EXPERT PANEL ENVIRONMENTAL FLOW ASSESSMENT OF VARIOUS RIVERS AFFECTED BY THE SNOWY MOUNTAINS SCHEME

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Abstract

This report was produced by the Department in 1998, and has had minor editing to improve readability and re-printed to make it available to water resource managers and the public. The report presents the results of an expert panel assessment of the impacts of the Snowy Mountains Hydro Electric Scheme on the rivers of the Snowy Mountains.

This expert panel assessed the environmental impacts of the Scheme on the upper reaches of the Murray, Murrumbidgee and Snowy rivers, and provided independent advice to the Snowy Inquiry on environmental flow requirements. The Expert Panel method was chosen for this assessment because it utilised scientific expertise and the available knowledge, facilitated interaction between scientific disciplines, and provided a rapid assessment of river health.

The Panel developed recommendations for new environmental flow regimes for each of the rivers. The Panel suggested that the recommendations should be implemented in an adaptive management framework. Where necessary, recommendations were also made for improved catchment management and river remediation works. These assessments and recommendations are contained within this report.

Additionally, new information about the Snowy River System has been generated since the publication of this initial report in 1998. The new information developed by the Snowy Flow Response Monitoring and Modelling program, builds on the initial understanding of these river systems and should be considered when reading this report.

1. Introduction

1.1 GENERAL

The Snowy Mountains Hydro-electric Scheme (“Scheme”) is located mostly within Kosciuszko National Park, in the Snowy Mountains region of south-east Australia. It captures and diverts the headwaters of numerous alpine and montane streams. This study pertains to the major rivers that are harvested and/or regulated for the Scheme, and that have not previously been assessed with regard to river flows. The Snowy River below Jindabyne Dam and the Murrumbidgee River below Tantangara Dam was investigated by previous expert panels.

The Scheme captures and diverts the headwaters of 12 rivers and 71 creeks (SMA, 1993: plan diagrams). It includes 16 dams, 18 aqueducts, 19 trans-mountain tunnels, 7 power stations and 2 pumping stations [DLWC, in prep.(a)]. The Scheme can be divided into two developments: i) the Snowy-Tumut development diverts waters from the upper Murrumbidgee, Goodradigbee, Eucumbene and Tooma Rivers to the Murrumbidgee River via the Tumut River; and ii) the Snowy-Murray development diverts waters from the Snowy and Geehi Rivers to the Murray River via the Swampy Plain River. Lake Eucumbene is the main storage in the scheme, with a capacity of 4,798,300 ML. In addition to generating electricity, the Scheme is used to regulate the supply of water for irrigation in the Murrumbidgee and Murray valleys in conjunction with downstream irrigation dams.

The Scheme captures and diverts 99% of the stream flows in the Snowy Mountains (SMA, 1993). The natural flows in the affected streams are therefore greatly reduced, and in some rivers the pattern of flow has also been changed by the operation of the Scheme [DLWC, in prep.(a)]. These changes to natural stream flow have greatly impacted on the geomorphology and ecology of streams in the Snowy Mountains.

The Snowy Water Inquiry (“Inquiry”) is an initiative associated with the planned corporatisation of the Scheme, which has been agreed to by the Commonwealth, New South Wales (NSW) and Victorian Governments. Under the Terms of Reference (NSW Treasurer, 1998), the Inquiry must examine the environmental impacts of the changed water flows caused by the operation of the Scheme, and consider options available for addressing the environmental impacts. The designated area of inquiry, the “Snowy Water Area," is defined as the course of the Snowy River to the coast at Marlo, the Murray River to Lake Hume, the Tumut River to Blowering Reservoir, and the Murrumbidgee River to Burrinjuck Reservoir. The options for the designated area of inquiry include environmental flows, improved catchment management, and river remediation works.

This expert panel assessment was undertaken to assess the environmental impacts of the Scheme on various rivers in the Snowy Mountains, and provide independent advice to the Inquiry on environmental flow requirements. The Expert Panel method was chosen for this assessment because it utilises scientific expertise and best current knowledge, facilitates interaction between Panel members of different disciplines, and provides a rapid assessment of river health (Swales and Harris, 1995; Banks *et al*., 1997). The limitations of the Expert Panel method are fully realised, and are accepted in the context of the scope of the study, which was governed by the brief time available to prepare for the Inquiry, and by the financial resources available for the assessment. The method is not intended to provide a comprehensive assessment of flow regulation impacts. A comprehensive assessment would require a much longer term study with greater financial resources. Rather, the method provides preliminary recommendations to be used in an adaptive water management process requiring ongoing monitoring over an extended period.

Panel members were selected for their expertise in hydrology, geomorphology, and aquatic ecology. After an initial meeting for a preliminary briefing, members of the Panel conducted a site selection field trip on 18 and 19 December 1997. The Panel's assessment of these sites was conducted from 11 to 15 January 1998. Information available to the Panel prior to this assessment, and/or at subsequent workshops, included:

- previous environmental flow assessments of rivers in the Snowy Mountains area (e.g. Upper Murrumbidgee River and Snowy River below Jindabyne Dam expert panel reports);
- other relevant studies in the area (e.g. water quality, macroinvertebrate and amphibian surveys);
- the wider scientific literature;
- historic hydrological information for the Snowy Water Area [DLWC, in prep.(a)]; and
- information on Snowy Mountains Scheme structures and operation (SMA, 1993).

On the basis of all this information, together with the findings of the site assessments, the Panel formed recommendations for an environmental flow regime that should be implemented in an adaptive management framework. Where necessary, recommendations were also made for improved catchment management and river remediation works such as Willow removal.

The scope of this preliminary study was limited by available financial resources and a short time-frame, therefore the Panel did not conduct quantitative or benchmarking studies of the environmental impacts of the Scheme. Assessment of the economic, social, agricultural and heritage impacts of the Scheme were also beyond the scope of this study. These issues require detailed investigation for the Inquiry along with further quantification of the environmental impacts of the Scheme. Furthermore, it is recognised that the economic, social and agricultural impacts of the recommended environmental flows must be investigated prior to implementation, and this will be undertaken by the Snowy Water Inquiry.

1.2 ENVIRONMENTAL FLOWS AND RIVER REHABILITATION

Erskine et al. (1999) proposed an environmental flow strategy for the Snowy River below Jindabyne Dam, and maintained that the rehabilitation of the regulated rivers in the Snowy Mountains requires the implementation of a "restoration protocol" (Stanford *et al*., 1996) or an "ecologically acceptable flow regime" (Petts, 1996) which will reverse the recent geo-ecological changes brought about by flow regulation. The Stanford *et al.* (1996) general protocol for the restoration of regulated rivers aims to effect recovery from the present degraded state by:

- restoring floods which reconnect and periodically reconfigure the channel and associated habitats;
- stabilising base flows to revitalise food-webs in shallow water habitats; reconstituting seasonal temperature patterns;
- maximising fish passage past dams;
- practising natural habitat restoration and maintenance;
- installing artificial in-stream structures; and
- practising adaptive ecosystem management.

Petts (1996) concluded that holistic river management requires the derivation of an "*ecologically acceptable flow regime*". Such a flow regime can be derived according to the following four steps:

- *ecological assessments* should be completed based on the classification of the river into reaches, the specification of a primary ecological objective for each reach and the setting of ecological targets;
- *benchmark flows* should be set to meet the ecological targets;
- *ecologically acceptable hydrographs* should be derived to determine acceptable frequencies and durations of the benchmark flows; and
- *an ecologically acceptable flow duration curve* should then be determined by combining the ecologically acceptable hydrographs.

Erskine *et al*. (1999) concluded that the essential components of a new environmental flow strategy (Petts, 1996; Stanford *et al*., 1996) should include the determination of at least:

- *Channel maintenance flows* which form and hence maintain the size, shape and bedforms of the channel and re-establish physical and ecological connectivity. This is a geomorphic process that has been virtually ignored by river managers in Australia;

- *Habitat maintenance flows* which are flushing flows to remove accumulating silt and organic detritus that form fine-grained sediment laminae (Droppo and Stone, 1994);

- *Minimum acceptable flows* to sustain the aquatic and semi-aquatic ecosystems within the river corridor;

- *Optimum flows* to provide the maximum habitat for target species; and the *Natural seasonal flow distribution*.

This Expert Panel assessment of rivers in the Snowy Mountains applied the approach of Petts (1996) to derive an environmental flow regime based on the essential components for the Snowy River below Jindabyne (Erskine *et al*., 1999), with some minor modifications. The essential flow components for rivers in the Snowy Mountains are:

- *Channel maintenance flows* (Erskine *et al.,* 1999)

- *Flushing flows* (the “Habitat maintenance flows” of Erskine *et al*., 1999); and

- *Minimum habitat utilisation flows* incorporating *natural seasonal flow patterns* (the minimum flow that will allow aquatic fauna to utilise an appropriate amount of habitat for survival and for completion of their life cycles.

As noted by Erskine *et al*. (1999), the use of adaptive ecosystem management (Stanford *et al*., 1996) would ensure that feedback occurs between operational flows and licence conditions. This is an iterative, step-wise approach where science-based management actions are effectively monitored and evaluated with adaptive revision of actions based on the monitoring information.

1.3 ADAPTIVE MANAGEMENT

It is critical that any environmental flow management strategy for rivers in the Snowy Mountains be adaptive. The five main reasons for this are:

- the difficulties of predicting environmental flow requirements;
- the evolutionary nature of river rehabilitation, e.g. requirements in 10 years time may differ from current requirements if the river is responding to environmental flows;
- uncertainty regarding longer term climate changes, and their impacts on river flow requirements;
- uncertainty over longer term policy or environmental objectives (for example, there may be a need to adapt flows to favour particular threatened species); and
- our evolving understanding of environmental processes.

The allocation of environmental flows is in its early days in Australia, and the attempt to determine river flows that provide for the vast and complex interactions in riverine ecosystems is beset by a lack of quantitative information on the interactions between flow and biological requirements. This is particularly pertinent to the Snowy Mountains area where the magnitude of flows have been greatly reduced in a large number of streams over an extensive and ecologically unique area, where the seasonal variability and timing of flows have been dramatically altered, and where other significant changes have also taken place (see Chapters 4, 5 and Appendix 1.). Few studies have been undertaken on the effects of these flow changes on rivers in the Snowy Mountains (see Banks *et al.,* 1996, 1997). Given the short time frame to prepare for the Snowy Water Inquiry, intensive quantitative research was not possible, and it is imperative that this be undertaken over the longer term in an adaptive management framework. The magnitude of the alterations to the flow regime in such a large number of rivers, in an ecologically unique environment, and with such a paucity of research and monitoring, is a situation which occurs nowhere else in mainland Australia (it does also occur in the Tasmanian Central Plateau). This necessitates long term quantitative research and application of knowledge gained from the research.

The Panel's recommendations, then, are a set of hypotheses on necessary environmental flow allocations based on the best available scientific knowledge. They must be implemented and monitored for their effectiveness in restoring ecological integrity. The following is a suggested process for adaptive management:

- baseline information will need to be collected, such as the exercise currently underway in the Snowy River below Jindabyne Dam [DLWC, in prep.(b)];
- the Panel's recommendations need to be translated into daily operational targets or rules and then implemented;
- physical, chemical and biological responses to these flows must be quantitatively monitored over an extended time period;
- the effectiveness of the environmental flows in re-establishing ecological integrity must be assessed; and
- if they are deemed inadequate or excessive for ecological integrity based on the monitoring surveys, the environmental flows must then be modified accordingly. This includes inter- and intra-annual variations to flow regimes.

An adaptive management approach is a complex process. This is because of the complex and little understood interactions between natural flow regime components (magnitude, timing, frequency, duration, and rate of change) and the regulatory factors which control ecological integrity (water quality, habitat, biotic interactions, and energy sources). Therefore, long time scales and intensive monitoring are required to measure riverine environmental responses to environmental flows.

In pristine rivers, flow regimes are variable to various degrees. Ecosystems are adapted to this natural variability. The only way to ensure that flows provide for all of the essential physical, chemical and biological processes in the aquatic and riparian ecosystems, and any dependent terrestrial processes, is to provide 100 % of the natural flows to the river. Given the purpose and operation of the Snowy Mountains Scheme, it is not possible to provide all components of the natural flow regime, particularly flow volumes, in many of the main rivers. However, it may be possible in some of the regulated tributaries of the main rivers. The impracticality of returning natural flows to most of the rivers in the Snowy Mountains means that all of the flow recommendations in this report are a compromise and have a risk of not returning some or all essential components of the natural flow regime. On the basis of this situation, adaptive management is imperative.

Adaptive management of environmental river flows is a principle of the NSW Water Reforms (EPA, 1997a,b) and a recommendation from other environmental flow assessments (Thoms *et al.*, 1996; Banks *et al.*, 1996, 1997). Figure 1 shows a process for adaptive management which could be used in the implementation of the Panel's environmental flow recommendations for rivers in the Snowy Mountains.

Figure 1. Possible process for adaptive management of environmental flows for rivers in the Snowy Mountains. Source: Modified from Bishop (1996).

1. SNOWY MOUNTAINS EXPERT PANEL
- held preliminary workshop with available information
- conducted preliminary field inspection and site selection
- conducted field assessment of 21 sites
- held workshops with available hydrologic data to reach consensus on hypothesised environmental flow requirements (flow recommendations)
- made other land and integrated catchment management recommendations
- produced report for consideration by Snowy Water Inquiry

2. SNOWY WATER INQUIRY
- Investigates economic and social aspects of implementing recommended flows
- Modifies flow regime on the basis of more detailed information

3. RESEARCHERS
- undertake benchmarking surveys of river reaches to determine the existing state of the river with respect to: geomorphology (including sediment size and distribution), water quality, macrophytes, algae, macroinvertebrates, fish, amphibians, riparian vegetation

4. SNOWY SCIENTIFIC COMMITTEE
- develop release or operational rules for allocated environmental flows on an annual basis

5. SNOWY HYDRO LTD
- implement flow recommendations as interim flow regime for 5 years

6. RESEARCHERS
On an annual basis:
- undertake monitoring of all variables surveyed during benchmarking survey (annually or seasonally depending on variable) to establish the effect of the interim flow regime on the river structure and ecology

7. SNOWY SCIENTIFIC COMMITTEE and RESEARCHERS
On an annual basis:
- interpret monitoring results, in the light of benchmarking survey results, to assess effects of environmental flows on these variables
- recommend modifications to environmental flows, if necessary
- recommend modifications to monitoring program, if necessary

8. SNOWY HYDRO LTD
- implement new flow recommendations (if modified) for the remainder of the five year period, or modify as advised

9. SNOWY SCIENTIFIC COMMITTEE and RESEARCHERS
- continue monitoring, review and modification of flow regime
- major review every 5 years
- recommend variations in environmental flow allocations

10. NSW GOVERNMENT
- alter flow allocations on the basis of recommendations of the Snowy Scientific Committee

1.4 ADVANTAGES AND LIMITATIONS OF THE EXPERT PANEL METHOD FOR ENVIRONMENTAL FLOW ASSESSMENT

The Expert Panel method was developed by NSW Fisheries to provide a method for determining the flow requirements of freshwater fish that requires little field data or financial resources, and which is suitable for the variable flow conditions of Australian Rivers (Swales and Harris, 1995). The method was first tested in the Peel River (Swales *et al*., 1994), and has since been used for assessing environmental flow requirements on regulated rivers in the Murray-Darling basin in NSW (Swales and Harris, 1995), the Barwon Darling River (Thoms *et al*., 1996), the Snowy River below Jindabyne Dam (Banks et al., 1996), the upper and lower Murrumbidgee River (Banks et al., 1997; Briggs et al., in prep), the upper Murray River (Thoms *et al*., in prep.). The advantages and limitations of the Expert Panel method have been previously summarised by Banks *et al.* (1997: 5-6) as:

"…The method was tested in the Peel River, with an Expert Panel assessing flows for fish, macroinvertebrates and geomorphology (Swales *et al*., 1994), and the method was compared to the flow duration curve and physical habitat analysis methods. The conclusion was drawn that each method had different advantages and limitations, so the choice of method would depend on time and resources (Swales *et al*., 1994)."

"Richardson (1986) noted the need for rapid and simple methods for conducting preliminary investigations for environmental flow studies in Australia, and an Expert Panel assessment is one such method. For example, an Expert Panel environmental flow assessment of the Snowy River (Snowy River Expert Panel, 1996) was undertaken as a preliminary investigation of the environmental flow needs of the regulated Snowy River. The report aimed to provide a starting point for the provision of environmental flows within an ongoing adaptive management framework, and recommended a 6-part research program for environmental flows for the river. A recent review of both the Expert Panel process and the Snowy River assessment noted that the Expert Panel method can reasonably be used as a preliminary assessment but should not be relied on as the sole or primary basis for determining environmental flows (Centre for Water Policy Research, 1996). Similarly, Swales and Harris (1995) concluded that the Expert Panel method can be usefully employed in a process which utilises various techniques for assessing environmental flow needs."

"One of the key strengths of the Expert Panel process is the synergy gained from the interaction across scientific disciplines, and between scientists and river managers (Snowy River Expert Panel, 1996). The Expert Panel method is inexpensive in comparison to other environmental flow assessment methods, requires few field measurements and little time, and can be applied to a wide variety of problems (Swales and Harris, 1995; Centre for Water Policy Research, 1996). The method is mostly qualitative, which necessitates subsequent surveys and implementation of recommendations within a framework of adaptive management. A practical constraint of the method is that an Expert Panel assessment may be conducted at a limited number of sites, which are selected to be representative of sections or reaches of the river. The Expert Panel does not assess the social and economic costs and benefits of environmental flows, but relies on the assessment of these issues being conducted with the information derived from the panel. The Centre for Water Policy Research (1996) noted that the method may be limited by the degree of expertise and by human behavioural factors such as judgements of the panel members, and values which may influence the panel's recommendations."

"A common criticism of the Expert Panel method is that the recommendations arising from the study are based on a brief view of the system at one point in time, whereas the parameters assessed are likely to vary in response to seasonality and other environmental factors...."

In the present study, several of the experts have been conducting research on geomorphology and ecology in the Snowy Mountains for over a decade, and this accumulated experience is integral to the Panel's assessment. Furthermore,

"...it is reasonable to assume that specialists in these parameters would be aware of this variability and that the current state of the river will reflect, to some degree, seasonal variability and longer term changes to parameters such as the flow regime. Seasonal variability of flow and other parameters can validly be addressed within an Expert Panel assessment (Snowy River Expert Panel, 1996) where assumptions and recommendations are based on the importance of natural variability to the riverine ecology and are supported by appropriate ecological monitoring upon implementation."

"Deficiencies in the current environmental flow research and methods should not inhibit action being taken to protect river ecosystem health (Fitzgerald et al., undated) nor postpone the development of water allocation strategies (Arthington *et al*., 1992a). This is consistent with the Precautionary Principle, which is defined as: "...where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation..." (National Strategy for Ecologically Sustainable Development, 1992)."

"The Expert Panel method provides direct communication between experts in different disciplines, and between experts and river managers (Centre for Water Policy Research, 1996), and is therefore a useful method for collaborative decisions about the management of riverine ecosystems (Swales *et al*., 1994). The determination of preliminary environmental flows from an Expert Panel, or other appropriate assessment method, should not be hindered by perceived limitations of the method, provided that the methods limitations are recognised and that flow management is progressed within an adaptive framework with a commitment to ongoing research, monitoring and review. This is consistent with the framework being progressed within NSW for the setting of River Flow Objectives, which acknowledges the desirability in some circumstances of the use of rapid assessment techniques, within the context of a longer term planning and management framework…"

1.5 AIMS OF THIS STUDY

The specific aims of this study are:

- Undertake a rapid appraisal of the environmental condition of rivers affected by the Snowy Mountains Scheme, using the best information currently available.
- Make an informed, qualitative field assessment of the impacts of flow regulation on the geomorphology, fish, macroinvertebrates, and amphibians of the affected rivers and river reaches.
- Define the important components of an environmental flow regime for each reach.
- Develop recommendations for an environmental flow regime for each river and/or other management or remediation options, where suitable hydrologic and/or other information is available.

2. Study area

2.1 TOPOGRAPHY

The Snowy Mountains are located on an elevated plateau and contain the highest elevations in Australia. The plateau is generally of undulating topography but has deeply dissected river valleys. The eastern slopes rise gradually from foothills, while the western slopes rise very steeply.

2.2 CLIMATE

The Snowy Mountains have an alpine climate. Mean annual precipitation ranges from 600 mm on the outer periphery to 3800 mm on the top of the main range, or 587mm at Jindabyne to 1859 mm at Charlottes Pass [DLWC, in prep.(a): Table 5]. The upper Snowy River and sections of the Tooma and Geehi Rivers have the highest mean annual rainfall (1600 – 1700 mm), while the upper Eucumbene and Murrumbidgee Rivers receive around 1100-1200 mm [DLWC, in prep.(a): Fig.7]. Snow occurs during winter and spring, with snowmelt beginning in spring and lasting for up to four months [DLWC, in prep.(a)]. Heavy rain, and snow at elevations above 1500 m, occurs on the western slopes in winter and spring, while the eastern slopes are in the rainshadow area and have lower precipitation. Summer and autumn are drier, with some thunderstorms occurring.

Temperatures in the Snowy Mountains are cool to cold because of the elevation of the mountains, and reach the coldest temperatures experienced in Australia. The temperature can fall to below zero at any time of year. A temperature of –22°C has been recorded in winter at Charlottes Pass (Bureau of Meteorology, 1991). Temperatures at Thredbo are commonly in the range of –5°C to 0°C in July, with a minimum of -15°C and a maximum of 12.4°C. Temperatures in February at Thredbo are commonly in the range of 7°C to 16°C, with a minimum of -8°C and a maximum of 27°C (Bureau of Meteorology, 1991).

2.3 GEOLOGY

The geology of the Snowy Mountains is largely composed of intrusive granite and granitic gneiss, with highly folded sedimentary and metamorphosed sedimentary rocks underlying most of the remaining areas (Wyborn *et al*., 1990). The original sediments were laid down under marine conditions about 450 million years ago, and have been metamorphosed by folding and granite intrusions to form siltstone, sandstone, quartzite, shale, slate, phyllite or schist, chert, andesitic lava and tuff (Costin, 1972; Colhoun and Peterson, 1986; Wyborn *et al.,* 1990). There are two large masses of cavernous limestone in the north-west area. Remnants of previously extensive basalt lava flows cap some of the highest areas. Glacial moraines occur near Mt Kosciuszko, from minor glacial activity 30,000 to 10,000 years ago (Galloway, 1963). The Snowy Mountains are traversed by faults of varying age, and minor earthquake activity continues.

2.4 VEGETATION

The vegetation of the Snowy Mountains is comprised of four floristic zones, these being alpine, subalpine, montane and tableland communities. The distribution of these zones are determined by variation in altitude, exposure, soil type and depth, and rainfall. The characteristics of these zones, and of riparian areas, are described below.

2.4.1 Alpine

Alpine areas (above 1850 metres) are dominated by tall alpine herbfields [Silver Snow Daisy - Snow Grass (*Celmisia-Poa*) alliance] and heathland communities. Some of the dominant plants in tall alpine herbfields are the Silver Snow Daisy, Billy Button (*Craspedia* sp.), Buttercup (*Ranuculus* sp.), herbs belonging to the genera *Chionogentias, Leucochrysum, Brachycome*, and *Senecio*, with the grasses and sedges Wallaby Grass (*Danthonia* sp.), Snowgrass (*Poa* sp.), Sedge (*Carex* sp.) and the genera *Chionochloa.* Other smaller communities occur where the growth of tall herbfields are limited by temperature, drainage, soil moisture and aspect. These include sod tussock grasslands, fens and bogs and the rare communities of short alpine herbfield, windswept feldmark and snowpatch feldmark that occur in the areas most difficult for plant growth (NPWS, 1988).

In the alpine area, sod tussock grassland replaces tall alpine herbfield in moist flat valley bottoms or sloping valley sides. This community also occurs in sub-alpine areas (between 1400 and 1850 metres) in frost hollows. Here it replaces sub-alpine woodlands in valley bottoms, where cold air drainage at night produces low temperatures that limit tree growth. This community is dominated by Snowgrass and Wallaby Grass. Sphagnum Moss (*Sphagnum* sp.) bog communities occur where the groundwater meets the ground surface, and *Carex* sp. fen communities on permanent watercourses or associated with bog communities (NPWS, 1988). The three vegetation associations that have the most limited distribution in the alpine area are short alpine herbfield, windswept feldmark and snowpatch feldmark. Short alpine herbfield grows below snow drifts and is dominated by a specialised ground hugging community of White Purslane (*Neopaxia australasica*) and Star Plantain (*Plantago meulleri*), and includes unique species such as Marsh Marigold (*Caltha introloba*) which commences flowering under snow cover (NPWS, 1988).

2.4.2 Subalpine

Subalpine areas (1400-1850m) are dominated by Snow Gum (*Eucalyptus pauciflora*) and associated alliances. Another Eucalypt species referred to as a Snow Gum is *E. niphophila,* which occurs at the upper limit of the treeline. Snow Gums *(E. pauciflora)* occur in association with Manna or Ribbon Gum (*Eucalyptus viminalis*), Candlebark (*E. rubida*), Tingaringy Gum (*E. glaucescens*), Black Sally (*E. stellulata*) and other Eucalyptus species. These forests have a shrub understory of heath vegetation. A number of species occur in the understory, including Leafy Bossia (*Bossiaea foliosa*), Yellow Kunzea (*Kunzea muelleri*), Thyme Heath (*Epacris serpyllifolia*), Alpine Grevillea (*Grevillea australis*), *Olearia* sp., Shaggy-pea (*Oxylobium* sp.) *Xerophila tasmanica* and many others. Of significance is the endemic understory species Ovate Phebalium (*Phebalium ovatifolium*), and the very slow growing Mountain Plum Pine *Podocarpus lawrencei*.

2.4.3 Montane

The Montane area occurs between 1100 and 1400 metres. Two main forest types occur in the Montane zone. These are tall open forest and Montane mixed forest. Tall open forest occurs in cool, moist areas. In particular aspect and altitudinal situations, Alpine Ash (*Eucalyptus delegatensis*) is dominant, while in other areas the dominant species may be Manna or Ribbon Gum, or Mountain Gum (*E. dalrympleana*) with associated occurrences of Southern Blue Gum (*E. bicostata*), Brown Barrel (*E. fastigata*) and others. At lower elevations, Montane mixed forests occur. The exposed western aspects are generally dominated by forests of Narrow-leaved Peppermint (*E. radiata*), Manna or Ribbon Gum and Candlebark Gum associations, with understoreys in the wetter areas of ferns, Blanket Leaf (*Bedfordia arborescens*) and Blackwood (*Acacia melanoxylon*), and some cool temperate rainforest gullies (NPWS, 1988).

2.4.4 Tableland

Tableland areas (below 1100 metres) are dominated by Eucalyptus woodlands. Very low rainfall occurs on the lower area on the eastern side of the Snowy Mountains main range. The association of Native Cypress Pine (*Callistris* sp.) and White Box (*Eucalyptus albens*) occurs on the dry, exposed slopes in this area. Other species that occur in this area are Yellow Box (*E. melliodora*), Blakely's Red Gum (*E. blakelyi*) and Candlebark. Mountain Gum and Manna or Ribbon Gum occur at higher altitudes on moist sites, while Broad-leaved (*E. dives*) and Narrow-leaved Peppermint become dominant on drier areas (NPWS, 1988).

2.4.5 Riparian

Water dependent riparian vegetation communities are widespread throughout Kosciuszko National Park, but generally only occur in lower elevation areas (eg. the Snowy River below Jindabyne Dam). The streams in the higher elevation areas of the Snowy Mountains are fast flowing and deeply incised, therefore generally have not provided a large area for riparian vegetation to develop. The species that are present along these streams are generally composed of species that occur in the understorey of adjacent vegetation communities. There are, however, some species that consistently occur in this type of habitat. Tea-tree (Leptospermum) can dominate riparian vegetation. Woolly Tea-tree (*Leptospermum lanigerum*), Mountain Tea-tree (*L. myrlifolium*) and Yellow Tea-tree (*L. polyalifolium* subsp. *polyalifolium*) all occur along streamsides. However, these species are not exclusively riparian and also occur in other moist areas. Other species that are generally associated with riparian vegetation include Mountain Correa (*Correa lawrenciana*), Burgan (*Kunzea ericoides*) and Bottle-brushes (*Callistemon* sp.). Exotic species have invaded some riparian areas, such as Willows (*Salix* sp.) and Blackberries (*Rubus* sp.). The riparian vegetation of the Tooma River floodplain has mostly been removed, however some River Red Gums (*Eucalyptus camaldulensis*) remain.

The endangered Leafy Anchor Plant (*Discaria nitida*) is one true riparian species in the Snowy Mountains, its distribution being associated with permanent water courses. It occurs on the Eucumbene, Little Thredbo and Gungarlin Rivers, and also along Racehorse, Sawpit and Cave Creeks. The rare plant Forest Bertya (Bertya findlayi) is associated with riparian vegetation.

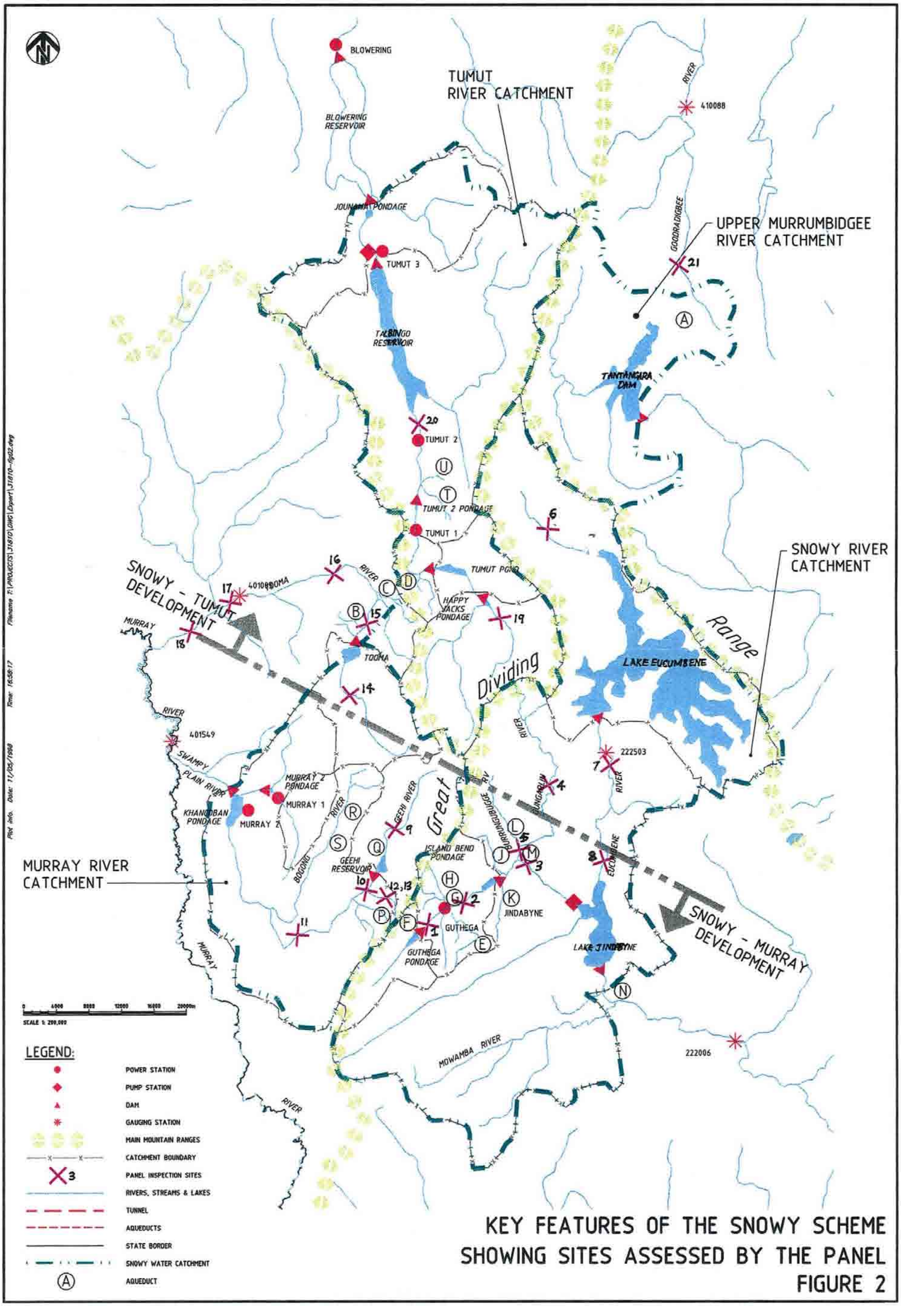
2.5 STREAM FLOWS

Stream hydrology for the study area is briefly outlined in the river reach summaries in Chapter 5, and based largely on the data in DLWC [in prep.(a)] with some supplementary information provided by the Snowy Mountains Hydro-Electric Authority and by the Panel hydrologist.

2.6 SNOWY MOUNTAINS SCHEME

Scheme structures and operation are briefly described in the introduction, and summarised for each river reach in Chapter 5. For a more detailed description of the Scheme operation, refer to SMA (1993).

Figure 2. Key features of the Snowy Scheme showing sites assessed by the Panel.



3. Assessment method and basis of recommendations

3.1 STUDY OBJECTIVES

The specific objectives of the study were to:

1) Use the Snowy River Bench-Marking and any other available information to consider the principles and recommendations of the Snowy River below Jindabyne Expert Panel Report (Banks *et al.*, 1996).

2) On the basis of the above review, consider the flow and ecological issues likely to be of importance to the rivers in the Snowy Mountains that are affected by the Scheme, and consider the field information needed to verify the importance of those issues.

3) Tabulate the above information into a format suitable for use in rapid field assessment.

4) Undertake a preliminary field assessment to define the reaches on the basis of geomorphological characteristics, and select sites for field assessment which are representative of the whole reach.

5) Undertake a field assessment of the condition of the geomorphology, fish, macroinvertebrates, and amphibians of the rivers in the Snowy Mountains.

6) Based on the assessment and other information, define the important components of an environmental flow regime and develop flow or other management recommendations.

7) Finalise the flow and management options at subsequent meetings.

8) Produce a report which describes the current geomorphological and ecological condition of the rivers in the Snowy Mountains, the impacts of the Scheme, and the options and recommendations for the environmental flow regime and other management options.

3.2 THE PANEL

As stressed by Cooksey (1996), it is essential to obtain the “right” experts for an expert panel assessment. The possible areas of expertise which were considered appropriate for the Snowy Mountains were:

- Hydrology*
- Fluvial geomorphology*
- Macroinvertebrate ecology*

- Riparian vegetation ecology
- Frog ecology*
- Algae and macrophyte ecology
- Fish ecology*
- Water quality
- Semi-aquatic and terrestrial animals such as mammals, reptiles and monotremes.

The number of people able to attend the assessment was limited by financial resources and the physical limitation of load in the two helicopters used for the field assessment. Therefore, only panel members with expertise in the above areas marked by (*) were selected for this assessment. These people were deemed to have sufficient knowledge of the other ecosystem components to make a general assessment of the impacts of flow regulation, based on their experience in river ecology (see below).

The criteria deemed important for selecting the right experts were:

- long association with the Snowy Mountains area;
- preferably, at least 10 years experience in a broad range of aspects of their field (to provide the breadth of experience that provide the diversity of an expert's knowledge base and is integral to their judgement and intuitive thinking);
- extensive field experience, as well as theoretical understanding and a knowledge of current research;
- preferably, experience in multi-disciplinary and rapid appraisal projects.

The experts selected are:

Hydrology:	Mr. Ian Varley
Fluvial Geomorphology:	Dr Wayne Erskine
Macroinvertebrate Ecology:	Prof. P. (Sam) Lake
Fish Ecology:	Dr. John Harris
Frog Ecology:	Mr. Graeme Gillespie

3.3 PRE-ASSESSMENT WORKSHOP (OBJECTIVES 1, 2, 3)

The Panel's first meeting was held on 8th December 1997. The composition of the Panel and the terms of the brief were confirmed. The process for the study was discussed at length, including the site selection and field assessment processes. The overall process and principles of the study were considered in relation to past Expert Panel exercises and the principles and processes of the NSW Water Reform (EPA, 1997a,b). The panel also reviewed available information such as previous studies and a preliminary review of the effects of the Scheme on the hydrology of streams in the Snowy Water Area [DLWC, in prep.(a)]. Preliminary information available from the Snowy Flow Response Monitoring and Modelling project [DLWC, in prep.(b)] quantified the observations of the Expert Panel assessment of the Snowy River below Jindabyne Dam (Banks *et al*., 1996).

Prior to the meeting, the components of the flow regime that were likely to be of most environmental importance were considered in relation to the environmental flow assessments of the Snowy River below Jindabyne (Banks *et al*., 1996), the Upper Murrumbidgee River (Banks *et al.,* 1997), and the preliminary hydrologic data. These flow components were tabulated for use in the field assessment. The field assessment tables were refined during the first Panel meeting and further refined in the first post-assessment workshop, to better reflect the important components of an environmental flow regime for the rivers of the Snowy Mountains.

3.4 SITE SELECTION (OBJECTIVE 4)

A spatial context is required for both the discussion in the report and the specification of environmental flows (Petts, 1996). This context can be provided by the identification and definition of river reaches. According to Kellerhals *et al*. (1976), river reaches are homogeneous lengths of channel within which hydrological, geological, and adjacent catchment surface conditions are sufficiently constant so that a uniform channel morphology is produced. The criteria used to define these reaches include channel pattern, cross-sectional form, type of channel bars, lateral and vertical confinement by bedrock or by other erosion-resistant materials, slope, bed-material size, etc (Kellerhals *et al.*, 1976; Rosgen, 1994). Reaches are identified by interpretation of vertical air photographs and topographic maps, aerial reconnaissance and field inspections. Erskine (1996b) and Erskine *et al*. (1999) have defined the channel reaches on the Snowy River below Jindabyne Dam and Erskine (1997b) has defined the channel reaches on the upper Murrumbidgee River below Tantangara Dam.

The field work was undertaken on 18th and 19th December 1997. An “unregulated” site was usually selected upstream of each dam, which was as comparable as possible in terms of channel morphology to the “regulated” sites downstream of each dam. The unregulated sites are comparisons rather than control sites because it was *impossible* to find unregulated sites which were identical to the regulated sites. There are virtually no unregulated accessible river reaches in the Snowy Mountains of the same stream order/magnitude, catchment area or stream length as the regulated sites because of the spatial extent of flow regulation associated with the Snowy Mountains Hydro-Electric Scheme. The purpose of the comparison sites was to indicate the hydrological, geomorphological, sedimentological, ecological, biological and botanical characteristics of unregulated rivers, allowing for the barrier effect of the downstream dam. Many river reaches were so steep as to limit access to the river by either helicopter or vehicle, and therefore some sites had to be selected primarily on the basis of access. No unregulated section was inspected on the Snowy River above Guthega Dam, because of time restrictions.

3.5 SITE ASSESSMENT (OBJECTIVE 5)

Panel members were briefed on the site assessment procedure on the evening of 11 January 1998. The Panel also discussed the project deadlines, subsequent meetings and report preparation. Field assessments were conducted from 12 to 14 January 1998. All sites were accessed by helicopter, as many of the sites were remote and inaccessible by road. The sites assessed by the panel were:

1. Snowy River below Guthega Dam
2. Snowy River below Guthega Power Station
3. Snowy River below Island Bend
4. Gungarlin River above aqueduct
5. Gungarlin River below aqueduct
6. Eucumbene River ~ 8km upstream of Lake Eucumbene top-water
7. Eucumbene River near Nimmo bridge, 9km below Eucumbene Dam
8. Eucumbene River ~22km below Eucumbene Dam and ~1km above Jindabyne Dam
9. Geehi River above Geehi Dam
10. Geehi River below Geehi Dam at Sullivans Spur bridge
11. Geehi River at Reeds Flat
12. Three Rocks Creek above aqueduct
13. Three Rocks Creek below aqueduct
14. Tooma River above Tooma Dam
15. Tooma River ~ 1km below Tooma Dam
16. Tooma River downstream of Tooma Dam at Maragle power line road bridge
17. Tooma River ~200m below National Park boundary
18. Tooma River on floodplain
19. Happy Jacks River upstream of Happy Jacks Dam
20. Tumut River below Tumut 2 Power Station
21. Goodradigbee River below aqueduct.

Prior to the assessment of each site, the Panel was flown at low level over the entire river reach. During this aerial inspection the sites were pointed out so that the Panel clearly understood the relationship of the site with the rest of the reach.

In most cases, the Panel assessed a site above each impoundment. These unregulated sites were not “reference” sites because they differed in altitude and sometimes in vegetation, hydrology and/or geomorphic characteristics. With due consideration of these differences, the Panel deemed the unregulated sites useful for indicating the river characteristics that would have occurred in the downstream reach prior to flow regulation. Given the natural low flow conditions occurring at these unregulated sites, their assessment gave a good indication of the flows experienced during summer low flows.

Circumstances where a site above the impoundment was not assessed were either: i) the river above the impoundment was also regulated (e.g. flows in the Snowy River above Island Bend Dam are regulated by Guthega Dam and power station); or ii) the river characteristics above the dam differed from the assessment reach to such an extent that the unregulated reach was not indicative of the likely pre-regulation conditions in the assessment reach (e.g. the Snowy River above Guthega Dam has markedly different vegetation, geomorphology and natural hydrologic characteristics to the river below the dam); or iii) access to the river above the dam was difficult, so a similar tributary was assessed instead (i.e. Happy Jacks River was assessed instead of the unregulated upper Tumut River).

A standard approach was used for assessing each site, as outlined below.

3.5.1 Individual assessment

Upon landing, the Panel was given 45-50 minutes to individually assess the reach site which extended over 10-14 channel widths in length. This permitted each individual to make their own assessment and draw their own conclusions without influence from other experts. The individual assessments were as follows:

- Stream hydrology (Mr. Ian Varley)
- Fluvial geomorphology (Dr. Wayne Erskine)
- Fish (Dr. John Harris, assisted by Mr. Brett Miners)
- Macroinvertebrates (Prof. P. (Sam) Lake, assisted by Ms. Robyn Bevitt and Mr. Derek Rutherford)
- Frogs (Mr. Graeme Gillespie)
- Macroalgae (Prof. P.(Sam) Lake)
- observations of macrophytes, riparian vegetation and other fauna by various Panel members
- measurement of water quality variables at some sites.

Fish were sampled with a backpack electrofisher for approximately 30 minutes in pool and riffle habitats, and identified on site, where possible. Macroinvertebrates were sampled with a

310μm mesh Freshwater Biological Association (U.K.) sweep net over a five minute period in each of pool, riffle, edge and run habitats (where present) and identified on site. Macroalgae were identified using field guides where necessary. Frogs and tadpoles were identified on site where possible. Water quality was measured using a YSI 3800 water quality logger.

3.5.2 Reporting

Following sampling and observations of the various ecological and geomorphological attributes at the site, the experts assembled as a group to report their findings individually. These discussions were facilitated by Mr Brett Miners and recorded by Ms. Robyn Bevitt and Mr. Derek Rutherford. The following questions were asked of each expert to provide a consistent framework:

- What parameters currently influence the ecological functioning of the river?
- What were the pre-regulation characteristics of the reach?
- What characteristics have changed since flow regulation?
- Is the reach in a stable long-term condition or is it still changing?

This process generally took approximately 30-40 minutes depending on the complexity of the reach. Most sites upstream of structures were discussed at the next site downstream, to allow comparisons to be drawn with the regulated sites, and because the less impacted nature of the upstream sites required less reporting.

3.5.3 Discussion

Facilitated discussions were then held to develop a group understanding of the river's condition, to determine what types of flow changes and management actions were required to return ecological integrity to the river reach, and to estimate some of the environmental flows required.

3.6 BASIS OF RECOMMENDATIONS (OBJECTIVES 6, 7)

On January 15 the Panel held its first post-assessment meeting to discuss the flow requirements for each reach (Objective 6). The panel met on 27 and 28 January to finalise the environmental flow recommendations for those sites which had available data on pre- and post-regulation hydrology. The Panel's final meeting was on 12 March to finalise recommendations for those sites which had previously not had sufficient hydrological information, and to discuss the draft report (Objective 7). There was a high degree of consistency between the environmental flows estimated in the field, and the flows deemed suitable for environmental purposes when pre- and post-regulation data were analysed. With a close fit evident between these two estimates of environmental flows, the panel then formalised their recommendations.

The flow recommendations arising from these meetings were based on the Panel's consensus on the flow required to reinstate and maintain ecological and geomorphological integrity. It is important to note that the panel did not make "ambit bids" for various types of flows. Underlying the determination of all environmental flow components was a consciousness of the structural and economic limitations of the Scheme in supplying environmental flows. Therefore, the panel tended to be conservative in their recommendations, knowing that to recommend flows in excess of those deemed likely to restore ecological integrity in any river reach may compromise the likelihood of another reach receiving sufficient environmental flows.

The first issue considered in the determination of environmental flows was the desired channel size for each reach, and the second issue considered was the essential components of an environmental flow regime.

3.6.1 Channel Set-point

A prerequisite for developing an environmental flow for a river, particularly one affected by regulation over a substantial period of time, is deciding an appropriate channel size. The decision on channel size is based on characteristics of the stream, including geomorphic constraints, and ecosystem function. In the river reaches assessed in the Snowy Mountains, channel contraction has occurred below impoundments, ranging from slight to severe. A fundamental decision was therefore required regarding a desirable long term channel size, which has been called the “set-point”. This set-point decision subsequently guided the flow recommendations for the reach.

There were three set-point options considered for each reach. The set-point decision was primarily made on the basis of the geomorphic configuration which would be most likely to provide the physical habitat and water quality conditions necessary for natural biotic elements of the river, and the essential interactions between aquatic and riparian areas for ecosystem function.

Information on the geomorphology of the reach was considered in the context of the parameters affecting the set-point decision. Panel members individually commented on the appropriateness of the set-point options for their area of expertise (i.e. fish, macroinvertebrates and frogs). Views on the appropriateness or relative benefits of the options were and discussed until the Panel was able to be unanimous in the set-point decision.

The panel tended to choose the smallest set-point considered feasible to reinstate ecological integrity within the reach. This was done on the understanding that water for the environment is limited and must be strongly justified, but also with the knowledge that the channel size must be adequate for maintaining ecosystem function within the reach, as well as close to the diversion structure. In most cases, there were other set-point options which had a greater capacity to reinstate ecological integrity, but these options would require larger flow volumes. The only situation in which the selected set-point was not the ‘minimum’ for basic ecosystem function, was when an option presented additional benefits to the reach, such as when tributaries downstream of dams had diversion structures, and their removal was recommended because of benefits additional to attaining the set point.

Once the set-point was selected, the development of channel maintenance flows was a relatively simple process using empirical relationships to calculate the flows required to entrain the appropriate particle size for that river reach (see 3.6.2.3 for explanation of the method used to calculate particle entrainment flows). Interpretation of the channel size arising from these flows and closeness of fit to the selected set-points was provided by the geomorphologist.

In some situations, the cause of channel deterioration may be complex and related to issues other than flow regulation, or regulation is so extreme within a reach that the prospect of maintaining a functional channel within the context of the existing structures is remote. In such instances, for example on the Tumut River between Tumut Pond and Talbingo Reservoir, an integrated land and water management plan which determines ecological objectives for the reach (which may be less than the complete restoration of natural biotic elements) is necessary before a decision on set-point is made.

3.6.1.1 Pre-regulation channel

Flow regulation primarily influences channel morphology by changing the dynamics of sediment transport and the mobility of bed material. This changes, over time, the major bedforms of a channel. For example, in a river typified by pool-riffle sequences, sedimentation will infill pools and cement cobbles and gravels within riffle areas, fundamentally influencing habitat characteristics.

Such changes will result in the deterioration of the riverine ecology over time. The rate of change will be dependent upon the extent of regulation (and therefore loss of energy), proximity to sediment sources, and sediment mobility, and may occur over decades or centuries.

Restoration and maintenance of the pre-regulation channel size is therefore necessary to create habitat of sufficient quality and quantity. This does permit some channel contraction, but seeks to restore and maintain the essential geomorphological characteristics.

3.6.1.2. Stream order reduction

In some instances, where sediment supply is adequate, regulation over a period of time has caused channel adjustment via contraction, bench formation, and vegetation encroachment. In such situations, maintenance of the smaller channel may be desirable and environmental flow recommendations need to be developed on the basis of preventing further contraction or vegetation invasion of the channel, and restoring the biological elements that would be found in that (reduced) size stream, altitude and geographic zone. This represents a reduction of stream order.

In many instances within the Scheme, sizeable tributaries below impoundments are captured and diverted back to the dam. An appropriately reduced stream order may often be achieved by restoring a currently regulated tributary in the reach immediately downstream of a dam by removal of its diversion structure. The water yield from the tributary may be used to set the channel size of the main river, or may be supplemented by flows from the dam. The removal of the aqueduct/s below an impoundment may be preferable to providing water from a dam as it will:

- provide longitudinal continuity and distribution of sand, organic matter and biota;
- avoid water quality problems associated with dam releases (e.g. very low temperatures and low dissolved oxygen);
- provide daily variability to the tributary and the main river without the need to manipulate releases to provide this variability; and

- removing the need to maintain the diversion structures.

3.6.1.3. Existing channel

In large, high altitude boulder step rivers with low sediment supply, the channel may be relatively unchanged by flow regulation. This is because the flows required to entrain boulders occur on a time-scale of 50 - 100 years (Grant *et al.,* 1990), and vegetation encroachment is occurring very slowly due to the lack of sediment supply and harsh climatic conditions. This results in the channel being laterally isolated from riparian vegetation because the wetted channel is greatly reduced. The boulder steps may not be functioning (i.e. with rapids, chutes and cascades), and longitudinal isolation may also be occurring.

In such situations the existing channel (which may be largely unchanged) primarily determines the flow requirements to provide critical ecosystem functions. This is different from the above two set point options for which flow is used to modify the channel to a determined point.

3.6.2 Environmental flow regime

The elements of the natural flow regime of a stream are magnitude, frequency, duration, timing and rate of change (Poff *et al.,* 1997). The components of the flow regime deemed essential by the Panel for reinstating and maintaining ecological and geomorphological integrity of streams in the Snowy Mountains encompass all of these elements. The components are: i) minimum habitat utilisation flows incorporating seasonal variability; ii) flushing flows incorporating fish migration requirements and fine sediment removal; and iii) channel maintenance flows.

3.6.2.1Minimum habitat utilisation flow regime

This is the minimum seasonal flow regime that will allow aquatic fauna to utilise a reasonable amount and diversity of habitat for survival and for completion of their life cycles. Minimum habitat utilisation flows inundate sufficient microhabitat sites and provide localised flow variability appropriate for the diversity of aquatic species expected to occur naturally in the reach. They provide water of adequate quality for aquatic ecosystems, particularly with regard to temperature, dissolved oxygen, and nutrient concentrations. In addition, a minimum habitat utilisation flow regime provides the variability in daily, weekly and monthly flows that are triggers for components of the life cycle of many macroinvertebrates, fish and other aquatic biota. The importance of natural flow variability and seasonality is well known for many native fish species, which require water quality, velocity and flow depths within specific ranges for successful spawning, migration and recruitment. Higher spring flows in a minimum habitat utilisation flow regime stimulate and enable some degree of longitudinal dispersal of aquatic species, thereby facilitating colonisation of under-utilised habitat, expansion of the gene pool, and preventing the over-crowding, competition and exposure to predation which occurs during lower flows.

Habitat utilisation flows are not adequate for maintaining habitat, rather they allow utilisation of habitat, therefore an environmental flow regime must incorporate flushing and channel maintenance flows to provide for habitat maintenance.

The first step in the process of reaching consensus on the minimum habitat utilisation flow regime was for the Panel members to indicate the minimum flow for the set-point channel size which would permit ecological processes to continue over the summer months. The key disciplines for determining these flows were macroinvertebrate and fish ecology (with frogs generally responding to particular river conditions rather than defining the flows required). Determining the appropriate flow regime involved an iterative process of questioning and discussion between the macroinvertebrate and fish ecologists with the hydrologist and geomorphologist, on river response to flows in terms of wetted area, flow depth and velocity, and water quality parameters. The fauna which had the highest flow requirements for minimum habitat utilisation was the determining factor in deriving the minimum habitat utilisation flow regime. Another important consideration in some reaches was the need to prevent alien fish from occupying ecological niches that had been created by regulated flows. For these reaches, the minimum habitat utilisation flows had to provide velocities high enough to disadvantage alien fish.

Consensus was aided by the fact that there was a lot of synergism between the requirements of the various biological elements in each reach.

The recommended minimum habitat utilisation flows were generally calculated from the flow required to provide a particular depth over a given channel width (for useable habitat for aquatic species, and adequate water quality), relative to that observed at the site. Summer flows were estimated in the field at each site, and in later Panel meetings the estimated flows were found to lie somewhere between the 80^{th} and 95^{th} percentile exceedence flows for the summer months for each site. The summer habitat utilisation flows estimated in the field tended to be closer to the 80^{th} percentile in reaches which had not contracted greatly, and closer to the 95^{th} percentile flow in reaches which had undergone significant channel contraction.

Spring flows were also defined in the field. They were estimated as the flows required to permit some lateral and longitudinal reconnection of the river. These estimated flows were found to be approximately an order of magnitude higher than summer flows, which was subsequently found to be the natural flow pattern. The estimated spring flows were close to the 95th percentile flow in spring.

Flows in most other months were generally chosen as the 95^{th} percentile. There were two exceptions to this. The first was in the Snowy River below Guthega and Island Bend Dams, where recommending the 95^{th} percentile flow in April resulted in April flows being lower than the recommended 80^{th} percentile flows in March. As this was contrary to the natural flow pattern, the 93^{rd} percentile flow was recommended for April, as this resulted in a gradual increase in flows from March to April, rather than a significant decrease in flows in April. The second exception to using the 95^{th} percentile flow was where the 95^{th} percentile flow in the snowmelt months equated to nearly half of the natural snowmelt flows (because snowmelt flows are consistently high). While not discounting the role these flows had in shaping and maintaining the ecological character of the rivers, the panel did not believe that such sustained high flows were necessary for minimum habitat utilisation. In addition, releasing half of the spring flows would have an enormous impact on the capacity of the Scheme for hydroelectricity generation. Therefore, the 95^{th} percentile for these months was recommended for only one week of each snowmelt month, with the 95^{th} percentile June flow (varied by up to plus or minus 25%) recommended for the remaining weeks of each snowmelt month. The Panel considered that these seasonal flow regimes, while being a compromise, would be adequate for minimum habitat utilisation.

It is very important that intra- and inter-month variability be incorporated into flow releases so that flows are not constant. Accordingly:

1) All monthly flows are to be varied on at least a weekly basis;

2) For months where the June 95th percentile flow is recommended for 3 weeks out of that month, this flow is to be varied on a weekly basis by up to plus or minus 25%.

The outcome of implementing the recommended minimum habitat utilisation flow regime will include environmental benefits such as:

- improved water quality through the dilution of nutrients, lowering of summer water temperatures and prevention of freezing over during winter;
- increased width and depth of riffles, runs and pools, which in turn will provide:
    - more available habitat for macroinvertebrates and fish; and
    - longitudinal connectivity for invertebrate drift, fish passage, and transport of sediment and organic matter;
- lateral connectivity between the wetted channel and riparian vegetation, which is necessary for shading, input of detritus, and availability of terrestrial biota as a food source (e.g. insects as a food source for fish);
- adequate hydrological heterogeneity for allowing macroinvertebrate life cycles.

3.6.2.2Flushing flows

These are flows which cause a relatively short but significant rise in river height and an increase in stream velocity and turbulence sufficient to flush accumulated nutrients and fine biogenic sediment. Prior to regulation, these flows had an important role in maintaining water quality by flushing fresh water through pools, removing built-up nutrients and biogenic material, and providing some flow variability, particularly over the summer months when flows were relatively low and uniform. They had an important role in entraining fine substrate, thereby helping to prevent sedimentation and providing clean substrate for fish spawning, and allowed fish migration by increasing the depth of flow.

Flushing flows were defined by the Panel in the field. Again, an iterative approach was necessary to satisfy water quality, substrate condition and life cycle trigger parameters, which involved all disciplines. Consensus was again aided because most of these elements had similar flow requirements. The flushing flows were generally based on the Panel's estimation of the flow volumes and velocities required to entrain small substrate, flush sediment and algae, flush or dilute nutrients, and facilitate fish migration. The fish migration requirements were calculated on the basis of flows that would provide a particular depth and velocity over a riffle of given channel width. It is important to note that for flushing flows to provide for the spawning and migration of native fish species, they must occur during periods of naturally high flows. There may be two or more events required annually, and they must be of natural duration and natural rate of rise and fall. In many cases, the flows estimated in the field for sediment entrainment and fish migration were found in subsequent meetings to be provided by the minimum habitat utilisation flows in the spring (snowmelt) months.

Flushing flows are generally modelled on a hydrograph of a thunderstorm event under natural conditions. Such a hydrograph gives an indication of the rate of rise and fall, size and duration of an event under pre-regulation conditions. Thunderstorm events are chosen because they represent short, peaked events that were part of the natural flow regime at a time when flushing is most needed.

The flushing flows recommended by the Panel will have the following outcomes:

- Prevent the cobble substrate from becoming embedded in fine sediment, thus maintaining interstitial spaces and clean gravels as habitat for many aquatic species, and providing adequate spawning conditions for fish species;
- Provide lateral connectivity between the channel and riparian vegetation;
- Provide longitudinal connectivity for invertebrate drift and fish migration, by providing sufficient flow depths over riffles;
- Redistribution of organic matter;
- Flushing of fine sediments, both biogenic and abiotic;
- Develop turbulence to prevent bottom anoxia in pools;
- Possibly carry fine sediment and/or nutrients to downstream reaches and/or dams if concurrent environmental flows are not provided in these downstream areas; and
- Reduce water temperatures and increase dissolved oxygen during summer.

3.6.2.3Channel maintenance flows

These are the range of flows which physically configure the river channel and substrate, thus regenerating much of the structural habitat. The high flows required for channel maintenance are also required for the ecological integrity of floodplains (e.g. the lower Tooma River floodplain). Flooding of floodplain wetlands is vital for nutrient dynamics, moving organic matter and woody debris, increasing both macrophyte and macroinvertebrate diversity and abundance, and stimulating breeding of native fish and other vertebrates such as frogs, turtles and water birds.

It is important to understand the various bedforms that exist in river channels in the Snowy Mountains. Natural bedforms are the physical basis of aquatic habitat and are essential for geomorphological and ecological integrity, hence they are a vital consideration in determining an environmental flow regime. Boulder steps are essential for maintaining the stability of steep gravel bed rivers (Chin, 1989; Grant *et al*., 1990). Medium scale bedforms (i.e. lengths of 10^0-10^1 channel widths) on gravel bed and bedrock channels similar to the upper Snowy, Geehi, Tooma and Tumut Rivers have been discussed in detail by Heede (1972), Chin (1989) and Grant *et al*. (1990), among others. These bedforms are now briefly described because the reader may not be familiar with all of them. Pools are deep areas of slow, subcritical flow without free surface instabilities under low flows. Riffles are shallow, faster flowing areas with local free surface instabilities and small hydraulic jumps over the larger bed roughness elements. Rapids have a greater area of supercritical flow than riffles and exhibit boulders organised into irregular ribs oriented more or less perpendicular to the channel. Cascades are steep staircase sections where supercritical flow tumbles over large boulders in a series of short, well defined steps separated by areas of subcritical flow. Steps are individual, channel-spanning ribs less than one channel width long separated from a backwater pool upstream and a plunge pool downstream. They are usually located where immobile boulders and bedrock outcrops trap smaller boulders and wood. Grant *et al*. (1990) found that steps are absent from pools and riffles but dominate the structure of rapids and cascades. They are composed of the coarsest gravels that are rarely transported because of supply-limited conditions (Grant *et al*., 1990). Associate Professor R.J. Loughran (1997, personal communication) found that boulder steps on a Scottish river were little modified by the largest flood on record despite the occurrence of widespread supercritical flow. Grant *et al*. (1990) found that floods with return periods of at least 50 years are required to transport some of the step-forming gravels. Clearly, environmental flows *cannot* be expected to maintain and develop bolder steps.

The above bedform sequence occurs at progressively steeper slopes (Chin, 1989; Grant *et al*., 1990). Furthermore, interstep spacing varies inversely with channel slope (Heede, 1972; 1981; Chin, 1989; Grant *et al*., 1990). This occurs because step height is constant and so an increase in slope must result in closer spaced steps over a given channel length as steps account for most of the fall (Heede, 1972; Grant *et al*., 1990).

Boulder steps and the associated step pools are an energy dissipating mechanism in steep channels (Chin, 1989; Grant *et al*., 1990). Without step pools to dissipate this energy, mountain streams adjust vertically by erosion, resulting in bed degradation (Chin, 1989). Boulder steps must never be disturbed for any purpose on steep gravel bed rivers in the Snowy Mountains.

The approach usually adopted for the selection of channel maintenance flows is that the channel-forming discharge(s) for the pre-regulation channel is identified and maintained after the commencement of flow regulation to ensure that channel morphology is not changed (Petts, 1996). However, while bankfull discharge is often equated to dominant discharge (Wolman and Leopold, 1957; Wolman and Miller, 1960), different aspects of channel morphology can be formed by different flows (Pickup and Warner, 1976; Neller, 1980; Erskine, 1994). It is now impossible to maintain the pre-regulation channel morphology in the Snowy Mountains because no attempt has been made since the commencement of the Snowy Mountains Hydro-Electric Scheme to release flows from dams equivalent to pre-regulation channel maintenance flows. Large-scale flood suppression has substantially reduced the frequency of physical disturbance to such an extent that even submerged macrophytes are now present in the steep, high energy, boulder step and step pool streams of the Snowy Mountains. As a result, channels have significantly contracted downstream of most dams by a combination of processes involving bed and bank deposition and vegetation encroachment (Erskine, 1996b; 1997b; Erskine *et al*., 1999). Flood disturbance is essential to prevent channel atrophy.

Erskine (1996b) and Erskine *et al*. (1999) suggested that to reverse channel atrophy (see Glossary for definition) due to substantial flood suppression, channel contraction, vegetation invasion and lichen colonisation of exposed bedrock and boulder surfaces, it is necessary to release channel maintenance flows that are capable of transporting boulders (256 mm intermediate diameter). Such flows would not only reverse the long term trend of contraction but would also remove some of the encroaching sediment and vegetation, and clean the gravelly bed material.

Boulder entraining flows were determined by applying the tractive force approach of Newbury and Gaboury (1993). Map-derived bed slopes were used to determine flow depths to entrain boulders (or a smaller gravel size where relevant) and these flow depths were converted to flows by Mannings Equation. This is, at best, an approximation of the corresponding flows because many of the streams have a boulder step-step pool sequence (Grant *et al*., 1990) and hence do not exhibit uniform steady flow. Furthermore, Downes *et al*. (1997) found that embedded gravel clasts (which occur on many regulated rivers in the Snowy Mountains) require a critical shear stress for movement that is an order of magnitude greater than for loose lying clasts (on which the tractive force method of Newbury and Gaboury (1993) is based). The best way of specifying boulder entraining flows is by the use of trial releases (Erskine *et al*., 1993) which can be implemented at a later date as part of adaptive management. Trial releases are also useful for determining flows that initiate bank erosion (Erskine *et al*., 1993; 1995).

Releases equivalent to channel-forming discharges (i.e. the recommended channel maintenance flows) will have the following outcomes:

- strip fine-grained sediment laminae from the bed surface;
- reconfigure large and medium scale bedforms, such as pools, riffles, runs and bars;
- reconfigure channel width and depth;
- remove accumulating sediment obstructions, such as tributary mouth bars;
- clean pore spaces between the gravelly bed material;
- remove obstructing vegetation; and
- re-establish physical and ecological longitudinal and lateral connectivity.

3.6.3 Hydrographs

A hydrograph is a graphical representation of flow in a river, which indicates how discharges (or flood levels) vary over time during the course of a flood event. Hydrographs typically have a skewed bell shape. Hydrographs can be divided into three distinct segments. The first portion of the curve, which is called the rising limb, depicts the early period of the flood when discharges are increasing; the middle portion shows the flood peak; and the final portion shows the flood recession, when discharges are decreasing. In natural flood events the rising limb is much steeper than the falling limb, i.e. the increase in discharge toward the peak is much quicker than the fall.

Hydrographs are generally generated directly from rainfall, with high flows persisting only for short durations after cessation of rainfall, but low flows can persist for very long periods in certain catchments. Catchments with steep topography produce fast flows with much steeper rising and falling limbs than flat catchments. Hydrographs are also affected by storm patterns and at a given location hydrographs from different storms may vary considerably. In areas subject to snow, high flows can be generated for extended periods of time during spring by snow melt.

It is essential for ecological integrity that the rate of rise and fall of flushing flows and channel maintenance flows for a particular river mimics the rising and falling limbs of a natural flood hydrograph for that or a similar river. This is because unnatural rates of rise and fall are likely to be detrimental to the geomorphology and ecology of rivers.

3.6.4 Flow duration curve analysis

A flow duration curve shows the portion of time (usually as a percentage) that flow exceeds a given rate at a particular location. It is derived by taking the daily or monthly recorded flows over the period of record, sorting these into descending order, and then plotting the flows (y axis) against the percentage of time the flow is exceeded (x axis). See Figure 6.1 in Chapter 6 for an example.

Stalnaker and Arnette (1976) described the use of flow duration curve analysis for determining flows for the instream needs of fish in mountain trout streams in North America. Following surveys of biological and physical attributes of the Frying Pan River, Colorado (Hoppe and Finnell, 1970 cited in Stalnaker and Arnette, 1976), flow duration curves for the river were analysed and the following environmental flows were recommended: i) flows for a 48 hour period for flushing spawning areas were deemed adequate at the 17th percentile level; ii) flows for spawning adequate at the 40th percentile level; and iii) flows for cover and food production at the 80th percentile level (pers. comm. cited in Stalnaker and Arnette, 1976).

The analysis of historical flow data provides a rapid and efficient appraisal of an extensive area from existing records, with little or no field data required (Stalnaker and Arnette, 1976). In a study comparing the flow duration curve analysis method, physical habitat analysis and expert panel methods for their suitability in determining environmental flows for the Peel River below Chaffey Dam, Swales *et al.* (1994) found that the flow duration curve method was the only method which provided both monthly and seasonal flow variability. It was concluded that the flow duration curve and holistic methods are particularly suitable for determining environmental flows in Australia, because they are based on the natural flow regime (Swales *et al*., 1994). It is important, however, that flow duration curves be analysed on a case by case basis for different rivers, because the percentile levels used by Stalnaker and Arnette (1976) may not be appropriate for the particular area. For example, in the Peel River study, Swales *et al.* (1994) adopted the 50th percentile flow for spawning flows instead of the 40th percentile (Stalnaker and Arnette, 1976) to allow for the variable high flows with which spawning and recruitment of Australian native fish occurs.

3.6.4.1Flow variability

Although the flow duration curve method provides monthly and seasonal flow variability (Swales *et al*., 1994), short duration high flows in low flow months are disguised in the flow duration curve and therefore not incorporated into the minimum flow recommendations (Chow, 1964; Richardson, 1986). The determination of minimum flows from flow duration curves assumes that the flow requirements of all life stages of aquatic species will be provided for by the most frequent conditions over the flow duration curve period of record (Richardson, 1986). It is therefore important on an ecological basis to maintain variability during low flows (Humphries *et al*., 1996). Flow variability during low flows is also important for maintaining geomorphic integrity, as a constantly maintained minimum flow can have detrimental effects.

4 Geomorphologic and ecological Issues

4.1 MORPHOLOGICAL EFFECTS OF FLOW REGULATION

Dam-induced changes in flow and sediment regimes and water quality are primary forcing functions of channel and ecological changes below dams (Petts, 1984a; Erskine, 1985; 1996a; Walker, 1985). Channels often respond to flow regulation in a complex manner which varies over time and space, as demonstrated by Erskine (1985), Sherrard and Erskine (1991) and Benn and Erskine (1994). However, channel adjustment to flow regulation is most rapid where there are active sources of sediment available for redistribution within the regulated main stream (Erskine, 1985; 1996a; Sherrard and Erskine, 1991; Benn and Erskine, 1994; Erskine *et al.*, 1999).

4.1.1 Channel contraction

Channel width is thought to be adjusted to dominant or channel-forming discharge according to a simple power function (Leopold and Maddock, 1953; Leopold and Wolman, 1960). Dominant discharge has been equated to a flood peak discharge with a return period of between 1.5 and about 10 years on the annual maximum series, depending on flood variability and floodplain morphology (see Wolman and Leopold, 1957; Dury, 1973; 1976; Pickup and Warner, 1976; Page, 1988; Erskine, 1994; Keshavarzy and Erskine, 1995; Erskine and Keshavarzy, 1996; Erskine and Livingstone, 1999). Erskine (1985; Sherrard and Erskine, 1991; Benn and Erskine, 1994; Erskine *et al.*, 1999) has documented some of the largest reductions in flood peak discharges due to flow regulation reported anywhere in the world (see Petts, 1984a). Channel width should, therefore, decrease provided there is a source of sediment for deposition in the overwide pre-dam channel (Sherrard and Erskine, 1991; Benn and Erskine, 1994; Erskine, 1996a) and provided the nature of energy expenditure within the channel has not been drastically altered. Channel contraction can occur by a number of processes, such as:

- the deposition of a mud littoral fringe at the base of the pre-dam channel banks which is subsequently invaded and stabilised by emergent macrophytes, sedges, and/or shrubs (Erskine, 1997b);
- oblique accretion directly on the channel banks (Sherrard and Erskine, 1991);
- in-channel bench formation and subsequent shrub invasion (Sherrard and Erskine, 1991);
- mid-channel bar formation and subsequent bank attachment by the abandonment of secondary channels (Sherrard and Erskine, 1991);
- tributary-mouth bar formation and the downstream dispersion of the bar sediments into pools and benches (Petts, 1984b; Benn and Erskine, 1994; Erskine *et al*., 1999);
- massive vegetation invasion of pre-dam bedforms exposed by substantial flow reduction (Erskine *et al*., 1999);

- peat formation in the wetland margins beside contracted riffles and the tail of remnant pools (Erskine and Turner, 1998); and

- formation of channel chokes by emergent macrophytes (Erskine and Turner, 1998).

The rate of channel contraction generally conforms to a rate law or hyperbolic function and hence exhibits an exponential decline over time (Williams and Wolman, 1984). Physical disturbance by floods of a magnitude comparable to pre-regulation conditions is required to reverse this trend.

4.1.2 Channel widening

Channel widening has been reported where interbasin water transfers have increased flows, especially bankfull flows which maximise energy expenditure on the channel boundary (Tilleard *et al*., 1994). The Snowy Mountains Scheme has caused channel widening on sections of the Tumut and Upper Murray Rivers by increasing the duration of near bankfull flows by diverting flow into these catchments from the Snowy River. Flood frequency and magnitude can be reduced but the channel widens when the duration of near bankfull flow is increased.

4.1.3 Bed degradation

Bed degradation often occurs below dams because of the high sediment trap efficiency of large dams (Erskine, 1985; 1996a; Sammut and Erskine, 1995; Erskine *et al*., 1999) and the consequent lack of sediment input to the downstream channel (Erskine, 1985; 1996a; Sherrard and Erskine, 1991; Benn and Erskine, 1994). However, there is little potential for bed erosion on many rivers in the Snowy Mountains because of bedrock confinement and very coarse gravels which effectively protect and often armour the bed (Erskine, 1985; 1996a; Benn and Erskine, 1994). The rate of bed degradation generally conforms to a rate law and hence exhibits an exponential decline over time (Williams and Wolman, 1984). Floodplain reaches are the most sensitive to flow regulation because the channel boundary contains large amounts of unconsolidated sediment. Preferential removal of the finer bed material produces a surficial armour layer of coarse well sorted gravels which veneers and hence protects the underlying sediment. Armour layer formation is a negative feedback process which eventually stops degradation (Petts, 1979;1984a).

4.1.4 Fine-grained sediment laminae

The bed of many regulated rivers which have experienced flood suppression, has a significant amount of fine-grained sediment infilling the voids between gravels and covering the exposed surface of gravels. Fine-grained sediment laminae are discrete surficial layers, 5-10 mm thick that drape the pre-existing bedforms and bed sediments (Droppo and Stone, 1994; Lambert and Walling, 1988). They are composed of low density flocs with a fluffy, highly porous fabric (Droppo and Stone, 1994) and have also been called biogenic veneers (Erskine and Turner, 1998) and bioclastic sediments (Erskine *et al*., 1999). This fine-grained sediment storage on the bed of regulated rivers reflects decreased flushing due to flood suppression. The frequency and duration of bed mobility have decreased significantly due to flood suppression on many regulated rivers (Erskine, 1985; 1996a; Benn and Erskine, 1994). One of the aims of flushing flows is to restrict the development of fine-grained sediment laminae in regulated rivers.

4.1.5 Changes in large scale bedforms

It is likely that the pool-riffle sequence and types of channel bars, especially in floodplain reaches, are not maintained on regulated rivers because of flood suppression (Erskine and Tilleard, 1997; Erskine *et al*., 1999). Such changes in large scale bedforms can drastically alter the physical habitat not only by decreasing the total amount available but also by restricting fish migration by creating long shallow uniform sections of channel. The ecological literature often totally ignores such impacts of flow regulation on bedforms.

4.1.6 Bed aggradation

Bed aggradation refers to the storage of sediment in the bed of a river when the rate of sediment supply exceeds the sediment transport capacity. This often occurs on regulated streams where unregulated tributaries debouche into a regulated main stream which has experienced substantial flood suppression (Sherrard and Erskine, 1991; Benn and Erskine, 1994; Erskine *et al*., 1999). Zones of aggradation often alternate with zones of degradation in downstream sequence so that many rivers exhibit a spatially variable river response (Sherrard and Erskine, 1991).

4.1.7 Accommodation adjustment

Petts (1979) coined the term “accommodation adjustment” for channels which have not responded to flow regulation because all dam releases are below the threshold for bed material transport and bank erosion. Hey (1979) recommended that this situation should be designed for when new dams or interbasin water transfers are constructed. While Erskine (1985) and Benn and Erskine (1994) have identified this type of channel response on selected NSW rivers, it is unlikely to be widespread in the Snowy Mountains because of the substantial change to flow regimes (see Erskine, 1996b; 1997b; Erskine *et al*., 1999).

4.1.8 Channel pattern changes

Channel pattern changes can be caused by flow regulation (Sherrard and Erskine, 1991). Discharge dependent threshold slopes have been identified at which channel pattern changes dramatically (for example, Leopold and Wolman, 1957; Lane, 1957; Ackers and Charlton, 1970; Schumm and Khan, 1971; 1972). It is only rivers that are close to the threshold zone that are sensitive to change by flow regulation. A reduction in flood peak discharges can convert a braided to a meandering stream, especially when combined with a reduction in bedload (Schumm, 1969). However, the distance of the river from the threshold is also a measure of sensitivity to change (Scott and Erskine, 1994).

4.1.9 River metamorphosis

River metamorphosis refers to the complete transformation of channel morphology produced by an altered hydrologic regime (Schumm, 1969). Sherrard and Erskine (1991) documented the metamorphosis of Mangrove Creek from a wide, active, large capacity sand-bed stream of relatively high width-depth ratio but low sinuosity to a narrow, small capacity, more sinuous, less active sand-bed stream.

4.1.10 Vegetation invasion

As noted by Erskine (1996a : p. 12) :

"...Regulated rivers are often invaded by vegetation because they have a stable substrate and because there is an absence of large disruptive floods. Furthermore, exposed bars and benches with shallow water tables are good sites for phreatophytes..."

A number of weeds, including Willows, poplars, Blackberry and scottish broome are present on regulated rivers in the Snowy Mountains. Seeding Willows have also been recently found (Cremer *et al*., 1995). Willow root mats anchor bed and bank sediments, effectively making them immobile. Furthermore, many species of attached submerged native macrophytes are now also common where they would not have been found previously. This is due to the lack of fluvial disturbance (i.e, flood pulses) because of flood suppression. While flood suppression has allowed vegetation invasion, the simple reinstatement of a flood pulse will not necessarily solve the problem due to the amount of vegetation now present on many regulated rivers.

4.1.11 Complex response

Complex response refers to a single trigger, such as dam closure, initiating a series of river responses which vary over time and space (Schumm and Parker, 1973). Different sections of the same river have exhibited simultaneous contraction, aggradation, degradation, accommodation adjustment, channel pattern changes, deposition of fine-grained sediment laminae, a change in large scale bedforms and vegetation encroachment following flow regulation (for examples, see Erskine, 1985; 1996a; Sherrard and Erskine, 1991; Benn and Erskine, 1994; Erskine *et al*., 1999). Rivers are complex biophysical systems and usually respond to changes in flow and sediment regimes in a complex manner. Furthermore, different river reaches exhibit different morphologies due to different biogeomorphic processes. Complex response should be expected following flow regulation.

4.2 ECOLOGICAL INTEGRITY

Ecological integrity covers the state at any locality in which the composition and abundance levels of the biota on biogeographical grounds are matched with the geomorphological and climatological settings and to the types and dynamics of the ecological processes in which the biota are involved. It is different from biological integrity that may not be concerned with ecological processes. Ecological integrity is based upon expectation: if the biota present matches that expected for natural ecosystems in a particular locality then the ecological integrity is said to be high; if there is a significant mismatch between the biota present at a locality and that expected for natural ecosystems in that locality then ecological integrity is said to be low.

In the case of running waters at a locality, the catchment conditions, hydrology and stream morphology set the stage for the biota. A mismatch in the biota between that expected for that locality under natural conditions and that actually found is taken to mean that not only is the biota unnatural but that important ecological processes have been disrupted.

4.3 LINKAGES BETWEEN FLOW AND THE ECOLOGY OF A STREAM

As clearly stated by Poff *et al.,* (1997), the flow regime of any stream is made up of five components; magnitude, frequency, duration, timing and rate of change. All of these components directly and indirectly influence the ecology of the biota from bacteria to fish. Karr (1991) clearly outlined how the flow regime, through its components, influences the four primary regulators of ecological integrity. These regulators are: water quality (e.g. temperature, suspended solids, nutrient levels), energy sources (e.g. allochthonous vs autochthonous), physical habitat (e.g. channel morphology, log jams, channel-riparian links, interstitial space availability) and biotic interactions (e.g. herbivory, predation, parasitism). In streams it is essential to understand that it is the temporal and spatial shifts in the strengths of the flow regime components that act upon these regulators to create continuous changes in physical, chemical and biotic conditions in the stream. And this shifting mosaic of physical and biotic conditions is the natural state. Alterations in the natural range of any of the components of flow regime cause a shift in the regulators and a change in ecological integrity. For example, lack of seasonal floods in a gravel bed stream may lead to an accumulation of fine sediment in the bottom gravels generating conditions favourable to a benthos of burrowing invertebrates tolerant of low oxygen levels, and not the normal clinging and clambering biota of such streams. Such conditions are also very unfavourable to the successful incubation of Macquarie Perch eggs.

The challenge in restoration of rivers impacted by flow regulation is to identify those components of the natural flow regime that have been altered and to find successful ways to replace, wholly or partly, those components deemed essential for successful restoration. Needless to say the validity of the prediction can only be tested by sound monitoring before and after the implementation of the restoration strategy.

4.4 THE CONNECTIVITY OF RIVERS AND EFFECTS OF BARRIERS

In their natural state, river systems and their biota have a high connectivity of their components. The obvious connection is water moving from source to mouth, but such downstream movement also applies to a wide range of other components, particularly sediments, chemicals (especially nutrients), and food resources such as detritus. This longitudinal connectivity is stressed in the River Continuum Concept (Vannote *et al.,* 1980). Rivers may also have lateral connections, notably on their floodplains. Thus periodic inundation of their floodplains by rivers is seen as vital to the maintenance of ecological integrity of both much of the biota of the river channel and the riparian and aquatic biota of the floodplain and its wetlands. This necessity of lateral connectivity is recognized in the Flood Pulse Concept (Junk *et al.,* 1989).

River regulation disrupts, if not breaks, the longitudinal connectivity of rivers (Ward and Stanford, 1983) and invariably alters greatly the flooding regime of floodplain rivers (Ward and Stanford, 1995). In regulated rivers dams may greatly reduce the amount of sediments, nutrients and organic detritus being transported downstream (eg., Ligon *et al.,* 1995; Ibanez *et al.,* 1996) and very greatly reduce the biodiversity and productivity of floodplain rivers by reducing the river's interactions with its floodplain (Heiler *et al.,* 1995).

It is now recognized that many species in rivers exist as metapopulations, that is local subpopulations exist in specific patches and as a conglomeration of patch subpopulations in the metapopulation. These subpopulations are linked by dispersal and gene flow in very varying amounts both spatially and temporally (Harrison, 1994; Stanford *et al.,* 1996).

Salmonid fish populations offer good examples of this phenomenon (e.g. Reisenbichler *et al.,* 1992). Populations depleted by disturbance may be replenished by recruits from other subpopulations. Such metapopulation structure may be drastically altered by damming leading to a breaking of connectivity and the generation of fragmentation (Zwick, 1992; Dynesius and Nilsson, 1994). By isolating subpopulations the likelihood rises of loss of genetic variability, population depletion and eventually extinction. This may happen to both aquatic species (Stanford *et al.,* 1996) and to riparian plant species (Nilsson, 1996). Finally, by acting as barriers to movement, dams may block essential upstream and downstream migration of animals, notably fish. Breeding may be curtailed for potamodromous species (those that migrate within a river system to breed), anadromous fish (those that migrate up rivers from the sea to breed, e.g. Pacific and Atlantic Salmon) and catadromous species (those that migrate from rivers to the sea to breed e.g. many Galaxiids).

In dealing with the effects of river regulation by dams, there are invariably the two very deleterious effects of the disruption of connectivity and the fragmentation of species populations and their habitats. Thus, predictably, alleviating these two effects by attempting to restore and augment connectivity is an essential and crucial part of the restoration of regulated rivers (Stanford *et al.,* 1996). This may even involve the removal of dams (e.g. Shuman, 1995).

4.5 SUMMARY OF GEOMORPHOLOGICAL AND ECOLOGICAL RESPONSES TO FLOW REGULATION IN THE SNOWY MOUNTAINS

The interactions between flow, geomorphology and ecology are very complex. To allow the reader to understand this complexity, flow diagrams showing some of the impacts of changes to the flow regime on ecology and geomorphology are presented below in Figure 3 to Figure 6.

Figure 3. Environmental impacts of low flows induced by the Scheme.

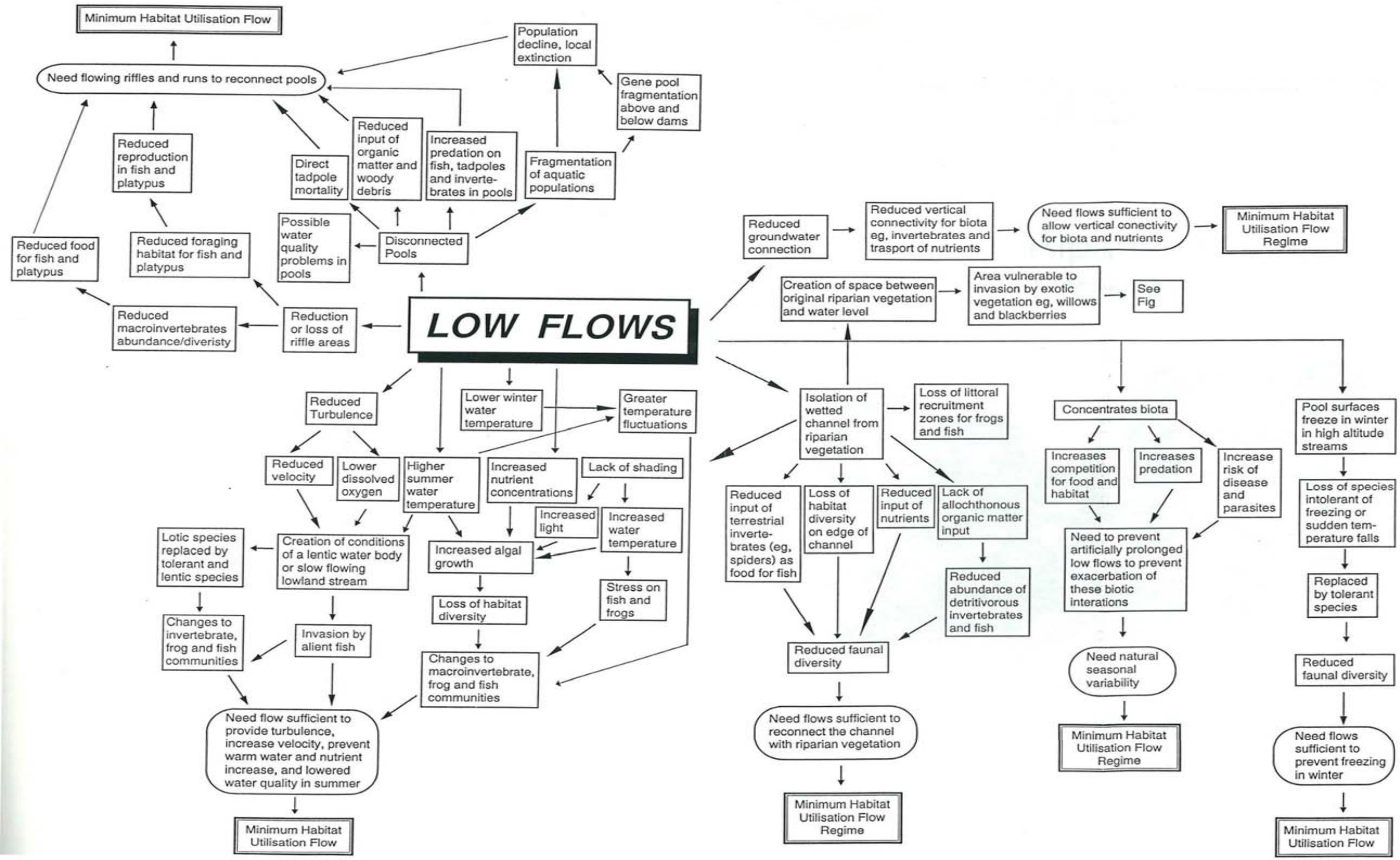


Figure 4. Environmental impacts of the loss of high winter/spring flows and mitigation of small to medium floods by the Scheme.

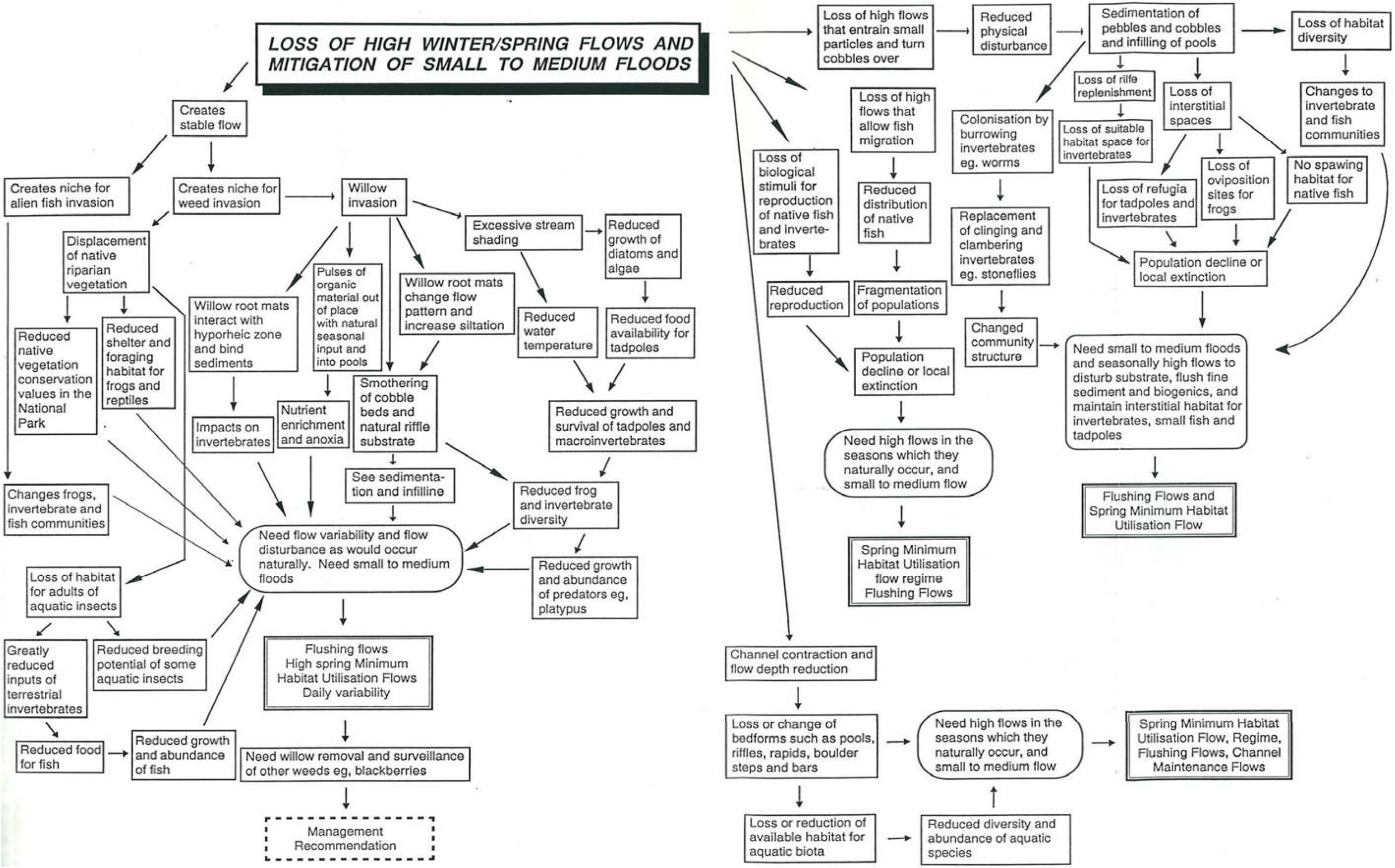


Figure 5. Environmental impacts of mitigation of large floods by the Scheme.

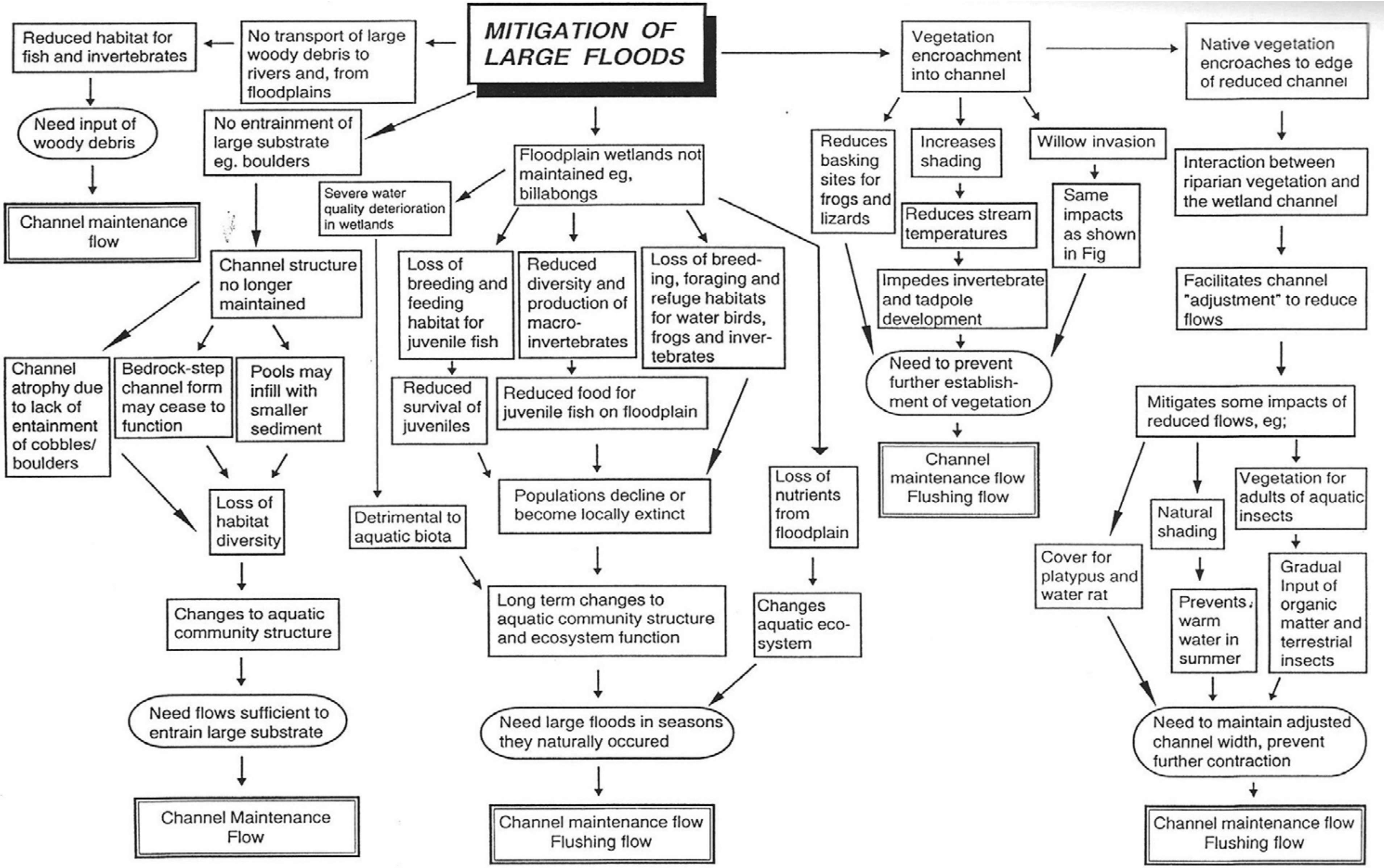
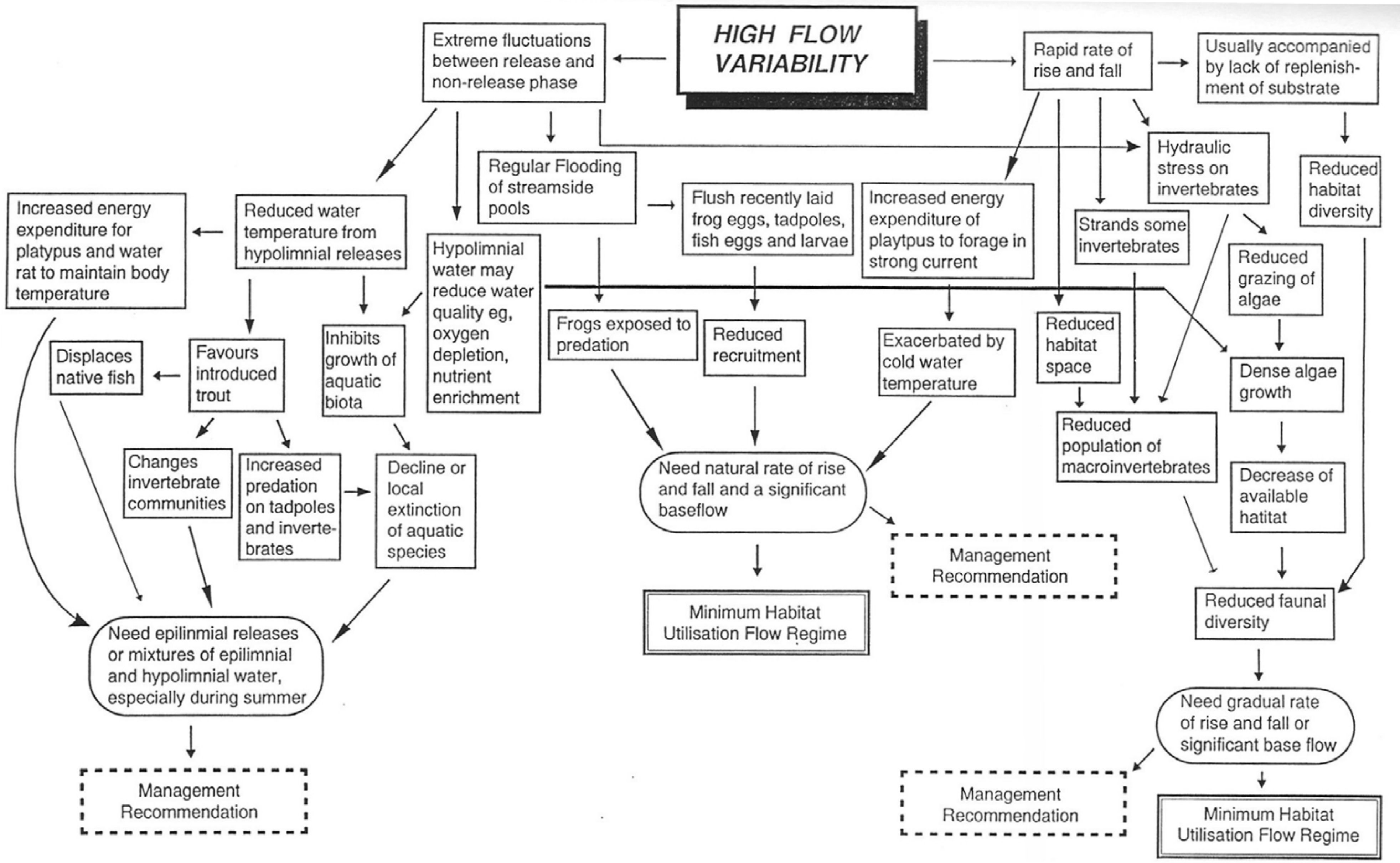


Figure 6. Environmental impacts of high flow variability induced by the scheme.



4.6 IMPACT OF SNOWY MOUNTAINS SCHEME UPON AMPHIBIANS

4.6.1 Distribution, conservation status and ecological requirements of frogs occurring along streams in the Snowy Mountains

There are five obligate stream-breeding frog species which occur in the catchments draining the Snowy Mountains (Gillespie and Hollis, 1996; Hunter and Gillespie, 1999). These species breed exclusively in streams and are mostly restricted to riparian habitats. At least eight other species are identified as facultative stream-breeders within these catchments (Gillespie *et al.,* 1995; Osborne *et al.,* 1996; Victorian and New South Wales Wildlife Atlases) (Table 1). These species breed in stream-side pools or pond habitats along riparian terraces (pers. obs.). However, they also utilise pond habitats away from permanent water courses, and are therefore less dependent upon these environments for maintenance of populations (Hero *et al.,* 1991; pers. obs.).

Table 1 Frog species which breed in lotic or lentic habitats associated with streams draining the Snowy Mountains

Obligate Stream-breeders	Facultative Stream-breeders
Booroolong Frog (*Litoria booroolongensis*)	Common Froglet (*Crinia signifera*)
Blue Mountains Tree Frog (*L. citropa*)	Banjo Frog (*Limnodynastes dumerilii*)
Lesueur's Frog (*L. lesueuri*)	Green and Golden Bell Frog (*Litoria aurea*)
Leaf-green Tree Frog (*L. phyllochroa*)	Brown Tree Frog (*L. ewingii*)
Spotted Tree Frog (*L. spenceri*)	Peron's Tree Frog (*L. peroni*)
	Warty Swamp Frog (*L. raniformis*)
	Whistling Tree Frog (*L. verreauxii*)
	Tablelands Swamp Frog (*L. flavipunctata*)

4.6.1.1. Obligate Stream-breeders

Three species (*Litoria citropa, L. lesueuri* and *L. phyllochroa*) are relatively widespread in south-eastern Australia (NSW and Victorian Wildlife atlases). *Litoria lesueuri* is the most abundant and widespread riverine species within the Snowy Mountains region, occurring in all of the major catchments, except the Tooma and Tumut, up to 1100 m a.s.l. (Hunter and Gillespie, in review). *Litoria phyllochroa* occurs in the Snowy, Upper Murray, Swampy Plains, Goodradigbee and Cotter Rivers (Gillespie and Osborne, 1994; Hunter and Gillespie, in review). Populations in the Goodradigbee and Cotter Rivers are isolated and morphologically distinctive. Further research is required to assess the taxonomic status of these populations. *Litoria citropa* occurs in the Snowy River below 300 m a.s.l (Victorian Wildlife Atlas).

Litoria booroolongensis and *L. spenceri* are rare species. Both have suffered substantial population declines in recent years (Gillespie and Hollis, 1996; Anstis *et al.,* in review; Hunter and Gillespie, in review). *Litoria spenceri* is listed as endangered nationally (ANZECC 1995; Tyler 1997). Two populations occur in the Snowy Mountains: Bogong Creek and the upper Murray River. *Litoria booroolongensis* has recently been provisionally listed as endangered (NSW NPWS Scientific Committee Determination Advice No. 97/27). One population persists in the Goobarragandra River and the species historically occurred in the Tumut River;

however, recent surveys have failed to locate it in this catchment (Hunter and Gillespie, 1999).

The obligate stream breeders all have similar ecological requirements (reviewed by Gillespie, 1997). All species spend a considerable proportion of time as adults in the immediate vicinity of the stream, sheltering and foraging amongst rock habitats or adjacent vegetation. At moderate to high altitudes exposed rocks along the stream margins are used for basking. Only two species, *L. citropa* and *L. lesueuri*, are known to disperse great distances from riparian habitats. All species breed in late spring after the onset of warmer weather and lower stream flows. All species lay their eggs within in-stream pools and larvae develop throughout summer. Juvenile frogs emerge from the water in February or March. *Litoria booroolongensis* and *L. lesueuri* also lay their eggs in isolated stream-side pools where available. Larvae are benthic detritivorous and herbivorous.

Factors which influence larval and juvenile survival are generally considered to be the main regulators of frog populations (Duellman and Trueb, 1996). The main factors which appear to influence larval survival in this species group are water temperature, stream flow and predation. Water temperature regulates growth rate and food productivity. Annual variation in stream temperatures at Bogong Creek has been found to significantly affect tadpole growth rate and onset of metamorphosis (Gillespie, 1997). Tadpoles are dependent upon low reliable stream flows in summer to maintain pool habitats. Unseasonal floods are capable of dislodging eggs and flushing tadpoles. Conversely, extremely low stream flows may result in drying of isolated pools and reduction of in-stream pool habitat availability. This may result in complete mortality of tadpoles in isolated pools, or increased competition and predation in remnant stream pools.

All species are unpalatable to native sympatric fish, such as *Galaxias* and *Gadopsis* sp., but not introduced trout. Introduction and spread of trout has been identified as a major cause of decline of *L. spenceri*, (Gillespie, 1997; Tyler, 1997) and has probably contributed to limiting the distribution and abundance of *L. phyllochroa, L. booroolongensis* and *L. lesueuri* at moderate to high altitudes in the Snowy Mountains (Gillespie, 1997).

Other factors which may adversely affect obligate stream breeding frogs are increased sediment loads, nutrient levels and weed invasion (Gillespie and Hollis, 1996). Increased deposited sediment may blanket stream substrates, limiting oviposition sites and refugia. Development of *L. spenceri* tadpoles has been found to be significantly slowed by increased deposited sediment loads (Gillespie, 1997). This would result in delayed metamorphosis which is likely to reduce juvenile survival. Increased nutrient levels may result in eutrophication which may adversely affect food availability. Changes to macroinvertebrate community composition resulting from increased nutrients may also influence predation pressure from invertebrates or fish. Weed invasion, particularly by Blackberries and Willows, displaces native riparian vegetation which adults utilise for shelter and foraging. Excessive Willow invasion increases stream shading which may reduce water temperatures and food availability, resulting in reduced tadpole growth and survival.

4.6.1.2. Facultative stream breeders

Most of these species are widespread throughout south-eastern Australia, with the exception of members of the *L. aurea* group (*L. aurea*, *L. flavipunctata* and *L. raniformis*). *Litoria aurea* and *L. flavipunctata* are classified as endangered (Tyler, 1997). *Litoria aurea* has declined throughout much of its former range in eastern NSW and disappeared from the Southern

Tablelands and Murrumbidgee catchment (Osborne *et al.,* 1996; Pyke and White, 1996). Populations still persist on the Snowy River flood plain (Gillespie, 1996). *Litoria flavipunctata* has disappeared from the southern tablelands and Murrumbidgee catchment, and may now be extinct (Osborne *et al,.* 1996). *Litoria raniformis* is classified as vulnerable (Tyler, 1997). Many populations have declined throughout its range of inland south-eastern Australia (Tyler, 1997). Populations persist along the flood plain of the Murray River.

While not exclusively dependent upon stream habitats, species within this group may be largely restricted to stream habitats and associated terraces in mountainous areas, due to the limited availability of standing water in these regions. Three species (*L. verreauxii*, *Limnodynastes dumerilii* and *Crinia signifera*) occur along streams throughout the Snowy Mountains up to at least 1700 m a.s.l. These species rarely breed in the flowing stream itself, but rather isolated pools or backwaters within the margins of the water course. All of the species occur at lower altitudes on the flood plains of water courses. Ephemeral ponds, billabongs and ox-bow lakes associated with the flood plains provide important breeding, foraging and refuge habitats in these regions.

Most species appear to be resilient to modification of terrestrial habitats through vegetation clearance and pastoral improvement, provided that suitable aquatic habitats are maintained. They appear to be able to breed in a broad range of temporary and permanent pond habitats. Most can breed throughout the year, taking advantage of seasonal variation in availability of standing water. Exceptions to this are members of the *L. aurea* group which only breed in spring and early summer. Their larval period is often longer than that for the other species; up to 12 months. As such these species tend to breed in permanent, or large, deep pond habitats. Members of the *L. aurea* species group may therefore be more reliant upon winter recharging of billabongs, ox-bow lakes and larger swamps along river flood plains.

4.6.1.3. Bogs and Soaks

The corroboree frog *Pseudophryne corroboree* has a restricted distribution, confined within the Kosciuszko National Park from 1300-1760 m altitudes. The breeding habitat requirements of this species are quite specialised (Osborne, 1988; 1990). Breeding typically occurs in pools or seepages within bog systems. Although not strictly associated with streams, these bog systems are associated with gullies and drainage lines in the alpine and sub-alpine zones. The frogs breed in summer, laying eggs in terrestrial nest sites amongst vegetation. Eggs and tadpoles develop over winter and may take up to nine months to reach metamorphosis. Tadpoles move into nearby pools after hatching to complete their development (Osborne, 1990). A range of physical environmental factors are likely to influence reproductive success of this species, such as winter temperatures, extent of snow cover and persistence of pools over the spring-summer period. Premature drying of pools has been identified as a major source of larval mortality during drought years (Osborne, 1998).

Pseudophryne corroboree has undergone a massive contraction in population size and geographic range over at least the past 15 years (Gillespie *et al.,* 1995; Osborne, 1998, 1989, 1998 in review). The species has now disappeared from at least 70 % of the sites at which it formerly occurred, the decline appears to be continuing, and the species is currently listed as Nationally Endangered (Tyler, 1997). The primary cause of this is unknown, however, drought is believed to be a contributing factor (Osborne and Davis, 1997).

Aqueducts and associated works which exacerbate the effects of drought have probably contributed to localised declines of this species.

4.6.2 Potential impacts of modified stream flows upon frogs

The impacts of modifying stream flows upon amphibian populations has not been documented. Impacts of extreme modification are fairly evident (pers. obs; this assessment; Gillespie and Hollis, 1996; Hunter and Gillespie, 1999). Obligate riverine species are displaced from impounded areas and water courses which are reduced to temporary seasonal flows, i.e. streams which only flow when structures spill or when run off from the remaining catchment is sufficient to produce flows. These stream reaches, typically below dams and intakes, do not flow at all during summer and water is restricted to pools. Based upon what is known of the ecological requirements of riverine frogs in south-eastern Australia, it is likely that other modifications to stream flows, such as increases or decreases in discharge, or changes in the seasonal variability of flows, may have adverse impacts. These changes are likely to have varying impacts, depending upon the species and type of stream habitat.

Some species are known to persist in streams with modified flow, and in some cases modified flow may have benefited populations. For instance, in Bogong Creek, L. spenceri is mostly restricted to a stretch of stream 1.6 km long, below the aqueduct intake and above a series of large waterfalls (Hunter and Gillespie, 1999). The species historically occurred downstream at least to the Alpine Way (Watson *et al*., 1991), and was probably widespread in the Upper Murray catchment. The reduced flow created by the aqueduct off-take, in conjunction with the waterfalls, excludes trout from this section of stream during summer, but provides adequate water for the frogs to breed. The suitability of the site for the frog has probably been enhanced in other ways as well, such as increased water temperatures. Up until recently, this stretch of stream supported much higher densities of *L. spenceri* than any other known population, and is an important refuge for the species. However, the stability of this population is unknown. Historically, every five years in December the aqueduct was closed for maintenance for several weeks, and the water was diverted down Bogong Creek. This is likely to have had a devastating impact upon eggs and larvae. The stream is also prone to flash flooding when the aqueduct overflows during heavy spring rains. Many egg clutches were washed away during such floods in 1995, and recruitment that season was significantly reduced (Gillespie, 1997). The entire population recently disappeared, the cause of which is unknown, but severe flood events in October 1996 can not be ruled out.

Reduced flows during the warmer seasons may not be significantly detrimental to obligate stream breeders, and as illustrated above, may have some benefits, as long as the stream continues to flow. If flows are reduced such that streams cease flowing, then larvae of most species are likely to be adversely affected. Reduced flows during natural peak flow periods may be detrimental to these species. Reduced peak flows may allow build up of sediments and colonisation of the stream channel by vegetation. Increased entrained sediments will reduce availability of oviposition sites and refugia for larvae. Encroachment of vegetation will reduce basking sites for adult frogs, and lower stream temperatures, which may reduce larval growth. Mitigation of winter and spring flood events by dams, such as on the Snowy River, is likely to reduce the maintenance of pond habitats on flood plains. This may reduce the availability of breeding habitat for some pond breeders, such as the *L. aurea* complex. It is possible that some species may benefit from these conditions due to other changes to the ecosystem. For instance, declines of fish populations may increase the availability of suitable breeding habitat for some facultative stream-breeding species. Either way, substantial changes to the amphibian community structure would be expected.

Increased flows during the warmer months, between November and February, are likely to have severe adverse impacts upon amphibian populations. Significant rises in water level and velocity during this period are likely to flush eggs and larvae. Facultative stream breeders are also likely to be affected. Isolated pools in which these species breed may become connected to the stream, resulting in flushing, and exposure to fish predation. Reduced water temperature of sub-surface releases from dams during the summer months is likely to inhibit larval growth and development of obligate stream breeders. These reduced temperatures may also favour introduced trout which may result in increased predation pressure. These factors may have contributed significantly to the decline of *L. booroolongensis* in the Tumut River (Hunter and Gillespie, 1999).

Factors which affect the hydrological maintenance of bog systems are likely to impact upon tadpole survival and recruitment of P. corroboree populations. Construction of aqueducts above corroboree frog habitats in the upper Snowy River catchment are likely to have resulted in the drying out of some important breeding sites, as a result of reduced drainage and lowered water tables (Osborne, 1998 in review). The corroboree frog appears to be locally extinct at several of these sites, although it is not clear if the construction activities caused the frogs to disappear as they have gone from other non-impacted sites in the same region (W. Osborne and D. Hunter, University of Canberra, pers. comm.).

A recent survey of the riverine frog fauna of the Murrumbidgee and Upper Murray catchments in NSW found all species to be uncommon or absent in most streams (Hunter and Gillespie, in review). The modifications to flows of many streams in these catchments may have contributed significantly to this result. Those species which were located below aqueducts or impoundments were generally found in only low numbers. The Bogong Creek population of *L. spenceri* was the only exception to this.

4.6.3 Refuge areas and important streams for frog conservation

Several streams supporting frog populations of high conservation value exist in the region. Bogong Creek below the aqueduct intake is an important refuge for *Litoria spenceri*, although the future viability of the population is unknown. This species has also been recorded in the Upper Murray River, upstream from reaches with modified flows. The Goobarragandra River has a natural flow regime, and it supports one of the few remaining populations of *L. booroolongensis*. The gorge section on the Goodradigbee River and the Cotter River above Bendora Dam support isolated remnant populations of *L. phyllochroa* (Hunter and Gillespie, 1999).

4.7 IMPACT OF SNOWY MOUNTAINS SCHEME UPON MACROINVERTEBRATES

4.7.1 The stream invertebrates of the Snowy Mountains region.

In this region there are two common stream types: i) stony upland streams with steep gradients and rapid turbulent flow (e.g. Snowy and Tumut Rivers); and ii) plateau streams with lower gradients and a series of large pools linked by short runs and/or riffles (e.g. Gungarlin and Eucumbene Rivers). Such streams are cool (5-15^{o}C), with high dissolved oxygen concentrations, low nutrient levels, and low conductivities (Campbell *et al.,* 1986).

There is no comprehensive account of the stream invertebrate fauna of the Snowy Mountains region. Studies have been done on the macroinvertebrates of the Snowy River, mostly below Jindabyne Dam (Grimes *et al.,* 1995), and the Thredbo River (eg. McKaige, 1986; Tiller, 1988; Parsons and Norris, 1992; Williams and Norris, 1995). The invertebrate fauna is strongly dominated by insects, with oligochaete annelids and crustaceans (amphipods) being important minor components. Many elements of this fauna are of great biogeographical significance, as not only are many species confined to the high altitudes but many groups have Gondwanan affinities (Campbell, 1981). [Gondwana was a supercontinent in the Southern Hemisphere that broke up from the Cretaceous to the Early Cenozoic (135 to 54 million years ago) into the land masses of Australia, Antarctica, South America, New Zealand, India and South Africa. This dispersal of land masses can be reflected in the distribution of plants and animals (eg. aquatic invertebrates). A Gondwanan distribution is where the distribution of a floral or faunal group is linked across southern Australia (including Tasmania), New Zealand, southern South America and southern South Africa (Banarescu, 1990)]. Endemicity of macroinvertebrates is high, for example the stoneflies *Leptoperla curvata* and *L. cacuminis,* and the mayflies *Tasmanophlebia lacuscoerulei* and *Ameletoides lacusalbinae*, are found only in this region (Campbell *et al.,* 1986).

In the insects, the important orders are Plecoptera (stoneflies), Ephemeroptera (mayflies), Trichoptera (caddis flies) and Diptera (true flies). In the stoneflies, four families are important; the Eustheniidae, the Austroperlidae, the Notonemouridae and the Gripopterygidae, with the latter being most common and widespread in the Snowy Mountains. Mayflies are especially abundant with members of the family Leptophlebiidae being particularly common and widespread. Other families of note include the Baetidae, the Oniscogastridae**,** the Coloburiscidae and the Ameletopsidae. The caddis flies are represented in the region by a wide array of families, including the Hydrobiosidae, the Hydropsychidae, the Leptoceridae, the Conoesucidae, the Philopotamidae, the Calocidae, the Philorheithridae and the Limnephilidae. As for most freshwater habitats, Diptera are well represented, with chironomids being abundant with many species. The dipteran family Blephariceridae is of note, being found mainly in fast-flowing montane torrents and grazing on epilithic algae at high current speeds.

4.7.2 Effects of river regulation on invertebrate fauna.

River regulation may basically have two major effects on the invertebrate fauna of a river. Firstly, there is faunal depletion. Regulated flows are usually substantially different in quantity, quality and periodicity from those flows that had occurred naturally. The new flows may lead to simplification and loss of physical habitat and of flow complexity, both leading to a loss of habitat complexity and heterogeneity (Petts, 1984; Boon, 1988; Allan, 1995). Water quality may be degraded by the release of hypolimnial water from the bottom of the dam (Gore, 1994; Allan, 1995). Such water may be cold, depleted in oxygen, and rich in nutrients, sulphides and metals. Regulation may also greatly reduce the normal movements of fauna in the river, as dams and weirs act as barriers to both upstream and downstream faunal movements. The Tooma River below Tooma Dam is an example of this situation: below the dam the fauna is depleted due to a loss of faunal input from upstream. Regulation may give rise to highly unnatural changes in flow. If the river below the dam is being used to supply irrigation water, the normal high winter-spring flows may become low due to storage demands and the natural low summer flows are replaced by high flow volumes of cold irrigation water (eg. Doeg, 1987). This occurs in the Tumut River below Blowering Dam and the Murray River below Khancoban pondage. If the river is below a hydro-electric dam it may be subjected to rapid level changes due to electricity generation demands. Such dramatic flow configurations are very difficult for a normal river fauna to survive in successfully (e.g. Trotzky and Gregory, 1974; Toelstrup and Hergenrader, 1990; Camargo and Garcia de Jalon, 1995). This condition occurs, for example, in the Snowy River below Guthega power station. All of the deleterious changes detailed above result in a depleted invertebrate fauna.

Secondly, river regulation results in faunal replacement. Regulation is often accompanied by water abstraction and diversion, leading to reduced flow volume in stream channels below dams. Thus a normally fast flowing, turbulent, cold montane river may be transformed into a slow moving series of pools that are warm and algae-rich in summer and may even become oxygen depleted. Such conditions favour a lentic fauna or a fauna characteristic of slow-flowing streams at a much lower altitude (Brittain and Saltveit, 1989; Harper, 1992). This situation is found, for example, in the Snowy River below Island Bend and in the Eucumbene River below Eucumbene Dam. If the flow reduction is very severe, a normal perennial river may be reduced to an intermittent trickle that harbours a fauna typical of temporary streams (e.g. Boulton and Suter, 1986). Such a situation occurs in the Gungarlin River below the Aqueduct.

4.8 IMPACT OF SNOWY MOUNTAINS SCHEME UPON FISH

Headwater streams of the eastern and western drainages of the Snowy Mountains support only four native fish species. These are the shortfinned eel, *Anguilla australis*; longfinned eel, *Anguilla reinhardtii*; mountain galaxias, *Galaxias olidus*; and two-spined blackfish, *Gadopsis bispinosus.* The eels occur only in the eastern (Snowy River) watershed, while the two-spined blackfish only lives in western-flowing streams. Mountain galaxias live on both sides of the Great Divide. Two more native fish species live in river reaches close to the Snowy Mountains, and may have lived within the area itself before it was affected by the establishment of alien fish species. These fish are the Macquarie perch, *Macquaria australasica*, and the trout cod, *Maccullochella macquariensis*. Both are threatened species and protected from fishing. The two eel species are commercially exploited in coastal areas.

Eight alien fish now also live in the area: Rainbow trout, *Oncorhynchus mykiss*; Brown trout, *Salmo trutta*; Brook char, *Salvelinus fontinalis*; Atlantic salmon, *Salmo salar*; Goldfish, *Carassius auratus*; Oriental weatherloach, *Misgurnus anguillicaudatus*; Gambusia, *Gambusia holbrooki*; and Redfin perch, *Perca fluviatilis*. The four salmonid species (*i.e.* the trouts, salmon and char) support a valuable recreational-fishing industry and are maintained in many waters by hatchery stocking, while the other fish include important pest species, particularly redfin perch and gambusia.

The ecology and life-history of the native fishes are fairly well known. All are predatory, with the eels, perch and cod eating prey such as insect larvae, shrimps and yabbies and smaller fish. Blackfish and galaxias also eat smaller insects and crustaceans, with the galaxias feeding extensively on small animals falling into the water from the riparian zone.

All freshwater native fish have some need to travel within their stream environments, and some make long-distance migrations. Eels, for example, travel enormously long and extraordinarily difficult pathways in completing their life cycles. The spawning grounds are in deep-sea areas north of Australia and the larvae migrate on ocean currents before metamorphosing as they enter estuaries and commencing to climb up the rivers, where they live for many decades before returning to the ocean to spawn and then die. In Lake Eucumbene, which blocked all such migrations, there are still significant numbers of eels that must now be over 45-50 years old. As juvenile eels are no longer able to migrate upstream, when this remnant population dies out the species will become locally extinct. The other native species make smaller-scale movements associated with dispersal from spawning and nursery areas, establishing territories and breeding. The short-term consequences of blocking these movements are generally evident as population declines and contraction of the range of distribution. In the longer term, barriers to migration affect the flow of genetic material within populations, fragmenting them and limiting their capacity to adapt to changing environments.

The native fish have distinctive breeding behaviour. Blackfish spawn in nests in submerged timber or under rocks, and guard the eggs and larvae during their development. Macquarie perch shed their eggs in fast-flowing riffles above pools and, like trout, require clean, well-oxygenated gravels for the successful development of their young. Galaxias lay adhesive clumps of eggs in riffles also, and they have similar requirements for successful spawning.

Water-resource development in the Snowy Mountains has profoundly affected the native fish. Extensive stream habitats have been almost totally eliminated by stream diversion. This has occurred in the Snowy River below Guthega Dam, the Tooma River below Tooma Dam, and the Tumut River below Tumut Pond Dam. Many small headwater creeks have also been diverted, leaving dry channels below. Further downstream from the dams, some habitat values are restored but many ecologically important attributes, such as the streamflow and temperature regimes, condition of the substrates, or interactions with the riparian zone are severely disturbed. The lack of flow in the Eucumbene River below the dam has so grossly disrupted the stream habitat that it now appears virtually devoid of fish. Many of the disturbed river reaches are prone to further invasion by alien pest fish species, especially Redfin perch, Oriental weatherloach, Gambusia and even the major pest fish, Carp.

Much of the natural stream habitat has been submerged under the water storages which support large trout populations at the expense of native fish. Native fish have been unable to survive in these altered environments. Also, because the dams provide refuges for trout, predation on native fish and competition between trout and native fish are increased in the riverine zones upstream of the dams.

The principles which need to be followed in rehabilitating Snowy Mountains streams for native fish are clear. Sufficient flows need to be returned to the rivers to restore ecological functioning. The essential elements of the rehabilitated streamflow regime include suitable flows for continuous habitat utilisation and food-web production, and for interaction between the channel and riparian vegetation. Periodic high flows are needed to clean substrates, control pest fish, redistribute populations and facilitate gene-flow. The adverse effects of some stream barriers may need to be offset by transporting migrating fish such as eels or by providing fishways. Major weed-control works are needed in reaches such as the lower Eucumbene and Tumut rivers, where Willows have flourished in the altered conditions, modifying the riparian zone and destroying important food sources for fish.

4.9 IMPACT OF SNOWY MOUNTAINS SCHEME UPON OTHER VERTEBRATES

There are several vertebrate species in the Snowy Mountains besides frogs and fish that utilise stream environments and may be affected by the Scheme. These include the platypus, water rat, eastern water dragon and Murray long-necked tortoise.

Flow regulation in the Snowy Mountains is likely to impact platypus (*Ornithorhynchus anatinus*) populations in a number of ways. The release of water for irrigation during the naturally low summer flow period can flood burrows and cause mortality of young lactating platypus, thereby reducing breeding success (Scott and Grant, 1997). The platypus must also expend extra energy to forage in the strong current during irrigation releases, and this energy expenditure is exacerbated by the cold water temperature. Riparian vegetation provides cover for platypus when moving between the water and its burrow (Scott and Grant, 1997). Isolation of the channel from riparian vegetation in many river reaches of the Snowy Mountains increases the risk of predation on platypus.

Other impacts of flow regulation on platypus are indirect. For example, macroinvertebrates are the main component of the platypus diet. Macroinvertebrate abundance is reduced through sedimentation, low winter and spring flows, cold water releases from dams, and high flows released for irrigation during summer. These impacts of flow regulation on macroinvertebrate abundance have a secondary impact of reducing availability for platypus (Scott and Grant, 1997). Another secondary impact occurs in many river reaches in the Snowy Mountains where flow regulation has reduced the river to a series of isolated pools (e.g. Snowy River), resulting in reduced riffle areas. Firstly, this has the direct impact of reducing valuable riffle foraging areas, and this has the indirect effect of reduced food availability for the platypus (since riffles are the most productive habitat for macroinvertebrates - Gippel and Stewardson, 1998), and may reduce reproductive success in the platypus (Scott and Grant, 1997).

The fragmentation of stream habitats caused by flow regulation may have a significant impact on platypus populations. Platypus occur at such low population densities in most of their habitat that their populations are unlikely to persist in isolation from other populations, even in large streams (Serena, 1995). Therefore, platypus habitat needs to be conserved throughout the entire catchment, not in isolated river reaches (Scott and Grant, 1997).

The water rat (*Hydromys chrysogaster*) is another vertebrate species in the Snowy Mountains. It is a highly adaptive animal that is able to utilise a range of environments and move overland to other habitats, and has a diverse and opportunistic diet (Scott and Grant, 1997). It is therefore not as restricted in terms of habitat and diet as the platypus, so is not greatly affected by flow regulation impacts and can benefit from flow regulation in some situations. It is, however, similarly impacted to the platypus by the release of cold water from storages, in terms of increased energy expenditure, and is also prone to predation in reaches where the stream is isolated from riparian vegetation (Scott and Grant, 1997).

The Eastern Water Dragon (*Physignathus lesueurii howittii*) occurs in the Murrumbidgee catchment, extending up the Tumut River to below the Tumut power station. It also occurs along the Snowy River below Lake Jindabyne. Flow regulation in the Snowy Mountains may impact water dragon populations in ways similar to the platypus. Changes to invertebrate abundance resulting from flow modification may result in reduced food availability. Reduced flow and subsequent encroachment of riparian vegetation into the channel will reduce availability of basking sites and increase fragmentation of suitable stream habitat.

The Long-necked Tortoise (Chelodina longicollis) occurs along the lower broad river valleys of the Murray, Murrumbidgee and Snowy catchments. This species appears to be fairly adaptive and is able to utilise a range of modified aquatic environments, including farm dams. It also able to disperse overland, and persist in modified rural environments (G. Gillespie pers. obs.). Flow regulation in the Snowy Mountains is unlikely to significantly impact this species.

Figure 7. Murrumbidgee River below Tantangara Dam, showing the transformation from a Montane river to a wetland and the invasion of vegetation resulting from flood flow suppression.

Figure 8. Snowy River below Island Bend Dam at the confluence with the Gangarlin River. Note the dewatered channel and isolation of remaining stream from riparian vegetation.

Figure 9. Snowy River below Guthega Dam, showing the lack of vegetation encroachment of the pre-regulation channel and the lack of provision of any environmental flow.

Figure 10. Eucumbene River below Eucumbene Dam showing the active channel contraction and invasion by willows. The fenced off area indicates benefits of reduced grazing pressure on riparian vegetation health.

Figure 11. Geehi River above Geehi Dam, showing the high energy environment, even under low summer flow, producing well oxygenated water and high habitat heterogeneity.

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Figure 12. Geehi River below Geehi Dam, showing the channel which has undergone 75% contraction since flow regulation.

Figure 13. Geehi River at Reeds Flat where residual catchment flows have sustained reasonable habitat, but low flows and the open channel result in high summer water temperatures.

Figure 14. Snowy River below Island Bend Dam, showing remnant pool. Reconnection of these pools will be an important benefit of environmental flows. Note also the very large original channel.

Figure 15. Goodradigbee River, approximately 5 kilometres below aqueduct, showing few impacts of regulation and excellent connection of the stream with the riparian vegetation.

Figure 16. Tooma River below Tooma Dam where the pre-regulation channel is difficult to discern and fine silt covers the remaining substrate.

Figure 17. Gangarlin River above aqueduct showing both the low energy conditions of the open plains and the high energy environment of the gorge.

Figure 18. Tumut River, showing the severe channel atrophy and the dominance of willows.

5 Summary of Findings

The characteristics of each river reach assessed by the Panel are summarised below and in Appendix 1.

5.1 SNOWY RIVER BELOW GUTHEGA DAM

This reach was extremely difficult to access, by either helicopter or walking. The only accessible site was downstream of a scree slope composed of tunnel spoil from an adit that was deposited during the construction phase of the Scheme. This was impacting on the site to some degree.

5.1.1 Scheme structures and operation

Guthega Dam was constructed in 1955. It impounds the Snowy River and diverts all low to medium flows to the Guthega Pressure Tunnel, which feeds into Guthega Power Station approximately six kilometers downstream of the dam (SMA, 1993). Tributaries downstream of the pondage and the power station are also diverted into the pondage or the pressure tunnel (through the surge tank) via aqueduct systems.

Due to its limited storage capacity, Guthega spills under high runoff conditions. In the 10 years between January 1987 and January 1997, 53 spills occurred, ranging from 600 ML/d to approximately 5 ML/d [DLWC, in prep.(a)]. The dam has a gross storage capacity of 1550 x 10^3m^3 and an active storage capacity of 1280 x 10^3m^3. The addition of flashboards increases gross capacity to 1830 x 10^3m^3 and active storage capacity to 1550 x 10^3m^3. The river outlet structure has a capacity of 49.6 m^3/s which is used for maintenance purposes (such as gate testing or removal of debris) (SMA, 1993; NPWS, pers. comm.). The structure is not operated to provide riparian releases from the dam.

5.1.2 Hydrology and water quality

The reach has severely reduced flows throughout the year [DLWC, in prep.(a):chart 7.3]. Hydraulic variability has been greatly reduced and thermal variation would be more extreme in summer and winter than pre-regulation conditions. Nutrient concentrations are higher because of very low flows.

5.1.3 Geomorphology

The geology of the reach is homogeneous granitoid rocks. The river is very steep (80m/km bed slope at the assessment site) and is characterised by a boulder and bedrock step, rapid and step pool sequence (Grant et al., 1990). It would have been a very high energy environment under natural flows. Supercritical flows over the boulder and bedrock steps are now restricted to narrow sections of the bed. The gravel from the artificial scree slope is subangular and is infilling the boulder steps and step pools at the assessment site. This is likely to occur for some distance downstream of the adit and artificial scree slope which is the source of the angular gravel.

5.1.4 Ecology

The aquatic habitat and biota are largely isolated from the riparian vegetation for much of the reach, because of the reduced flows. Vegetation encroachment of the channel is occurring, but at a very slow rate, due to the lack of substrate and the harsh climatic conditions. The aquatic flora is dominated by macroalgae, mostly Cladophora, Spirogyra and with some Microspora. The macroinvertebrate fauna is dominated by genera which are favoured by still water (lentic) conditions. Low numbers of Brown trout (*Salmo trutta*) but no native fish were observed. The modified flow regime in this reach has created suitable conditions for exotic fish such as Oriental weatherloach (*Misgurnus anguillicaudatus*). No evidence of frogs was observed at this site, but none was expected because the site is above the altitudinal limit of most frog species.

5.2 SNOWY RIVER BELOW GUTHEGA POWER STATION

5.2.1 Scheme structures and operation

Guthega Power Station was completed in 1955 and generates electricity with the waters diverted from Guthega Dam 6 km upstream (SMA, 1993). The dam has a small storage and a limited capacity to regulate flow. Hence, during spring the power station operates continuously at full capacity and the dam spills for extended periods. In the dryer months, all flow is captured and the power station is operated to match peak daily power demand.

5.2.2 Hydrology

The flows in the river between Guthega power station and Island Bend Dam have the same annual flows as under natural conditions, because all water from the upstream catchment is released from the Power Station [DLWC, in prep.(a)]. There are no significant changes to seasonal flows in this reach. However, the pattern of daily flow is highly modified, with a marked diurnal (daily) pattern of flow due to the regular releases from the power station during the peak power demand.

5.2.3 Geomorphology

This reach is also a steep gravel and bedrock channel (26.7m/km bed slope at the assessment site) with boulder and bedrock steps, step pools, rapids, runs, pools and riffles. Large, well vegetated islands are present in slight valley expansions and are composed of large boulders. The islands and boulder steps were formed by very large floods but control the flow, bed sediments and physical habitat at lower flows. A single lichen limit (Erskine *et al*., 1999) is present and is composed of large specimens, indicating that small to moderate floods have not been significantly suppressed. Bedrock is discontinuously exposed in the bed and banks. Dense riparian shrubs usually flank the channel. The bed material is highly variable in grain size, ranging from sand and biogenic veneers to large boulders.

5.2.4 Ecology

The aquatic flora is dominated by prolific and unconsumed Red algae (*Audouinella*) in the main channel, and the presence of aquatic moss in the second channel indicates that fairly stable low flows occur. Native fish are naturally limited in this reach, although eels would have occurred prior to regulation. Only Rainbow trout (*Oncorhynchus mykiss*) were observed. Two species of frog that would be expected at this site under natural flow conditions were not observed. The macroinvertebrate fauna of the main channel was fairly low in abundance and diversity, which would not be expected under natural flow conditions. However, the macroinvertebrate fauna in the secondary channel was more abundant and diverse, and reasonably close to the expected community composition for such a stream under natural flows. The backwater condition of the secondary channel may prevent the channel from being exposed to the effects of the rapid flow changes created by electricity generation at Guthega power station.

5.3 SNOWY RIVER BELOW ISLAND BEND DAM

5.3.1 Scheme structures and operation

Island Bend Dam impounds the headwaters of the Snowy River, either released directly from Guthega Dam or via the power station. Water is then diverted via the Snowy-Geehi Tunnel to Geehi reservoir, or via the Eucumbene-Snowy Tunnel to Lake Eucumbene. Island Bend Dam has a storage capacity of 3020 x 103m3, and a river outlet structure comprising of two outlets each of which has a release capacity of 28.3 m3/s. Water is only released from the river outlet works for maintenance purposes, (NPWS, pers. comm.), and no riparian releases are made. The dam is operated to minimise discharge over the spillway, but spills are common because the dam storage is small. Forty-five spills occurred in the 10½ year period between April 1986 and October 1996, with discharges ranging from approximately 1800 ML/d to less than 5 ML/d [DLWC, in prep.(a): chart 8.4].

5.3.2 Hydrology and water quality

Diversion of the Snowy River headwaters to the Snowy-Geehi and Eucumbene-Snowy tunnels has greatly reduced river flows in this reach [SMA, 1993; DLWC, in prep.(a): chart 7.4]. Flows also lack seasonal variation. Water temperatures (especially in summer) and nutrient levels are higher than they would have been under natural flow conditions.

5.3.3 Geomorphology

This reach is also a steep gravel and bedrock channel (17.8 m/km bed slope) with boulder and bedrock steps, step pools, rapids, runs and pools. Lack of flow and flood suppression have resulted in vegetation invasion by *Carex*, *Leptospermum* and *Eucalyptus*, and the exposure of most of the former river bed. The channel has been dewatered along the margins of pools and over most of the boulder and bedrock steps, rapids and runs. Lack of sediment input has constrained channel contraction. Lichens are actively invading exposed bedrock and boulder surfaces closer to the river bed since 1965. Large, well vegetated islands of large boulders and sand are still present but pools are only remnants of their pre-regulation condition. The channel changes direction abruptly at the Gungarlin River junction to follow a fault to Lake Jindabyne.

5.3.4 Ecology

The reduced flows and lack of hydraulic variation has decreased the amount of habitat for native species, and has changed the faunal communities. One lotic frog species, Lesueuri's frog (*Litoria lesueuri*), was present; one lentic species, the Banjo frog (*Limnodynastes* *dummerilii*) has also colonised the reach. The macroinvertebrate community is suggestive of a lowland to lentic environment, and not a fast flowing montane river. Juvenile trout were observed at the site. The changed water quality has encouraged the proliferation of macroalgae, particularly *Cladophora* and *Spirogyra.* Blue-green algae were observed (*Stigeoclonium*), although this may have occurred naturally in the backwaters of this reach during summer low flows. Willow invasion is active in the reach, facilitated by the reduction of floods and high flows.

5.4 GUNGARLIN RIVER

5.4.1 Scheme structure and operation

The Gungarlin Aqueduct captures the headwaters of the Gungarlin River and diverts the water to the Burrungubugge Intake of the Eucumbene-Snowy Tunnel (which diverts the water to Lake Eucumbene). The pipe is 2.44 metres in diameter and has a discharge capacity of 14.7 m3/s (SMA, 1993). No flow is released from the Gungarlin River Aqueduct except for maintenance (NPWS, pers. comm.)

5.4.2 Hydrology and water quality

Streamflows below the aqueduct are severely reduced, being derived only from groundwater and small tributaries entering the river below the aqueduct. Flows are low in all seasons and there are limited spills. Temperature variations would be greater than under natural conditions.

5.4.3 Geomorphology

The reach above the aqueduct is characterised by an upland pool, riffle, run stream with an alluvial floodplain, changing to a steep mountain torrent near the diversion weir. The assessment site was located at the transition from upland to gorge. It exhibited a large pool with submerged macrophytes, muddy bed sediments, and large boulders scattered through the gravel and sand riffle. The sandy banks were often undercut and commonly covered with shrubs. Active bank erosion was occurring at the assessment site due to disturbance by stock.

The reach below the aqueduct has a very steep gradient and is a shrunken high energy stream with bedrock falls, boulder steps and step pools. Reduced flows result in trickles over boulder steps instead of energetic supercritical flows producing hydraulic jumps in the downstream step pool. Biogenic sediment veneers cover most of the bed surface. Two lichen limits of the foliose *Xanthoparmelia* sp. are present with the higher limit being composed of much larger lichens (thallus diameters > 133mm) than the lower limit (thallus diameters < 92 mm). This colonisation closer to the bed is caused by flood suppression (Erskine *et al*., 1999).

5.4.4 Ecology

The site upstream of the aqueduct had good interaction with riparian vegetation and a diversity of habitat. There were abundant macrophytes (*Potamogeton* and *Myriophyllum*), and very little macroalgae apart from blue-green algae (*Rivularia*) nodules on the *Potamogeton* stems. The macroinvertebrate fauna was diverse, with many grazing and predatory species, and represented a montane lentic fauna which is expected for this low gradient site. There were Whistling tree frog tadpoles (*Litoria verreauxii*) in the stream. The presence of this lentic species was probably due to the protection provided by the macrophytes from predatory trout. Galaxiids (*Galaxias* sp.*)* were expected but were not present, and there were abundant populations of Brown and Rainbow trout.

The assessment site downstream of the aqueduct had no riparian vegetation interaction and poor habitat, given the severity of the sedimentation and lack of woody debris (both due to the reduction of flushing flows). The macroinvertebrate community lacked diversity and abundance and was typical of the fauna that would be expected in an ephemeral stream, not in a high energy montane stream in a high rainfall area. Trout were sampled at this site, and no Galaxiids, however Galaxiids were not expected to have occurred here under natural flows because the conditions would have been too torrential. There were abundant Lesueuri's frog tadpoles that probably reflect the absence of trout, higher water temperatures and lower flows.

5.5 EUCUMBENE RIVER UPSTREAM OF EUCUMBENE DAM

A site approximately 1 km above Lake Eucumbene top-water was chosen as a comparison site for the Eucumbene River below the dam. However, the field assessment revealed that the selected site is occasionally influenced by backwater from the lake. An alternative site approximately 8 km above the dam was therefore selected during the Panel assessment as an unregulated comparison site. This site was in a frost hollow above a gorge. The upstream site is not directly comparable to the two sites below the dam because of the differences in landform, vegetation and natural flow characteristics, but there were no better alternatives.

5.5.1 Scheme structures and operation

The two assessment sites are unregulated. The only influence of the Scheme upstream of the lake is the impact of backwater when the lake water level is high.

5.5.2 Hydrology

Flow is unregulated at the upstream site, therefore it has natural seasonal and daily variability, prolonged high flows during the snowmelt period and occasional flushing flows after storms.

The backwater site has some disruption to normal flows in that water levels are higher when the lake backwaters rise, however the timing or frequency of this is unknown.

5.5.3 Geomorphology

The upstream site was located in an upland valley and was characterised by riffles, runs and long shallow pools. Cobbles and boulders were present on the riffles. Low, gently sloping banks marked the transition to the floodplain and were vegetated with *Carex*. Submerged macrophytes were growing in pools and runs.

The backwater site was characterised by a fairly low energy pool, riffle, run sequence at the lower end and a high energy boulder step, step pool and run sequence further upstream. A floodplain was present on the left bank and bedrock was occasionally exposed in the right bank and in the bed. Cobbles and boulders were only occasionally veneered by thin biogenic sediments. *Carex* flanked the channel below a Tea-tree fringe. There were no indications of channel contraction or vegetation invasion at either site.

5.5.4 Ecology

Time constraints allowed the assessment only of macroinvertebrates at the upstream site, and these were found to have the diversity and abundance expected of a montane river. Riffle and edge habitats were quite diverse and there was abundant organic matter and *Myriophyllum.* Bankside vegetation consisted of alpine meadows dominated by *Carex.*

There was abundant clumps of *Carex* at the backwater site, and also Red algae. The macroinvertebrate fauna had a low diversity with high numbers of oligochaete worms in the pools. This may be due to pollution from stock access, and/or high water temperatures may have stimulated the hatching of insect larvae. Backwater from the lake has drowned numerous eucalyptus trees at this site.

5.6 EUCUMBENE RIVER BELOW EUCUMBENE DAM

There were two assessment sites downstream of the dam. These were approximately 9 and 22 km downstream of Eucumbene Dam. The sites are discussed together here because they were found to be very similar.

5.6.1 Scheme structure and operation

Eucumbene Dam is the major storage in the Scheme, receiving and regulating the headwaters of five rivers.

The waters of the Snowy River are transferred from Island Bend when storage is required, by the Eucumbene-Snowy Tunnel to Lake Eucumbene (SMA, 1993). Equivalent flows are later transferred to the Murray River via Geehi Dam and the Swampy Plains River.

The headwaters of the Upper Murrumbidgee River are diverted to Lake Eucumbene from Tantangara Dam via the Murrumbidgee-Eucumbene Tunnel. These waters and the headwaters of Lake Eucumbene are stored in the lake for diversion to the Tumut River via the Eucumbene-Tumut Tunnel (SMA, 1993).

The waters of the Tooma and Tumut Rivers are diverted to the lake during high flow periods, for storage until the water is diverted elsewhere (SMA, 1993).

Eucumbene Dam was completed in 1958. It has a storage capacity of 4 798 400 x $10^3 m^3$, and a river outlet structure with a capacity of 0.07 m^3/s. There have been no spills since construction of the dam [DLWC, in prep.(a)].

5.6.2 Hydrology and water quality

Almost all flow in the Eucumbene River is captured in Lake Eucumbene and diverted elsewhere. Mean monthly flows in the wettest month (October) prior to dam construction were 50000 ML, now they are less than 2000 ML (i.e. less than 4% of natural flow). Natural mean monthly flows for the driest month (February) were 5,000 ML, now they are less than

500 ML (i.e. less than 10% of natural flow). Flows are similarly reduced across all months, and the natural seasonal variability is severely suppressed [DLWC, in prep.(a)].

The pools in both sites were stratified. Occasional to frequent anoxia occurs in the water column and substrate, because of the lack of flooding and sediment input from catchment disturbance, including grazing.

5.6.3 Geomorphology

The natural channel morphology of both assessment sites has been dramatically altered by the changed flow regime. Remnant pools have been converted into lakes, runs have become shallow pools, and riffles have greatly contracted and become choked with Willows and Willow root mats due to reduced flows and flood suppression. Vegetated channel margins have developed by grass, Carex, Tea-tree and Willow invasion. Siltation and biogenic accumulation on the original cobble bed is severe, and submerged and emergent macrophyte growth is prolific across most of the channel. The cause of the sedimentation is the post-regulation loss of high flows and floods, which is exacerbated by erosion associated with dam construction, channelisation of the reach below the dam and grazing.

5.6.4 Ecology

The ecology of this reach has been highly modified by flow regulation. The reduced flows have facilitated Willow invasion. The macroinvertebrates in all habitats were lentic communities that prefer the modified habitat conditions. There were two frog species in this reach that typically occur in lentic habitats and would not be expected in this river under the natural flow and habitat conditions existing prior to the Scheme. The only organism caught in the fish survey was a small yabbie. Prior to the Scheme, there were Blackfish (*Gadopsis* sp.), Long-finned eels (*Anguilla reinhardtii*), Short-finned eels (*Anguilla australis*), Brown and rainbow trout and Goldfish (*Carassius auratus*) in the Eucumbene River. The abundant growth of Carex and Phragmites in this reach of the river would not have occurred under the natural flow regime.

5.7 GEEHI RIVER ABOVE AND BELOW GEEHI DAM

5.7.1 Scheme structure and operation

Geehi Dam was completed in 1966, impounds 70 % of the Geehi catchment (some of which is diverted from numerous aqueducts) and temporarily stores the water diverted by the Snowy-Geehi tunnel (ie. Snowy River water from either Island Bend Pondage, Lake Jindabyne, or via Lake Eucumbene) (SMA, 1993; NPWS, in prep). The water is then diverted via the Murray 1 Pressure Tunnel to Murray 1 Power Station and discharged to the Murray 2 Dam on Khancoban Back Creek. Geehi Dam has a gross capacity of 21000 x 103m3 and a river outlet structure with a capacity of 42.5 m3/s (SMA, 1993). Water is only released from the river outlet works for maintenance purposes (NPWS, pers. comm.), and no riparian releases are made. There are five years of spill records for Geehi Dam between November 1991 and November 1996, showing two minute spills of 14 ML/d and 26 ML/d [DLWC, in prep.(a): chart 8.2].

5.7.2 Hydrology

Flows in the Geehi River above the dam are typified by prolonged high flows during the snowmelt period, natural seasonal and daily variability, and occasional flood peaks after storms.

The flows released from Geehi Dam are almost negligible, being only for maintenance purposes, therefore all flows in the river below the dam are from groundwater and the residual catchments. In the reach assessed below the dam the flow is severely reduced, and seasonal variability and high flows no longer occur.

5.7.3 Geomorphology

Above the dam, the channel is a very steep, high energy boulder and bedrock river with occasional islands. It has hydrodynamically functioning boulder and bedrock steps and step pools. The substrate is very clean, having only normal summer diatom coverage and ranges from sand to boulders in size. The riparian vegetation interacts closely with the channel. Only one low crustose lichen limit was present.

Below the dam at the bridge site, the channel has undergone approximately 75% contraction due to the reduced flows. It is now adjusted to the post regulation flow regime by the development of in-channel benches within the pre-regulation bed and their invasion by Carex, Tea-tree and Willows. However, the boulder steps are not functioning hydrodynamically under the reduced flows, and siltation of the substrate has occurred. Two crustose lichen limits are present with a high limit of large lichens formed by pre-regulation flows and with a low limit of small lichens adjusted to the post-regulation reduced flows (see Erskine *et al*., 1999). A greater frequency of physical disturbance by floods is required to improve channel conditions.

5.7.4 Ecology

The site upstream of the dam had a diverse riparian plant community. *Chara* was the only macrophyte present. The algal community was made up of considerable amounts of Red algae, with some *Cladophora, Stigeoclonium* and *Ulothrix*. The macroinvertebrate fauna was very diverse and abundant, as expected for such a stream in its natural state. No frogs were found at this site, however none were expected because it is probably above the altitude limit for lotic frogs. Trout were found at this site, but no native fish. The site has good habitat for native fish and the side tributaries have good spawning habitat for native species. Macquarie perch (*Maquaria australasica*) and Trout cod (*Maccullochella maquariensis*) would probably have migrated to this site prior to construction of the Scheme dams.

At the bridge site downstream of the dam, there was filamentous algae on all substrate and surfaces. The macroalgal taxa were *Batrachospermum* and *Cladophora.* The macroinvertebrate community was extremely depauperate, being composed of a small number of species, in low abundance, which tolerate high organic matter load. There were no native fish but considerable numbers of Rainbow trout, which was unexpected given the poor habitat. Frogs would be expected at the altitude of this site, however none were found, probably due to the severely degraded habitat and abundance of trout.

5.8 GEEHI RIVER AT REEDS FLAT

5.8.1 Scheme structure and operation

The Geehi Dam is approximately 19 km upstream of this site, however it still influences the hydrology of this reach, although the impacts of flow regulation are more subtle than at the bridge site.

5.8.2 Hydrology and water quality

There is no long term hydrological data for the assessment site, however there was geomorphological evidence of reduced flows, reduced frequency and duration of flushing flows, and flood attenuation. The Panel considered that residual tributary flows (i.e. those without aqueducts) are probably providing some daily and seasonal flow variability in this reach. The water temperature at this site was elevated.

5.8.3 Geomorphology

This reach of the river is an alternating riffle-run sequence on low slopes and boulder step - step pool sequence on steeper slopes next to mid-channel bars. The channel has contracted by about 20% from its pre-Scheme width, and is adjusting to this smaller width by encroachment of riparian vegetation such as *Carex*, Tea-tree and Willows. Silt accumulation has covered the pebbles and embedded the cobbles along the edges of the channel, indicating that flushing flows are no longer sufficient for entraining cobbles. Furthermore, stoss and lee-side shadow deposits of sand and fine gravel are associated with boulders, indicating that the mobile bed load is now sand and fine gravel instead of the matrix-forming cobbles and boulders.

5.8.4 Ecology

There was reasonably good interaction of the channel with riparian vegetation at this site. There were only two species of macroalgae at this site, Cladophora and Stigeoclonium. The macroinvertebrate fauna was low in abundance and diversity in all habitats, being mostly composed of species that tolerate poor habitat and/or water quality, and more representative of a lowland river than this montane river. Trout were observed at this site, and Blackfish were sampled. It is likely that Macquarie perch and Trout cod were present before flow regulation. Tadpoles of Lesueuri's frog were present in low numbers and the Leaf-green tree frog (*Litoria phyllochroa*) is likely to be here, since it is found downstream (Hunter and Gillespie, 1999). The endangered Spotted tree frog (*L. spenceri*) probably occurred here historically, as it is present elsewhere in the Swampy Plain catchment (Hunter and Gillespie, 1999). Flow modifications may have contributed to the decline of this species, but its absence here is probably due mainly to the presence of trout.

5.9 THREE ROCKS CREEK

5.9.1 Scheme structure and operation

Three Rocks Creek is a tributary of the Geehi River approximately 5 km below the dam. Three Rocks Creek aqueduct diverts the creek's water to the dam via Geehi aqueduct. Releases are only made for maintenance purposes and spills are rare.

5.9.2 Hydrology and water quality

The aqueduct diverts the majority of natural flows, and the creek virtually restarts downstream of the weir. This results in severely reduced flows and more extreme temperature variations.

5.9.3 Geomorphology

This is a high energy stream with a boulder step, step pool and boulder field channel. The creek naturally transports sand, so the blockage to flow caused by the weir has led to the formation of a delta in the upstream end of the weir pool. A lot of woody debris has been trapped in the weir pool, preventing its downstream transport. There are localised Scheme impacts of this weir, mainly the dewatered state of the channel and sediment from roadworks below the weir. The geomorphology of the creek below the weir is otherwise little changed by the reduced flows.

5.9.4 Ecology

This stream has remnant cool-temperate rainforest vegetation, and good riparian interaction with the channel. It provides potential remnant habitat for the endangered Spotted tree frog, although no frogs were found at the site. There was very little macroalgae (*Batrachospermum*) above the aqueduct. The macroinvertebrate fauna was diverse, abundant, and as expected for a small, high energy mountain stream. The electrofisher did not function at this site. The only fish identified was a Galaxiid caught in the sweep net with the macroinvertebrate sample.

There was a large amount of *Cladophora* below the aqueduct, however this was considered likely to be a result of nutrient addition from soil disturbance associated with road works. Numerous fish were observed in a pool below the aqueduct and causeway. It was not possible to determine whether these were Galaxiids or trout. The macroinvertebrate fauna was not as diverse as the site above the aqueduct. As for the above site, there were no frogs found.

5.10 TOOMA RIVER ABOVE AND BELOW TOOMA DAM

5.10.1 Scheme structure and operation

Tooma Dam captures the headwaters of the Tooma River, which are then diverted to the Tumut Pond Reservoir via the Tooma-Tumut Tunnel (SMA, 1993). The dam was completed in 1961. It has a gross capacity of 28,100 x $10^3 m^3$ and a river outlet structure with a capacity of 17 m^3/s. Water is only released from the river outlet works for maintenance purposes

(NPWS, pers. comm.), and no riparian releases are made. These releases are less than 100 ML/d [DLWC, in prep.(a): chart 7.7]. One spill occurred in the 10 years between 1986 and 1996, with a flow less than 5 ML/d [DLWC, in prep.(a): chart 8.10].

5.10.2 Hydrology

Flows above the dam are typified by prolonged high flows during the snowmelt period, natural seasonal and daily variability, and occasional flood peaks after storms.

As less than 4% of the original flow volume is released from Tooma Dam, almost all flow in the river below the dam is from groundwater and residual catchments. In the reach below the dam the flow is severely reduced, and seasonal variability and high flows no longer occur. The assessment site was only approximately 1 km below the dam, therefore the impact on flows is more severe than for the sites assessed on other rivers, which were further below dams.

5.10.3 Geomorphology

The site above the dam at the gauging station exhibited a low slope, pool-riffle-run sequence. This is not representative of the high slope boulder step, step pool, rapid and mid-channel bar sequence present upstream and downstream. It was influenced by debris flows from alluvial fans that ponded the upstream channel by forming a coarse gravel bar on the downstream bend. A lot of sand was present in the backwater reach. No vegetation invasion had occurred and there was only one limit of crustose lichens.

Prior to regulation, the reach assessed below the dam was a high energy boulder step system with many boulders, rapids and waterfalls. It is now a series of remnant pools interspersed by short runs through and around boulders, and abandoned secondary channels beside former mid-channel bars. Snow gums and Mountain Plum Pine have colonised the original mid-channel bar and secondary channel, resulting in the loss of divided channels. Potholes in the boulders and high level large woody debris indicate that high energy flows and large floods occurred prior to the Scheme. Two crustose and foliose lichen limits are present with a high limit of large lichens formed by pre-regulation flows and with a low limit of small lichens adjusted to the post-regulation reduced flows (see Erskine *et al*., 1999). This site has been dewatered and is in urgent need of physical disturbance by floods to prevent complete channel atrophy.

5.10.4 Ecology

There was diverse habitat at the upstream site despite the large amount of alluvial sand. Blackfish were observed along with a large trout population of adults and fry. Tadpoles of the Common froglet (*Crinia signifera*) were present in stream side lentic pools. This site is out of the altitude range of lotic species. The macroinvertebrate community was as diverse and productive as expected for a pristine alpine stream.

Habitat was extremely poor at the site downstream of the dam, with the only substrate being large boulders. All smaller substrate was embedded in fine silt. However, there was some *Chara* in the pools. Lichen colonisation was significant, indicating the lack of floods and flushing flows. The diversity of macroinvertebrate fauna was very low, and the absence of certain species indicated the river may stop flowing at times. Only one trout was found during sampling at this site. There were no frogs at this site. Tadpoles of Lesueuri's frog would be expected here. The cause of their absence from the entire catchment (Hunter and Gillespie, 1999) is unclear but may be due to hydrological changes.

5.11 TOOMA RIVER AT MARAGLE POWER LINE ROAD BRIDGE

5.11.1 Scheme structure and operation

The Tooma Dam is approximately 18 km upstream of this site, and still exerts a significant influence on the hydrology.

5.11.2 Hydrology and water quality

Flow volumes are reduced in all seasons, and the natural high spring flows are suppressed. The reduced flow volume has resulted in warmer water temperature than would naturally occur. The absence of many fauna at this site suggested that it may be polluted, therefore benthic sediment samples were taken after the Panel's assessment. Laboratory analysis for a range of metals did not indicate abnormally high levels.

5.11.3 Geomorphology

This is still a high energy environment, despite flood events being suppressed. Boulder and bedrock steps and step pools are present and are forming fast, turbulent flow conditions. The channel has contracted to the reduced flows via vegetation invasion of in-channel benches. Sand is transported through the boulder steps and biogenic veneers are accumulating on the bottom of large structural pools between the steep boulder step sequences. Physical disturbance by floods would prevent continued bench construction and vegetation invasion.

5.11.4 Ecology

This site has good habitat for all biota, except for the warm water temperatures in the pools. The macroinvertebrate fauna was very poor in the pool and very productive and diverse in the riffles, with long-lived species indicating the lack of floods. The lack of lichen encroachment indicates that flushing flows occur here. There were no frogs or tadpoles and very few fish sampled (only two small trout). Frog, native fish and trout populations were expected to be sizeable here, given the observed flow and the availability and quality of habitat.

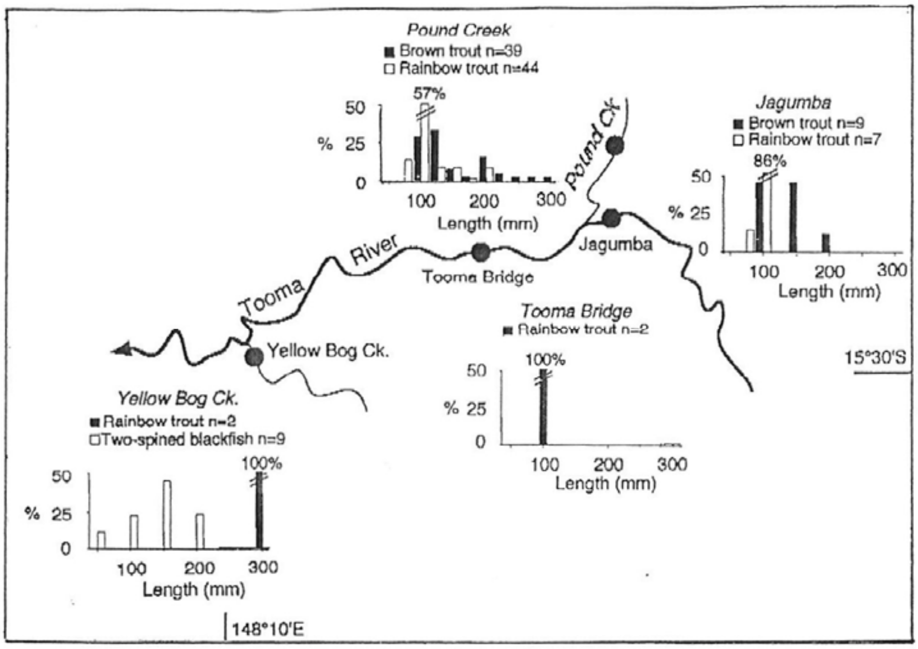
5.11.5 Results of fish surveys on the Tooma River

Routine fish sampling in the Tooma River during the Panel's site assessment in January 1998 showed unusual results. At two river sites over 18 km downstream of Tooma Dam, habitat conditions appeared suitable to sustain a fish community, but very few fish were recorded. Macroinvertebrate sampling reflected some type of ecological disturbance, although evidence of physical disturbance was not apparent.

Because of the Panel's concerns about the condition of this river reach and its potential importance for rehabilitating threatened fish species, fish were re-sampled on 1st and 2nd March 1998. Fish were sampled with standard backpack electrofishing at four sites. Two sites were in the Tooma River (Jagumba and Tooma bridge, see Figure 5.1 below) and one in each of two tributaries, Pound Creek and Yellow Bog Creek. Sediments at the river sites were also sampled for heavy metals analysis.

Results confirmed that there were relatively few fish in the river (total = 18) relative to the tributaries (total = 94), and river fish were all small individuals (Figure 19). The only larger river fish was a Rainbow trout at Jagumba, which was found dead. The results suggest the possibility of occasional loss of fish from the river reach, with replacement of young fish from the creeks between these events. Heavy metal concentrations were within the expected levels and there was no obvious explanation for the apparent ecological disturbance in this reach. Further investigations will be needed to clarify the true condition of the lower Tooma River.

Figure 19. Location of fish and sediment sampling sites in the Tooma River and its tributaries below Tooma Dam. Graphs show the catch numbers and percentage frequency of fish sizes at each site.



5.12 TOOMA RIVER ~200M BELOW NATIONAL PARK BOUNDARY

5.12.1 Scheme structure and operation

The Tooma Dam is approximately 31 km upstream of this site, and still influences flows in this reach, although there is a higher percentage of residual sub-catchments than at the previous site.

5.12.2 Hydrology

About 75% of the natural flow in this reach is captured by Tooma Dam, with 25% of the natural flow remaining due to input from the residual catchments. Flow variability matches natural flow conditions.

5.12.3 Geomorphology

This is a lower energy, straight, channel with a pool-riffle-run sequence dominated by long pools and runs. Siltation of the substrate has occurred but it is not as severe as below the Tumbarumba Creek junction. This reach of the river receives sufficient flows for silt entrainment, therefore the silt accumulation is probably due to stock erosion exceeding the rate at which the flow can flush the silt. Boulders and cobbles dominate in riffles but there is sand overpassing the gravel substrate. Flushing flows are required here to improve the quality of the bed material.

5.12.4 Ecology

This site is approximately 200 metres downstream from the boundary of the National Park, yet it is highly impacted by stock access, with the banks being severely eroded, large amounts of faecal matter on the banks and in the river, and siltation of the substrate. There is limited interaction between the wetted channel and riparian vegetation, the latter existing only on parts of the bank that are fenced off or too steep for stock, and being mostly Willows and Blackberries. The macroinvertebrate fauna was abundant but lacked diversity. The habitat seemed good for native fish, therefore Blackfish and Galaxiids, as well as Smelt (Retropinna semoni) and Carp (Cyprinus carpio), were expected. Only small numbers of Brown trout and yabbies were present. One or two species of frog would have been expected here under natural conditions, however none were observed. This is considered to be due to the siltation of the interstices, clearing of the native riparian vegetation and adjacent forest, and the presence of introduced fish.

5.13 TOOMA RIVER ON FLOODPLAIN

The impacts of flow regulation in this reach are not easily determined because of severe degradation from livestock and landuse in the catchment. Therefore, the Panel's recommendations are integrated land management recommendations.

5.13.1 Scheme structure and operation

The Tooma Dam approximately 40 km upstream of this site, and still influences flows in this reach, although there is a higher percentage of residual sub-catchments than at the previous site.

5.13.2 Hydrology

This is naturally a low energy environment. About 50% of the natural flow in this reach is captured by Tooma Dam, and some flow input is from the Tumbarumba Creek catchment. Flow variability matches natural flow conditions. This site is artificially affected by backwater from the Swampy Plains River due to consistent high flows induced by the Scheme.

5.13.3 Geomorphology

The river has a sinuous channel pattern between Tumbarumba Creek and Greg Greg Bridge, but then changes to anastomosing further downstream. Anastomising rivers exhibit multiple channels separated by floodplain and develop as repeated avulsions (see glossary) (Schumm *et al*., 1996). Detailed analysis of historical surveys and photographs for this study has shown that at least two avulsions have occurred since first settlement. The triggers for these avulsions was the downstream passage of a sand slug that can be traced to the Tumbarumba Creek catchment. As the sand slug migrated through the upstream sinuous reach there were cutoffs, channel straightening and channel widening as predicted by Schumm's (1969) model of river metamorphosis for an increase in sand supply. Sand storage in the former sinuous channel resulted in a decrease in channel capacity and the displacement of flow onto the floodplain, where two channels were cut in relatively continuous depressions at the margin of the floodplain. As predicted by the Erskine *et al*. (1990) and Schumm et al. (1996) model of channel evolution following avulsion, new channels have large capacities, low sinuosity, large meander wavelength and steep gradients, and gradually contract over time as sinuosity increases (Figure 20 and Figure 21). Floodplain waterlogging, tree deaths, sand splay formation and reactivation of old abandoned channels are all associated with these avulsions and the consequent disruption of drainage.

Figure 20. Sketches illustrating a six-stage model of incised-channel evolution. (a) Valley cross section showing old channel prior to development of anabranch by incision; (b) initial incision of new channel in valley; (c) incision and widening of new channel; (d) increased sediment delivery from upstream causes deposition in the incision; (e) channel narrowing and sinuosity increase; (f) channel is raised by deposition and natural levees form. Source**: Schumm *et al*. (1996).**

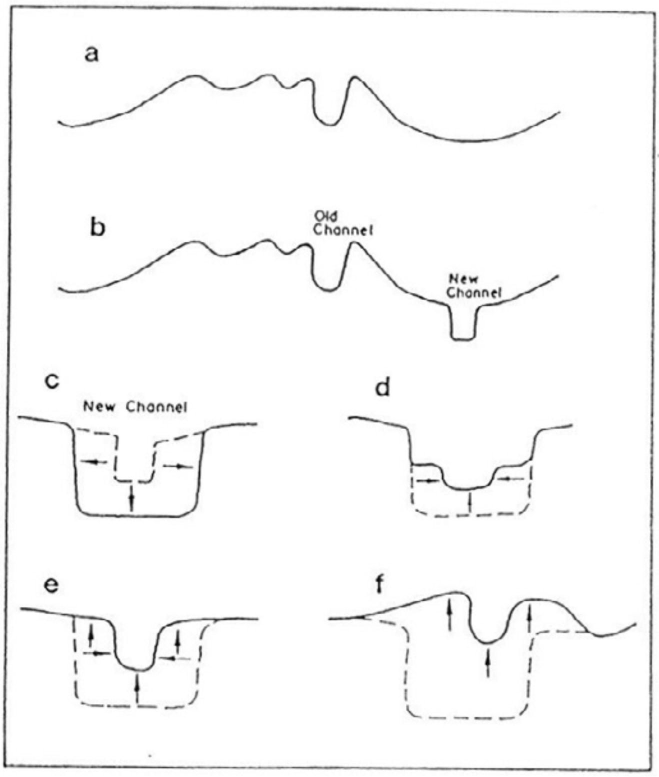
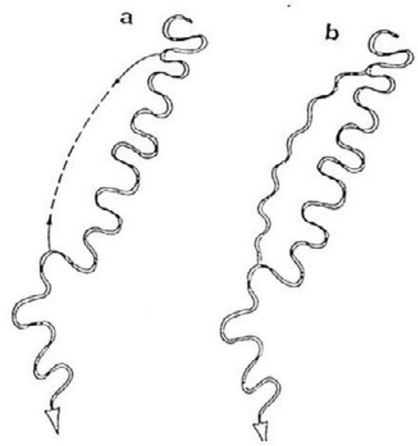


Figure 21. Sketches showing (a) early stage of anabranch development before the up-valley and down-valley segments have joined, and (b) new anabranch bypassing, a sinuous and inefficient reach of the main channel. Source: **Schumm *et al*.(1996).**



Anastomising channels and avulsions are characteristic of floodplain rivers of the Murray-Darling basin (Schumm *et al.,* 1996). What is unusual on the lower Tooma River is that anastomosis and associated avulsions, waterlogging and sedimentation only seem to have occurred since first European settlement. Flow regulation of the Tooma River has reduced the rate of development of anastomosing channels by flood suppression. Control of the sand slug is essential to effect improvement in channel and floodplain conditions. The Panel did not inspect the Tumbarumba Creek catchment, however it appears to be the primary source of the sand because the Tooma River upstream of the confluence exhibits cobble and boulder riffles with sand overpassing. Catchment management works will be required to address the sand supply issue.

5.13.4 Ecology

There are numerous impacts on the ecology of this reach. These include:

I. the input of sand to the river and the immobile sand bed;

II. nutrient enrichment;

III. waterlogging on the floodplain (discussed in previous section);

IV. impairment of important ecological linkages between the river and floodplain;

V. changes to vegetation.

Points i, ii, iv and v are discussed below.

5.13.4.1 Sand

The input of sand to this reach of the river is due mostly to active bank erosion and catchment erosion from livestock and landuse. Tumbarumba Creek appears to be the major sediment source. Other likely sediment sources are erosion gullies, and gold mining in the past is likely to be a contributing factor.

The channel is now composed largely of shifting sand. This provides very poor habitat for macroinvertebrates and native fish, because shifting sand:

- buries substrate;
- grinds organic matter to very small sizes;
- lacks backwaters; and
- has a uniform cross-section.

These are ideal conditions for Carp and Weatherloach. The only habitat for native biota in the channel is isolated patches of bedrock and woody debris, and some detritus on the edge in fenced off areas. The macroinvertebrate fauna on the edge amongst debris had reasonable diversity and abundance, however the macroinvertebrate fauna in the channel was extremely low in abundance and diversity due to the mobile sand bed.

5.13.4.2 Nutrient enrichment

Nutrient enrichment is a major problem in this area, and is caused by:

- nutrients from livestock faeces;
- the loss of riparian and wetland vegetation filters through vegetation clearing and stock damage; and
- sediment addition from erosion banks by channel widening and stock access.

The impacts of this nutrient enrichment are:

- blue-green algal blooms in wetlands (particularly those on the edge of the floodplain) and farm dams;
- low faunal diversity and low abundance; and
- eutrophication.

5.13.4.3 Linkages between the river and floodplain

Linked with the ecology of the river assessment site is that of the nearby wetlands. There are numerous billabongs and oxbow lakes on the floodplain that were observed from the air. These wetlands are greatly impacted by similar land and water management issues as the river. Dead River Red Gums indicate that inundation patterns have been greatly altered. There are blue-green algae blooms in the wetlands furthest from the river on the edge of the floodplain, due to a combination of insufficient flushing and nutrient enrichment from fertiliser use in the catchment. There are up to six species of frog which would have occurred in these wetlands under natural conditions, however sampling was not carried out to verify their presence. There were no frogs at the river assessment site.

There are essential ecological linkages between the river and floodplain that require river flows of suitable magnitude, timing and duration. Such flows are essential for such functions as:

- fish breeding on the floodplain;
- the redistribution of nutrients;
- macroinvertebrate production and diversity; and
- importing woody debris.

It is likely that these important interactions have been severely impaired on the floodplain by flow regulation in the Tooma River.

5.13.4.4 Vegetation changes

There was little riparian vegetation at the assessment site as most has been cleared. There are a few remnant River Red Gums (aged and unhealthy) and some Tea-tree in fenced off areas. Willow and Cottonwood invasion is active and has negative impacts on stream ecosystems (as described for the Eucumbene and Tumut Rivers). River Red Gums on the floodplain are dying because of livestock, clearing and changes to the timing, duration and magnitude of flows.

5.14 HAPPY JACKS RIVER UPSTREAM OF HAPPY JACKS DAM, AND TUMUT RIVER BELOW TUMUT 2 POWER STATION

The unregulated section of Happy Jacks River is similar in most physical, climatic and hydrological characteristics to the adjacent unregulated section of the Tumut River. As Happy Jacks River is more easily accessed that the Tumut River, and given its similarity, it was chosen for the upstream comparison reach for the Tumut River below Tumut 2 power station.

5.14.1 Scheme structure and operation

The first structure on the Tumut River is Happy Jacks Dam, which captures the waters of the Happy Jacks and upper Tumut Rivers for diversion to Lake Eucumbene via the Eucumbene-Tumut Tunnel (SMA, 1993). The dam has a storage capacity of 271 x $10^3 m^3$ and two river outlet structures with a total capacity of 31 m^3/s.

Tumut Pond Reservoir, approximately 3 km below Happy Jacks Dam, collects the waters of the Tumut River below Happy Jacks and the waters diverted through the Eucumbene-Tumut and Tooma-Tumut Tunnels, to provide the head pondage for Tumut 1 Power Station (SMA, 1993). The dam has a storage capacity of 52,800 x $10^3 m^3$, and has two river outlet structures with a total capacity of 200 m^3/s. Water is only released to the river during valve maintenance (NPWS, pers. comm.). Water is diverted to Tumut 1 Power Station, and returned to the Tumut River approximately 6 km below Tumut Pond Dam by Tumut 1 Tailwater Tunnel, which has a capacity of 124.6 m^3/s (SMA, 1993).

This water is captured in Tumut 2 Dam, approximately 9 km below Tumut Pond, to form the head pondage for Tumut 2 Power Station. Tumut 2 Dam has a capacity of 2,700 x $10^3 m^3$. It has two river outlet structures with a total capacity of 170.8 m^3/s (SMA, 1993), but water is only released to the river during valve maintenance (NPWS, pers. comm.). The water is diverted to Tumut 2 Power Station and returned to the Tumut River approximately 16 km below the dam, via Tumut 2 Tailwater Tunnel, which has a capacity of 125 m^3/s (SMA, 1993).

There are three more dams on the Tumut River below Tumut 2. The first is Talbingo Dam which forms the head pondage for the Tumut 3 Power Station. Journama Dam is located downstream of Tumut 3 Power Station and is used to capture flows released during the day (when hydropower is generated). The water is pumped back to Talbingo Dam at night using off peak power. Blowering Dam is downstream of Journama Dam. It stores water for irrigation which is released to the Murrumbidgee River.

5.14.2 Hydrology

The assessment site on Happy Jacks River was above Happy Jacks Dam, therefore flows are unregulated. Streamflow in Happy Jacks and the Upper Tumut River are typified by prolonged high flows during the snowmelt period, natural seasonal and daily variability, and occasional flow peaks after storms.

Flow patterns in all reaches of the Tumut River are highly modified. Flows in most reaches of the Tumut River between Tumut Pond Dam and Talbingo Dam are negligible, because of the diversion of water through the pressure pipelines [DLWC, in prep.(a)]. Tributaries below many of the dams are also diverted. Flows in the Tumut River between Tumut 1 Power Station and Tumut 2 Dam, and between Tumut 2 Power Station and Talbingo Dam, are characterised by reduced flow volumes and rapid rates of rise and fall below Power Station Tailwater Tunnels. Seasonally high flows in winter/spring no longer occur. Flows in the Tumut River below Blowering Dam are increased because of the release of water transferred from the Tooma, Eucumbene and upper Murrumbidgee River, therefore natural low flows no longer occur.

5.14.3 Geomorphology

Happy Jacks River is characterised by a pool-riffle-run sequence, with considerable amounts of bedrock in the channel. Well vegetated mid-channel, boulder bars are also present at the assessment site in the upland valley. Shrubs dominate the riparian vegetation because of the frost hollow and continuously flank the channel.

The Tumut River below Tumut 2 Dam has undergone 75-80% channel contraction since construction and operation of the Scheme. The old secondary channel is now colonised by well established Willows, Blackberries and Tea-tree. Willows are continuing to cause channel contraction. The site has been highly disturbed by bulldozing of the channel in the past. Prior to regulation this was a high energy boulder and bedrock step and step pool channel. The remaining channel is now contracted boulders and bedrock steps and step pools with extensive marginal in-channel benches invaded by vegetation.

5.14.4 Ecology

Happy Jacks River above the dam is a pristine alpine stream. There is good interaction between the channel and native riparian vegetation, and good habitat in the channel and pools with sand through to cobble and bedrock, and macrophytes *Chara* and *Myriophylum.* There was some Red algae on riffle rocks. The macroinvertebrate fauna was diverse and productive. The site is above the altitudinal limit of lotic frogs. There were abundant rainbow trout, but no native fish in the river or a nearby tributary.

Flow regulation has greatly impacted the ecology of the Tumut River below Tumut 2 Dam. Reduced flows have facilitated Willow invasion, which is causing severe channel contraction, Willow root mats are interacting with the hyporhoeic zone, and Willows are shading the stream much more than natural riparian vegetation. Thick *Carex* clumps have invaded the reduced channel and are also creating heavy shading, which is unsuitable for frogs. Willow and other deciduous detritus has accumulated in the pools. The great reduction in stream flows has caused dissolved oxygen depletion in the pools and occasional anoxia. The macroinvertebrate fauna is similar to that of a foothill stream, rather than the montane stream fauna that would have occurred here under natural flows. Rainbow trout, Brown trout and

Redfin perch were found at this site, with no native fish. Blackfish were expected to occur here, so the habitat is probably too degraded. No evidence of frogs was found at the assessment site, which is likely to be due to the habitat lost through sedimentation, the heavy shading, and the presence of three species of introduced fish. Water dragons were observed here which are an important component of the native vertebrate fauna, and will be displaced if the current conditions continue.

5.15 GOODRADIGBEE RIVER BELOW AQUEDUCT

5.15.1 Scheme structure and operation

The Goodradigbee River aqueduct diverts the headwaters of the Goodradigbee River and five other streams to Tantangara Dam on the upper Murrumbidgee River. It has a discharge capacity of 2.8 m^3/s (SMA, 1993).

5.15.2 Hydrology

Flows are negligible below the aqueduct, and are reduced for some distance downstream of the aqueduct. However, tributary inflows below the aqueduct help mitigate the impact of flow diversion, which involves a relatively small portion of the catchment.

5.15.3 Geomorphology

The channel appears unimpacted by flow regulation at the assessment site, which was approximately 5 km below the aqueduct. However impacts closer to the aqueduct were observed from the air. The natural configuration is a pool-rapid sequence with boulder ramps.

5.15.4 Ecology

There was excellent interaction between the channel and riparian vegetation in this reach. There was good habitat diversity, with a cobble bed, diatoms and detritus. The macroinvertebrate fauna was diverse and abundant, although there was an absence of normal riffle fauna, which suggests that flows are reduced in this reach. Galaxiids and Blackfish were expected to occur, however none were sampled. There was a dense population of Rainbow trout. There were no lotic frogs at this site as it is above the altitudinal limit for frogs.

6 Recommendations

The Panel's environmental flow, management and research priorities are presented in this section. The environmental flow recommendations comprise three components:

I. Minimum habitat utilisation flow regime incorporating seasonal variability;

II. Flushing flows; and

III. Channel maintenance flows.

The recommendations for each of these environmental flow components are presented for each river reach. Firstly, for each reach below a dam, a flow duration curve is provided which shows the dam inflows (i.e. natural flows) and target flows (i.e. minimum habitat utilisation flow regime, flushing flows, and channel maintenance flows). The area under each curve shows the volume of inflows and target flows, and gives an indication of the proportion of natural flows that the target flows represent.

Secondly, the monthly minimum habitat utilisation flows are presented. Minimum habitat utilisation flows are defined in Section 3.6.2.1. They vary each month to represent natural flow patterns, and are therefore lowest in summer and highest in spring. The recommended monthly flows are shown in a table for each reach below a dam, and illustrated in a histogram.

Thirdly, flushing and channel maintenance flows are presented. These are defined in Sections 3.6.2.2. and 3.6.2.3. respectively. They are larger flows which are required for short periods of time. These flows will often be provided by adding an additional volume to the highest minimum habitat utilisation flow (i.e. in spring) to reach the target flow. However, in some cases the timing of these flows are recommended in summer for water quality purposes, therefore releases must be additional to the summer minimum habitat utilisation flow.

For all of the recommended flows in this chapter, there are three important rules which must be applied when releasing environmental flows from dams. These are:

1) It is very important that intra- and inter-month variability be incorporated into flow releases so that flows are not artificially constant. Accordingly:

   All monthly flows should be varied on at least a weekly basis;

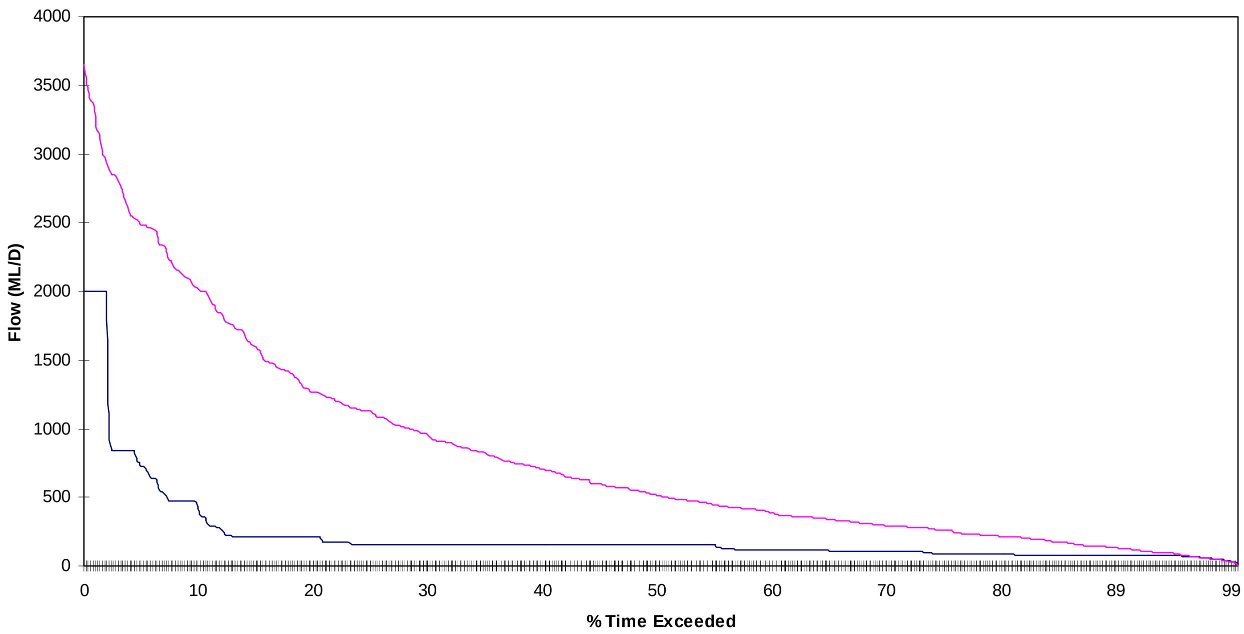
   For months which the June 95th percentile flow is recommended for 3 weeks out of that month, this flow is to be varied on a weekly basis by up to plus or minus 25%.

2) It is very important that short duration high flows (i.e. elevated flows for one week in the spring months, flushing flows and channel maintenance flows) be released in a pattern that represents the natural hydrograph shape. This is because the rates of rise and fall of water level must be natural.

6.1 SNOWY RIVER BELOW GUTHEGA DAM

Figure 22 below is a flow duration curve for dam inflows and target flows, which gives an indication of the proportion of natural flows that the target flows represent (approximately 24% of natural flows, as shown in Figure 23).

Figure 22. Annual flow duration curve for Guthega Dam showing inflows and target flows (including flushing and channel maintenance flows).



6.1.1. Minimum habitat utilisation flow regime

The monthly minimum habitat utilisation flows for Guthega Dam are shown below in Table 2, and illustrated in Figure 23.

The monthly target flows shown in Table 2. for minimum habitat utilisation are as follows:

i) **January, February and March**: 80th percentile flows

ii) **April**: 93rd percentile flow

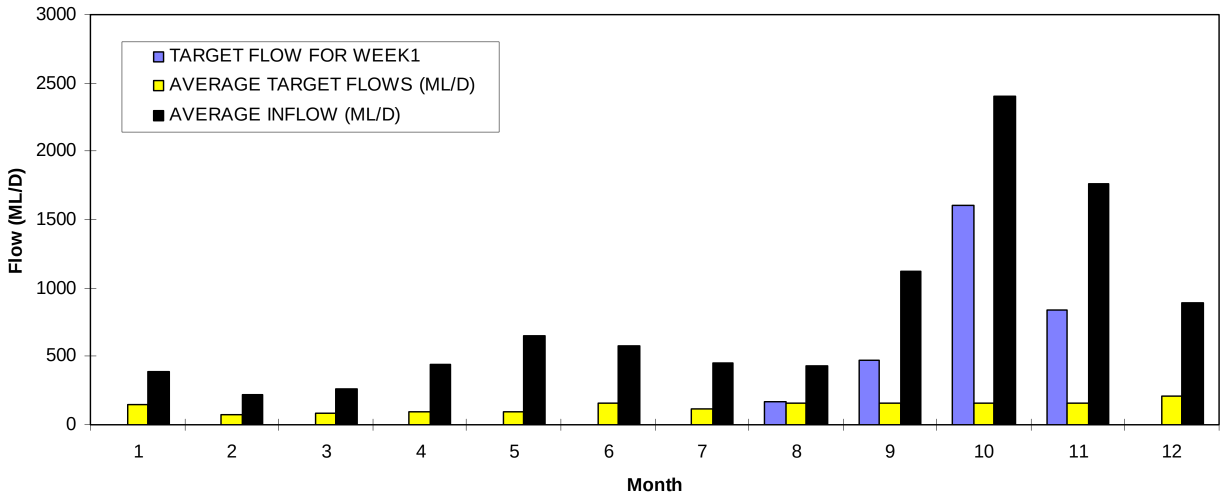
iii) **May, June, July, August and December**: 95th percentile flows

iv) **September, October and November**: 95th percentile flows for 1 week in each month (natural hydrograph shape). Flows in the remaining 3 weeks of each month should be the 95th percentile flow for June (153 ML/d) varied by up to +/- 25% on at least a weekly basis.

Table 2. Monthly target flows and inflows for Guthega Dam. Total annual target flows are shown as percentage of inflows and include flushing and channel maintenance flows.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Annual Target Flows as Percentage Annual Inflow
Target Flows (ML/d)	145	69	82	90	99	153	117	153	153-474	153-1603	153-837	208	24%
Average Inflows (ML/d)	391	222	259	443	653	572	447	428	1126	2404	1759	889	100%

Figure 23. Monthly target flows and inflows for Guthega Dam, showing the release of 95th percentile flows in spring months for one week and June 95th percentile flows for the remainder of these months.



6.1.2 Flushing flows

- These will be provided by the elevated habitat utilisation flow of 1603 Ml/d for one week in October.

6.1.3 Channel maintenance flows

- 1500-2000 ML/d for one week. One event per year is desirable, 2 events in 3 years is essential. These flows may be provided by the elevated minimum habitat utilisation flow of 1603 ML/d for one week in October.

This is based on a flow depth of 0.31m required to entrain 256mm boulders on an 80m/km bed slope. Because of this extremely steep slope, higher flows are not needed for boulder entrainment.

These flows may be also met by dam spills, or by releasing additional volumes during valve maintenance releases.

These flows need to be adaptively managed. If addit gravels are not being redistributed then these flows need to be modified.

6.1.4 Management and research recommendations

1. Feasible options for stabilisation of the scree slope, or its isolation from the river channel, should be investigated.

2. The modification or decommissioning of aqueduct structures should be considered as a possible means of providing, or contributing to, environmental flows for the reach. The existing river outlet works from Guthega Dam would draw water from the hypolimnion when the dam is stratified and may, therefore, require modification to provide flows of an acceptable quality.

6.2 SNOWY RIVER BELOW GUTHEGA POWER STATION

6.2.1 Minimum habitat utilisation flow regime

- The habitat utilisation flow regime recommended for Guthega Dam should meet minimum habitat utilisation flow requirements below Guthega Power Station.

6.2.2 Flushing flows

- This will be provided by the elevated minimum habitat utilisation flow of 1603 ML/d for one week to be released from Guthega Dam.

6.2.3 Channel maintenance flows

- This will be provided by the channel maintenance flow of 1500-2000 Ml/d for one week to be released from Guthega Dam, or may be provided by the elevated minimum habitat utilisation flow of 1603 Ml/d for one week in October.

6.2.4 Management and research recommendations

1. Power station releases need to mimic the natural rate of rise and fall of river height as per pre-regulation flood hydrographs. There are three options for achieving this:

    I. attenuate the releases from Guthega Power Station. This would have a significant economic impact through loss of peak power generation;

    II. conduct river works to increase habitat heterogeneity. This will also increase the habitat availability for grazing invertebrates, which are currently in low numbers. Increased grazer abundance will help control the growth of Red algae, the young filaments of which are consumed.

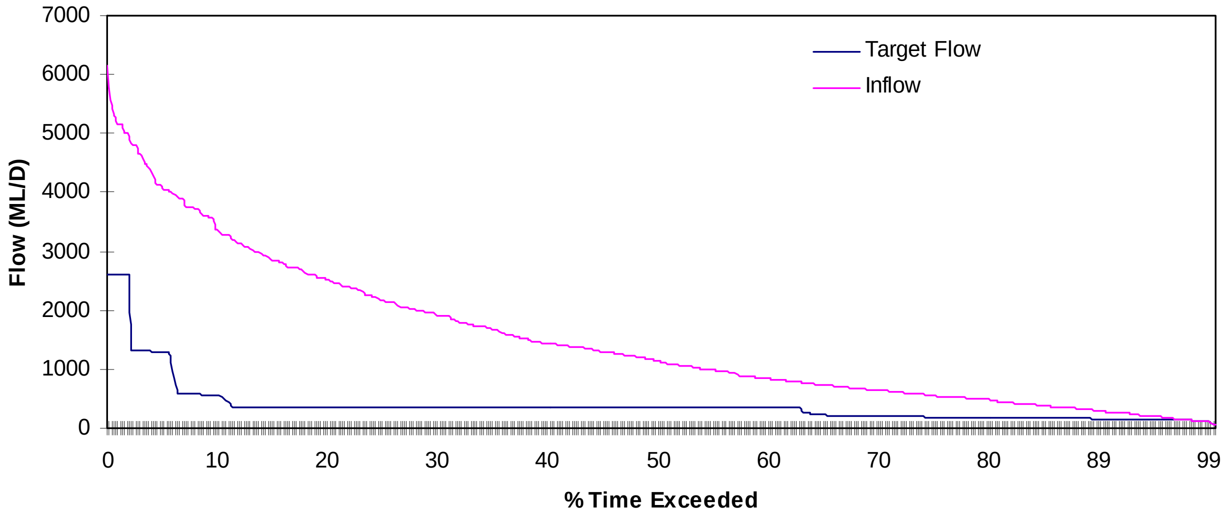
    III. build a re-regulation weir on either the Munyang or Snowy River to attenuate the rate of rise and fall of power station releases. Munyang River is the preferred option as this will not create any disruption to environmental flows from Guthega Dam, although it will require additional works to divert power station releases to Munyang River.

2. The modified flow regime in this reach has created suitable conditions for exotic fish such as Oriental weatherloach. Improved flow management is necessary to prevent invasion by such species.

6.3 SNOWY RIVER BELOW ISLAND BEND DAM

The flow duration curve in Figure 24 for Island Bend Dam shows inflows (i.e. natural flows) and target flows (i.e. minimum habitat utilisation flow regime, flushing flows, and channel maintenance flows).

Figure 24. Annual flow duration curve for Island Bend Dam, showing inflows and target flows (including flushing and channel maintenance flows).



6.3.1 Minimum habitat flow utilisation flow regime

The monthly minimum habitat utilisation flows for Island Bend Dam are shown below in Table 3, and illustrated in Figure 25. The monthly target flows shown in Table 3 for minimum habitat utilisation are as follows:

i) **January, February and March**: 80th percentile flows

ii) **April**: 93rd percentile flow

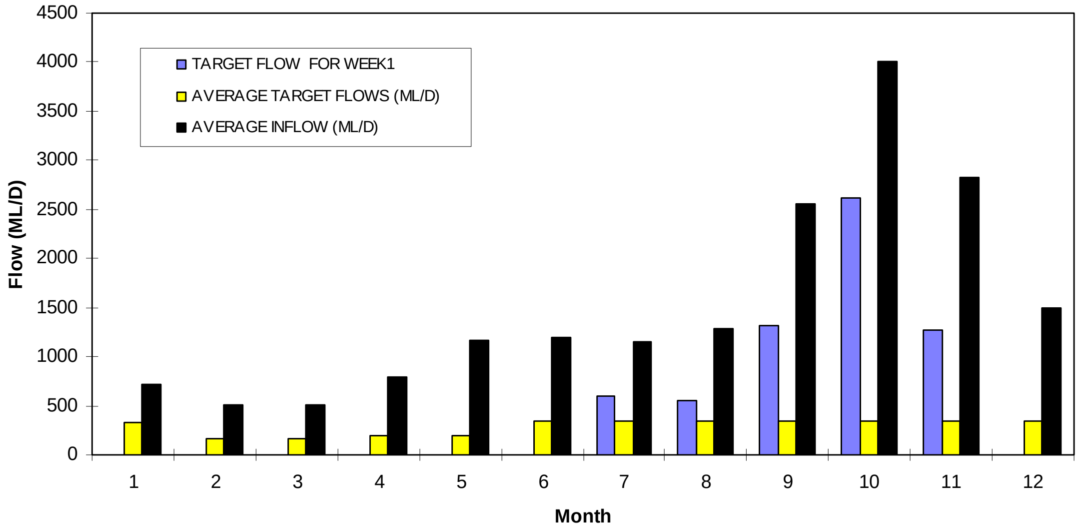
iii) **May, June, and December**: 95th percentile flows

iv) **July, August, September, October and November**: 95th percentile flows for 1 week in each month (natural hydrograph shape). Flows in the remaining 3 weeks of each month should be the 95th percentile flow for June (346 ML/d) varied by up to +/- 25% on at least a weekly basis.

Table 3. Monthly target flows and inflows for Island Bend Dam. Total annual target flows are shown as percentage of inflows and include flushing and channel maintenance flows.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Annual Target Flows as Percentage Annual Inflow
Target Flows (ML/d)	333	166	166	193	200	346	346-595	346-551	346-1314	346-2617	346-1276	340	25%
Average Inflow (ML/d)	721	509	509	794	1159	1195	1149	1284	2564	4000	2828	1494	100%

Figure 25. **Monthly target flows and inflows for Island Bend Dam, showing the release of 95th percentile flows in spring months for one week and June 95th percentile flows for the remainder of these months.**



6.3.2 Flushing flows

- Will be provided by the elevated habitat utilisation flows for one week in each of September (1314 ML/d), October (2617 Ml/d) and November (1276 Ml/d).

6.3.3 Channel maintenance flows

- 5000 ML/d for one week annually.

The flow of 5000 ML/d is based on a compromise between the flow depths needed to entrain 256mm boulders on a bed slope ranging from 17.8-27m/km. These flow depths range from 0.95-1.42m (3300-7700 ML/d) depending on bed slope.

6.3.4 Management recommendations

1. The modified flow regime in this reach has created suitable conditions for exotic fish such as Oriental Weatherloach. Improved flow management is necessary to prevent invasion by such species.

2. Willows should be removed, to slow channel degradation.

6.4 GUNGARLIN RIVER

6.4.1 Flow management recommendation

There are two options for providing environmental flows to the Gungarlin River. Both options will provide flows of suitable timing, magnitude, and duration for minimum habitat utilisation flows, flushing flows and channel maintenance flows.

- Option 1: Remove the aqueduct and return natural flows to the river.
- Option 2: Release 20-30% of inflows as passing flows.

Option 1 is considered highly desirable because it will provide flows with seasonality and natural variability to a portion of the Snowy River below Island Bend. It will also have the advantage of providing water without the quality problems associated with releases from Island bend Dam. Another advantage of Option 1 is that it will provide valuable connectivity between part of the Snowy River below Island Bend Dam, and the upper Gungarlin River which is in an alpine area.

6.4.2 Research recommendations

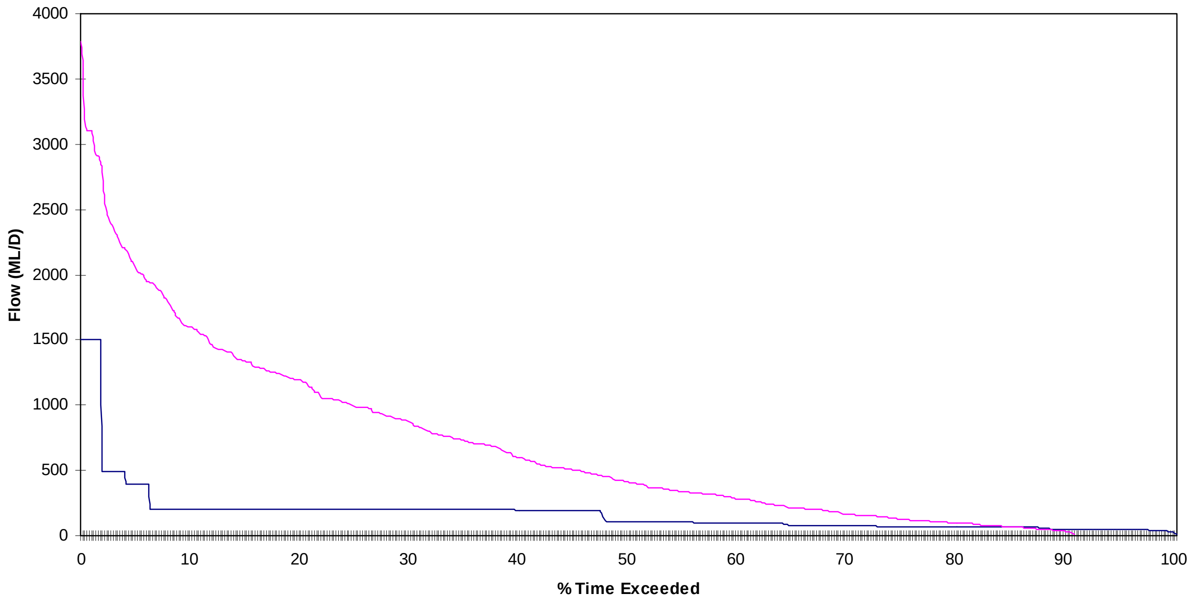
1. Investigate if there are water quality and habitat impacts of livestock on the upstream Gungarlin River, and whether this landuse will effect river restoration.

2. Investigate trout occurrence above Burrungubugge falls, in terms of potential for native fish recolonisation in the reach above the falls.

6.5 EUCUMBENE RIVER BELOW EUCUMBENE DAM

The flow duration curve in Figure 26 below for Eucumbene Dam shows inflows (i.e. natural flows) and target flows (i.e. minimum habitat utilisation flow regime, flushing flows, and channel maintenance flows).

Figure 26. Annual flow duration curve for Eucumbene Dam, showing inflows and target flows (including flushing and channel maintenance flows).



6.5.1 Minimum habitat utilisation flow regime

The monthly minimum habitat utilisation flows for Eucumbene Dam are shown below in Table 4, and illustrated in Figure 27.

The monthly target flows shown in Table 4 for minimum habitat utilisation are as follows:

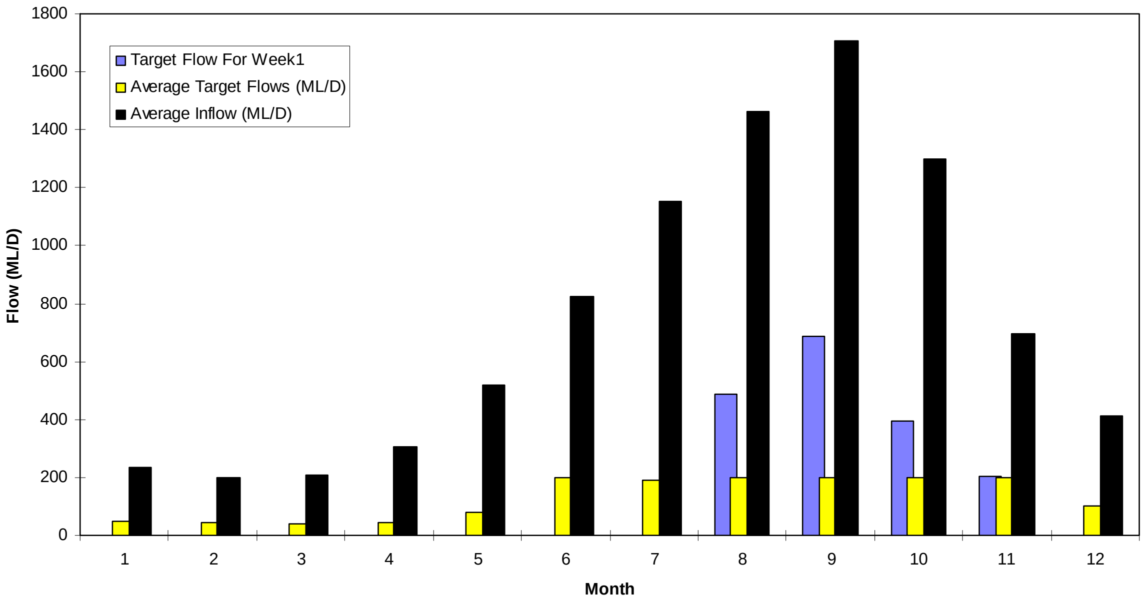
I. **January, February, March, April, May, June, July, November and December**: 95th percentile flows

II. **August, September, and October**: 95th percentile flows for 1 week in each month (natural hydrograph shape). Flows in the remaining 3 weeks of each month should be the 95th percentile flow for June (198 ML/d) varied by up to +/- 25% on at least a weekly basis.

Table 4. Monthly target flows and inflows for Eucumbene Dam. Total annual target flows are shown as percentage of inflows and include flushing and channel maintenance flows.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Annual Target Flows as Percentage Annual Inflow
Average Target Flows (ML/d)	48	43	39	45	78	198	191	198-489	198-687	198-395	205	102	27%
Average Inflow (ML/d)	237	201	07	306	518	826	1152	1461	1709	1300	696	414	100%

Figure 27. Monthly target flows and inflows for Eucumbene Dam, showing the release of 95th percentile flows in spring months for one week and June 95th percentile flows for the remainder of these months.



6.5.2 Flushing flows

- Remove willows.
- 1000 ML/d for 1-2 weeks, 2 events per year, in summer (to prevent severe water quality problems).

The flushing flow is based on providing 8-10m wide riffles, ~0.5m depth, and velocity 1m/s.

6.5.3 Channel maintenance flows

- Remove willows.
- Release initial large floods for channel maintenance.
- Undertake channel restoration works to reinstall the pool-riffle sequence below Eucumbene Dam, using natural channel design.
- The average size of the cobble substrate needs to be quantified for this reach.
- Then channel maintenance flows should be calculated using the tractive force approach of Newbury and Gaboury (1993) (see Section 3.6.2.3) to attain the appropriate flow depth to entrain the average cobble size on the bed slope of 3.5-18.2 m/km. This flow is thought to approximate 1500 ML/d and should be released for one week annually. There should be at least 1 event every 3 years, even during drought years.

Timing of channel maintenance flows is not critical for geomorphology so it should be timed for ecological reasons (i.e. during natural spring snowmelt period).

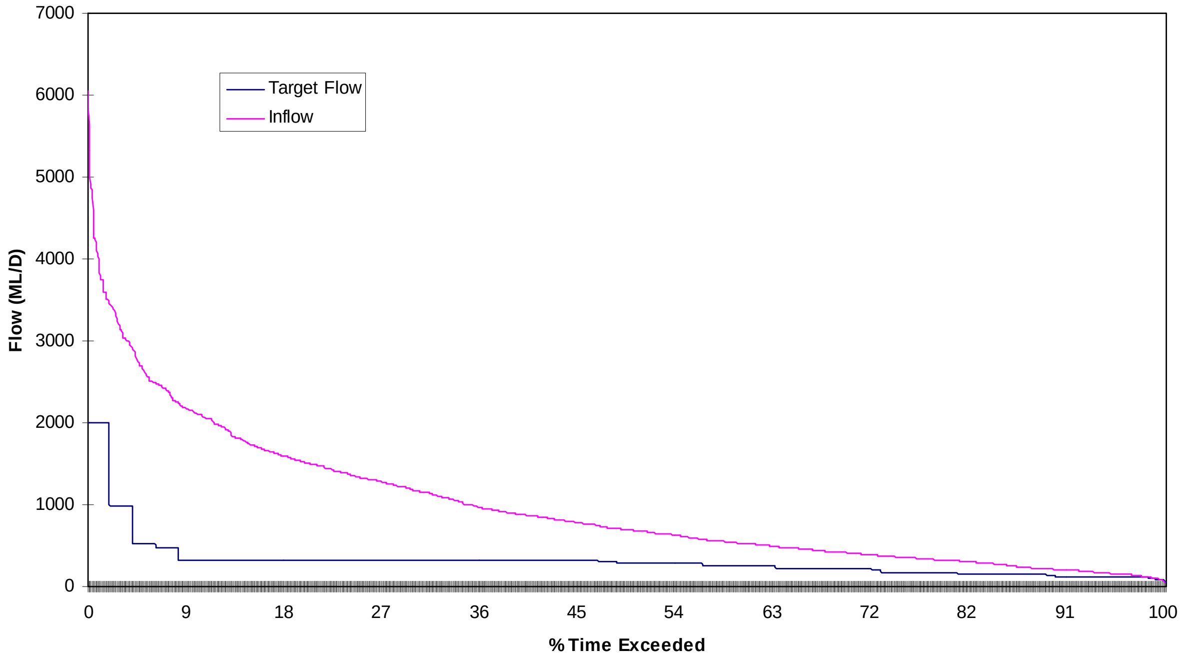
6.5.4 Management recommendations

1. Willows must be removed prior to releasing flushing and channel maintenance flows, however the stumps should be left. The stumps will prevent erosion and will gradually decay.
2. Riparian revegetation with native species must be undertaken.
3. High flows for channel re-shaping will be required initially, and channel works may also be necessary. Flushing or channel maintenance flows will then need to be implemented.
4. Erosion to the east of the river should be addressed, as this may be causing nutrient enrichment.
5. Other erosion and sediment sources must also be managed.
6. A new outlet with multiple level offtakes will be required at the dam to facilitate the environmental flows.
7. Nutrient inputs to Jindabyne Dam need to be managed. This may require the flushing and channel maintenance flows to be released when the dam is not stratified (i.e. release in winter). It may also be necessary to make releases concurrent with those from Jindabyne Dam, to facilitate the movement of nutrients through the storage.

6.6 GEEHI RIVER BELOW GEEHI DAM

The flow duration curve in Figure 28 below for Eucumbene Dam shows inflows (i.e. natural flows) and target flows (i.e. minimum habitat utilisation flow regime, flushing flows, and channel maintenance flows).

Figure 28. Annual flow duration curve for Geehi Dam, showing inflows and target flows (including flushing and channel maintenance flows).



6.6.1 Minimum habitat utilisation flow regime

I. The monthly minimum habitat utilisation flows for Geehi Dam are shown below in

Table 5, and illustrated in Figure 29.

The monthly target flows shown in Table 5 for minimum habitat utilisation are as follows:

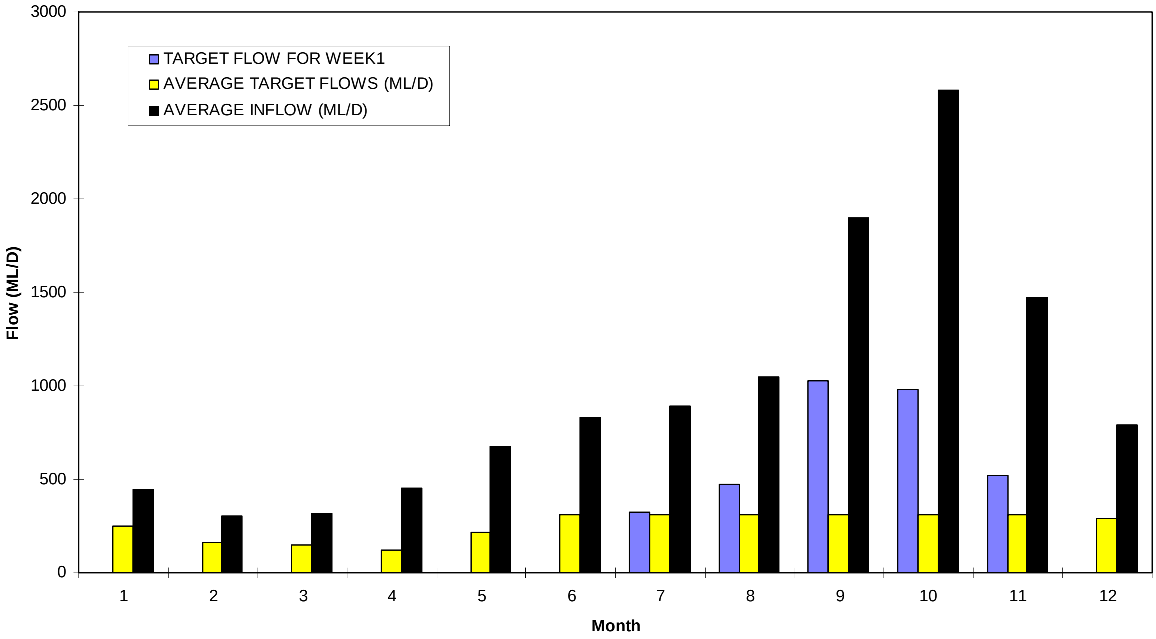
II. **January, February, March, April, May, June, July, and December**: 95th percentile flows

III. **August, September, October and November**: 95th percentile flows for 1 week in each month (natural hydrograph shape). Flows in the remaining 3 weeks of each month should be the 95th percentile flow for June (312 ML/d) varied by up to +/- 25% on at least a weekly basis.

Table 5 Monthly target flows and inflows for Geehi Dam. Total annual target flows are shown as percentage of inflows and include flushing and channel maintenance flows.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Annual Target Flows as Percentage Annual Inflow
Average Target Flows (ML/d)	185	120	107	119	213	312	312	312-472	312-1025	312-977	312-517	291	30%
Average Inflow (ML/d)	444	302	320	451	676	830	893	1045	1899	2582	1474	791	100%

Figure 29. Monthly target flows and inflows for Geehi Dam, showing the release of 95th percentile flows in spring months for one week and June 95th percentile flows for the remainder of these months.



6.6.2 Flushing flows

- 1000 ML/d for 1-2 days, 2 events, mainly in summer (to ameliorate high nutrient and algal levels.

6.6.3 Channel maintenance flows

- 1000 ML/d annually for 2-3 days in September or October.

This is based on a flow depth of 0.77m to entrain 256mm boulders on a bed slope of 33.3 m/km.

6.6.4 Management and research recommendations

1. The source/s of nutrient enrichment in this reach should be investigated. Specifically:

   I. investigate sediment and nutrient inputs from the gravel pit. If significant inputs are occurring, this will need to be addressed;

   II. investigate phosphorus sources in the catchment, i.e. from deep forest soils, and/or nutrients being transported down the system from bushfires in the 1970/80's;

   III. investigate whether nutrient enrichment is exacerbated by earth works below the dam; and

   IV. investigate whether high Total Phosphorus and silt loads in Geehi Dam are contributing to high macroalgae levels.

2. The dam stratifies which results in anoxia, high iron and manganese levels on the bottom, and low rates of breakdown of organic matter. The options for managing the quality of release water are:

    I. de-stratify the dam;

    II. use a siphon to prevent sediments being flushed; or

    III. de-silt the dam. If de-silting is undertaken, a flood event must follow (i.e. ~ 1000 ML/d for significant duration). Potential impacts of de-silting are nutrient enrichment downstream from silt flushed from dam. SMA may require a pollution licence if de-silting of Geehi Dam takes place, because of the iron, manganese and nutrient loads.

3. Investigate sediment sources and transport mechanisms below the dam.

4. Remove Willows.

5. Look at impacts of mobilising sediment in the channel through flushing flows.

6. Revegetate with native species below the dam to stabilise the soil and prevent erosion and possible nutrient enrichment.

7. Investigate options for providing environmental flows: by releases from the dam, or remove aqueducts on the northern slopes. Aqueduct removal will facilitate recolonisation of the main river by riverine species.

6.7 GEEHI RIVER AT REEDS FLAT

6.7.1. Minimum habitat utilisation flows

<u>Summer</u>: Flows should not fall below 200 ML/d even in the driest months. This flow will provide a depth of 0.5m and velocity 0.2m/s over a 20m channel, which is necessary for minimum habitat utilisation in summer.

This flow may be partly satisfied by minimum habitat utilisation flows for the upstream reach.

<u>Spring</u>: The natural seasonal flow pattern is an order of magnitude change between summer and spring. Spring flows should therefore be approximately 2000 Ml/d in the wettest month. Such flows could be provided by removing Geehi aqueduct, which has a capacity of 2000 Ml/d.

6.7.2. Flushing flows

Flushing flows should be higher in this reach than the upstream reach, given the larger channel and catchment area. They may be provided by piggy-backing dam releases with flows from tributaries.

6.7.3 Channel maintenance flows

- 9000 - 10 000 ML/d annually for 2-3 days in September.

This flow equates to the flow depth of 2.24m required to entrain 256mm boulders on an 11.4m/km bed slope.

6.7.4. Management and research recommendations

1. Investigate options for aqueduct removal to provide environmental flows. There are 17 aqueducts on streams in this catchment, any number of which may have the capacity to provide minimum habitat utilisation flows and seasonality. The water quality of these streams is also probably much better than that of Geehi Dam. Furthermore, reconnecting the flow of these streams to the main river will facilitate recolonisation of riverine biota and reconnection of the gene pool.

2. Carp have invaded the Swampy Plain River, but the above flow recommendations could prevent invasion of the Geehi River by providing cooler water temperatures and higher flows. Carp should be monitored and flows adapted to inhibit their spread.

3. Investigate the potential for a frog recovery program.

4. Investigate the potential for restoring threatened native fish in this reach.

6.8 THREE ROCKS CREEK

6.8.1 Flow management recommendation

There are two options for providing environmental flows to Three Rocks Creek. Both options will provide flows of suitable timing, magnitude, and duration for minimum habitat utilisation flows, flushing flows and channel maintenance flows.

- Option 1: Remove the aqueduct and return natural flows to the river.

- Option 2: Release 20-30% of inflows as passing flows.

6.8.2 Management and research recommendations

1. Aqueduct removal is recommended as this stream is worth preserving, for the following reasons:

    - the sampling site above the structure had the highest diversity and abundance of macroinvertebrates of all the sites assessed, indicating its pristine state;

    - it had a good galaxiid population;

    - it provides remnant habitat for the endangered Spotted tree frog;

    - it contains remnant cool-temperate rainforest vegetation; and

- aqueduct removal would achieve (at least partially) the environmental flow recommendations for the Geehi River at Reeds Flat.

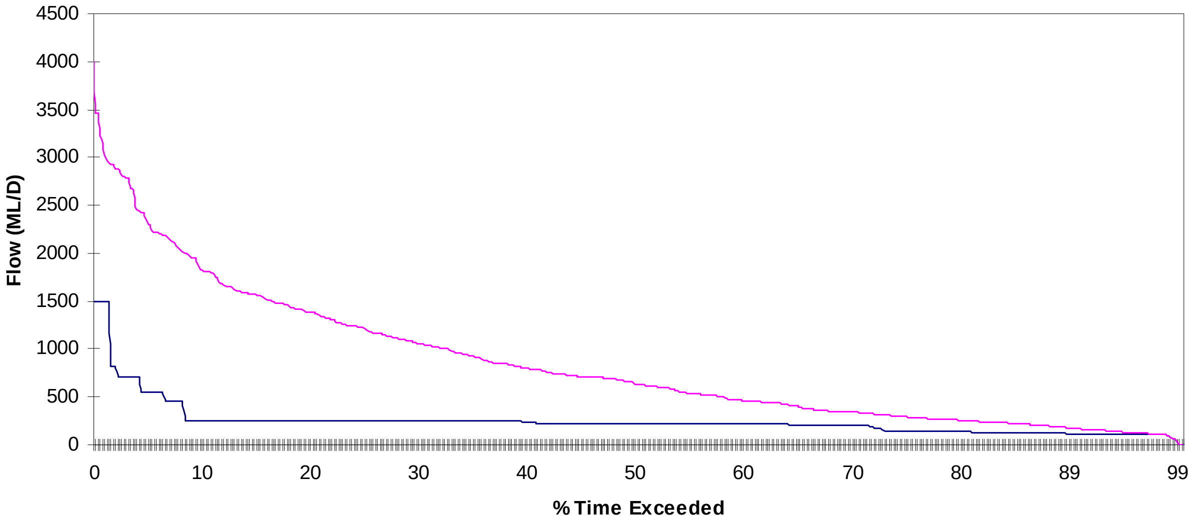
2. Investigation of frog populations should be carried out in this reach.

3. Investigation of fish populations should be carried out, to determine why there is such a healthy galaxiid population compared to all other assessment sites (i.e. investigate whether this is due to the absence of trout here because the stream is small, or if the habitat is diverse enough to partition resources).

6.9 TOOMA RIVER BELOW TOOMA DAM

The flow duration curve in Figure 30 below for Tooma Dam shows inflows (i.e. natural flows) and target flows (i.e. minimum habitat utilisation flow regime, flushing flows, and channel maintenance flows).

Figure 30. Annual flow duration curve for Tooma Dam, showing inflows and target flows (including flushing and channel maintenance flows).



6.9.1 Minimum habitat utilisation flow regime

The monthly minimum habitat utilisation flows for Tooma Dam are shown below in Table 6, and illustrated in

Figure 31.

The monthly target flows shown in Table 6 for minimum habitat utilisation are as follows:

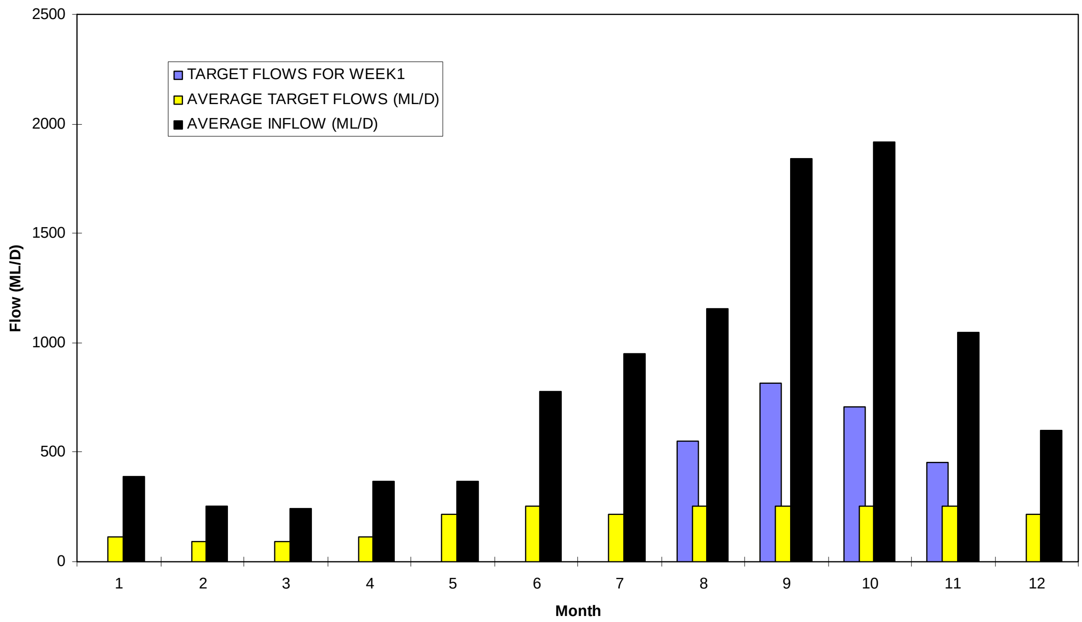
I. **January, February, March, April, May, June, July, and December**: 95th percentile flows

II. **August, September, October and November**: 95th percentile flows for 1 week in each month (natural hydrograph shape). Flows in the remaining 3 weeks of each month should be the 95th percentile flow for June (255 ML/d) varied by up to +/- 25% on at least a weekly basis.

Table 6 Monthly target flows and inflows for Tooma Dam. Total annual target flows are shown as percentage of inflows and include flushing and channel maintenance flows.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Annual Target Flows as Percentage Annual Inflow
Average Target Flows (ML/d)	113	90	90	113	216	255	216	255-552	255-816	255-706	255-453	217	29%
Average Inflow (ML/d)	388	254	244	368	368	779	950	1158	1840	1915	1049	600	100%

Figure 31. Monthly target flows and inflows for Tooma Dam, showing the release of 95th percentile flows in spring months for one week and June 95th percentile flows for the remainder of these months.



6.9.2. Flushing flows

- 1000 ML/d in winter or spring, 1 event per year.

Regular flushing flows may be needed to remove Carp from downstream reaches, thus reducing the risk of invasion in this reach.

6.9.3. Channel maintenance flows

- 1500 ML/d for 5 days duration, downstream of Ogilvies junction, at least annually.

This flow equates to the flow depth of 0.78-1.28m over a 14-15m channel required to entrain 256mm boulders on a bed slope of 20-33.3m/km. See below for recommendations for achieving these flows.

6.9.4 Management recommendations

1. Removing the aqueducts on Outstation Creek (capacity of 60ML/d), Ogilvies Creek (976 ML/d) and Deep Creek (95 Ml/d) will provide the recommended environmental flows, and will restore ecological integrity to these streams. Flows from the left bank aqueduct (Tooma River aqueduct) should be diverted to below the dam wall to provide improved baseflow in the river above these tributaries.

   - These aqueduct recommendations have the advantage of ensuring the release of water of good quality, and will require no ongoing management (as would be necessary if environmental flows were released from the dam).

   - A small length of the channel of the main river (i.e. ~2km between the dam wall and Outstation Creek) is being sacrificed in these flow recommendations, because the benefits of providing environmental flows from the tributaries outweigh those of providing them from the dam.

6.10 TOOMA RIVER AT MARAGLE POWER LINE ROAD BRIDGE

6.10.1 Minimum habitat utilisation flow regime

- Will be satisfied by minimum habitat utilisation flows for the upstream reach, provided there is additional flow input from tributaries.

6.10.2 Flushing flows

- 1000 - 1400 ML/d for 3-4 days duration, 1 event per year.

- Larger flood of one week duration every 1-2 years.

6.10.3 Channel maintenance flows

- Will be satisfied by channel maintenance flows for the upstream reach, provided there is also some contribution from tributary flows.

6.10.4 Research recommendations

1. As benthic sediments did not indicate pollution, the cause of the low diversity and abundance of most fauna (particularly fish and frogs) requires further investigation.

2. If these investigations do not show the river is polluted, it has good potential for recolonisation of Macquarie perch.

6.11 TOOMA RIVER ~200M BELOW NATIONAL PARK BOUNDARY

6.11.1 Minimum habitat utilisation flow regime

- The recommended flows for the two upstream sites, combined with residual catchment flows, are expected to provide significant benefits.

6.11.2 Flushing flows

- 1000-2000 ML/d for 5 days in mid-summer.

6.11.3 Channel maintenance flows

- 10 000 ML/d for 5-7 days, annually.

6.11.4 Management and research recommendations

1. Improved landuse management is necessary at this site, because the impacts of livestock access are severe (i.e. bank erosion, destruction of riparian vegetation, nutrient enrichment through addition of faecal matter and eroded sediment). This poor land management is as important as flow regulation.

2. Investigate why there are low numbers of fish at this site.

6.12 TOOMA RIVER ON FLOODPLAIN

The impacts of flow regulation in this reach are not easily determined from those of landuse and livestock. The Panel has therefore made no specific flow recommendations for this reach. The flow recommendations for the upstream reaches will provide significant benefits in this reach. Improved land management is required in the catchment, as recommended below.

6.12.1 Integrated land and water management recommendations

1. Control erosion, sand supply to the river, and nutrient enrichment, through the following actions in the catchment (including Tumbarumba Creek catchment):

    I. fence riparian areas to prevent stock access and bank erosion;

    II. revegetate riparian areas to provide filter strips;

III. improve stock management on land throughout the catchment to reduce erosion and nutrient supply; and

IV. rehabilitate former gold mine sites if these are contributing sediment or toxins to the river.

2. Investigate whether backwater from increased flow in the Swampy Plains River is contributing to waterlogging on the floodplain.

3. Reconnect the River with the floodplain above Greg Greg Bridge. This will require environmental flows that reflect the timing, duration and magnitude of natural flows.

4. Address the death of River Red Gums through the actions in 1) and 3) above.

5. Remove and manage Willows and Cottonwoods.

6.13 TUMUT RIVER BELOW TUMUT 2 POWER STATION

6.13.1 Minimum habitat utilisation flow

Summer: 60-70 ML/d in driest month. This is based on the observed flow of 12-16 ML/d being inadequate for summer minimum habitat utilisation flows.

Spring: 600 ML/d in wettest months. This is based on the natural order of magnitude change between flows in summer and spring.

6.13.2 Flushing flows

- Remove Willows and Blackberries.
- 1800 ML/d, 2 events per year in summer.

6.13.3 Channel maintenance flows

- 18000 ML/d for 2 days, 2 events in 3 years.

This flow equates to the flow depth required to entrain 200mm boulders on a bed slope of 6.15m/km.

6.13.4 Management and research recommendations

1. Preserve the high conservation value of this area:

- High public usage for recreation
- Potential for recovery of fish population
- Importance of general river restoration.

2. The hyporhoeic zone is now composed of Willow root mats. Willows must be removed, as the root mats will then eventually die. Revegetation with native species will then need to be undertaken.

3. This site is good trout cod habitat but the presence of three exotic fish species (Rainbow trout, Brown trout, Redfin perch) will need to be addressed before recolonisation can take place.

6.14 GOODRADIGBEE RIVER

6.14.1 Flow management recommendation

There are two options for providing environmental flows to the Gungarlin River. Both options will provide flows of suitable timing, magnitude, and duration for minimum habitat utilisation flows, flushing flows and channel maintenance flows.

- Option 1: Remove the aqueduct and return natural flows to the river.
- Option 2: Release 20-30% of inflows as passing flows.

6.14.2 Research recommendations

1. Investigate fish populations above the aqueduct for potential for native fish re-establishment.

2. Investigate whether the access road has impacts on the stream.

3. Investigate whether the artificial scree slope has impacts on the geomorphology and/or ecology of the stream.

6.15 GENERAL MANAGEMENT AND FURTHER INVESTIGATION RECOMMENDATIONS

1. There are a number of scree slopes across the Scheme area resulting from construction and maintenance activities, particularly on the Tumut and Snowy Rivers. All of these sites require investigation for their impacts on stream environments and, where necessary, long term management to minimise their impacts.

As part of the assessment of these scree slopes it will be necessary to:

I. Investigate phosphorus release from scree slopes of different rock types;

II. Investigate the extent and distribution of algae, and any relationship with unnatural scree slopes;

III. Investigate the role of scree slopes in channel infilling and degradation of habitat; and

IV. Recommend possible restoration and other amelioration techniques.

2. The modification or decommissioning of aqueduct structures is a possible means of providing, or contributing to, environmental flows. The aqueduct options are:

    I. removal or decommissioning;

    II. releasing a percentage of inflows as passing flows; and

    III. fitting of outlet works to permit regulation of inflows;

It is recommended that further investigations be undertaken into the structural, hydrological, economic and ecological ramifications of these options.

3. There are some situations where tributaries contain populations of native fish and frogs that are largely unimpacted by exotic fish (mainly trout). The reason for this may be that trout are unable to migrate because of natural or artificial barriers (e.g. aqueduct weirs). It is recommended that investigations be carried out into the opportunities and benefits for installing barriers for trout (and other alien fish) on tributaries with important native fish and frog populations, including Bogong Creek and tributaries of the Geehi River such as Three Rocks and Lady Northcotes Creeks.

4. Investigate the possibility of interbasin transfer of fish through tunnels. This may be the cause of *Galaxius brevipinis* migrating to the Murray River from the eastern seaboard, and if so there is the possibility that alien fish such as weatherloach may also migrate through these tunnels and establish in regulated river reaches which now provide ideal conditions for them. If investigation reveals that there is a likelihood of this invasion occurring via tunnels, this will need to be addressed to prevent invasion of other systems from occurring.

5. The interactions of flow regulation, residual catchment flows, environmental flows, and environmental outcomes are complex. It is recommended that investigations be carried out into methods for maximising environmental outcomes by understanding and managing hydrological elements of the Snowy catchments.

6. Bogong Creek was not assessed by the Panel because of time restraints, however it is known to contain a relic population of the endangered Spotted tree frog (Gillespie, 1997). To preserve this population, it is necessary that:

    I. The main pondage on Bogong Creek should be maintained, however maintenance flows should only be released from the pondage between April and October. (Maintenance flows include releases for de-silting the pondage, and flows redirected from the tunnel for tunnel maintenance). No flows should be released before April or after October, as this would disrupt the breeding ecology of the endangered Spotted tree frog.

    II. The aqueducts on the tributaries of Bogong Creek (North Cascade and South Cascade Creeks), which are diverted to the Bogong Creek pressure tunnel, should be removed to improve environmental flows in Bogong Creek downstream of Bourke’s Gorge. This in turn will also assist in enhancing Spotted tree frog habitat in this stream.

7 Conclusion

The Snowy Mountains Scheme has impacted the hydrological, geomorphological and ecological condition of many streams in the Snowy Mountains. These impacts are particularly severe in the Tumut, Eucumbene, Snowy and Gungarlin Rivers, and some reaches of the Tooma and Geehi Rivers.

The impacts of the Scheme on stream flow in most of these rivers are: reduced flood frequency and magnitude; reduced volumes of flow at all times; reduced seasonal flow variability; and, in some cases, unnaturally rapid and aseasonal changes in water level from power station releases.

The geomorphological outcomes of these changes to stream hydrology have been: channel contraction due to reduced discharge; lack of channel adjustment to reduced flows in some reaches, resulting in isolation of the channel from riparian vegetation; loss of rapids, chutes and riffles in many reaches; lateral isolation of pools; and sedimentation.

The impacts of the hydrologic changes on water quality are greatest in the pooled sections of streams, and include: warmer summer water temperatures and freezing over in winter because of the reduced flows; lower dissolved oxygen; nutrient concentration due to low flows; high algal productivity; and anoxia and stratification in the Tumut and Eucumbene Rivers.

Ecological integrity has been greatly affected by the Scheme, both directly (through the changes to the natural flow regime) and indirectly (through the impacts of the changed hydrology on geomorphology and water quality). Macroinvertebrate communities have changed from lotic to lentic in many areas where the flow, habitat and water quality have changed from those typical of a mountain stream to those typical of a lake or lowland stream. This indicates that important ecological processes have been disrupted, and ecological integrity is low. This is clearly not conducive to the conservation of a valuable native fauna in a National Park.

The impacts of the Scheme on frogs are somewhat varied. Some species are colonising reaches or increasing in abundance because of the modified conditions such as warmer water temperatures (e.g. Snowy River near Gungarlin confluence), which would not have occurred naturally. Other species are affected by loss of refuge and oviposition sites through sedimentation, by reduced pond habitats on floodplains due to flood mitigation, and the larvae of some species are likely to be impacted by flow regulation where flows cease in summer or are reduced in natural peak flow periods. The effects of trout on frog populations confound the significance of the above factors. Similarly, the effects of the Scheme on native fish populations are confounded by the effects of introduced trout on native species such as Galaxiids. However, reduced riparian and lateral connectivity, and mitigation of high spring flows that are necessary for facilitating migration and cleaning the substrate for spawning, are detrimental to native fish. The modified habitat and flow conditions are likely to facilitate the invasion of alien fish species such as oriental Weatherloach in some reaches.

The environmental flows recommended by the Panel are based on components of the natural flow regime that are known to be essential for channel maintenance and ecological integrity. The flow recommendations are based on the need to maintain and/or provide: an adequate volume of flow at all times; seasonal variability; and high flows and floods that are of natural hydrograph shape and duration, and in seasons they would naturally occur.

In some reaches of the streams assessed, the impacts of flow regulation were not easily discernible from the effects of agricultural land use. For example, the lower Tooma River is undergoing active bank erosion from livestock access, which is creating nutrient enrichment along with the input of organic matter from livestock. In other streams, such as reaches of the Eucumbene and Tumut Rivers, Willows are having such an adverse impact on the structure of the channel that flow regulation may not be the major impediment to ecological integrity. In such cases, the Panel's flow regulations will need to be implemented along with additional recommendations for improved land or riparian vegetation management.

The communities of macroinvertebrates, frogs, fish, algae and macrophytes in the Snowy Mountains must be surveyed intensively before, during and after the implementation of environmental flows. These surveys will enable the effects of environmental flows to be assessed, and if such flows are deemed inadequate or excessive for ecological integrity based on the monitoring surveys, new flow recommendations must be derived and implemented in an adaptive management approach.

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9 Glossary

Abiotic: Non-living components of an ecosystem.

Adaptive management: See section 1.3.

Alien species: Species of plants or animals that are not native to Australia. Also referred to as introduced or exotic.

Allochthonous: Organic material originating from outside the stream and subsequently moved into the stream; sedimentary material originating from a locality different to that in which it is deposited.

Alluvial: A deposit of sediment (silt, sand etc) laid down by flowing water.

Anastomising: Rivers which have undergone wholesale changes in course from one location on the floodplain to another exhibit multiple channels separated by floodplain.

Anoxic: Contains no oxygen.

Aseasonal: Unnatural seasonality (eg. When high flows naturally occur in winter but are captured by a dam or diverted, resulting in low flows in winter).

Atrophy: Loss of a river by decay and eventual terrestrialisation; reduction in size and functional power of a river channel through lack of water.

Autochthonous: Organic matter produced from within the stream; sedimentary materials that originate and are deposited at about the same location.

Avulsions: Wholesale changes in river course from one location on the floodplain to another. Refers to a larger scale in channel location than the cut off of one bend in the channel.

Bars: Large scale bedforms which have lengths of the same order as the channel width or greater and heights comparable to the mean depth of the generating flow.

Bedform: Geometric configurations of bed sediment on the river bed surface which are more than one grain diameter high and which are formed by streamflow.

Bedrock step: A channel-spanning rib between two pools that is less than one channel width long and composed of bedrock.

Biota: All living things (micro-organisms, plants, animals etc) occurring within a given area.

Boulder step: As for bedrock step, however it is composed of boulders rather than bedrock.

Cascades: Steep staircase sections where supercritical flow tumbles over large boulders in a series of short, well-defined steps separated by areas of supercritical flow.

Channel maintenance flow: See definition Section 3.6.2.3.

Confluence: Junction of two or more streams.

Deoxygenated: No or little oxygen. Water loses its dissolved oxygen for reasons such as rising water temperature, eutrophication, stagnation or bacterial consumption.

Ecological integrity: See definition Section 4.2.

Endemic: Belonging to a particular area.

Entrainment: Transport of sediment by flowing water.

Ephemeral: A stream which conveys water episodically.

Eutrophication: Elevated nutrient levels resulting in excessive levels of aquatic plant growth, especially algae.

Facultative breeding: Breeding that can occur under more than one specific set of environmental conditions.

Flushing Flow: See definition Section 3.6.2.2.

Geomorphology: The characteristics, origin and development of landforms, such as rivers, floodplains and lakes.

Hypolimnetic: The bottom, denser layer of water in a lake, reservoir or river which is thermally, oxygen or salt stratified. This layer is usually cold, and often deoxygenated, resulting in the release of nutrients and other chemicals from the bottom sediments.

Hyporheous: Zone of interaction between groundwater, substrate and water above the substrate.

In-channel bench: A discontinuous sediment body occurring at intermediate elevations between the river bed and the main valley flat, that is sometimes paired, elongate, tabular, often vegetated and usually bank-attached.

Interstices: Spaces between gravels, pebbles or cobbles.

Lateral connectivity: Connection of water in the river channel with riparian vegetation.

Lee-side shadow deposit: Fine sediment deposited on the upstream side of boulders.

Lentic: Still water.

Lotic: Flowing water.

Minimum habitat utilisation flow: See definition Section 3.6.2.1.

Obligate breeding: Breeding that can only occur under very specific environmental conditions.

Passing Flow: Inflows to a weir that pass through an outlet in the weir to the river downstream.

Rapid: Areas of fast flowing water over boulders organised into irregular ribs oriented more or less perpendicular to the channel.

Riffle: Shallow, fast flowing area of a stream with local free surface instabilities and small hydraulic jumps over pebbles and cobbles.

Riparian: Adjacent to water or influenced by water from streams (eg. Stream bank vegetation).

Sedimentation: Deposition of fine sediment on stream substrate. Usually leads to the infilling of pools and interstices.

Set-point: Desired channel width for each reach based on a range of environmental factors (see section 3.6.1 for more detail).

Stagnation: When water has ceased to flow and has become deoxygenated and anoxic.

Step pool: A deep area of slow, sub-critical flow between steps that are without free surface instabilities under low flows.

Stoss-side shadow deposit: Fine sediment deposited on the downstream side of boulders.

Stratification: Development of two layers of water of different density distinguished by different water temperature, salinity, turbidity, dissolved oxygen and other characteristics.

Subcritical flow: slow or moderate flow in which the velocity is less than the speed at which a disturbance (wave) would travel given the depth and roughness, and hence backwater effects are observed.

Substrate: The stream bed, usually made up of silt, sand, gravel, pebbles, cobbles, boulders and /or bedrock.

Supercritical flow: Rapid flow which exceeds the speed at which a disturbance (wave) would travel given the depth and roughness, and hence backwater effects do not exist.

Appendix 1. Summary of flow regulation impacts and flow recommendations for each reach

The following tables present the geomorphological and ecological impacts of flow regulation that require environmental flows, followed by the flow recommendations and likely outcomes. This approach was deemed appropriate given the large number of river reaches assessed and the limited time available to prepare this report, however the Panel acknowledges the shortcomings of simplifying complex interactions in this manner. The complex interactions between flow, geomorphology and ecology are represented in Figure 3 to Figure 6.

SNOWY RIVER BELOW GUTHEGA DAM

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	High summer water temperature, low dissolved oxygen. Freezing of shallow pools in winter due to reduced flows. Unnaturally high algal growth in summer. Nutrient enrichment from weathering of fresh granite. Accumulated dead algae and biogenic sediment on bottom of step pools. Lotic macroinvertebrate fauna replaced by lentic macroinvertebrate fauna. Lack of lateral connection between channel and riparian vegetation, lack of detritus input. Lack of cascades and insufficient rapid depths. Inadequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Lack of input of large woody debris. Loss of biological stimuli for reproduction of aquatic species due to low spring flows.	Jan = 145 ML/d (80th percentile) Feb = 69 ML/d (80th percentile) Mar = 82 ML/d (80th percentile) Apr = 90 ML/d (93rd percentile) May = 99 ML/d (95th percentile) Jun = 153 ML/d (95th percentile) July = 117 ML/d (95th percentile) Aug = 153 ML/d (95th percentile) 95th percentile flows should be used for 1 week in each month of Sep, Oct and Nov, with natural hydrograph shape and within month variability. Flows in the remaining 3 weeks of each month should be the 95th percentile flow for June. These flows are recommended because the 95th percentile flows for these 4 months equate to half or more of the natural flow because of the consistently high flows from snow melt. It is imperative that flow variability of plus or minus 25% is incorporated on a weekly basis into the release of the 95th percentile June flow, so that the monthly seasonal flow spikes do not return to a constant baseflow. Sep = 474 ML/d for one week (with natural hydrograph shape), and 153 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Oct =1603 ML/d for one week (natural hydrograph shape), remainder of month 153 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Nov = 837 ML/d for one week (natural hydrograph shape), remainder of month 153 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Dec = 208 ML/d (95th percentile).	Summer/Autumn Flows: Inundate ~1/3 of the channel width. Provide more cascades and deeper step pools. Return the fauna to that of a montane river. Adequately dilute nutrients. Prevent prolific algal growth. Provide suitably cooler summer water temperatures. Increase dissolved oxygen. Increase rapid depths. Winter/Spring Flows: Provide adequate flow and depth to prevent pools from totally freezing. Transport organic matter to the channel (food source for aquatic fauna). Provide lateral connectivity with riparian vegetation. Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Provide biological stimuli for reproduction in aquatic species.

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Flushing flow	Lack of longitudinal connectivity for migration and redistribution of native fish and other aquatic biota. Potential invasion of exotic fish. Water quality, algal and biogenic sediment accumulation.	Provided by the elevated habitat utilisation flows in September/October, i.e: 474 ML/d in Sep. 1603 ML/d in Oct 837 ML/d in Nov.	As for winter/spring flows, plus: Provide longitudinal connectivity for migration and redistribution of native fish and other aquatic biota. Clean stones, gravels and interstitial spaces. Prevent vegetation invasion. Flush algae, sediment, biogenics and nutrients. Displace invading exotic fish such as Weatherloach.
Channel maintenance flow	Set-point (see Section 3.6.1) = Existing channel Channel has a very slow rate of channel contraction because of sediment starvation and the very steep slope, hence high energy. Angular gravels from the artificial scree slope are in-filling the boulder steps and step pools. Pools are isolated. Extreme floods created the boulder steps. Very large floods entrain large boulders, reconfigure channel substrate and maintain habitat heterogeneity.	1500-2000 ML/d for one week (based on a flow depth of 0.31m required to entrain intermediate (256mm) boulders on an 80m/km bed slope. Because of this extremely steep slope, higher flows are not needed for boulder entrainment). 1 event per year = desirable 2 in 3 years = essential These flows may be met by dam spills, or by releasing additional volumes during valve maintenance releases. These flows need to be adaptively managed. If adit gravels are not being redistributed then these flows need to be modified.	More boulder steps will function with alternating supercritical flow over steps and subcritical flows in downstream step pools. Provide greater lateral and longitudinal connectivity. Entrain intermediate boulders and move artificial angular gravels. Reconfigure substrate. Improve habitat heterogeneity.

SNOWY RIVER BELOW GUTHEGA POWER STATION

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	There are vegetated, very course boulder bars in the middle of the channel which lead to flow bifurcation and secondary channels. Proliferation of Red algae in the main channel, which dominates habitat and is unconsumed by most species. High nutrients from the bottom of the dam via power station releases may be the cause. Aquatic moss in secondary channel indicates fairly constant low flows. Unnaturally high rates of rise and fall of river height (due to power station releases) of ~30 cm/d create hydraulic stresses and flow changes which result in increased algae and low numbers of grazing invertebrates. The main channel had low invertebrate diversity, being comprised of species which tolerate high velocities, while the side channel has much more diversity. Possible reasons: side channel is higher than the main channel so may be buffered to some extent from pulsing flows; the higher percent of sand in the side channel abrades the algae; channel probably has less hydraulic stress due to less volume of water than main channel; has greater habitat heterogeneity than main channel; smaller channel size means less distance to shelter; however possible population isolation from recruitment areas.	The habitat utilisation flows for the site below Guthega Dam should meet the requirements here. The 2-3 ML/d baseflow observed during the assessment is inadequate for habitat utilisation. Power station releases need to mimic the natural rate of rise and fall of river. See Section 6.2.4. The operation of Guthega Power Station needs to be reviewed and either alterations made to the release pattern, or a re-regulation weir installed, to attain a more natural rate of rise and fall of release flows. Releases should more closely resemble the rate of rise and fall that would occur during thunderstorms, to reduce the hydraulic stress on macroinvertebrates of the power station releases. Water quality (temperature and dissolved oxygen) need to be addressed through a re-regulation weir or other options. Three options for mitigating the impacts of power station releases are presented in Section 6.2.4.	*Summer/Autumn Flows:* Provide more cascades and deeper pools. Return conditions to those of a montane river. Adequately dilute nutrients. Prevent prolific algal growth. Increase riffle depths. *Winter/Spring Flows:* Transport organic matter (food source for aquatic fauna). Provide lateral connectivity with riparian vegetation. Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Other: Provide a buffer which, together with the measures recommended in Section 6.2.4., will help mitigate the impact of the Power Station on flows. There will also be less water diverted through the power station because of these and the upstream minimum habitat utilisation flows, which will potentially lessen the rates of rise and fall or the frequency of pulsing events may diminish. Reconnect the main channel with the secondary channel. Improve water quality, particularly dissolved oxygen.

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Flushing flow	Lack of longitudinal connectivity for migration and redistribution of native fish and other aquatic biota.	Will be provided by October minimum habitat utilisation flows from Guthega Dam of 1603 ML/d.	As for winter/spring flows, plus: Provide longitudinal connectivity for potential migration and redistribution of native fish and other aquatic biota. Clean gravels and interstitial spaces. Prevent vegetation invasion. Flush algae and sediment. Displace any invading exotic fish.
Channel maintenance flow	Set-point = Existing channel. Main channel is boulder step, bedrock step, step pool in reasonable condition. Secondary channels are boulder step, step pool channels in reasonable condition, beside vegetated course boulder mid-channel bars or islands. Very large floods entrain large boulders, reconfigure channel substrate and maintain habitat heterogeneity.	Will be provided by the channel maintenance flow recommended for the upstream reach (1500 - 2000 ML/d for one week from Guthega Dam).	Entrain intermediate boulders, roll stones and reconfigure substrate. More boulder steps will function with supercritical flow. Provide greater lateral and longitudinal connectivity.

SNOWY RIVER BELOW ISLAND BEND

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	High water temperature in summer. Sedimentation in remnant pools which now behave as ponds. Nutrient enrichment. Algal growth. Lotic fauna replaced by lentic fauna. Certain frog species present that are favoured by the regulated conditions. Unsuitable conditions for Galaxiids, suitable conditions for exotic fish. Riffles, cascades and rapids are largely dry. Shallow pools. Lack of organic matter input, including large woody debris. Lack of lateral connection with riparian vegetation. Inadequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Lack of interstitial spaces between substrate. Loss of biological stimuli for reproduction of aquatic species due to low spring flows. Biogenic veneers coating inundated surface of gravels. Divided channel around vegetated course boulder mid-channel bars or islands.	Jan = 333 ML/d (80th percentile) Feb/Mar = 166 ML/d (80th percentile) Apr = 193 ML/d (93rd percentile) May = 200 ML/d (95th percentile) Jun = 346 ML/d (95th percentile) 95th percentile flows should be used for 1 week in each month of Jul, Aug, Sep, Oct and Nov, with natural hydrograph shape. Flows in the remaining 3 weeks of each month should be the 95th percentile flow for June. These flows are recommended because the 95th percentile flows for these 4 months equate to half or more of the natural flow because of the consistently high flows from snow melt. It is imperative that flow variability of plus or minus 25% is incorporated on a weekly basis into the release of the 95th percentile June flow, so that the monthly seasonal flow spikes do not return to a constant baseflow. Jul = 595 ML/d for one week (natural hydrograph shape), 346 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Aug = 551 ML/d for one week (natural hydrograph shape), 346 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Sep = 1314 ML/d for one week (natural hydrograph shape), 346 ML/d varied by up to +/- 25% on a weekly basis for rest of month Oct = 2617 ML/d for one week (natural hydrograph shape), 346 ML/d for varied by up to +/- 25% on a weekly basis for rest of month. Nov = 1276 ML/d for one week (natural hydrograph shape), 346 ML/d varied by up to +/- 25% on a weekly basis for rest of month Dec = 340 ML/d (95th percentile).	Summer/Autumn Flows: Provide more cascades and rapids and deeper pools. Return conditions to those of a montane river. Adequately dilute nutrients. Prevent prolific algal growth. Provide suitably cooler summer water temperature. Encourage return of lotic fauna and discourage lentic macroinvertebrate fauna by lowering the residence times for pool fauna. Increase riffle, rapid and cascade depths. Winter/Spring Flows: Provide for habitat utilisation for most species most of the time. Deliver organic matter (food source for aquatic fauna). Provide lateral connectivity with riparian vegetation. Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Encourage the return of lotic frogs and discourage lentic frogs. Prevent invasion of exotic fish such as Weatherloach. Favour Galaxiids rather than exotic species. Provide biological stimuli for reproduction in aquatic species.

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Flushing flow	Sedimentation as above. Algal and water quality problems as above. stripping of biogenic veneers from bed surface. Vegetation encroachment across whole channel (especially *Carex*) Lack of longitudinal connectivity for migration and redistribution of native fish and other aquatic biota. Potential invasion by exotic fish such as Weatherloach..	Will be provided by the 95th percentile flows for one week in spring, i.e.: 1314 ML/d in Sep. 2617 ML/d in Oct. 1276 ML/d in Nov.	As for winter/spring flows, plus: Clean gravels and interstices. Flush encroaching vegetation. Provide longitudinal connectivity for migration and redistribution of native fish and other aquatic biota. Prevent vegetation invasion. Flush algae and fine-grained sediment. Displace invading exotic fish such as Weatherloach.
Channel maintenance flow	Set-point = Stream order reduction. Vegetation encroachment. Long term state of continuing degradation. Insufficient flow for boulder steps and step pools to function. Very large floods entrain large boulders, reconfigure channel substrate and maintain habitat heterogeneity. Greater need for channel maintenance than at the two upstream sites.	The flow depth needed to entrain intermediate (256mm) boulders on a bed slope of 17.8-27m/km is 0.95-1.42m, which equates to approximately 5000 ML/d (varies depending on slope between 3300 to 7700 ML/d).	Entrain intermediate boulders and reconfigure substrate. Boulder steps will function with supercritical flow. Provide greater lateral connectivity. Replenish habitat and provide greater habitat heterogeneity.

GUNGARLIN RIVER BELOW AQUEDUCT

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	Ephemeral macroinvertebrate community indicates that the stream dries up occasionally, which would not occur naturally in such a river. The fauna should be that of a montane river in a high rainfall area. Warm summer water temperatures and low dissolved oxygen are additional problems due to flow diversion. Nutrient enrichment. High levels of algal growth. Fine silt and biogenic sediment accumulation on surface of inundated bed. Lack of lateral connectivity with riparian vegetation. Insufficient amount of habitat. Lack of input of organic matter, including large woody debris. Insufficient depth of flow in rapids and cascades. Shallow step pools. Loss of biological stimuli for reproduction of aquatic species due to low spring flows.	1) Remove aqueduct to provide natural flows, or 2) Release 20-30% of inflows to diversion weir downstream.	Provide more cascades and deeper step pools. Return the fauna to that of a montane river. Adequately dilute nutrients. Prevent prolific algal growth. Provide suitably cooler summer water temperature. Increase dissolved oxygen. Deliver organic matter (food source for aquatic fauna). Provide lateral connectivity with riparian vegetation. Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Increase amount of habitat. Similar benefits in the Snowy River below the confluence. Spring flows will flush out fine sediment, biogenics and algae. Increase depth of flow in rapids. Spring flows will provide biological stimuli for reproduction in aquatic species.
Flushing flow	Lichen limits indicate two age populations (i.e. pre and post regulation), indicating severe flood suppression (except very large floods) and chronic lack of flow. Sedimentation as above. Water quality and algal problems as above. Significant reduction in small floods and flushing events. Insufficient longitudinal connectivity for migration and redistribution of native fish and other aquatic biota. Lack of scouring of substrate. Lack of interstitial spaces between substrate.	Will be provided by natural or passing flows	Natural floods will provide adequate scouring to prevent lichen encroachment. Flush out fine sediment, biogenics and algae. Improve flushing of algae and silt in the Snowy River below the confluence. Clean gravels and interstices. Provide longitudinal connectivity for migration and redistribution of native fish and other aquatic biota. Prevent vegetation invasion. Displace invading exotic fish such as Weatherloach.

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Channel maintenance flow	Set-point = Existing channel. Extreme flood events created the boulder step channel. Insufficient flow for boulder steps and step pools to function. Very large floods entrain large boulders, reconfigure channel substrate and maintain habitat heterogeneity. Sand supply to Snowy River cut off by the sand trap on the Gungarlin aqueduct.	Will be provided by natural or passing flows	Entrain intermediate boulders and reconfigure substrate. Transport sand to the Snowy River. Boulder steps and step pools will function normally. Import large woody debris. Increase habitat heterogeneity. Increase lateral and longitudinal connectivity.

EUCUMBENE RIVER BETWEEN EUCUMBENE AND JINDABYNE DAMS

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	Stratification and stagnation in pools. Occasional to frequent anoxia in water column and substrate in pools. Much more macrophytes than would occur under natural flow conditions. Original gravel-cobble bed replaced by silt, biogenics, prolific emergent macrophytes (Carex and Phragmites) and submerged macrophytes, and willow invasion. Unsuitable habitat for native fish but may favour 2 frog species. Lotic fauna replaced by lentic fauna. Nutrient enrichment. Reduced depth and occurrence of riffles due to willow invasion and reduced flow. Inadequate hydraulic diversity to stimulate life cycles of lotic macroinvertebrates. Lack of input of large woody debris. Loss of biological stimuli for reproduction of aquatic species due to low spring flows.	Jan = 48 ML/d (95th percentile) Feb/Mar = 43 ML/d (95th percentile. Apr = 45 ML/d (95th percentile) May = 78 ML/d (95th percentile) Jun = 198 ML/d (95th percentile) Jul = 191 ML/d (95th percentile) 95th percentile flows should be used for 1 week in each month of Aug, Sep, and Oct, with natural hydrograph shape. Flows in the remaining 3 weeks of each month should be the 95th percentile flow for June. These flows are recommended because the 95th percentile flows for these 4 months equate to half or more of the natural flow because of the consistently high flows from snow melt. It is imperative that flow variability of plus or minus 25% is incorporated on a weekly basis into the release of the 95th percentile June flow, so that the monthly seasonal flow spikes do not return to a constant baseflow. Aug = 489 ML/d for one week (natural hydrograph shape), 198 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Sep = 687 ML/d for one week (natural hydrograph shape), 198 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Oct = 395 ML/d for one week (natural hydrograph shape), 198 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Nov = 205 ML/d (95th percentile). Dec = 102 ML/d (95th percentile).	Summer/Autumn Flows: Adequately dilute nutrients. Provide suitably cooler summer water temperature. Increase dissolved oxygen and reduce occurrence of anoxia. Insufficient to prevent stratification and stagnation of some pools. Decrease pool residence times, to enable return of more lotic fauna (along with flushing flows). Winter/Spring Flows: Provide reasonable lateral connectivity with riparian vegetation. Provide reasonable riffle depths. Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Prevent stratification, anoxia and stagnation in most pools. Provide biological stimuli for reproduction in aquatic species.

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Flushing flow	Gravel-cobble bed lost through sedimentation, submerged and emergent macrophyte proliferation and willow invasion. Severe water quality problems as above. Willow invasion is too severe for flushing flows to remove them.	1) Willow removal. 2) 1000 ML/d for periods of 1-2 weeks, 2 events per year in summer, with natural hydrograph shape. This will provide 8-10m wide riffles, ~0.5m depth, velocity 1m/s.	Clean gravels and interstitial spaces. Displace invading exotic fish such as Weatherloach. Flush biogenics and algae. Prevent anoxia. Prevent stagnation and stratification of pools. Prevent algal blooms from nutrients that will be moved during the channel re-shaping flows. Remove some macrophytes and prevent further proliferation. Following willow removal and channel maintenance flows, will gradually return some natural conditions required by native fish, frogs and macroinvertebrates. Flows for migration and redistribution of native fish and other aquatic biota will be provided by channel maintenance flows in spring.
Channel maintenance flow	Set-point = Pre-regulation configuration but with some contraction. The channel has contracted to varying degrees in this reach. The channel is no longer a pool-riffle sequence, it is now a series of lake-like pools. Willows and willow root mats have covered the gravel substrate and are causing severe channel contraction on riffles. Cobbles are now embedded in fine sediment and organic matter. Gravel substrate in riffles replaced with willow roots.Carex and Phragmites extend across the whole channel in some areas. Large floods entrain coarse sediment, reconfigure channel substrate and maintain habitat heterogeneity. Advanced deterioration.	1) Manual willow removal. 2) Initial large floods for channel re-shaping. 3) Need channel restoration works to reinstall pool-riffle sequence below Eucumbene dam using natural channel design. 4) The average size of the cobble substrate needs to be quantified for this reach. Then channel maintenance flows should be calculated using the tractive force approach of Newbury and Gaboury (1993) (see Section 3.6.2.3) to attain the appropriate flow depth to entrain the average cobbel size on the bed slope of 3.5-18.2 m/km. This flow is thought to approximate 1500 ML/d and should be released for sustained for one week annually, with natural hydrograph shape. There should be at least 1 event in 3 years, even during drought years. Timing of channel maintenance flows is not critical for geomorphology so it should be timed for ecological reasons (during natural spring snowmelt period, for fish migration).	Manual willow removal is essential for channel restoration. Willows must be removed before channel re-shaping flows are released so that willow debris does not cause renewed invasion and debris dams. Channel re-shaping and maintenance flows: Pools will be smaller than pre-regulation size. Carex and Leptospermum will probably survive channel maintenance flows. Will remove biogenics, anoxic sediments, and macrophytes. Entrain sand and gravels.Restore riffles to gravel substrate. Maintain approximately 50% of original channel size. Provide for fish migration in spring (flushing flows are in summer for water quality) Channel maintenance flows will distribute nutrients and silt, some to Jindabyne (see management recommendations) but also onto floodplain sections, which is desirable for floodplain ecology.

GEEHI RIVER BELOW DAM AT SULLIVANS SPUR BRIDGE

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	Filamentous algae (especially Cladophora) on all substrate surfaces. Silt and biogenic accumulation. Poor habitat. Invertebrate fauna of low diversity and largely consists of pollution tolerant taxa. Lack of organic matter input, including large woody debris. Insufficient rapid and cascade depths. Inadequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Lack of interstitial spaces between substrate. Loss of biological stimuli for reproduction of aquatic species due to low spring flows.	Need a flushing flow before implementing these flows (see below). Jan = 185 ML/d (95th percentile) Feb = 120 ML/d (95th percentile Mar = 107 ML/d (95th percentile) Apr = 119 ML/d (95th percentile) May = 213 ML/d (95th percentile) Jun/Jul = 312 ML/d (95th percentile) 95th percentile flows should be used for 1 week in each month of Aug, Sep, Oct and Nov, with natural hydrograph shape. Flows in the remaining 3 weeks of each month should be the 95th percentile flow for June. This is recommended because the 95th percentile flows for these 4 months equate to half or more of the natural flow because of the consistently high flows from snow melt. It is imperative that flow variability of plus or minus 25% is incorporated on a weekly basis into the release of the 95th percentile June flow, so that the monthly seasonal flow spikes do not return to a constant baseflow. Aug = 472 ML/d for one week (natural hydrograph shape), 312 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Sep = 1025 ML/d for one week (natural hydrograph shape), 312 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Oct = 977 ML/d for one week (natural hydrograph shape), 312 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Nov = 517 ML/d for one week (natural hydrograph shape), 312 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Dec = 291 ML/d (95th percentile).	Summer/Autumn Flows: Provide more and larger cascades and rapids. Encourage the return of montane fauna. Prevent prolific algal growth. Provide suitably cooler summer water temperature. Increase dissolved oxygen. Increase step pool, rapid and cascade depth. Winter/Spring Flows: Deliver organic matter (food source for aquatic fauna). Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Provide biological stimuli for reproduction in aquatic species.

Component of Environmental Flow Regime:	**Issues:**	**Requirements:**	**Expected Outcomes:**
Flushing flow	Prolific filamentous algae and fine sediment accumulation require fluvial disturbance. Lack of longitudinal connectivity for native fish migration and distribution.	1000 ML/d for 1-2 days, 2 events, mainly in summer. Water quality of dam releases will need to be addressed.	As for winter/spring flows, plus: Clean gravels and interstitial spaces. Prevent vegetation invasion. Flush algae, nutrients and sediment. Prevent proliferation of algae. Displace invading exotic fish. [illegible]
Channel maintenance flow	Set-point = Stream order reduction. However, some channel reconfiguration is needed below the dam. The channel has adjusted to reduced flows through 75% contraction (from 10-15m to 4-5m) and the development of new bars and marginal in channel benches. Boulder steps no longer functioning. Extreme flood events created the boulder step channel. Very large floods entrain large boulders, reconfigure channel substrate and maintain habitat heterogeneity.	1000 ML/d (for flow depth of 0.77m to entrain intermediate (256mm) boulders on a bed slope of 33.3 m/km). This should be released annually for 2-3 days in Sept-Oct.	Boulder steps will function. Entrain intermediate boulders, roll stones and reconfigure substrate.. Provide greater longitudinal connectivity. Improve habitat heterogeneity. Transport large woody debris.

GEEHI RIVER AT REEDS FLAT

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	Warm water temperature from constant low flows (resulting in macroinvertebrate fauna of a lowland stream, rather than a montane river). Habitat has been simplified on the edge of the channel by the accumulation of fine sediment which has smothered pebbles. Limited interstitial spaces between substrate. Active weed and riparian plant invasion. Mid-channel bars with boulder steps and step pools, vegetation invasion of bars. Macroinvertebrate community is comprised of species that tolerate poor habitat and/or water quality. Shallow riffle depths. Insufficient lateral connection with riparian vegetation. Inadequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Loss of biological stimuli for reproduction of aquatic species due to low spring flows.	200 M/L in the driest month to provide a depth of 0.5m and velocity 0.2m/s over a 20m channel, This flow could be partly satisfied by minimum habitat utilisation flows for the upstream reach. ~2000 ML/d in the wettest month in spring. This is based on the natural pattern of an order of magnitude increase in flows between summer and spring. Such flows could be provided by removing Geehi aqueduct, which has a capacity of 2000 ML/d.	Summer/Autumn Flows: Return conditions to that of a montane river. Discourage lowland fauna and encourage return of semi-lowland montane fauna. Provide suitably cooler summer water temperature. Increase dissolved oxygen. Increase riffle depths. Winter/Spring Flows: Deliver organic matter (food source for aquatic fauna). Provide lateral connectivity with riparian vegetation. Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Provide biological stimuli for reproduction in aquatic species.
Flushing flow	Lack of longitudinal connectivity for native fish migration and distribution. Water quality problems as above.	May be provided by piggybacking dam releases with flows from tributaries.	As for winter/spring flows, plus: Clean gravels and interstitial spaces. Prevent vegetation invasion. Flush nutrients and sediment. Displace invading exotic fish such as Carp. Provide longitudinal connectivity for migration and redistribution of native fish and other aquatic biota. Potential downstream water quality problems with initial flushes.

Component of Environmental Flow Regime:	**Issues:**	**Requirements:**	**Expected Outcomes:**
Channel maintenance flow	Set-point = Stream order reduction. The channel has contracted by about 20% to 20-30m, and there has been some Carex invasion. This reduced channel size should be maintained. Very large floods entrain large boulders, reconfigure channel substrate and maintain habitat heterogeneity. Mid-channel bars with boulder-steps and step pools have been invaded by vegetation (mainly Carex) on lee and stoss-side shadow deposits (see glossary).	9000 to 10 000 ML/d (to attain a flow depth of 2.24m to entrain intermediate (256mm) boulders on an 11.4m/km bed slope).	Entrain intermediate boulders and reconfigure substrate. Provide greater lateral and longitudinal connectivity. Improve habitat heterogeneity.

THREE ROCKS CREEK BELOW AQUEDUCT

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	Reduced diversity of macroinvertebrates below aqueduct in comparison to invertebrate fauna above aqueduct. Weir pool and sand downstream of road are the main impacts on habitat. Remnant temperate rainforest vegetation. Potential remnant habitat for an endangered frog species.	1) Remove aqueduct to provide natural flows, or 2) Release 20-30% of inflows as passing flows.	Total or near total restoration of a valuable montane stream.
Flushing flow	No flushing flow has occurred below the weir for 1 or 2 years.	Will be provided by natural or passing flows.	As above.
Channel maintenance flow	Set-point = Pre-regulation channel. Extensive delta formation above the weir (indicates sand transport from catchment). Boulder step, step pool channel otherwise unimpacted.	Will be provided by natural or passing flows.	As above.

TOOMA RIVER BELOW TOOMA DAM

Component of Environmental Flow Regime:	**Issues:**	**Requirements:**	**Expected Outcomes:**
Minimum habitat utilisation flow (includes seasonal flow variability)	Fine silt and biogenic sediment accumulation on all surfaces (mostly boulders). Warm summer water temperature. Lots of Carex, some Chara. Poor habitat for fish, frogs and riffle fauna. Water is rich in dissolved organic matter. Riffles not functioning. Very poor habitat, mostly large boulders and silt. Insufficient lateral connection with riparian vegetation. Inadequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Loss of biological stimuli for reproduction of aquatic species due to low spring flows. Massive loss of habitat by total abandonment of side channels beside mid-channel bars. Massive vegetation invasion of dry channel elements.	Jan = 113 ML/d (95th percentile) Feb/Mar = 90 ML/d (95th percentile) Apr = 113 ML/d (95th percentile) May = 216 ML/d (95th percentile) Jun = 255 ML/d (95th percentile) Jul = 216 ML/d (95th percentile) 95th percentile flows should be used for 1 week in each month of Aug, Sep, Oct and Nov, with natural hydrograph shape. Flows in the remaining 3 weeks of each month should be the 95th percentile flow for June. These flows are recommended because the 95th percentile flows for these 4 months equate to half or more of the natural flow because of the consistently high flows from snow melt. It is imperative that flow variability of plus or minus 25% is incorporated on a weekly basis into the release of the 95th percentile June flow, so that the monthly seasonal flow spikes do not return to a constant baseflow. Aug = 552 ML/d for one week (natural hydrograph shape), 255 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Sep = 816 ML/d for one week (natural hydrograph shape), 255 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Oct = 706 ML/d for one week (natural hydrograph shape), 255 ML/d varied by up to +/- 25% on a weekly basis for rest of month. Nov = 453 ML/d for one week (natural hydrograph shape), 255 ML/d varied by up to +/- 25% on a weekly basis for rest of month Dec = 217 ML/d (95th percentile).	Summer/Autumn Flows: Provide more and larger cascades. Encourage the return of montane fauna. Provide suitably cooler summer water temperature. Increase dissolved oxygen. Increase pool, rapid and cascade depths. Increase turbulence in step pools. Winter/Spring Flows: Deliver new organic matter (food source for aquatic fauna). Provide lateral connectivity with riparian vegetation. Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Provide biological stimuli for reproduction in aquatic species.

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Flushing flow	Reduced frequency of physical disturbance to the channel. Sedimentation as above. Active lichen colonisation on rocks. Lack of longitudinal connectivity for native fish migration and distribution. Potential for invasion of exotic fish such as Carp. Wholesale loss of some channel features: mid-channel bars are no longer in the middle of the channel.	1000 ML/d in winter/spring, 1 per year, natural flood hydrograph (may be satisfied by channel maintenance flows) May want regular flushing flows to remove Carp from downstream reaches, thus reducing the risk of invasion.	As for winter/spring flows, plus: Improve spawning habitat, eg. Macquarie perch Prevent vegetation invasion. Help prevent invasion by exotic fish such as Carp. Flush silt and biogenic sediment. Provide longitudinal connectivity for migration and redistribution of native fish and other aquatic biota. Recover and reactivate lost channel features.
Channel maintenance flow	Set-point = Stream order reduction. Significant channel contraction and wholesale loss of some channel features. Advanced channel atrophy - complete loss of side/secondary channels Vegetation invasion of old mid-channel bar and second channel. Loss of functioning of boulder steps, rapids and cascades. Pools only remnants which are accumulating biogenics, will eventually be lost. Riffles in a severe state of degradation No longer a high energy boulder step channel. Loss of very large floods which entrain large boulders, reconfigure channel substrate and maintain habitat heterogeneity.	1500 ML/d for 5 days duration, downstream of Ogilvies junction, at least annually. This will provide a flow depth of 0.78-1.28m over a 14-15m channel to entrain intermediate (256mm) boulders on a bed slope of 20-33.3m/km. These flows will be provided by removing the aqueducts on Outstation Creek (capacity of 60 ML/d), Ogilvies Creek (976 ML/d) and Deep Creek (95 ML/d) (as well as restoring ecological integrity to these streams). These aqueduct recommendations have the advantage of ensuring releases of good quality water, and will require no ongoing management (as would be necessary if environmental flows were released from the dam). Flows from the left bank aqueduct should be diverted to below the dam wall to provide improved baseflow in the river above these tributaries. A small length of the channel of the main river (i.e. ~2 km between the dam wall and Outstation creek) is being sacrificed in these flow recommendations, because the benefits of providing environmental flows from the tributaries outweigh those of providing them from the dam.	Entrain intermediate boulders and reconfigure substrate. Scour gravels to provide suitable spawning conditions (flushing flows are insufficient for gravel entrainment at this site). Provide greater lateral and longitudinal connectivity. Improve habitat heterogeneity. Deliver large woody debris. Reactivate secondary channels. Partially remove encroached vegetation. Re-establish hydraulic differentiation between boulder steps and step pools.

TOOMA RIVER AT MARAGLE POWER LINE ROAD BRIDGE

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	Warmer summer water temperatures than natural. Poor macroinvertebrate fauna in pools. Habitat otherwise seems good for macroinvertebrates, frogs and fish. Insufficient riffle depths and cascades. Limited lateral connection with riparian vegetation - channel not adjusted. Inadequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Loss of biological stimuli for reproduction of aquatic species due to low spring flows. Vegetation invasion and subsequent channel contraction.	Will be satisfied by minimum habitat utilisation flows for the upstream reach, provided there is additional flow input from tributaries.	Summer/Autumn Flows: Provide more cascades and deeper step pools. Provide suitably cooler summer water temperature. Increase dissolved oxygen. Increase riffle depths. Winter/Spring Flows: Deliver organic matter (food source for aquatic fauna). Increase lateral connectivity with riparian vegetation. Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Provide biological stimuli for reproduction in aquatic species.
Flushing flow	Metal contamination and warm water temperature as above. Some fine sediment accumulation in pools. Long-lived macroinvertebrates may indicate lack of floods. Insufficient longitudinal connectivity for native fish migration and distribution. Some scouring flows are occurring because there is no lichen colonisation on bedrock near the bed.	1) 1000 - 1400 ML/d of 3-4 days duration. At least annually 2) Additionally, one large flood of 1 week duration every 1-2 years.	As for winter/spring flows, plus: Provide greater longitudinal connectivity for migration and redistribution of native fish and other aquatic biota. Clean gravels and interstitial spaces. Control vegetation invasion. Redistribute sediment and nutrients. With higher flows over waterfalls there may be a small number of adult Carp invading, but conditions in this reach are unsuitable for breeding of Carp.
Channel maintenance flow	Set-point = Stream order reduction. Channel is not completely adjusted to regulated flows, it has contracted somewhat via some invasion of Carex, blackberry and tea-tree. Extreme flood events created the boulder step channel. Very large floods entrain large boulders, reconfigure channel substrate and maintain habitat heterogeneity.	Channel maintenance flows for the site below the dam will provide the same for here, provided there is also some contribution from tributary flows	More boulder steps will function. Provide greater lateral and longitudinal connectivity. Entrain intermediate boulders and reconfigure substrate. Improve habitat heterogeneity. Deliver large woody debris.

TOOMA RIVER ~200M BELOW NATIONAL PARK BOUNDARY

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	Active bank erosion from clearing of vegetation and stock access. Burial of substrate with fine sediment. Infilling of interstitial spaces between gravel. Nutrient enrichment. Lack of lateral connection with riparian vegetation. Inadequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Loss of biological stimuli for reproduction of aquatic species due to low spring flows.	The recommended flows for the two upstream sites, combined with residual catchment flows, are expected to provide significant benefits.	Summer/Autumn Flows: Increase dissolved oxygen. Increase flow depths over riffles. Provide cooler summer water temperature. Winter/Spring Flows: Deliver new organic matter (food source for aquatic fauna). Increase lateral connectivity with riparian vegetation. Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Provide biological stimuli for reproduction in aquatic species. Flush silt cover from rocks and stones.
Flushing flow	Sedimentation as above. Nutrient enrichment as above. Insufficient longitudinal connectivity for native fish migration and distribution, particularly Macquarie perch.	1000-2000 ML/d for ~5 days in mid-summer.	As for winter/spring flows, plus: May provide sufficient longitudinal connectivity for Macquarie perch migration and redistribution, as juveniles will be large enough in mid-summer to disperse. Clean gravels and interstitial spaces. Flush and prevent algae. Flush nutrients and organic matter from livestock. Flush sediment and lessen the damage caused by livestock access. Upstream reaches will also benefit.
Channel maintenance flow	Set-point = Pre-regulation channel. Channel width is 15-20m. Channel is in reasonable condition apart from bank erosion due to livestock. Large floods entrain large sediment, reconfigure channel substrate and maintain habitat heterogeneity.	10,000 ML/d (over 5-7 days) with natural flood hydrograph shape.	Provide greater lateral and longitudinal connectivity. Entrain large sediment. Reconfigure substrate. Improve habitat heterogeneity. Deliver large woody debris. Maintain pool-riffle sequence.

TOOMA RIVER ON FLOODPLAIN

Component of Environmental Flow Regime:	Impact of Flow Regulation and Landuse:	Requirements:	Expected Outcomes:
All Components: Minimum habitat utilisation flow (includes seasonal flow variability) Flushing Flow Channel Maintenance Flow	The impacts of flow regulation in this reach are not easily determined because of degradation from livestock and landuse. Impacts are as follows: 1) Nutrient enrichment is a major problem in this reach and floodplain wetlands, due to: livestock access, the loss of riparian and wetland vegetation filters through vegetation clearing and stock damage, and sediment addition from erosion of banks by channel widening as a result of aggradation and stock access. The impacts of nutrient addition are: blue-green algal blooms in wetlands (particularly those on the edge of the floodplain) and farm dams, low faunal diversity and low abundance, and eutrophication. 2) Active bank erosion due to stock access and clearing of riparian vegetation. 3) Sediment input to the river due to bank erosion from livestock and erosion in the catchment due to landuse, gullying and possibly past gold mining. 4) Shifting sand in the channel is a major problem in the river. Tumbarumba Creek appears to be a major sediment source in this reach and may be causing or contributing to the shifting sand problem. Mobile sand provides very poor habitat for native fish and macroinvertebrates because: it buries substrate grinds organic matter to very small sizes lacks backwaters, and has a uniform channel cross-section.	The environmental flow regime recommended for the Tooma River in upstream reaches is required here. Most problems in this reach are catchment and riparian land management issues, therefore integrated land management actions are required, as follows: 1) ,2), 3) and 4) To reduce sediment and nutrient input to the river and floodplain system: fencing of riparian areas to prevent stock access and bank erosion. revegetation of riparian areas to provide filter strips. better stock management on land in the surrounding area. sediment reduction through bank stabilisation and controlling catchment erosion. Rehabilitation of old mining sites if these are contributing sediment to the river.	Recommended environmental flows for the Tooma River upstream should help address impacts caused by a combination of flow regulation and land management. The recommended integrated land management actions will improve the ecological integrity of the river and floodplain environments as follows: 1), 2), 3) and 4) Control of erosion, reduced input of sediment and nutrients to the river. Improved conditions for native aquatic biota.

Component of Environmental Flow Regime:	Impact of Flow Regulation and Landuse:	Requirements:	Expected Outcomes:
	(These are ideal conditions for Carp and Weatherloach). The only habitat for native biota in the channel is the occasional bedrock section or snag. The sand slug from Tumbarumba Creek has caused avulsions and anastomosis (wholesale change in river course and multiple channels have developed. The sand slug is contributing to channel straightening and widening		
	5) Interaction between the river and floodplain wetlands has been altered, therefore important ecological functions have been disturbed (see adjacent Outcomes).	5) Flows need to reflect the natural timing, duration and magnitude of natural flows.	5) Improved connection of the river and floodplain will: allow fish breeding redistribute nutrients increase macroinvertebrate diversity import woody debris to the river help control Carp (native predatory fish eat juveniles).
	6) Red gums are dying and not regenerating because of livestock, clearing and changes to the timing, duration and magnitude of flows.	6) Address River Red Gum death and regeneration through appropriate land management (eg fencing to exclude stock) and water management (ie timing, duration and magnitude of flows needs to be more natural).	
	7) There is a waterlogging problem on the floodplain, which may be exacerbated by backwater from increased flow in the Swampy Plains and Murray Rivers.	7) Investigate whether increased flow in the Swampy Plains and Murray Rivers is contributing to waterlogging on the floodplain.	
	8) Backwater from increased flow in the Swampy Plains and Murray Rivers is also likely to have other impacts.	8) Investigate and address impacts of backwater.	
	9) Willow and cottonwood invasion is active and has negative impacts on stream ecosystems (as described for Eucumbene and Tumut Rivers).	9) Remove and manage willows and cottonwood.	9) Reduced impacts of willows.

TUMUT RIVER BELOW TUMUT 2 POWER STATION

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	Slightly anoxic occasionally. Dissolved oxygen depletion in pools. Embedded cobbles. Thick Carex and heavy shading are unsuitable for frogs. Site is biogeographically isolated because of the dams, this limits aquatic species recolonisation. Willow invasion. Hyporheic zone is now composed of willow root mats. Accumulated willow and other detritus in pools. Inadequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Lack of input of large woody debris. Loss of biological stimuli for reproduction of aquatic species due to low spring flows.	60-70 ML/d in driest month, based on observed flow of 12-16 ML/d 600 ML/d in wettest months (based on the natural order of magnitude change between the driest and wettest month).	Summer/Autumn Flows: Provide more cascades and deeper step pools. Help dilute nutrients. Provide suitably cooler summer water temperature. Increase dissolved oxygen. Increase riffle depths. Will not prevent anoxia in deep pools. May not return the fauna to that of a montane river, because of biogeographical isolation. Will not displace Redfin (requires ~ 1 m/s in 5m channel - ~100 ML/d - for sustained period). Winter/Spring Flows: Remove Redfin. Deliver organic matter (food source for aquatic fauna). Provide lateral connectivity with riparian vegetation. Provide adequate hydraulic and habitat heterogeneity to allow the completion of macroinvertebrate life cycles. Provide biological stimuli for reproduction in aquatic species.
Flushing flow	Embedded substrate as above. Water quality problems as above. Willow problem as above. Lack of longitudinal connectivity for migration and redistribution of native fish and other aquatic biota.	1) Willow and Blackberry removal 2) 1800 ML/d, 2 events in summer, natural summer thunderstorm hydrograph.	Displace alien fish . Reduce algal growth (which may increase when willows are removed, due to less shading). Flush algae, sediment, organic matter and fine sediment. Provide limited longitudinal connectivity for native fish redistribution within the reach (ie. limited by dams). Clean gravels and interstitial spaces. Prevent further vegetation invasion.

Component of Environmental Flow Regime:	**Issues:**	**Requirements:**	**Expected Outcomes:**
Channel maintenance flow	Set-point = Stream order reduction. Channel has contracted by 75-80% from just over 20m to 5m. Old secondary channel invaded by vegetation. Willows are obliterating the current channel. Much bulldozing has occurred at part of the site assessed.	1) Willow and Blackberry removal 2) 18,000 ML/d for 2 days, 2 events in 3 years, natural hydrograph shape (based on attaining flow depth of 3.25m to entrain 200 mm boulders on a bed slope of 6.15m/km).	Reconfigure step pools and substrate. Prevent sedimentation of the cobble bed. Replenish habitat by cleaning and redistributing the substrate. Prevent willow invasion and remove willow detritus. Provide greater lateral and longitudinal connectivity. Entrain intermediate boulders and move artificial angular gravels. Deliver large woody debris.

GOODRADIGBEE RIVER BELOW AQUEDUCT

Component of Environmental Flow Regime:	Issues:	Requirements:	Expected Outcomes:
Minimum habitat utilisation flow (includes seasonal flow variability)	Good water quality. Little evidence of habitat degradation at assessment site, except that riffles are more like runs (evident in macroinvertebrate fauna).	1) Remove aqueduct to restore natural flows, or 2) Release 20-30% of inflows as passing flows , or 3) Remove minor stream diversion on smaller tributary near aqueduct	Restore longitudinal connectivity. Provide daily and seasonal flow variability. Restore waterfall and riffle fauna. Improve the river where most impacted (~2-3 km downstream).
Flushing flow	Some biogenic or silt accumulation, however this may be natural.	Will be provided by natural or passing flows.	Flush biogenics and sediment. Provide longitudinal connectivity for migration and redistribution of native fish and other aquatic biota. Clean gravels and interstitial spaces.
Channel maintenance flow	Channel has restarted as a smaller stream. Inspection site was too far downstream of the aqueduct to observe any impact on the channel.	Will be provided by natural or passing flows.	Provide greater lateral and longitudinal connectivity. Entrain large sediment and move artificial angular gravels. Reconfigure substrate. Improve habitat heterogeneity. Deliver large woody debris.