydrocotyle muscosa (h)	*Epacris mucronulata* (ls)	*Galium australe* (h)
Hymenophyllum peltatum (f)	*Histiopteris incisa* (f)	*Hymenophyllum flabellatum* (f)
Lilaeopsis polyantha (h)	*Hymenophyllum peltatum* (f)	*Hymenophyllum rarum* (f)
Myriophyllum pedunculata (h)	*Juncus bassianus* (gd)	*Juncus bassianus* (gd)
Nothofagus cunninghamii (t)	*Libertia pulchella* (gd)	*Lagenifera stipitata* (h)
Pimelea drupaceae (ls)	*Nothofagus cunninghamii* (t)	*Libertia pulchella* (gd)
Pomaderris apetala (ts)	*Notolea ligustrina* (ts)	*Milligania longifolia* (gd)
Pratia spp (h)	*Phyllocladus asplenifolia* (t)	*Notolea ligustrina* (ts)
Viola hederacea (h)	*Tasmannia lanceolata* (ls)	*Oxalis radicosa* (h)
Wahlenbergia sp (h)		*Phymatosorus diversifoliium* (f)
		Pimelea drupaceae (ls)
		Tmesipteris billardieri (f)
		Uncinia riparia (gd)
		Viola hederacea (h)

Table 5. Means of environmental variables for classification groups of channel sites (0 – 1.5 m above water level) in the Gordon River.

classification groups	**A**	**B**	**C**	**D**	**E**
n	32	5	38	7	1
site	island/bank	island	island	island	bank
ht. above water (m)	0.8	0.6	0.8	0.7	0
substrate depth (cm)	7.0	0	6.1	4.6	0
richness	4.8	5.4	4.8	3.7	3
total cover (%)	44.4	9.2	45.2	28.4	23
litter (%)	12.3	0	8	1	0
moss (%)	12	4	20.6	1.8	0
rock (%)	78.8	87.5	52.5	60.8	87.5
bare ground (%)	59.8	19.3	23.7	47.1	4
trees (%)	4.3	0.3	2.5	0	0
tall shrubs (%)	34.2	2.6	29.3	14.9	0
low shrubs (%)	1.8	3.4	3	0	0
herbs (%)	2.2	0.4	1.4	9.1	4
grass (%)	0.2	0	2.6	2.4	0
graminoids (%)	1.5	0.6	6.1	2	19
ferns (%)	0.2	1.8	0.3	0	0

Table 6. Means of environmental variables for classification groups of low bank sites (1.6 – 2.5m above water level) in the Gordon River.

classification groups	**A**	**B**	**C**	**D**	**E**
n	2	11	7	2	16
site	bank	island	island/below Denison	island	island
ht. above water (m)	2.0	2.2	1.8	2.3	2.0
substrate depth (cm)	15	15	2.1	15	15
richness	8.5	9.9	9.4	12.5	9.7
total cover (%)	114.3	88.4	53.3	152	133.2
litter (%)	9.5	20.1	0	20.8	6.1
moss (%)	1.0	26.5	2.0	50.0	25.6
rock (%)	0	15	73.6	0	4.0
bare ground (%)	87.5	58.6	21.9	20.8	29.5
trees (%)	0	16.2	13.6	62	14.2
tall shrubs (%)	69	45.2	3.7	61	48.3
low shrubs (%)	6.0	9.4	13.6	10	39.4
herbs (%)	3.0	3.5	11.4	0	2.9
grass (%)	0	3.8	10.3	17	12.1
graminoids (%)	26.8	8.1	0.7	0.5	15.0
ferns (%)	9.5	2.3	0	1.5	1.4

Table 7. Species list for Gordon River

a) Abel Gorge to Second Split

Acacia dealbata
Acacia melanoxylon
Acacia verticillata
Acaena novae-zelandiae
Acradenia frankliniae
Anodopetalum biglandulosum
Anopterus glandulosus
Atherosperma moschatum
Bauera rubioides
Blechnum nudum
Blechnum wattsii
Callitriche sp
Calorophus elongata
Carex sp
Cennarhennes nitida
Clematis aristata
Coprosma nitida
Coprosma quadrifida
Ctenopteris heterophylla
Cyathodes glauca
Cyathodes juniperina
Dianella tasmanica
Drymophila cyanocarpa
Epacris impressa
Erharta spp
Erharta tasmanica
Eucalyptus nitida
Eucryphia lucida
Gahnia grandis
Gleichenia dicarpa
Gnaphalium spp
Grammitis magellanica
Gratiola nana
Herb 1
Histiopteris incisa
Huperzia varia
Hydrocotyle hirta
Hydrocotyle muscosa
Hymenophyllum peltatum
Isolepis crassiuscula
Isotoma fluviatilis
Juncus pauciflorus
Lagarostrobus franklinii
Leptospermum riparium
Libertia pulchella
Lilaeopsis polyantha
Melaleuca squarrosa
Monotoca glauca
Myriophyllum pedunculata
Nothofagus cunninghamii
Olearia phlogapappa
Orites diversifolia
Oxalis radicosa
Parsonsia straminea
Phebalium squameum
Phyllocladus asplenifolia
Phymatosorus diversifoliium
Pimelea drupaceae
Pimelea lindleyana
Pittosporum bicolor
Pomaderris apetala
Prostanthera lasianthos
Pultenaea juniperina
Ranunculus amphitrichus
Restio tetraphyllus
Richea pandanifolia
Richea procera
Schoenus maschalinus
Sticherus tener
Tasmannia lanceolata
Tetraria capillaris
Triglochin striatum
Trochocarpa cunninghamii
Viola hederacea

b) Denison Mouth to Ewarts Gorge

Acacia melanoxylon
Acacia mucronata
Acacia verticillata
Acaena novae-zelandiae
Acradenia frankliniae
Anodopetalum biglandulosum
Anopterus glandulosus
Atherosperma moschatum
Bauera rubioides
Blechnum fluviatele
Blechnum nudum
Blechnum volcanicum
Blechnum wattsii
Clematis aristata
Coprosma nitida
Coprosma quadrifida
Epacris impressa
Epacris mucronulata
Erharta spp
Erharta tasmanica
Galium australe
Gonocarpus teucrioides
Grammitis magellanica
Herb 1
Hydrocotyle hirta
Hydrocotyle muscosa
Hymenophyllum peltatum
Isolepis crassiuscula
Isotoma fluviatilis
Juncus pauciflorus
Lagarostrobus franklinii
Lagenifera stipitata
Leptospermum riparium
Libertia pulchella
Lilaeopsis polyantha
Nothofagus cunninghamii
Oreomyrrhis sessiflorus
Orites diversifolia
Oxalis radicosa
Pimelea drupaceae
Pittosporum bicolor
Plantago paradoxa
Podocarpus lawrencii
Pomaderris apetala
Prostanthera lasianthos
Schoenus maschalinus
Tasmannia lanceolata
Viola hederacea

Table 8. Complete species list for the Franklin River

Acacia dealbata	*Eucalyptus nitida*	*Myriophyllum pedunculata*
Acacia melanoxylon	*Eucryphia lucida*	*Nothofagus cunninghamii*
Acaena novae-zelandiae	*Galium australe*	*Notolea ligustrina*
Acradenia frankliniae	*Gnaphalium spp*	*Oreomyrrhis sessiflorus*
Anopterus glandulosus	*Gonocarpus teucrioides*	*Orites diversifolia*
Asplenium flaccidum	*Grammitis magellanica*	*Oxalis radicosa*
Aristotelia pedunculata	*Gratiola nana*	*Phyllocladus asplenifolia*
Atherosperma moschatum	*Histiopteris incisa*	*Phymatosorus diversifoliium*
Blechnum chambersii	*Huperzia varia*	*Pimelea drupaceae*
Blechnum nudum	*Hydrocotyle hirta*	*Plantago paradoxa*
Blechnum wattsii	*Hydrocotyle muscosa*	*Polystichum proliferum*
Callitriche sp	*Hymenophyllum flabellatum*	*Pomaderris apetala*
Carex appressa	*Hymenophyllum peltatum*	*Pratia spp*
Carex sp	*Hymenophyllum rarum*	*Prostanthera lasianthos*
Cennarhennes nitida	*Hypericum japonicum*	*Restio tetraphyllus*
Clematis aristata	*Hypochaeris radicata*	*Richea pandanifolia*
Coprosma quadrifida	*Juncus bassianus*	*Rumohra adiantiformis*
Dicksonia antarctica	*Juncus pauciflorus*	*Schoenus maschalinus*
Diplarrena latifolia	*Lagenifera stipitata*	*Sticherus tener*
Diplazium australe	*Lagarostrobus franklinii*	*Tasmannia lanceolata*
Epacris impressa	*Leptospermum riparium*	*Tmesipteris billardieri*
Epacris mucronulata	*Libertia pulchella*	*Trochocarpa cunninghamii*
Epilobium sarmentaceum	*Lilaeopsis polyantha*	*Uncinia riparia*
Epilobium perpusillum	*Milligania longifolia*	*Viola hederacea*
Erharta spp	*Monotoca glauca*	*Wahlenbergia sp*

Table 9. **Complete species list for Denison River**

Acacia dealbata	*Eucryphia lucida*	*Nothofagus cunninghamii*
Acacia melanoxylon	*Gahnia grandis*	*Nymphoides exigua*
Acacia mucronata	*Galium australe*	*Oreomyrrhis sessiflorus*
Acaena novae-zelandiae	*Gaultheria hispida*	*Orites diversifolia*
Anodopetalum biglandulosum	*Gleichenia dicarpa*	*Oxalis perennans*
Anopterus glandulosus	*Gnaphalium spp*	*Oxalis radicosa*
Atherosperma moschatum	*Grammitis magellanica*	*Phyllocladus asplenifolia*
Bauera rubioides	*Hydrocotyle hirta*	*Phymatosorus diversifoliium*
Blechnum nudum	*Hydrocotyle muscosa*	*Pimelea drupaceae*
Blechnum penna-marina	*Hymenophyllum flabellatum*	*Plantago paradoxa*
Blechnum wattsii	*Hymenophyllum peltatum*	*Polystichum proliferum*
Callitriche sp	*Hypericum japonicum*	*Pomaderris apetala*
Calorophus elongata	*Juncus astreptus*	*Potamatogeton ochreatus*
Carex appressa	*Juncus pallidus*	*Prionotes cerinthioides*
Carex sp	*Juncus pauciflorus*	*Prostanthera lasianthos*
Cennarhennes nitida	*Lagenifera stipitata*	*Ranunculus amphitrichus*
Clematis aristata	*Lagarostrobus franklinii*	*Restio tetraphyllus*
Coprosma quadrifida	*Lepidosperma filiforme*	*Schoenus maschalinus*
Deyeuxia monticola	*Leptospermum riparium*	*Sticherus tener*
Dicksonia antarctica	*Leptospermum scoparium*	*Tasmannia lanceolata*
Epacris impressa	*Libertia pulchella*	*Trochocarpa cunninghamii*
Epilobium sarmentaceum	*Melaleuca squarrosa*	*Viola hederacea*
Epilobium perpusillum	*Monotoca glauca*	*Wahlenbergia sp*
Erharta spp	*Myriophyllum pedunculata*	

PLATES

Plate 2: Andrew Gibbons assesses plant cover and abundance on a cobble island in the Denison River. The shrubs visible are principally *Acacia melanoxylon* and *A. mucronata*. The herbs are principally *Plantago paradoxa, Acaena novae-zelandiae* and *Viola hederacea*.

Plate 3: The Franklin River near the junction with the Jane River, showing the upper extent of the riparian zone as a line in the vegetation caused by debris carried by the river during flood.

Plate 4: The Denison River 7 km upstream of Marriotts Gorge showing riparian vegetation down to the water level bedrock bars (foreground) and cobble islands (background).

Plate 5: Herbs cover sand mounds at Flat Island in the Franklin River

Plate 6: **Shrubs graminoids and mosses cling to a blade of rock near Flat Island in the Franklin River.**

Plate 7: **Plimsoll line on a sandy bank of the Gordon River approximately 8 km below the Gordon Dam.**

Plate 8: View from the plimsoll line at 2.5 m on sandy river bank to the Gordon River 10.5 km below the dam.

Plate 9: Large cobble bank at G6, just upstream from Second Split (12 km from the dam) where the plimsoll line is approximately 3.5 m on the river bank. Evidence of past vegetation is provided by remaining dead stems of *Leptospermum riparium*.

Plate 10: Vegetated rock island immediately below First Split showing the plimsoll line at approximately 2 m.

Plate 11: ***Leptospermum riparium*** **dominated riparian vegetation on an island at base of Abel Gorge in the Gordon River, 7.4 km below the Gordon dam, showing zones:-**

0-1.5 m - comprised of mineral substrate and bare roots
1.5- 2.5 m - comprised of grasses, graminoids, herbs and shrubs scoured by water
2.5 m – a plimsoll-line
>2.5 m – surviving canopies of *L. riparium*

Plate 12: **Mineral substrate, bare roots and dead stems of *Leptospermum riparium* in zone 0-1.5 m in the riparian vegetation on an island in the Gordon River, 7.4 km below the Gordon dam.**

Plate 13: *Leptospermum riparium* with masses of adventitious roots on the lower stems.

Plate 14: *Leptospermum riparium* roots at the soil surface where they can absorb oxygen from highly oxygenated water during power station operation.

Plate 15: Loss of riparian plants below the plimsoll line on bedrock 17 km below the dam.

Plate 16: Loss of riparian plants below the plimsoll line on log debris 7.4 km below the dam.

Plate 17: Loss of riparian plants below the plimsoll line on silty substrate where a tributary creek meets the Gordon River 10.5 km below the dam. Waterlogging is most severe on fine textured substrates and may result in the death of *Leptospermum riparium*.

Plate 18: Mosses are an important component of the riparian vegetation, extending to near the water level on the banks of the Franklin River.

Plate 19: Moss communities stabilising sand which has been deposited on a log.

Plate 20: Moss growing on bedrock near the water's edge

Plate 21: A moss mound in the middle of the river channel on the leading edge of an island in the Franklin River.

Plate 22: Inundation and waterlogging in the Gordon River has killed may mosses and much of the epiphytic flora which grows on the trunks of trees at 2.5 m on the river bank exposing masses of adventitious roots which grow in the sand and silt trapped by these epiphytic communities.

Plate 23: Inundation, waterlogging and scouring by water in the Gordon River has removed the epiphytic flora which grows over the roots and on the trunks of trees, exposing bare roots and stems at 1.5 m on the river bank.

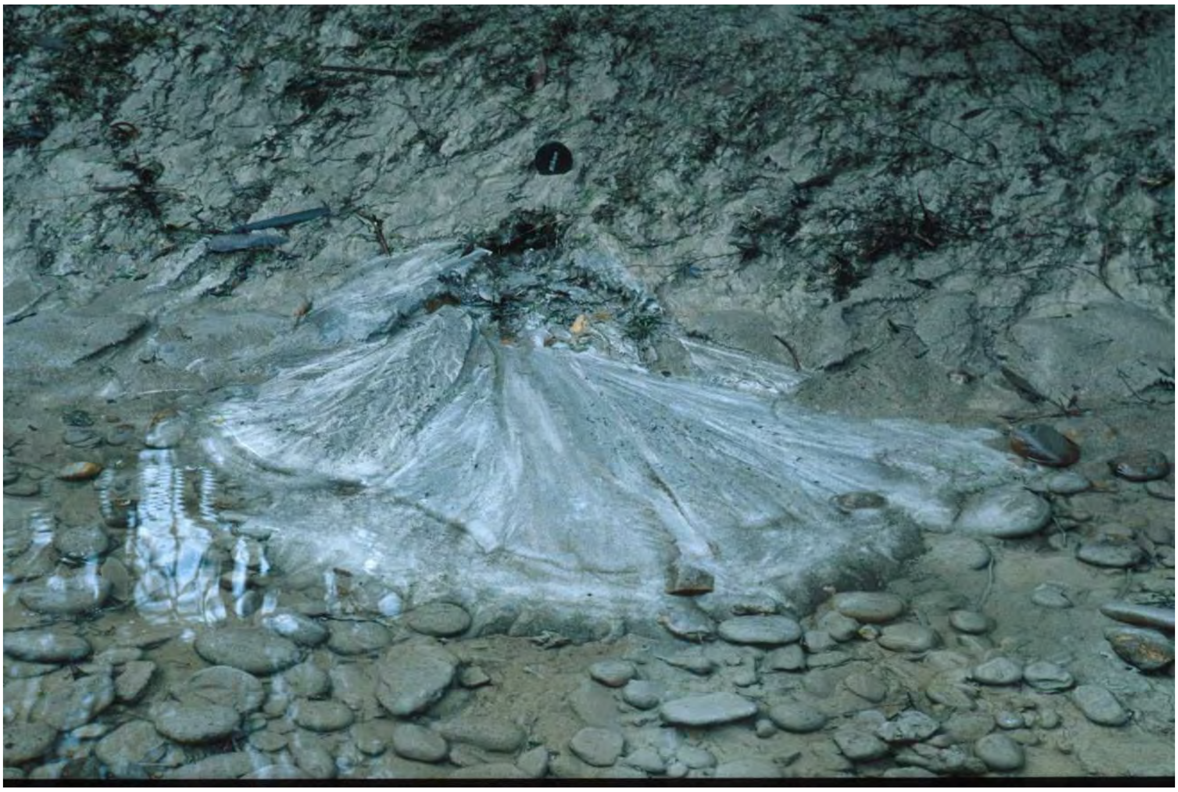


Plate 24: **Outflow of sediments from beneath the peat and root mats of vegetation on an island at the bottom of Abel Gorge in the Gordon River, 7.4 km below the Gordon dam.**

Plate 25: **Rilling in a sandbank below the root systems of *Leptospermum riparium* on an island at the bottom of Abel Gorge in the Gordon River, 7.4 km below the Gordon dam.**

Plate 26: **The undermining of roots of riparian vegetation by outflow of sediments on an island at the bottom of Abel Gorge in the Gordon River, 7.4 km below the Gordon dam.**

Plate 27: Landslip on the banks of the Gordon River.

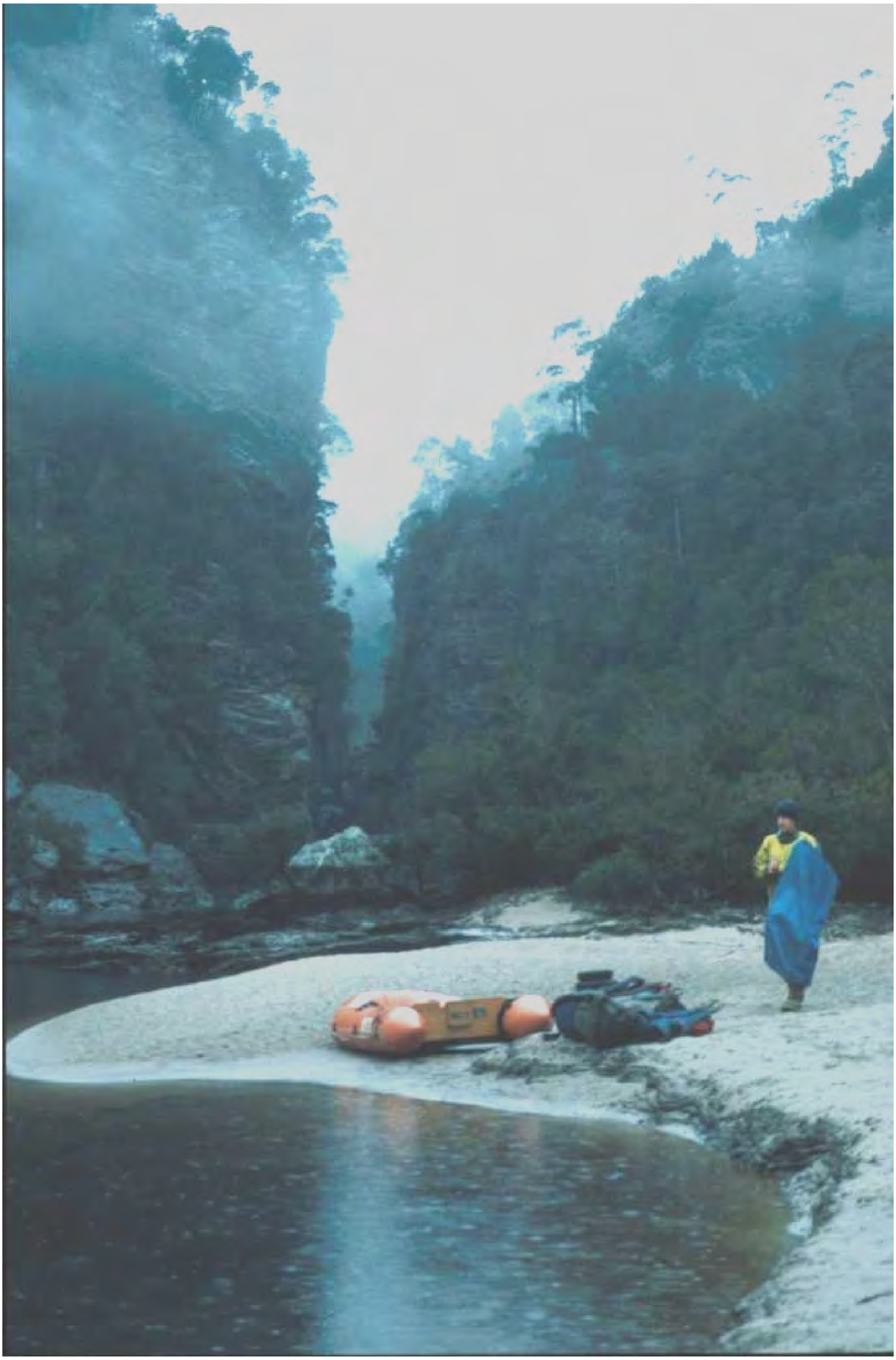


Plate 28: **A linear sand bar deposited behind a bedrock bar just below First Split, at a position in the river where flow is reduced. Sand bars of this sort are completely unvegetated**

Plate 29: **The eroded and undermined leading edge of an island of vegetation on a cobble bank at Site 71.**

Plate 30: **The eroded and undermined tail end of an island of vegetation on a cobble bank at Site 71**

Plate 31: **An island of vegetation attached to a rock platform at the top of Snake Rapids (300m below First Split) has been torn from the rock by the force of the water.**

ATTACHMENT 1

The effect of waterlogging on soils

Well-structured and well-drained soils have a complex network of air-filled pores that efficiently ventilate the root systems of plants. Waterlogging replaces the air with water, almost eliminating any gaseous exchange.

Well drained soils of adequate porosity contain about 60 litres of air for every square metre of soil. The respiration rates of roots and micro-organisms can consume as much as 3.5 to 17 litres of O_2 per metre square of soil per day. However there is generally enough gas-filled porosity in soils for diffusion along shallow concentration gradients to maintain high partial pressures of O_2 at the root. Partial pressures of 0.15 atm have been measured at 2m depth within soils supporting active plant communities in comparisons with the 0.20 atm partial pressures of O_2 in the atmosphere.

Waterlogging totally fills the pore spaces in soil with water. Diffusion rates of O_2 in water are 10 000 times slower than in air. Consequently, the oxygenated zone within waterlogged soils may only extend to within a few mm of the soil surface.

If soils become waterlogged while soil temperatures are low, low respiration rates of roots and micro-organisms may mean depletion of O_2 takes several days to weeks. However, at high temperatures this may happen within hours to days. This response is complicated by the fact that smaller amounts of O_2 can be dissolved in warm water than in cold.

Once O_2 is depleted, respiration switches from aerobic to anaerobic (alcoholic fermentation) and anaerobic micro-organisms use molecular and ionic species other than O_2 as proton acceptors. The soil then becomes chemically "reduced" and differs from aerobic soils in three respects:-

i) pH falls (soils become more acid) and there is the appearance of more organic acids, e.g. humic acid, tannic acid in soil solution,
ii) appearance of reduced molecular species, e.g. hydrogen sulphide (H_2S), and methane (CH_4) and
iii) appearance of reduced ionic species, e.g. manganese ($Mn.^{2+}$), iron (Fe^{2+}) and nitrite (NO_2^-).

There is also an effect on soil and plant nutrition. In the long term (weeks to months), the concentrations of the important macro-nutrients nitrogen (N), phosphorus (P) and potassium (K) decline in plant tissues. This is primarily due to:-

i) inhibition of ion uptake due to impaired root function,
ii) denitrification by soil microbes, i.e. the breakdown (reduction) of Nitrate (NO_3^-) to nitrogen gas (N_2) limiting the availability of nitrogen to plants, and
iii) the high concentrations of Fe^{2+} in the soil which tightly binds phosphorus (P) making it unavailable to plants.

Injury to roots

Root growth ceases once the partial pressure of O_2 in the meristematic (root tip) cells declines below 0.02 atm. Respiration can continue in loosely packed cortical cells at O_2 partial pressures as low as 0.001 atm but at these levels root tips are killed.

Although O_2 deficiency is the trigger for root injury, root tip death may be caused by one of a number of secondary effects (after Drew 1983):-

i) Toxic substances in the soil (organic acids, ionic species) produced in the reducing environment created by O_2 deficiency can directly effect root function.

ii) Toxic end products of anaerobic respiration (ethanol and acetaldehyde) may impair root function.

iii) There may be a shortage of energy and lack of respiratory substrates such as starch to fuel metabolism, repair injury and support growth of roots.

The energy supply to plant roots

The last of the points above (point iii) needs further explanation. Oxygen deficiency limits aerobic respiration (glycolysis), a biochemical pathway (Equation 1) by which starch manufactured in the leaves by photosynthesis is converted by the roots into energy (ATP) with the release of carbon dioxide (CO_2) and water (H_2O).

$$C_6H_{12}O_6 + 6O_2 \quad \text{-----} \quad 6CO_2 + 6H_2O + \text{energy (36 ATP)} \qquad (1)$$

The alternative is anaerobic respiration (alcoholic fermentation) a biochemical pathway used to extract energy from starch in the absence of oxygen. In this pathway (Equation 2) the end products are lactic acid ($C_3H_6O_3$), ethanol (C_2H_6O) and carbon dioxide, with the release of only 1/18 of the energy of glycolysis.

$$C_6H_{12}O_6 \quad \text{-----} \quad C_3H_6O_3 + C_2H_6O + CO_2 + \text{energy (2 ATP)} \qquad (2)$$

Therefore in anoxic soils where anaerobic respiration is the predominant pathway for starch metabolism in roots there is, within hours to days, a depletion of respiratory substrates (starch) and a lack of energy (ATP) to drive root growth and metabolism.

Adaptation of roots to a waterlogged environment

Some plants, however, have the capacity to adapt their root systems to an anaerobic soil environment and in these waterlogging-tolerant plants a number of morphological and anatomical changes occur under the mediation of the plant hormone ethylene. The most important of these adaptations is the production of aerenchyma, which involves a lysing of cortical parenchyma cells in the stem and root to form a continuous air channel from the base of the stem (stem hypertrophy) to the root tip, thus supplying oxygen to the root tip when the soil is anaerobic. For most plants this requires the development of a new adventitious root system (one that arises from the base of the stem). The old primary root system usually dies under anaerobic conditions.

For herbaceous plants and tree seedlings exposed to waterlogging at room temperature (20 °C) in pots the effects of waterlogging become evident after about 30 days. At this point, for waterlogging-tolerant plants, the old primary root system is dying and the new adventitious root system is still in the process of development. Therefore, there is a period of stress imposed on the plant while it develops a new root system that is adequate to service the needs of the stem and leaves for water and nutrients. Intolerant plants that are unable to adapt morphologically die rapidly from 30 days onward.

Injury to shoots

The injuries incurred by aerial parts of the plant (those not submerged) during waterlogging differ fundamentally from those of roots but are a consequence of root injury. Impaired root function leads to:-

i) insufficient supply of essential substances to the shoot (water, nutrients, phytohormones)

ii) abnormal supply of toxic substances originating in the soil or the root.

The early visual symptoms of waterlogging injury include: reduced growth, chlorosis (yellowing) of older leaves, premature leaf abscission and stunted root systems.

Physiological measurement on the leaves of waterlogged plants will reveal reduced stomatal conductance (in the early stages a direct effect of the hormone ethylene), reduced transpiration and photosynthesis and a decline in the water status, manifest as lower water potentials (see Figure 1; from Drew, 1983). Ironically, in the later stages of injury from waterlogging, damage to root systems leads to reduced water uptake and water deficits in the shoot. If the root system is killed, the shoot dies of drought. Therefore, waterlogged plants are particularly sensitive to high temperatures and dry air as this places a high evaporative stress on a root system with limited capacity to take up water.

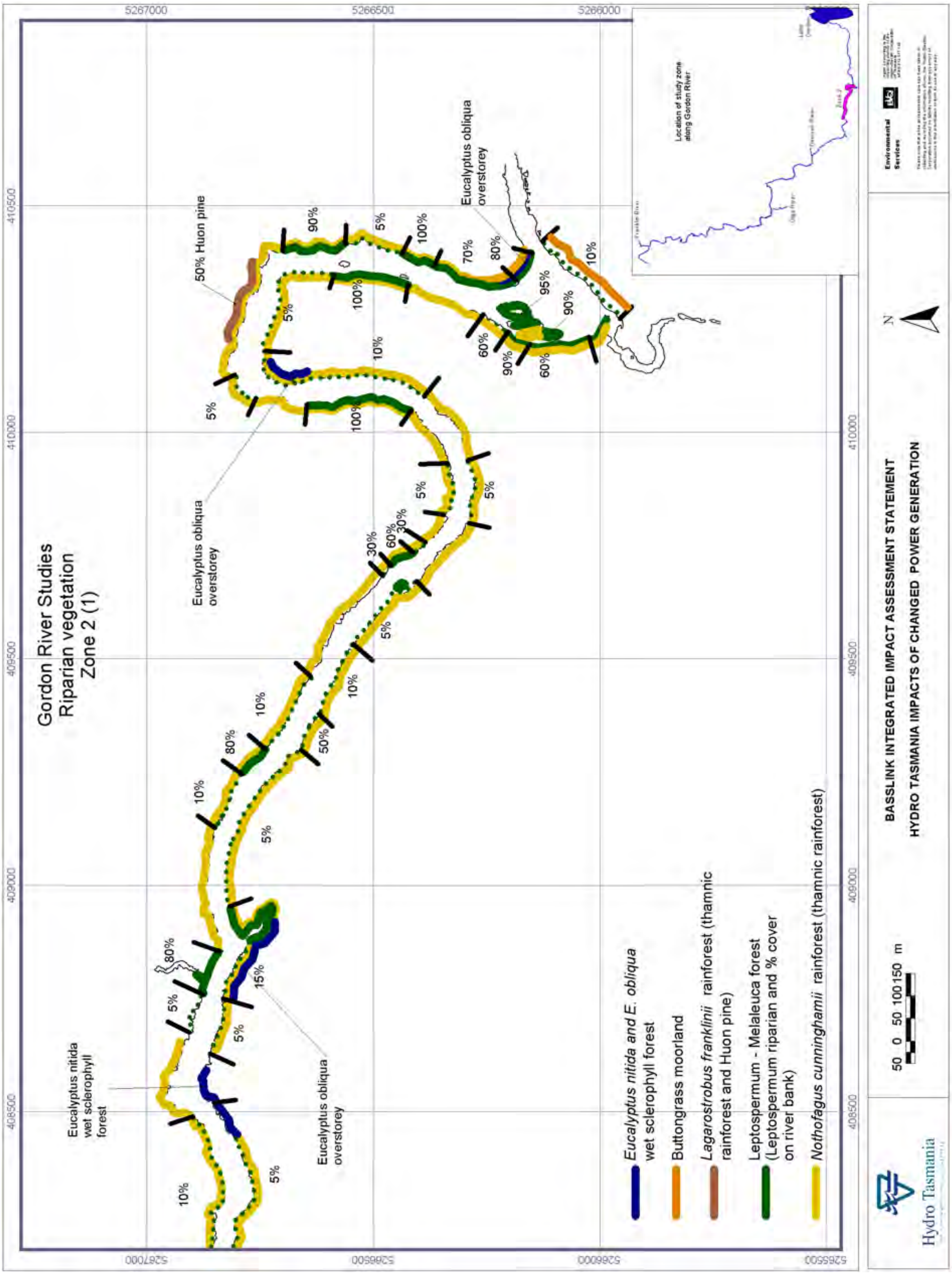
For mature trees with deep root systems growing in cold climates the rate of onset of these symptoms may be very slow. The roots may sample soil over a wide area and may also tap deep horizons in which oxygen is at higher concentrations. Cold climate reduces the demand for oxygen by plants as metabolic rates are slow. Further, the micro-organisms responsible for rapidly depleting oxygen in soils have low activity at low temperatures.

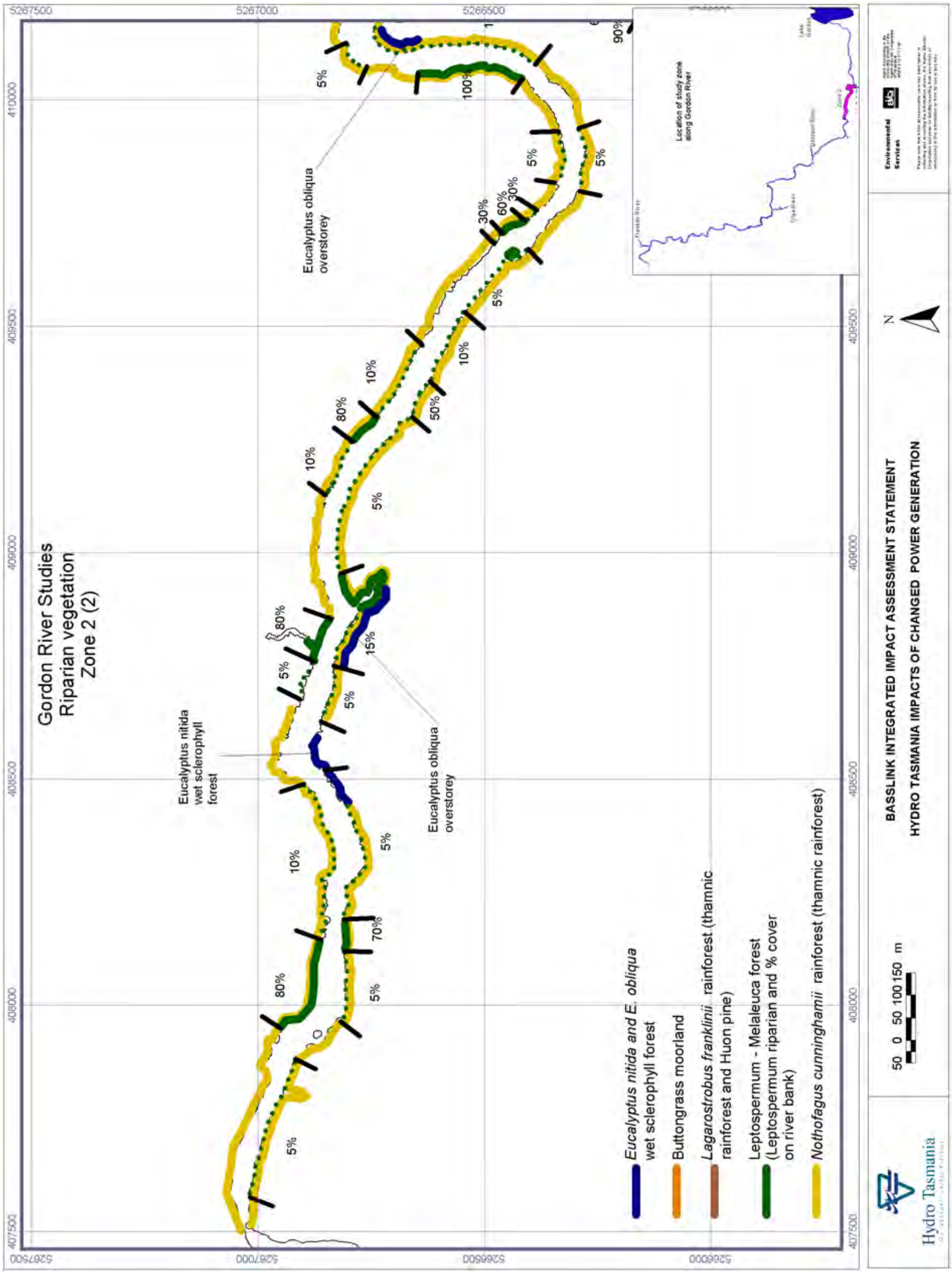
However, even the hardiest plants (those with the capacity to adapt morphologically to waterlogged conditions) cannot survive in environments that are permanently waterlogged. These adaptations provide a means for surviving temporary waterlogging only.

Where plants are entirely submerged (inundation), death is rapid as a result of inhibition of the gas exchange of leaves. Where the environment is flooded so the water submerges parts of the stem, injury may be more severe because lenticels in the hypertrophied part of the stem (the part through which air passes to aerate the root) are under water.

ATTACHMENT 2

Map of riparian plant communities in the Gordon River between the Abel Gorge and the Second Split


Gordon River Studies
Riparian vegetation
Zone 2 (1)
Eucalyptus nitida wet sclerophyll forest
Eucalyptus obliqua overstorey
Eucalyptus obliqua overstorey
Eucalyptus obliqua overstorey
50% Huon pine
Eucalyptus nitida and E. obliqua wet sclerophyll forest
Buttongrass moorland
Lagarostrobus franklinii rainforest (thamnic rainforest and Huon pine)
Leptospermum - Melaleuca forest (Leptospermum riparian and % cover on river bank)
Nothofagus cunninghamii rainforest (thamnic rainforest)
50 0 50 100 150 m
N
Location of study zone along Gordon River
BASSLINK INTEGRATED IMPACT ASSESSMENT STATEMENT
HYDRO TASMANIA IMPACTS OF CHANGED POWER GENERATION
Environmental Services
Hydro Tasmania


Gordon River Studies
Riparian vegetation
Zone 2 (2)
Eucalyptus nitida wet sclerophyll forest
Eucalyptus obliqua overstorey
Eucalyptus obliqua overstorey
Eucalyptus nitida and E. obliqua wet sclerophyll forest
Buttongrass moorland
Lagarostrobus franklinii rainforest (thamnic rainforest and Huon pine)
Leptospermum - Melaleuca forest (Leptospermum riparian and % cover on river bank)
Nothofagus cunninghamii rainforest (thamnic rainforest)
50 0 50 100 150 m
N
Location of study zone along Gordon River
BASSLINK INTEGRATED IMPACT ASSESSMENT STATEMENT
HYDRO TASMANIA IMPACTS OF CHANGED POWER GENERATION
Environmental Services
Hydro Tasmania

ATTACHMENT 3

Ordination, vector fitting and classification

Ordination

Ordination techniques are a group of methods for data reduction and exploration leading to hypothesis generation. Most simply they can be seen as a means of summarising the floristic data collected in the field, in scatter diagrams. The purpose of ordination then is to recover underlying structure in the pattern of species entries and in the process show how species are responding to prevailing environmental factors.

Ordination diagrams examine the similarity or dissimilarity of floristic composition of vegetation samples or quadrats and are expressed in graph form. Each point on the graph represents a quadrat of species data collected in the field. The distance between the points on the graph is taken as a measure of their degree of similarity or difference. Points which are close together will represent quadrats that are similar in species composition; the further apart any two points are, the more dissimilar or different the quadrats will be (Kent & Coker 1995).

Vector fitting

Relationships between floristic trends displayed in ordination diagrams and environmental variables are investigated by the technique of vector fitting. Vector fitting finds the direction across an ordination space, such that the coordinates of quadrats along a vector pointing in that direction are maximally correlated with the variable of interest (Fensham *et.al* 2000). In other words, for each environmental variable the location of the best-fitted vector in the ordination space is found. In ecological terms the question is: “is the species data responding in any systematic way to the environmental attributes?” (Belbin 1994).

The resulting ordination diagram with fitted vectors thus expresses not only patterns of variation in floristic composition but also demonstrates relationships between species and each of the environmental variables (Kent & Coker 1995).

Classification

The aim of classification is to group together a set of quadrats on the basis of their floristic composition. The end product of a classification is a set of groups derived from individuals where, ideally, every individual within each group is more similar to the other individuals in that group than to any individuals in any other group. Unlike ordination classification emphasises discontinuities rather than continuous variation in data. When classification groups are plotted in a ‘good’ ordination, however, they will often correspond to clusters in the ordination space.

The groups derived from a set of individual quadrats through classification on the basis of their floristic content are usually taken as the plant communities of the area under study (Kent & Coker 1995).